PART II.

WORKSHOP 96
BRNO, JANUARY 22–24, 1996

PART II.

These are the Proceedings of the Fifth Annual university-wide seminar WORKSHOP 96 which will take place at the Technical University in Brno from 22–24 January, 1996.

The aim of the seminar is to present and discuss the latest results obtained by researchers especially at the Czech Technical University in Prague, Technical University in Brno and at collaborating institutions.

The organizing committee has selected a total of 494 contributions divided into 22 different areas of interest.

Part II has contributions in the areas of:

- engineering mechanics
- theory of construction
- materials science in mechanical engineering
- materials science in electrical, chemical and civil engineering
- power systems and electrical engineering
- electronics, measuring and communication engineering

Organizing committee:
Chairman: P. Chmela
Co-chairman: M. Káral

Prague, December 1995

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Section 7

ENGINEERING MECHANICS
PVM PARALLELIZATION OF EXPLICIT FINITE ELEMENT PROGRAMS

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Key words: parallelization, PVM, finite elements, explicit integration

Explicit finite element programs for non-linear dynamics are of rather simple logical structure. If the inherent characteristics of this logic are exploited in the design and implementation, an "object-oriented" programming style leads to elegant, extendible and maintainable programs. Firstly, a high-level representation for the explicit time integrators is formulated. The parallel algorithm is then stated, and it is shown that the star-shaped configuration of a "master" program communicating with a number of "workers" is well suited to the parallel formulation. Finally, it is shown how to create different versions of the integrator, which correspond either to the master or to the worker.

There are several formulations of the explicit central difference (CD) integration scheme. In order to be able to use the advantages of the time stepping scheme (in particular the fact, that no matrix inversions are necessary), two variants can be considered most efficient: (i) the Newmark variant resulting from the well-known implicit $\beta$ method for $\gamma = \frac{1}{2}$ and $\beta = 0$, and (ii) the Nystroem variant constructed from a finite difference approximation to the first and second time derivative.

The notion of a CD integrator object can be extracted from the general observation that the CD algorithms are specified without explicitly defining the vectors of displacements, internal and external forces (loads), and the mass (damping) properties of the structure. Thus the algorithms can be encapsulated by defining: (i) The physical domain object, which is responsible for setting up the equations, assembling of the mass, etc., (ii) starting time and initial time step length, and (iii) the procedures (iiia) calc_eff_loads() to compute the effective loads, (iiib) solve_for() to solve for the primary unknowns, (iiic) update_config() to update the configuration (displacements, velocities etc.), and (iiid) change_dt() to change the time step $\Delta t$ during the time integration. The methods defined for a central difference integrator are: (i) get_t(), and get_dt() to access the current time and current time step, and (ii) advance() to advance the integrator in time by $\Delta t$. Then the "advance" methods can be written for the two variants as

```c
static void Nystroem_advance(cd_integrator_t *i)
{
    i->calc_eff_loads(i->domain);
    i->solve_for(i->domain);
    i->update_config(i->domain);
    i->t += i->dt;
    if (i->change_dt != NULL)
        i->dt = i->change_dt(i->domain);
}

static void Newmark_advance(cd_integrator_t *i)
{
    i->update_config(i->domain);
    i->calc_eff_loads(i->domain);
    i->solve_for(i->domain);
    i->t += i->dt;
    if (i->change_dt != NULL)
        i->dt = i->change_dt(i->domain);
}
```

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The parallel version of the explicit finite element program is based on the following simple idea: Split the original mesh and assign the partitions to the processors (workers). Define interfaces as such nodes which are shared by two or more partitions. Then for each time step compute the solution for the partitions in parallel, assemble the nodal forces for the nodes at the interfaces between partitions globally at the master, and distribute them to workers. (The actual implementation could be rather complicated by dynamic load balancing. This is an active area of on-going research, for which no simple solutions exist. Only the case of static problem decomposition was considered here.) The computation is thus distributed between the master (it is responsible for starting up the workers, and for the assembly and distribution of the interface forces), and the workers (they are working on the partitions as if they were serial programs, with the exception of the assembly of the effective forces at the interface, which must be sent to the master and then retrieved in their globalized form). The actual implementation was done by defining macros and conditional compilation units in the serial code. Thus it is possible to maintain only a single version of the program and to generate either the serial program, or the PVM-based parallel programs (master or worker). We can demonstrate the implementation on a code fragment, which corresponds to the worker's computation of the initial time step by running a loop over all elements of the partition, computing the time step and sending it to the master. Master collects this information from all workers, and then broadcasts the global minimum. Workers receive the time step and return it just as a serial version of the program would. (The PVM functions were hidden by macros to ease maintenance of the code.)

```cpp
double WD_comput8_dt(W_domain_t *d) {
    double dt = INFINITY;
    ELEM_LOOP(dt = min(dt, WE_suggested_time_step(theELEM)));
    INITSEND();
    PACK(double, &dt);
    SEND(theMASTER, TIME_STEP_ANSWER_TAG);
    RECEIVE(theMASTER, TIME_STEP_ANSWER_TAG);
    UNPACK(double, &dt);
    return dt;
}
```

There is not enough space here to discuss additional issues such as the computation of the inertial properties of the interface nodes, or of the energy balance. The reader is referred to the technical report [1].

The parallel version of the explicit finite element program proved to be easily maintainable. The main difficulty is a need for automatic partitioning of the finite element domain, which should minimize the communication bandwidth, and at the same time balance the worker load.

References:


This research has been conducted at the Department of Structural Mechanics as part of the research project "Material Models for Concrete ..." and has been supported by GACR grant No. 103/93/1175.
TRIANGULATION OF 3D SURFACES BY THE ADVANCING FRONT TECHNIQUE

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Key words: triangulation, 3D surface, advancing front

This article is directly related to the paper presented in the last year workshop [1]. The originally proposed approach for triangulation of spatial surfaces utilizes the bijective mapping between the tensor product polynomial surface and its parametric space. The actual triangulation is performed in the parametric space, using the local mesh control function, and the obtained mesh is then mapped onto the original surface. Although this methodology proved, in most cases, to provide quite satisfactory results several drawbacks have been identified. Firstly, there is a tendency to generate at most two triangles sharing the corner of the parametric space even if this is a reentrant corner on the original surface. This results apparently in badly shaped triangles around this corner. Secondly, the mapping is generally not affine. This implies presence of element distortion and stretching when mapped between the real and the parametric spaces and requires a special treatment to deal with singular cases [2] introduced by degenerated or badly parameterized surfaces.

In the approach presented in this paper, the meshing algorithm is constrained directly to the physical surface and the parametric space is used only to enhance the efficiency of the algorithm [3]. A widely known advancing front technique with some modifications allowing for surface curvature is employed. Firstly, the initial front consisting of edges constituting the boundary of the surface (including inner loops) is established. Once the initial front has been set up the mesh generation continues on the bases of the edge removal algorithm according to the following steps until the front becomes empty:

• the first available edge $AB$ is pulled from the front
• the position of "ideal" point $P$ (forming the new $\triangle ABP$) is calculated taking into account local surface curvature and mesh size variation
• the projection $P'$ of point $P$ to the surface is evaluated
• the local neighbourhood of point $P'$ is established
• the neighbourhood is searched for the most suitable candidate $C$ to form a new $\triangle ABC$
• the intersection check is carried out to avoid overlapping of the created triangle with an already existing one in the neighbourhood
• the front is updated to account for newly formed $\triangle ABC$

To make the algorithm applicable to a wide variety of surfaces with a reasonable level of complexity the family of tensor product polynomial surfaces (e.g. Rational Bezier surface, B-spline surface, NURBS, etc.) is considered in the presented study. This brings in several advantages. Since these surfaces are widely used in CAD and modeling systems a natural and consistent interface between the modeler and the mesh generator is ensured.
All these surfaces enable relatively simple evaluation of surface normal and gradients at
discrete locations on the surface which are the only quantities required during the generation.
And finally, the parametric space of these surfaces allows for some procedures (namely the
intersection checks) to be performed more efficiently than in 3D.

The spatial localization for the intersection checking and the front management, in
terms of edge selection and searching, are considered to be the general bottlenecks of the
advancing front procedure. Both aspects are addressed in the presented approach. The
spatial localization is implemented using the \( O(\log d) \) computational complexity which be-
comes nearly constant for reasonable octree depth \( d \). The octree is also used to control the
element size gradation. To ensure the gradual variation of element size the maximum one
octree level difference of octants sharing an edge is enforced. This avoids the necessity to
implement special algorithm to pull an edge from the front and therefore the simplest ap-
proach was chosen which always uses the first edge in the front. This obviously leads to the
constant computational complexity. The remaining procedures are similar to the conven-
tional advancing front method and thus the overall computational complexity approaches
\( O(n) \) with \( n \) being the number of elements, which makes the proposed methodology very
competitive for practical use.

To demonstrate the performance of the algorithm an example is presented. A sequence
of uniform meshes of SGI logo has been generated. One of the meshes is depicted in Fig. 2.
The relation between the number of elements and time consumed for various mesh densities
is given in Fig. 1.

Fig. 1: Time vs. number of elements. Fig. 2: Surface mesh of SGI logo.

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Engng.

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RATE DEPENDENT ANALYSIS
OF CONCRETE STRUCTURES

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Key words: dynamic analysis, elasto-plasticity, strain rate, concrete, numerical modelling

Despite relatively scare experimental data, there is a clear experimental evidence of stress or strain rate dependence of behaviour of concrete and similar materials. The most prominent features are:

a) the significant increase of strength parameters as the average rate of straining increases from the quasi-static rate (approx. $10^{-5}$ sec$^{-1}$) to the higher strain rates associated with a seismic excitation (approx. $10^{-2}$-$10^{-4}$ sec$^{-1}$) and especially to very high strain rates under impact loads (approx. $10^{4}$ sec$^{-1}$);

b) the increase of Young’s modulus of elasticity with increasing strain rate.

It is generally known from the experimental study (e.g. [4]) that the strain rate effect of concrete is more sensitive for tension than for compression. Going to the extreme loading conditions concrete can exhibit near doubling of its strength, a factor that cannot be ignored in any realistic analysis. An increase of the modulus of elasticity is not so significant, e.g. for the strain rate $10$ sec$^{-1}$ it is approximately 10-15%. On the other hand it is necessary to say that there is no important property of concrete which decreases its value with higher strain rates. From a designer’s point of view this is quite a positive feature. The increase of strength is sometimes only a few percent which may not be considered in some loading conditions - e.g. traffic and gas explosions.

Strain rate dependency of the material properties can be included in the numerical model by the following three fundamental ways: a) elasto-plasticity, b) elasto-viscoplasticity, and c) fracture mechanics models.

In this project the rate effects are included into the elasto-plastic model. Mohr Coulomb surface, for example, can be uniquely defined by the uniaxial compressive and tensile strength values, i.e. $f_{cu}$ and $f_t$. Rate hardening models lead to an instantaneous breathing surface (they may expand or shrink depending on the rate of process), as both $f_{cu}$ and $f_t$ are made strain rate dependent and expressed as

$$f_{cu}^d = f_{cu}^s * H_{RC} (\dot{\varepsilon}_{eff})$$

$$f_t^d = f_t^s * H_{RT} (\dot{\varepsilon}_{eff})$$

where superscripts $d$ and $s$ denote dynamic and static values of the strength, $H_{RC}$ or $H_{RT}$ are rate dependent hardening parameter for compressive or tensile behaviour and $\dot{\varepsilon}_{eff}$ is an effective strain rate of the process. Per analogiam, the instantaneous elastic modulus can also be made strain rate dependent (rate hardening parameter is $H_{RE}$). Typical formulas for the rate hardening parameters are shown on Fig. 1.
During numerical computations it is necessary to decide whether the rate of process is measured from an invariant of strain rate tensor components or as a rate of strain tensor invariants. In some cases both choices lead to the same measure, but not in general. Several measures of strain rate and rate hardening definitions has been included into the computer program MIXDYN [3].

Fig. 1 shows a response of the concrete dam where the loading vs. time curve represents an idealisation of an impact by a Boeing 747 aircraft. The comparative displacement response indicates relatively minor difference between rate independent and rate dependent response, despite the fact that the histories of strain rate and rate hardening parameter indicate considerable fluctuation. Various measures of effective strain rate have been used and it has been concluded that different definitions of strain rate give almost identical results.

\[
H_{RC} = H_{RFR} = a_1 + a_2 \cdot \ln(i_{eff}) + a_3 \cdot [\ln(i_{eff})]^2
\]

\[
H_{ 提 } = 1.0
\]

\[
a_1 = 1.6, a_2 = 0.104, a_3 = 0.0045
\]

Fig. 1: Impact on a concrete dam

References:


This research has been conducted at the Department of Structural Mechanics as part of the research project "Rate Dependent Modelling of Concrete" and has been supported by CTU grant No. 10018224.
In the proposed paper the condensation process was developed based on the combination of static condensation and Rayleigh-Ritz method. It is demonstrated, that for beam element the dynamic condensation leads exactly to the same results which are obtained from the series expansion of analytical solution. The algorithm is suitable for parallelization. The free vibration is defined by the following equation

\[ \begin{pmatrix} -\omega^2 M + K \end{pmatrix} y = 0. \]

To apply static condensation in the eigenvibration analysis, we have to concentrate the inertial properties of the structure in just a few degrees of freedom. The approach described next is applicable: The degrees of freedom of the discrete model are grouped into mass degrees of freedom, \( y_a \), and massless degrees of freedom, \( y_b \). The matrices \( K \) and \( M \) are split into submatrices corresponding to the two groups of degrees of freedom:

\[
\begin{pmatrix}
K_{aa} & K_{ab} \\
K_{ba} & K_{bb}
end{pmatrix}
\begin{pmatrix}
y_a \\
y_b
end{pmatrix}
= \begin{pmatrix}
\Omega_a^2 & O \\
O & O
end{pmatrix}
\begin{pmatrix}
M_a & O \\
O & O
end{pmatrix}
\begin{pmatrix}
y_a \\
y_b
end{pmatrix}.
\]

The vector \( y_b \) can be expressed in form

\[ y_b = -K_{bb}^{-1} K_{ba} y_a. \]

We get the reduced problem of eigenvibration

\[ K_a y_a = \Omega_a^2 M_a y_a, \] where \( K_a = K_{aa} - K_{ab} K_{bb}^{-1} K_{ba}. \)

Static condensation is being currently replaced by the Rayleigh-Ritz method. The method is based on the Rayleigh principle. The Rayleigh quotient is computed by the Ritz method. The vectors minimizing Rayleigh quotient will be sought in the space of linear combinations of (linearly independent) vectors \( \psi_i \). The coefficients \( c_i \) will be collected into a vector \( c \). Vectors \( \psi_i \) will be collected into a matrix \( \Psi \) of type \((n,p)\) similarly to the eigenmodes, which means that the individual vectors \( \psi_i \) will constitute columns of \( \Psi \). Vectors \( \varphi \), constituting the trial space for Rayleigh quotient minimization, are

\[ \varphi = \Psi c. \]

Let us substitute (5) into the expression for Rayleigh quotient

\[ \rho(\varphi) = \frac{c^T \Psi^T K \Psi c}{c^T \Psi^T M \Psi c}. \]
Because $\partial p/\partial c = 0$, we get from (6) a condition for $c$ in the form of a system of linear homogeneous equations

$$Kc = \rho M c.$$  \hfill (7)

That means that by the Ritz method we have reduced the original problem with $n$ degrees of freedom into an eigenvalue problem with $p$ degrees of freedom.

Let us show here that the static condensation method with the Rayleigh-Ritz method yields a consistent approach to the condensation of the mass matrix. Starting from equation (3), we can write

$$\left\{ \begin{array}{l} y_a \\ y_b \end{array} \right\} = \left[ \begin{array}{c} \mathbf{I} \\ -K^{-1}K_{ba} \end{array} \right] y_a = \Psi y_a,$$  \hfill (8)

which is analogous to (5). However, $y_a$ and $y_b$ are not here mass and massless degrees of freedom. This transformation can be written for the whole structure, substructure, or for an isolated element.

Thus, using (8), the matrices $K$ and $M$ will be transformed from the generalized coordinates $y_a$, $y_b$ into the generalized coordinates $y_a$. We get

$$K^* = \Psi^T K \Psi, \quad M^* = \Psi^T M \Psi.$$  \hfill (9)

Substitution of (8) into the first relation of (9) leads to $K^* = K_a$ ($K_a$ from equation (4)).

The numerical implementation of the condensation process can be advantageously based on these two alternative ways:

1. Condensation of the stiffness matrix is carried out by the Gaussian elimination.
2. Condensation is carried out unknown-by-unknown. Therefore, it is sufficient to formulate the algorithm for a single degree of freedom. In that case the transformation matrix can be written as

$$\Psi = \left[ \begin{array}{c} \mathbf{I} \\ \mathbf{t}^T \end{array} \right],$$  \hfill (10)

where $\mathbf{t}$ is a vector of Gauss multipliers, which are needed for zeroing of a single column.

Substituting (10) into the second relation (9) we get

$$M^* = M_{aa} + t M_{ab} + M_{at}^T + t M_{bt}^T.$$  \hfill (11)

$M_{bb}$ is a scalar for the condensation of the single degree of freedom. The described approach is sometimes called the Guyan reduction.

References:


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NONLINEAR ANALYSIS OF CONCRETE STRUCTURES

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Key words: concrete, plasticity, cracking.

The long-time changes of mechanical properties of structures made of reinforced concrete should significantly change reliability and durability of such structures. The attention was focused on relatively new cooling towers situated in Nuclear power plant Dukovany, which are now strongly damaged due to aggressive environment conditions. In order to be able to design effective reconstruction, the software for numerical analysis of shells structures made of reinforced concrete was developed. The computational model includes such important effects like plasticity, cracking and creep. The algorithm used at material level to consistently describe plasticity and cracking in quasi-brittle materials like mortar or concrete is shortly presented in this paper.

Incremental plasticity approach with generally non-associate normality and arbitrary hardening rule is implemented. This approach agrees with experimental evidence and is widely used in most applications. The material model describing crack behavior must be physically realistic and suitable for numerical implementation. Currently, two approaches are widely used to model crack behavior: the discrete and smeared approach. The smeared model, which is computationally much more simpler then the discrete one, has been used. Such model does not require topology changes during solution process. Concrete damage is simulated as a system of parallel cracks smeared over the whole finite element. Before cracking, the material is assumed to be isotropic, linearly elastic. When principal stress violates tension strength criterion, crack is introduced with direction normal to the corresponding principal stress. Crack is modeled by switching from isotropic to orthotropic behavior, reducing material stiffness in the direction of normal.

In its original form (proposed by Rashid 1968), the smeared approach assumes the slope of softening branch to be a material property. This model coupled with simple strength criterion leads to results dependent on the mesh size. Such approach also cannot model the size-effect. In this paper we will follow the crack band model proposed in [1], which is three parametric (tensile strength, fracture energy and size of the fracture process zone). Such model provides mesh-independent results and can model size effect. In this paper, attention is focused on the development of consistent incremental material stiffness matrix, taking into account both plasticity and concrete cracking. Approach presented here can be easily enhanced to incorporate such effects as creep and shrinkage. The basic assumption of our treatment is that the total strain rate vector $\dot{\varepsilon}$ is decomposed into concrete strain rate $\dot{\varepsilon}^c$ and several crack strain rates denoted as $\dot{\varepsilon}^l$, $\dot{\varepsilon}^{ll}$, etc. Finally it follows

$$\dot{\varepsilon} = \dot{\varepsilon}^c + \dot{\varepsilon}^s + \dot{\varepsilon}^0,$$

where $\dot{\varepsilon}^c = \dot{\varepsilon}^c + \dot{\varepsilon}^p$ and $\dot{\varepsilon}^s = \{\dot{\varepsilon}^l, \dot{\varepsilon}^{ll}, \ldots\}$. The strain rate $\dot{\varepsilon}^0$ is the stress independent part of strain rate (for example caused by thermal dilatation or shrinkage). Further is assumed that $\dot{\varepsilon}^0 = 0$. 

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For 3D stress state the crack can be imagined as a crack plane with local coordinate system, where local x-axis is normal to the crack plane and axes y and z are lying in the crack plane. Then only 3 of total 6 components of local crack strain rate are nonzero (the normal one and two shears in crack plane). Local crack strain rate vector has the form \( \dot{\varepsilon}_i^c = (\dot{\varepsilon}_{1c}, \dot{\varepsilon}_{2c}, \dot{\varepsilon}_{3c}, \dot{\varepsilon}_{4c}, \dot{\varepsilon}_{5c}, \dot{\varepsilon}_{6c})^T \). Global crack strain rate is a sum of contribution of all local crack strain rates transformed to global coordinate system.

\[
\dot{\varepsilon}^c = N_i \dot{\varepsilon}_i^c + N_s \dot{\varepsilon}_s^c + \cdots = N \dot{\varepsilon}^c.
\]

(2)
The local non vanishing crack strain rates are assumed to be related to stress rate vector via \( \dot{\sigma} = D^c \dot{\varepsilon}^c \). Matrix \( D^c \) in general case allows coupling between normal and shear strains. Now we proceed to derivation of a general form of incremental constitutive matrix, taking into account possible plasticity and cracking in multiple directions. We have

\[
\dot{\sigma} = D^e \left( \dot{\varepsilon} - N \dot{\varepsilon}^c - \lambda \frac{\partial g}{\partial \sigma} \right).
\]

(3)

After premultiplying (3) by \( \left( \frac{\partial f}{\partial \sigma} \right)^T \) and \( N^T \) we obtain two equations. By some math, we finally obtain:

\[
\dot{\sigma} = \left( D^{el} - \frac{D^{el} \left( \frac{\partial g}{\partial \sigma} \right) \left( \frac{\partial f}{\partial \sigma} \right)^T D^{el}}{h + \left( \frac{\partial f}{\partial \sigma} \right)^T D^{el} \left( \frac{\partial g}{\partial \sigma} \right)} \right) \dot{\varepsilon}.
\]

(4)

with \( D^{el} = D^e - D^c N A^{-1} N^T D^e \) and \( A^{-1} = [D^c + N^T D^e N]^{-1} \). Structure of this matrix is similar to well known elasto-plastic incremental tangent stiffness, but \( D^{el} \) is used instead \( D^e \), which considers possible cracking in various directions.

Material model presented here, is implemented in pilot version of OOFEM program. This program, written in object-oriented language, is designed to be general purpose finite element prototype code and has been shortly described in [3].

References:


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ANALYSIS OF STRUCTURES USING TRANSFORMATION FIELD ANALYSIS

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Key words: transformation field analysis, composite materials, bounded domain

In recent years some papers have been devoted to homogenization of composite or laminated materials, [3]. In the present paper we concentrate our attention on homogenization of nonhomogeneous bodies by means of a special treatment proposed by Dvorak, [1], and apply it to the solution of composite structures. The main idea consists in separating the mutual effect of eigenstrains $\mu_{ij}$ (eigenstresses $\sigma_{ij}$) from one inclusion (internal cell) to another. One of the most suitable techniques dealing with homogenization is the boundary element method (BEM). The influence functions may be computed at each point of the internal cells with high accuracy, nonlinearities in inclusions and matrix can easily be introduced and are effectively computed.

The influence functions enable one, according to the paper [1], to solve the elastic-plastic and viscoplastic composite systems based on a change of eigenstrains or eigenstresses, while the other quantities remain unchanged during the iteration process. The procedures of this kind suite very effectively to applications in sense of BEM.

We extend the Hashin-Shtrikman variational principle, [4], by introducing both eigenstrain and eigenstress fields into the formulation. Assume that no body forces are present.

An equivalent formulation may be obtained by variation of the extended functional

$$ U = U^0 - \frac{1}{2} \int_\Omega \left[ (L_{ijkl})^{-1} (\tau_{ij} - \lambda_{ij}) (\tau_{kl} - \lambda_{kl}) - 2\tau_{ij} \varepsilon_{ij}^0 - \varepsilon_{ij}^* \tau_{ij} - \lambda_{ij} M_{ijkl}\lambda_{kl} \right] d\Omega $$

with respect to the fields $\tau_{ij}$ (stress polarisation) and $\varepsilon_{ij}^*$, where $M_{ijkl} L_{ijkl} = I_{ijkl}$, $L_{ijkl}$ is the stiffness matrix. We have denoted

$$ U^0 = \frac{1}{2} \int_\Omega \sigma_{ij}^0 \varepsilon_{ij}^0 d\Omega = \frac{1}{2} \int_\Omega L_{ijkl}^0 \varepsilon_{ij}^0 \varepsilon_{kl}^0 d\Omega. $$

and the quantities with superimposed 0 belong to homogeneous body, primed quantities are differences between real and homogeneous body. For details see [2].

It can be proved that the stationary value $U^*$ of the functional $U$ is equal to the actual potential strain energy stored in the anisotropic and heterogeneous body.

After variating $U^*$ we get the integral equation

$$ u'_i(\xi) = \int_\Gamma u_{ik}(x, \xi) p_k(x) d\Gamma(x) - \int_\Omega \varepsilon_{ijkl}^* (x, \xi) \tau_{kl}(x) d\Omega(x) $$

where the starred quantities are known kernels.

Differentiating the last equation with respect to $\xi$ we arrive at the expression

$$ \varepsilon_{ij}^* (\xi) = \int_\Gamma [h_{ijk}(x, \xi) p_k(x) d\Gamma(x) - \int_\Omega \psi_{ijkl}^* (x, \xi) \tau_{kl}(x) d\Omega(x) - \tilde{C} \tau_{ij}(\xi)] $$

where $\tilde{C}$ is the convected term.
Willis, [3], proved that the last relation is a positive definite and symmetric integral operator in the standard norm.

Our goal now is to derive the relation between the strains and the eigenstresses of the form

\[ \varepsilon = A \varepsilon^0 + F \lambda, \]

where \( A \) and \( F \) are the influence function matrices (\( A \) is mostly referred to as the mechanical concentration function matrix). Note that once computed, these matrices do not change their values during iteration processes for nonlinear solution of plasticity, optimization, etc. They completely depend only on the shape of the body under study and its material properties in the initial stage of the iteration.

After discretization of the boundary and after discretization of the domain \( \Omega \) into internal cells, the integral equations take the form

\[
U p' - E' \varepsilon - E \lambda = 0, \quad \varepsilon' = H p' - \Psi' \varepsilon - \Psi \lambda,
\]

where \( U \) is a square matrix \((3N \times 3N)\) and \( 3N \) is a number of degrees of freedom on the boundary, \( p' \) is the vector of discretized tractions at nodal points of boundary \( \Gamma \), \( E, E' \) are the matrices \((3N \times 6M)\) of influences of the strains and eigenstrains in the discretized domain, \( H \) is a \((6M \times 3N)\) matrix and, finally, \( \Psi \) and \( \Psi' \) are square matrices \((6M \times 6M)\).

As the regular matrix \( U \) may be inverted, elimination of \( p' \) gives

\[
S \varepsilon = \varepsilon^0 + T \lambda, \quad S = I + \Psi' - HU^{-1}E', \quad T = -\Psi + HU^{-1}E.
\]

Obviously, \( S \) is a regular \((6M \times 6M)\) matrix, as for a given \( \lambda_{ij} \) (\( i, j \) being fixed) a unique response \( \varepsilon \) may be expected. The searched influence function matrix \( F \) is equal to \( S^{-1}T \) while \( S^{-1} \) is the mechanical concentration function matrix \( A \).

In this short contribution we have presented only the fundamental idea of the proposed approach to nonhomogeneous and anisotropic bodies. Based on the extended Hashin-Shtrikman theorem in combination with the BEM it is possible to obtain the strain influence matrices relating the strains \( \varepsilon_{ij}, \varepsilon_{ij}^0 \) and the eigenstrains/eigenstresses.

References:


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TUNNEL LINING IMPROVEMENT
BY OPTIMIZED ANCHORING

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Key words: tunnel lining, anchoring, bearing capacity

In previous papers [1, 2], the authors have formulated an effective approach to the analysis of nonhomogeneous bodies and have used the transformation field analysis for relating the components of stress or strain tensors and the components of eigenstrains or eigenstresses. Mathematical background of this approach can be found in [3]. This paper deals with an extended dual variational principle for bounded nonhomogeneous bodies. By means of internal parameters, eigenstrains \( \gamma_{ij} \) and/or eigenstresses \( \sigma_{ij} \) it is possible to increase the bearing capacity of structures, or to minimize the stress excesses. The BEM is used as a powerful tool for a numerical solution to the problem of optimal prestraining of anchors in the rock surrounding a tunnel. The basic results are briefly summarized in this paper and the theory is applied to the optimization of prestress in the anchors.

An analysis of heterogeneous bodies in general may be based on extended dual Hashin-Shtrikman variational principle

\[
U^* = U^{0*} - \frac{1}{2} \int_\Omega \left\{ [M_{ijkl}]^{-1} (\gamma_{ij} - \mu_{ij}) (\gamma_{kl} - \mu_{kl}) - 2 \gamma_{ij} \sigma_{ij}^{0} - \sigma_{ij}' \gamma_{ij} \right\} d\Omega
\]

where variations are considered with respect to the fields \( \gamma_{ij} \) (polarizations) and \( \sigma_{ij}' \). We have denoted

\[
U^{0*} = \frac{1}{2} \int_\Omega \sigma_{ij}^{0} \epsilon_{ij}^{0} d\Omega = \frac{1}{2} \int_\Omega M_{ijkl}^{0} \sigma_{ij}^{0} \sigma_{kl}^{0} d\Omega
\]

and the quantities with superscript 0 are responses of the homogeneous body while primed quantities are differences between real and homogeneous bodies. \( M_{ijkl} \) is the compliance tensor.

It can be proved that the stationary value \( U^{**} \) of the functional \( U^* \) is equal to the actual complementary energy stored in the anisotropic and heterogeneous body.

Performing a variation of \( U^* \), integrating by parts, and setting the fundamental solution for the variation of \( \sigma_{ij}' \), we get

\[
c_{ij}(\xi) u_{ij}(\xi) = - \int_\Gamma p_{ik}(x, \xi) u_k(x) d\Gamma(x) + \int_\Omega \sigma_{ik}^{*}(x, \xi) \gamma_{kl}(x) d\Omega(x).
\]

Using the kinematic and the constitutive equations, we derive

\[
\sigma_{ij}^{*}(\xi) = - \int_\Gamma s_{ij}^{*}(x, \xi) u_k(x) d\Gamma(x) + \int_\Omega \sigma_{ij}^{*kl}(x, \xi) \gamma_{kl}(x) d\Omega(x) + \tilde{C}[\gamma_{ij}(\xi)],
\]

where the starred quantities are known kernels. The convected term \( \tilde{C} \) arises at the internal point \( \xi \in \Omega \) by the exchange of the order of integration and differentiation.
After discretization of the boundary into boundary elements as well as of the domain into internal cells with constant stress and eigenstrain distributions we get

\[ Pu' - S' \sigma - S \mu = 0, \quad \sigma' = -Bu' + \Sigma \epsilon + \Sigma \mu, \]

As the regular matrix \( P \) may be inverted, elimination of \( u' \) gives

\[ V \sigma = \sigma^0 + Z \mu, \quad V = I - \Sigma' + B P^{-1} S', \quad Z = \Sigma - B P^{-1} S. \]

Obviously, \( V \) is a regular matrix. The influence function matrix is equal to \( V^{-1} Z \) while \( V^{-1} \) is the mechanical concentration function matrix.

As, for the sake of simplicity, we assume that in each cell constant distributions of both stress and eigenstrain fields are prescribed, the relation between stresses \( \sigma^k \) in the subdomains \( \Omega_k, k = 1, \ldots, m \), and the eigenstrains \( \mu^l, l = 1, \ldots, n \), reads

\[(\sigma_i^k) = \sum_{j=1}^6 \sum_{l=1}^{m} (B_{ij})^{kl} (\sigma_i^0)^l + \sum_{j=1}^6 \sum_{l=1}^n (G_{ij})^{kl} (\mu_j^l)^l, i = 1, \ldots, 6, k = 1, \ldots, m \]

where \( B = V^{-1} \) and \( G = V^{-1} Z \). The stresses \( (\sigma_i^0)^k \) are known quantities.

A natural requirement is to assure that the stresses be as small as possible. This means that the variance

\[ I(\mu_j^l) = \left( \sum_{i=1}^6 \sum_{k=1}^m (\sigma_i^k)^2 \right) \rightarrow \text{minimum} \]

Differentiation of \( I \) with respect to \( (\mu_j^0)^l \) leads to a system of linear algebraic equations for unknown \( (\mu_j^0)^l \).

To study the behavior of the optimal radial prestrain of anchors the surrounding rock of a tunnel, a sample example has been prepared. The first layer represents the concrete lining, the inner radius of which is 3.5 m and the outer radius is 4 m. The thickness of the rock considered is 1 m. Concrete B25 has the following stiffnesses: \( L_{ii} = 33.545 \text{ MPa}, \) \( L_{ij} = 5.5568 \text{ MPa}, \) \( i, j = r, \theta, z \) and the anchors are placed in a sandstone, its stiffnesses are \( L_{ii} = 12.019 \text{ MPa}, \) \( L_{ij} = 3.125 \text{ MPa}, \) \( i, j = r, \theta, z. \) Outer compression is 2 MPa. The length of the structure is 5 m. The results are measured at \( z = 0 \) and the structure is considered to be symmetric with respect to the plane \( Oxy. \)

When no eigenstrain is applied, the volume averaged hoop stress in the lining is 12.95 MPa, while in the rock it is 3.53 MPa. Prestraining of the rock by \( \mu_r = 0.006276, \) we get the following optimized volume averaged hoop stresses: 4 MPa in the lining and 8 MPa in the sandstone.

References:

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LARGE DISPLACEMENT ANALYSES
OF SHELLS

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Key words: unbalanced, incremental, shell

Different possibilities of computation of unbalanced forces are described in this paper. Assumptions are small strains and medium rotations. The updated Lagrangian formulation and the constant arc-length incremental method are used [1]. The stiffness matrix is based on the Green-Lagrange strain tensor. In an incremental form this tensor is decomposed into linear and nonlinear parts. The discretization of the linearized principle of virtual displacements can be written as

\[
([K_L] + [K_{NL}]) \{\Delta r\} = \{\Delta R\} - \{\Delta F_r\} = \{g_r\}
\]

where \([K_L],[K_{NL}]\) are the linear and non linear parts of stiffness matrix respectively, \(\{\Delta r\}\) is the incremental displacement vector and \(\{g_r\}\) represents the unbalanced force vector.

A triangular shell element is assembled from a membrane element with rotational degrees of freedom about z-axis and a thin plate bending element. Both stiffness matrices are derived using natural deformations and subsequently extended for a rigid body motion [3]. The equation is solved by minimizing the unbalanced force vector as well as possible.

![Unbalanced forced vector](image)

Fig. 1: Unbalanced forced vector

Regarding the incremental form of the displacement vector, we can compute the unbalanced force vector from the global or natural displacements or from the global displacements of the plate and natural displacements of the membrane. The latter alternative seems to be better. We can then remove the false natural displacements due to second order effects.

With respect to the type of stiffness matrix we can divide the method of evaluation of the unbalanced force vector into two basic groups: 1) Numerical computation related to the last stiffness matrix at the beginning of the increment \([K_t]\) – this way is suitable for structures with prevailing bending effects. 2) Computation related to the updated nonlinear part of the stiffness matrix \([K_s]\) – suitable for shell structures.
Sample solutions. A cylindrical shell subjected to a concentrated load at the center is simply supported along straight edges and free along the curved ones. Large displacement response of the cylindrical shell at the center point is compared with the result by Krysl and Kratzig [2]. There are no bifurcation points along the loading path. From Fig. 2, excellent correlation is evident. For obtaining the critical point, three load increments are sufficient if the Newton iteration is used. When applying the Modified Newton iteration, it is necessary to reduce the load increment. In Fig. 2, the comparison of the above two approaches is presented.

References:

This research has been conducted at the Department of Structural Mechanics as part of the research project "Reability - Based Design of Composite Plates and shells" and has been supported by CTU grant No. 10018225.
The process of structural optimization implies producing the best possible design for a structure under prescribed loading conditions. The process of optimization has many aspects, but as a rule, in structural optimization we deal only with parameters which have direct influence on mechanical behaviour of the structure. We do not include the technological aspects. Anyway, this reduced understanding of optimization can be also very complicated, especially in multicriteria structural optimization. In all cases the formulation of optimization task have to be provided very carefully.

The aims of optimizations are various. We can optimize weight, shape, stresses, distribution of deformations and so on. According to aims, we have to choose the right method of optimization. There are two main groups of these. The first one is based on strictly mathematical formulation of optimization task which includes the formulation of objective and constraint functions and numerical solution by the mathematical programming methods. The second group of methods is more intuitive. In these methods the analogies with processes in biological organisms are used. As examples we can mention Jenkin's work [1] based on genetic algorithm or Mattheck's works [2, 3] based on growing processes of organisms. Next, we will describe a variant of the method used by Rodriguez-Velazquez and Seireg [4] and more recently by Xie and Steven [5, 6]. The aim of described optimization is to improve a distribution of stresses in the structure. The main idea of optimization lies in the fact that the parts of the structure with very low stress level have very small carrying facility so these parts can be extracted from the structure. If we apply for analysis the finite element method, the consequence of this is that we extract the understressed finite elements. The question is what is a criterium for the exclusion. It was proved that at the very beginning of optimization we can extract the elements with stresses under 1 or 2 percent of the average stress in the structure and after reanalysis we try again to apply the same rule. If there are no elements that fulfill our criterium for extraction we increase the percentage for extraction and recompute the computation. In order to have the same "weight" contribution of every finite element to computation of average stress all elements used must have the same size and shape. The extraction of the finite elements can be provided by natural way. However, in our computations we extracted the finite elements artificially by decreasing the Young's modulus. Advantage of this is that the programming is more simple. Drawback is in the fact that we do not decrease the number of equations in the finite element analysis.

On the Fig. 1 you can see the structure before optimization, and Fig. 2 shows you the final shape. The ratio of average stress in the i-th iteration to average stress at the beginning of optimization you can find in Fig. 3.
Fig. 1: Structure before optimization  
Fig. 2: Structure after optimization  

Fig. 3: Ratio of actual average stress to average stress before optimization

References:


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FATIGUE LIFE OF BRIDGE

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Key words: simulation, fatigue life, service life, crack prediction, fracture mechanics, Wöhler curve, PREFFAS model, ONERA model, CORPUS model

The EVA (Enabling Vibration Analysis) system was developed by Čulík at the department of Structural Mechanics in the Faculty of Civil Engineering at the Czech technical University in Prague. The system makes it possible to simulate on a computer the evolution of stress in time for some part of a structure during the passage of road or railway vehicles along a bridge.

The simulation model has two parts, the model of bridge vibration and the model of vehicle vibration which influence each other. The whole model makes it possible to determine the evolution of stress in time for some part of a structure for various velocities and roadway surface unevennesses, some arrangement of vehicles, some distance between the vehicles etc.

The traffic reconnaissance should have already made known the traffic density at the place where the bridge will be designed, and this means that the average numbers of vehicles per time unit, divided according to vehicles types, will be known.

We divided the all vehicles to simulation experiments. Each simulation experiment has a type of vehicle or some arrangement of vehicles, velocity, roadway surface unevenness etc. The result of each simulation experiment is the evolution of stress in time for the observed part of the structure.

The evolution of a stress is decomposed into the basic harmonic modes and the effect on the material fatigue life is watched. The material fatigue life can be determined using the concept of Wöhler curves, or, alternatively, crack growth based on linear elastic fracture mechanics.

If the bridge material fatigue life is observed then two simulation stages have to be computed: the crack initiation stage and the crack growth stage. The second stage is decisive. The concept of Wöhler curves considers the both stages. The concept of linear elastic fracture mechanics can be used if the initial length of crack is known or if a small initial crack is supposed in a newly built structure.

The EVA system makes it possible to determine a fatigue life according to Wöhler curves or according to fracture mechanics.

If the concept of Wöhler curves is used the evolution of stress is decomposed by the rain flow method into basic harmonic modes. The number of periods up to the time of critical crack length $N_i$ for each harmonic mode is computed according to the formulas which was published at Czech standard ČSN 736205, ČSN 731401 or PENV 1994-1-1 (new Czech standard ČSN 731401).

The oscillation is not harmonic, therefore the Palmgren–Miner hypothesis will be used

$$\sum_{i=1}^{m} \frac{T_{r_i}}{n_i} = 1$$

(1)
where $T$ is the fatigue life and $r_i$ is a number of periods in each group (the number of vehicles corresponding to the experiment type). The fatigue life is calculated from (1).

If the concept of linear elastic fracture mechanics is used then the crack growth is simulated from the initial length till the critical length and corresponding time is summarized according to Paris law

$$\frac{da}{dN} = C \Delta K^n$$ (2)

The following alternative formula can be used

$$\frac{da}{dN} = A \left( (\Delta KH)^\theta - \Delta K_0^{\theta(1-\alpha)} \Delta KH \right)$$

where $a$ is the crack length, $N$ is the number of periods, $\Delta K$ is the range of intensity stress factor, $\Delta K_0$ is threshold stress intensity factor, $\sigma_0$ is average stress, $\Delta \sigma$ is stress range and $C, n, A, \beta, \alpha$ are material constants.

The above described methods don't consider the stress history and the result can be not correct.

The PREFFAS, ONERA and CORPUS models calculate maximum and minimum of the stress intensity factors at each stress cycle. The models calculate the opening stress intensity factor and then they calculate for the effective range of stress intensity factor (maximum minus opening value) the crack length difference according to the Paris law (2). The calculation algorithms of opening stress intensity factors are different for the PREFFAS, ONERA and CORPUS models. This models give more correct results because the stress history is respected.

The PREFFAS model considers the opening stress intensity factor $K_{op}$ as a maximum of

$$K_{op,i,k} = K_{max,i} - \left( A + B \frac{K_{min,k}}{K_{max,i}} \right) (K_{max,i} - K_{min,k})$$

for $j = 1$ to $i - 1$ and for all $k \in (j,i)$, where $A, B$ are material constants.

The ONERA model considers that the crack is opened if the stress forms a new plastic zone.

The CORPUS stress opening model is based on a loss of connection during the crack opening at the highest place of a crack surface.

References:

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STATIC ANALYSIS OF CABLE-STAYED BRIDGE SYSTEMS

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Key words: bridges, statics, theory, automation, stiffening girder, cable, towers, suspensions

Recently, modern aesthetic and economically very advantageous cable-stayed bridges and cable footbridges for pedestrians have been used for bridging wide vales and rivers more frequently. For static analysis of cable-stayed bridge systems a new method based on the second order theory has been derived which is fully computer automated. By means of this method, safe and economical design of basic carrying elements of the system can be carried out.

Fig. 1 Cable-stayed bridge

A scheme of a cable-stayed bridge with a stiffening girder (1), towers (2), skew cable suspensions (3) and anchor cables (4) is given in Fig. 1. The stiffening girder is of constant cross section; it is supported by one exterior rigid support (immovable joint) and by other remaining supports movable in horizontal direction. At the places where the skew elastic cable suspensions are attached to the stiffening girder, vertical elastically flexible supports of the girder are considered. The system of skew suspension cables can be arranged in the longitudinal direction of the bridge either symmetrically with suspension on two towers (Fig. 1) or asymmetrically on one tower. The forking of suspension cables can be bundle- (Fig. 1), harp- or fan-shaped. The towers are straddling the stiffening girder and can be hinge or joint fixed at the footing. The anchor cables are attached to the tower heads and anchored either into the stiffening girder (Fig. 1) or into the anchoring blocks. It is considered a dead and arbitrary live loading of a continuous stiffening girder as well as a movable one with respect to the temperature changes.

We carry out the statical solution of cable-stayed system by means of the force method. The degree of static indetermination of the system \( n_s = a + p_e - 3 \), where \( a \) is the components.
number of the reactions of exterior supports of the stiffening girder and \( p_s \) is the number of cable suspensions. As statically indeterminate magnitudes \( x_i \) (\( i = 1, 2, \ldots, n_s \)) we choose the bending moments of the stiffening girder over exterior supports and at attachment places of suspension cables to the girder. The basic statically defined system is formed by simple girders, the number of which equals the number of continuous girder spans on elastic supports. The support moments over the exterior supports and at places of cable suspensions are solved from a system of \( n_s \) five-moment equations. From the known support moments, the remaining statical magnitudes of stiffening girder can be determined, inclusive of the reactions in its exterior attachments and in elastically flexible supports, as well. It is possible to determine the tensile axial forces in suspension cables by means of these magnitudes and then we can determine from them the normal forces in anchor cables and compressing forces of the towers.

We solve the influence of movable loading on the continuous stiffening girder by means of influence lines using the combination of kinematic method (the shape of an influence line) with the analytical method (determining of the ordinates). By means of the computational programm BRIDGES it is possible to construct the influence lines of statical magnitudes, basic carrying elements of cable-stayed bridge system. From the calculated ordinates each influence line can be drawn and its evaluating for uniform loading can be carried out.

References:


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CRACK GROWTH SIMULATION

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Key words: energy release rate, equivalent modes, maximum circumferential stress theory, notch analysis, propagation laws

Numerical modeling of crack propagation is of great importance to the life prediction of engineering structures. For this purpose, among other methods, the so called Element Free Galerkin one has proved to be most competent of late. It demands nodes only and expresses the external and internal boundaries, the dividing line of the model, too, no element connexion being required. Hence it followed that exact stress intesity factors may be calculated by means of EFG without enlarging the displacement field and that crack growth can be plainly simulated for it necessitates nearly no refining of a element mesh.

Fig. 1: Fatigue crack propagation problem

E.g., the growth of fatigue cracks issuing from holes in a plate with tension loading (Fig. 1) is described by dint of both the Paris-Erdogan relation and, if need be, another commonly used propagation laws (published by the authors Forman, Walker).

Otherwise, conforming with [2], the propagation law is assumed in a generalized form:

\[
\frac{da}{dN} = f(\Delta K_{eq})Z(a),
\]

where \(Z(a)\) is a random function and \(f(\Delta K)\) the deterministic function suggested by I.C. Newman:

\[
f(\Delta K_{eq}) = C(1 - R^m)\Delta K_{eq}^n(\Delta K_{eq} - \Delta K_{eq,th})^p[(1 - R)K_c - \Delta K_{eq}]^{-q},
\]
\[ C, m, n, p \text{ and } q \text{ being material dependent parameters and } \Delta K_{eq} \ldots \text{ the range of equivalent mode I stress intensity factors:} \]

\[ \Delta K_{eq} = K_{eq}^{max} - K_{eq}^{min}, \quad (3) \]

where \( K_{eq}^{min} \) and \( K_{eq}^{max} \) are the minimum and maximum equivalent mode I stress intensity factors.

According to [1], to simulate mixed-mode behaviour, fatigue phenomena are expressed by the equation for \( \Delta K_{eq} \), as follows

\[ \Delta K_{eq} = \Delta K_1 \cos^3 \frac{\Theta}{2} - 3 \Delta K_{II} \cos^2 \frac{\Theta}{2} \sin \frac{\Theta}{2}, \quad (4) \]

The crack propagation in case of the initial angle \( \Theta = 45^\circ \) is depicted in Fig. 2 that demonstrates contour diagrams for the stresses at two computation phases. At that rate, no crack bridging emerges, the cracks evidently pass over each other.

\[ \text{Fig. 2: Effective stress in the crack growth process } \Theta = 45^\circ, \text{ final stadium} \]

The method presented is likely to prove operative even to the solution of fracture problems: kinking and blunt cracks, transient analysis and the moving boundary. The results indicate the EFG method being particularly effective in the investigation of processual fracture as it may precisely determine stress intensity factors for irregular layout of nodes.

References:


This research has been conducted at the Department of Engineering Structures of Klokner Institute as part of the research project “Limit States of Steel Plate Elements” and has been supported by GAČR grant No. 103/94/0086.
A simplified design of struts with a variable cross-section, Fig. 1, according to Eurocode No. 3, Cl. 5.5.1.3-(2), Ref. [1] has been suggested, based on the modification of the basic procedure for prismatic members. Sections at any position along the strut length may appear critical. Their design buckling resistances (1) can be calculated with the aid of tables or charts with buckling coefficients (2) depending on modified relative initial imperfections (3) and relative slendernesses (4). A detailed explanation of the procedure can be found in Ref. [2]. The main formulas are accumulated in Fig. 1.

**Key words:** steel structures, buckling, non-uniform struts

\[
N(x)_{BD} = \chi(x) \beta(x) A(x) f_y / \gamma_M
\]

Buckling coefficient for individual sections at \( x \)

\[
\chi(x) = \frac{1}{\Phi(x) + \sqrt{\Phi(x)^2 - \Lambda(x)}}
\]

where \( \Phi(x) = 0.5 \left[ 1 + \overline{m}(x) + \Lambda(x) \right] \) ... function of (3) and (4)

\[
\overline{m}(x) = \alpha \left[ \Lambda(x) - 0.2 \right] k_y(x) \gamma(x) \quad \text{... relative initial eccentricity}
\]

\[
\gamma(x) = C \tan \frac{\pi}{2Lx} \int_{0}^{x} \sqrt{\vartheta(t)} \, dt + D \cos \frac{\pi}{2Lx} \int_{0}^{x} \vartheta(t) \, dt
\]

with \( D, K \) ... from boundary conditions \( \gamma(0) = \gamma(L) = 0 \)

\[
C \quad \text{... select to obtain max}(x) = 1 \quad \text{...} \quad \omega(x) = \frac{f_{\text{uw}}}{f(x)}
\]

\[
\Lambda(x) = \frac{\lambda(x)}{\gamma(x)} \sqrt{\frac{E}{f_y}} \quad \text{... relative slenderness}
\]

\[
\lambda(x) = L \sqrt{\frac{A(x)}{I_{\text{om}}}} \quad \text{... absolute slenderness}
\]

\[
I_d = \gamma I_{\text{om}} \quad \text{...} \quad \gamma \text{ from Table 1}
\]

Here \( \alpha, \beta, \gamma, k_y \) ... coefficients defined in (1)

\[
k_y(x) = (1 - k_x) + 2k_y \Lambda(x)
\]

\[
\lambda_i = \frac{E}{f_y} \quad \text{... slenderness corresponding to yield stress} f_y
\]

---

Fig. 1: Main formulas
Tab. 1: Coefficients $\gamma$ for calculating the ideal moment of inertia $I_{id} = \gamma I_{max}$

<table>
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<tr>
<th>$I_{id} / I_{nc}$</th>
<th>Section type</th>
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<th>B</th>
<th>C</th>
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References:


This research has been conducted at the Department of Engineering Structures of Klokner Institute as a part of the research project "Limit States of Steel Plate Elements" and has been supported by GAČR grant No. 103/94/0086.

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FAILURE HISTORY OF SLOPES WITH PREDESTINATED SLIP SURFACE

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Key words: slope stability, failure history, mechanics, predestinated slip surface

In the framework of experimental study the laboratory has been completed by apparatuses that enable one a continual record of tailings deformations.

New material has been developed, based on epoxy resin, that simulates a slip at the tailings bottom. This slip layer will make it possible the movement of the tailings body. Three models has been build up and the deformation of the slopes has been observed, including the cracks development. The cracks has been created in the originally homogeneous material of the tailings when tilting the stand by 10 or 15 degrees. At the toe of the tailings a pile has been bored, instrumented with strain gages, for observing pile reactions (the forces, that is developed by the pile when restraining the slope movement). Photogrammetric evaluation of tailing movements was made at department of geodesy at CTU Prague.

A numerical modeling study was initiated using both UDEC and FLAC distinct element modeling codes. Previous numerical modeling had been performed on the project, however it had used finite element modeling. It is resulting in accuracy only to the point of initiation of failure. Distinct element modeling allows large displacements to occur within the model, more accurately simulating real world and physical modeling results. Initial studies were performed with UDEC, however FLAC was subsequently chosen because it more accurately simulates soil mechanics such as those encountered in the studies tailings deposits.

A sequence of studies was completed using material properties and model geometry which matched the physical model – a sloped tailings deposit located above a dipping shear surface. The body was modeled in an unreinforced state as well as a reinforced condition. The physical models reinforce the toe of the slope with a pile; such reinforcement was not available in the numerical modeling, however a plate on the surface of the slope tied back with a cable into the slope simulated the pile well. A effect of reinforcement strength was studied by varying the yield strength and cross-sectional area of the cable.

Attached figures show some typical results.

This research has been conducted at the Department of Engineering Structures, Klokner Institute CTU and Denver Research Center and is based on work sponsored by the U.S.-Czechoslovak Science and Technology Joint Fund in cooperation with MPO CR and BOM USA, as part of the research project “Depot Capacity”, No. 94 028 (No. CTU 1671001).
Decomposition of tailings body during slip

\[ T_0 + 3\text{h} 45\text{min} \]

Grid plot
Initial grid

Grid plot
No tieback, 2000 steps

\[ T_0 + 46\text{h} \]

Movings of individual points during the slip

Grid plot
No tieback, 4670 steps

\[ T_0 + 70\text{h} \]

Change of surface during slip

Displacement vectors
Vector Length: \(3.0000\times10^8\)
Boundary plot
No tieback, 4670 time steps

Grid plot
Cable plot
Beam plot
Cable yield strength = 2.8e4 Pa
Cable area = 1e-3 m^2
16860 time steps
COUPLING OF PHYSICAL AND MATHEMATICAL MODELS IN GEOTECHNICS

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Key words: tunnel heading, boundary element method, physical modeling, coupled modeling, material properties of rock

In the paper we discuss a possible solution of the stability of an opening (e.g. tunnel) in a rock continuum under assumption that the mechanical behavior of the continuum is approximately known from the physical model. The stability of the opening is studied by means of the BEM, being formulated as a contact problem. By virtue of this technology, the limit state analysis is carried out. The mathematical model involves the Uzawa’s algorithms solving the classical problem of the generalized Coulomb’s friction model. The distribution of material properties is simulated as a parametrical study in the mathematical model.

This procedure was successfully applied to an assessment of behavior of the rock mass in vicinity of an opening excavated in mine area near the town of Ostrava. The paper brings about some results following this study.

Principles of new design methods of underground construction works in soft rocks can be formulated on the basis of results from extensive tests on physical models, as well as from mathematical models, and, eventually, from comparison of results from both the models. Properties of these rocks differ from site to site. Rocks are frequently separated by discontinuity planes. These planes and the weakening zones cause disintegration or susceptibility to disintegration of the rock mass into structural units of various forms, size and properties. Their properties change also with the stress mode and depend on the stressing force to which the rock was exposed in the past.

It results from the above mentioned facts that the properties of the rock environment cannot be measured neither on small rock samples nor by the isolated sporadic tests in site. In the first case, we cannot evaluate the effect of weakening planes, and in the other one the dispersion variance caused by inhomogeneities of the rock mass. In both cases, the necessary conditions of the physical similitude are usually not observed. These conditions would require to measure the rock properties under stress conditions equal to stressing force to which they are exposed during construction and after completion of construction works. These requirements can very easily be observed on physical models from equivalent materials.

Results from laboratory tests can directly be used as input data to mathematical solution provided the constitutive relation between the stress tensor and strains is known and provided the relative homogeneity and isotropy are assumed.

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On the other hand the stresses are difficult to obtain from the physical modeling. This is the moment when the mathematical model can help and coupling of both models can approximate the real state of the rock continuum and the underground structure (e.g. lining).

A very important conclusion results from some selected rock mechanics problems, by the method of physical and mathematical modeling, and from their mutual comparison. It is possible, by means of a test on the physical model, to establish conditions which are of primary interest for us (e.g. when the resistance of internal forces against failure is minimum). For conditions thus established, the deformation and stress of the rock environment in the neighborhood of the underground opening are determined by the boundary element method (used here) or with the aid of the FEM or by combination of FEM & BEM. A part of the problem can therefore be resolved by tests on the physical model and the results obtained can be used as input values for final solution by some numerical method. In this way, both procedures can be adequately combined and completed, advantages and drawbacks of both of them acting complementarily.

A stability study concerning an influence of the backfill of the opening was carried out in 2D (longitudinal direction of the opening was preferred), based on the BEM computation. The domain above the tunnel heading was split into two parts (two subdomains \( \Gamma_1 \) and \( \Gamma_r \)) and along the boundaries of these parts the surface forces were computed from Uzawa’s algorithm. They simulate an admissible relative displacement distribution along the boundary between these parts. Another forces were simulating the influence of the third direction and were applied along the faces at the bottom and at the roof of the opening. These forces were expressed by virtue of a kind of Winkler’s coefficient \( k \) [MPa/m]. Material constants of the domain had the following values: \( E = 55 \, 000 \, \text{MPa} \), \( \nu = 0.29 \). The capacity \( s \) of the fictitious contact line is expressed by the relation:

\[
s = \frac{l_0}{l} \times 100\%
\]

where \( l_0 \) is the length of the part where \( [u] \), \( \neq 0 \) and \( l \) is the total length of the contact between \( \Gamma_1 \) and \( \Gamma_r \). \([u]_t\) is the difference between tangential displacements with respect to \( \Gamma_1 \) and \( \Gamma_r \).

Other studies were carried out by the authors and in the future, this model should improve the information on the mechanic behavior of the system studied.

References:


This research has been conducted at the Department of Structural Mechanics as part of the research project “Stability of Tunnel Heading” and has been supported by GA ČR grant No. 103/95/1265.
MICROMECHANICAL MODELLING IN THEORY OF COMPOSITE MATERIALS

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Key words: micromechanics, method of cells, microstrains, microstresses, engineering constants

The micromechanical analysis has emerged as a critical research area investigating properties of composite materials by modelling the behaviour of its constituents, their geometric properties (shape and packing), interface conditions, internal damage initiation and accumulation mechanisms.

The micromechanical modelling experienced considerable qualitative advancement from models based on classical solutions to complex models requiring application of fast computers with large capacity and advanced software. Among such micromechanical models, the Aboudi's model [1] has a specific position, being based on simple geometric modelling of the phases (in form of rectangular blocks) and simple approximation of the microvariables allowing the fulfillment of the microcontinuity (microtransfer) conditions in the "micro-integral" sense only. From the educational point of view, all this features are in favour of the adoption of this method in the learning process.

The original version of the method can be easily generalized by considering multivolume representative cell \( \{\alpha_1, \alpha_2, \alpha_3\}; \alpha_i = 1, \ldots, \rho_i; \) with \( \rho_i \) cell volume subdivisions in each coordinate direction. In each subcell \( \{\alpha_1, \alpha_2, \alpha_3\}, \) a local coordinate system \( \xi_i^{(\alpha)} \) is introduced, in which the subcell interfaces are defined as \( \xi_i^{(\alpha)} = \pm \frac{1}{2} h_i \alpha_i. \) The microdisplacements are then modelled as

\[
u_i^{(\alpha_1, \alpha_2, \alpha_3)} = w_i^{(\alpha_1, \alpha_2, \alpha_3)} + \sum_{j=1}^{3} \xi_j^{(\alpha)} \phi_i^{(\alpha_1, \alpha_2, \alpha_3)}.
\]

and from the conditions of displacement continuity we can derive relations between micro- and macro-displacements (denoted as \( w_i \))

\[
\sum_{k=1}^{\rho_j} h_{j,k} \phi_i^{(\beta_i, \beta_j, \beta_k)} = \mathcal{H}_j \frac{\partial w_i}{\partial x_j}, \quad \mathcal{H}_j = \sum_{k=1}^{\rho_j} h_{j,k},
\]

\[
w_i = w_i^{(\alpha_1, \alpha_2, \alpha_3)} \quad (i, j, l = 1, 2, 3; \beta_i = k \quad \text{if} \quad l = j, \\
\beta_i = 1, \ldots, \rho_i \quad \text{if} \quad l \neq j).
\]

Additional equations are provided by the interface microstress transfer conditions

\[
\sigma_{ji}^{(\alpha_1, \alpha_2, \alpha_3)} = \sigma_{ji}^{(\beta_1, \beta_2, \beta_3)} \quad (i, j, k = 1, 2, 3),
\]

\[
\alpha_j = 1, 2, \ldots, \rho_j - 1; \quad \beta_j = \alpha_{j+1}; \\
\alpha_k = 1, 2, \ldots, \rho_k, \quad \beta_k = \alpha_k \quad \text{if} \quad k \neq j;
\]

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and by microvolume constitutive equations (with the matrix $C^{(\alpha_1 \alpha_2 \alpha_3)}$ of the component elastic coefficients).

The relations between average (macro-) and micro- stresses and strains may be expressed in the form

$$
\bar{\sigma}_{ij} = \sum_{\alpha_1 \alpha_2 \alpha_3} v^{(\alpha_1 \alpha_2 \alpha_3)} \sigma_{ij}^{(\alpha_1 \alpha_2 \alpha_3)}, \quad \bar{\varepsilon}_{ij} = \sum_{\alpha_1 \alpha_2 \alpha_3} v^{(\alpha_1 \alpha_2 \alpha_3)} \varepsilon_{ij}^{(\alpha_1 \alpha_2 \alpha_3)}
$$

with $v^{(\alpha_1 \alpha_2 \alpha_3)}$ denoting the "volume-fraction" factor pertaining to the subcell $(\alpha_1 \alpha_2 \alpha_3)$.

The equations (2) to (4) allow the elimination of all the microvariables. The resulting equations acquire the form of the overall constitutive equations

$$
\{\bar{\sigma}_{11}, \bar{\sigma}_{22}, \bar{\sigma}_{33}, \bar{\sigma}_{12}, \bar{\sigma}_{23}, \bar{\sigma}_{31}\}^T = \bar{C} \cdot \{\bar{\varepsilon}_{11}, \bar{\varepsilon}_{22}, \bar{\varepsilon}_{33}, \bar{\varepsilon}_{12}, \bar{\varepsilon}_{23}, \bar{\varepsilon}_{31}\}^T,
$$

the matrix of the average elastic coefficients of the analyzed composite material being denoted as $\bar{C}$.

On the basis of the equations (2) to (5), the computer program has been developed to help the students to acquire the basic knowledge on the elements of the micromechanical modelling. It is envisioned, that postgraduate students will further develop this program by including procedures describing viscoelastic and plastic effects in composite material behaviour as well as effects associated with initiation and accumulation of damage.

The most simple version of this program corresponds to the original Aboudi's model for fibrous composites ($\rho_1 = 1$, $\rho_2 = \rho_3 = 2$) with the fiber being modelled by the subcell $(1,1,1)$ and the subcells $(1,1,2)$, $(1,2,1)$ and $(1,2,2)$ having material properties of the matrix. A few results of the program application are shown in the following table:

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References:


This research has been conducted at the Department of Composite Materials and Structures as part of the research project "Development of the Interdisciplinary Study in the Field of Composite Materials" and has been supported by Higher Education Development Grant (FRVS) No. 0339/2.
Kevlar- fibre reinforced composites with epoxy matrix subjected to loading develop matrix cracks and fibre failure preceding fibre debonding. The behaviour of epoxy matrix in standard conditions (20°C, 50% r.h.) is brittle and is related to the deformation and failure micromechanisms. Damage initiation and growth consists of the development of matrix cracking accompanied by debonding between fibres and matrix and fibre failure. The debonding is dependent on the properties of epoxy matrix, kevlar fibres and interface.

Experimental measurements have been performed on kevlar-epoxy composites from prepreg Vicotex 913/120 with 50% content of kevlar fibres 49. A set of the specimens have been prepared in warp, weft and 45° direction. The specimens have been subjected to monotonic loading (speed 1 mm.min⁻¹) in longitudinal direction and the load, longitudinal and transverse strains have been measured and data collected by Hewlett-Packard system HP 3852, Fig. 1 [1].

The curves between longitudinal stress and strain have been plotted. A typical stress-strain curve doesn’t reveal clear characteristic features, such as proportional limit, strain hardening/softening region etc. Therefore they have been approximated by a quadratic regression technique.

We attempt to correlate the stress-strain behaviour with failure mechanisms deduced from nondestructive measurements (NDM). An ultrasonic NDM has been used recently [2]. Fibre-matrix debonding and initiation of cracks is difficult to observe directly. Indirect proof of these effects has been obtained through acoustic emission (AE) measurements.
Cumulative AE counts and AE events increase roughly linearly with strain and in very small
region suddenly changes the slope as illustrated in Fig. 2. In that region the initialization and
fibre debonding is assumed. Corresponding values for the set of specimens above mentioned
have been determined.

Fig. 2: Longitudinal stress and AE counts vs. strain

References:
in Graphite/Epoxy Laminates, Conf. ICCE/1, New Orleans, Proceedings, August 1994

This research has been conducted at the Department of Composite Materials and Structures
as a part of the research project “Micro- and Macromechanics of Composite Structures”
and has been supported by grant No. 103/93/1046 of the Grant Agency CR.
CYCLE MODELING OF RECIPROCATING AIR COMPRESSOR

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Key words: reciprocating compressor, cycle modeling, computer program, pressure and temperature diagrams, polytropic exponent

Working cycle of compressors and pneumatic machines consists of operations which work during an approximate constant pressure but are not represented as isobaric thermodynamic operations and of operations which are usually seen as polytropic operations with a constant polytropic exponent. For air compressors, for example, its value is given in the range of 1.20-1.50.

Today's availability corresponding with a computer technique allows to try to reach a more detailed evaluated solutions of operations which go on in the pneumatic cylinder originating at the first law of thermodynamics application by an open or closed system and of heat transfer laws. The starting series of computation during the course of gas compression and expansion having a constant velocity of the piston came up from a differential equation of the first law of thermodynamics for a closed system and an ideal gas complimented by a Newton law of heat transfer by convection. Runge-Kutta method of the 4th degree has been used for its solution. Because the working action has been aimed more to the problematics of reciprocating compressors, the next stage has derived the elementary energy balance equations of evaluation of four basic parts of compressor cycle which come out from a time discreditation of action and allow to solve more common cases after some adjustments including changes of boundary conditions and physical properties of gas during one cycle. A sinus course of piston velocity at the constant angular velocity with regard to the infinite length of the connecting rod has already been taken into account in all performed calculations.

The course of compression and expansion in all individual time intervals is a result of system solution of two linear equations – equation of state of an ideal gas and an equation of elementary energy balance for a closed thermodynamic system where heat transfer by convection is expressed by dependance on immediate area of inner heat transfer surface of the cylinder, heat-transfer coefficient from gas to the inner walls and an immediate temperature difference between gas and inner walls of the cylinder. Solution of discharge and suction arises from assumption of an unsteady process in an open thermodynamic system having a constant pressure, including the enthalpy flow of gas input or its output. A quadratic equation for gas temperature at its final point is obtained in each time interval.

System of computed programs have been used for basic orientational computation of compressive and expansion courses in cylinders of reciprocating compressors with a goal in mind to get first insight of courses and influences of some basic parameters (slimness of a cylinder, average piston velocity, compression ratio, relative size of an clearance space). Computed interactions and dependancy p-V, T-s, values of total heat transferring, wasted and performed work and corresponding total polytropic exponent from the starting and ending state of gas have been also obtained. By now it can be said, that the calculated
values of the total polytropic exponents, even in case of limited values of usual parameters, shows to be higher than usually presented in the literature.

A programme for basic quantities calculations of the whole reciprocating compressor has been set up from partial programes of elementary energy evaluations. First alternative came up as a result of probable constant temperature of the cylinder's inner wall during the whole cycle. This doesn't take into account the physical heat quantities of the compressor's cylinder part and any conditions for a heat transfer from the cylinder into the space around (cooling). The second alternative is an effort to include basic parts of the cylinder into a given thermodynamic system under much simplified conditions (infinitely high heat conductivity of the material the cylinder is made of, the same conditions for heat transfer for all its parts). The result of some of the calculation of the reciprocating air compressor cycle model with the overall heat transfer through the cylinder walls are marked on into diagrams p,T-FI (crank's angle). Consideration has been given to the simplification mentioned above as well as to the lack of detailed evidence as to the conditions of heat transfer inside of the cylinder. It is possible to make a conclusion only to the quality characteristics. The following conclusions dealing with the temperature and pressure during its course of work from the research of air compressors working in the usual range shows:

- The temperature of the cylinder wall is almost constant and its value ranges in the dependance on the compression ratio and cooling of the cylinder within 30–80°C.
- With the same values of the input gass mass, the slimness of the cylinder is not really a decisine factor.
- Influence of the average piston velocity as to the increase or decrease of gas temperature during compression or expansion is important only during an intensive cooling of the compressor's cylinder. Otherwise the course of compression and expansion is almost adiabatic.
- Obtained results of calculations dealing with probable values of the heat-transfer coefficient inside of the cylinder, corresponding total polytropic exponents in case of compression 1.32–1.40 and in case of expansion 1.40–1.42, are in agreement. Exponent of expansion shows always to be higher than the compression exponent. During the suction temperature of 20 °C, the air temperature at the end of compression reaches upto 350°C – values that are much higher than temperature in the oil lubricated cylinders of air compressors usually allowed.

With regard to the lack of literary facts about the conditions of heat transfer from gas to the cylinder walls, comparison as to the more precise calculations with a given experiment is necessary. Indication of an air compressor 2JSK-75-S is being prepared with a mutual cooperation of VKDI Compressors Orlik.

References:

*This research has been conducted at the Department of Thermodynamics as part of the research project "Modeling of compression and expansion in the pneumatic cylinders" and has been supported by TU Brno grant No. FP 959428.*
A NUMERICAL SOLVER FOR ELASTOHYDRODYNAMICALLY LUBRICATED LINE CONTACTS

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Key words: elastohydrodynamics, line contact, numerical solution, control volumes

This paper describes a developed numerical solver (computer program) for solution of pressure distribution in heavy loaded line contacts. A constant temperature is assumed, i.e. only small slip occurs within the contact. Solids of the contact are assumed to be elastically deformable and the deformations are essential. A fluid is not expected to flow across the contact within line contact. Because of very large changes of pressure up to three gigapascals, viscosity and density can be no longer assumed to be constant. Surfaces of solids in the contact area are supposed to be smooth. The contact is working under steady state conditions.

The fluid flow in narrow gap between the surfaces is described by one-dimensional Reynolds equation. The equation is derived from Navier-Stokes equations. Mass inertia forces are neglected. Boundary conditions of zero pressures in the inlet and outlet are applied. Moreover, a cavitation condition, i.e. only positive or zero pressure values are allowed. The deformation of the contact solids is evaluated via Timoshenko's integral formula. The film thickness is determined as a sum of geometric separation of non-deformated contact surfaces and the elastic deformation of them. A Roelands' viscosity pressure dependence is used. The density changes are approximated by Dowson and Higginson's formula. To deal with this problem, one have to solve a non-linear integro-differential boundary value problem. The position of the outlet boundary condition is unknown, because of the cavitation condition.

A control volume approach described in [4], is used to perform a discretization. It results to a system of non-linear algebraical equations. For the calculation of first "conductive" term in Reynolds equation a central discretization is used. The second "convective" term is calculated via upstream discretization. For the film thickness evaluation, it is supposed, that the pressure is constant over the control volume.

Because of a strong nonlinearity of viscosity, a robust method has to be use to reach high loads. It was found in [2], that the simple Gauss Seidel's iterative method is acceptable for moderate loads only. This solver is based on a Gauss Seidel's relaxation combined with one-dimensional method of cuttings. The method used in [3] is similar, but they used a one-dimensional Newton's method and the derivation has been performed analytically instead of numerically. That is not suitable for testing different discretization schemes. This method is sufficient for high loads (up to 3 GPa of Hertzian pressure). An underrelaxation factor about 0.25 is commonly used. Nodes are visited from the inlet to the outlet during the sweep. Algebraical equations are supposed to be satisfied, when a maximal residue is smaller than $10^{-9}$. 

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As a check of the validity of results, a comparison with minimum film thickness formula [2] has been performed. There has been chosen several groups of dimensionless parameters [1] to cover majority of real situations that can occur in hard EHL. Differences for film thicknesses are about 5\% which is good. A most typical situation, which illustrates a good convergence of the solver, (Hertzian pressure is equal to one GPa) is depicted.

The program in C language is available at the author's address. Computations has been performed on the SGI power challenger machine.

References:


This research has been conducted at the Department of Thermomechanics as part of the research project "A Numerical Solution of EHL Line and Contact Problem" and has been supported by TU of Brno grant No.359560
A BALL-PLATE MACHINE
FOR MEASURING ANTIWEAR FILMS
IN CONCENTRATED CONTACTS

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Key words: elastohydrodynamic lubrication, experimental equipment, antiwear films

Both the partial elastohydrodynamic and boundary lubrication are mostly used types of lubrication of rubbing surfaces and at the same time one of the most developing region of the tribology. Once the load is applied to the contact bodies the surface asperities start to contact one another. After that the lubrication film cannot do its main function i.e. reduction of friction and wear of the rubbing surfaces. To diminish friction and wear losses ZDDP antiwear additives are added to lubricating oils. These multifunction additives react with rubbed metals to form (on rubbing surfaces) antiwear surface films. Neither processes of forming antiwear additive films on rubbing surfaces have been understood thoroughly yet nor the thickness of these additive films have been measured correctly. The estimated values of the thickness of these additive films depend on used physical methods (transmission or scanning electron microscopy; reflection infrared spectroscopy; X-ray fluorescence; X-ray spectroscopy; ellipsometry...). These values are cited from that of monomolecular layers up to some hundred nanometers. The determination of the thickness of these additive films is one of the main factors in understanding of mechanisms of wear reduction. Antiwear additive films of the thickness about tenths nanometers reduce wear and friction through reduction of the modulus and yield stress of metals of the rubbing surfaces. While that of thickness of hundreds nanometers do not allow the surface asperities to contact one another at all. Optical interferometry (chromatic and monochromatic) is one of the most significant methods in measurement of the thickness of ZDDP additive films.

The aim of our research is to consider the validity of the hypotheses of function of antiwear ZDDP additive films forming on rubbing surfaces during partial EHD and boundary lubrications. It is possible then to evaluate the processes which lead to a scuffing of rubbing surfaces. The research of the behaviour of ZDDP additive films in different operating conditions includes determination of the thickness of the lubricating film between the rubbing surfaces, determination of the thickness of the additive antiwear film on the rubbing surfaces and measurement of the friction coefficient.

The first step of this research was the construction of experimental equipment so-called ball-plate machine. This experimental equipment (Fig. 1) enables the observation of the lubrication film and rubbing surfaces in the whole visible and infrared region of the electromagnetic spectrum and in a wide range of operating conditions (load, temperature, speed of rubbing surfaces, geometry and material of rubbing surfaces, lubricant, etc.). Its basic element is a couple of friction elements, consisting of a monocrystalline saphire disk of 20 mm in diameter, and of a shaped cylinder of 25.4 mm in diameter made of bearing steel 14209. The shaped cylinder driven through the shaft by DC servomotor (pure sliding)
is placed in the lubricant chamber that allows the oil and contact bodies to be heated on evaluated temperatures.

The results of this stage of studying of ZDDP additive films are thought as necessary introductory condition of the complex study (both physical and chemical) of additive films on rubbing surfaces. Thickness of both the lubricating and additive films will be determined by monochromatic and chromatic optical interferometry combined with photometric analysis. Chromatic interferometry will be used in order that to verify the data obtained from for this purpose for the first time used monochromatic interferometry.

![Experimental equipment](image)

Fig. 1: Experimental equipment

This research has been conducted at the Institute of Design as part of the research project "Experimental Study of Antiwear Aditive Films in Elastohydrodynamic and Boundary Lubrication" and has been supported by TU grant No. F-14-95.
RIGID-PLASTIC SIMULATION
OF FORMING PROCESSES
BY FINITE ELEMENTS

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Key words: forming simulation, flow formulation, rigid-plastic material, finite element method, rolling

Rigid-plastic model of material has a long tradition in the theory of forming. Its application simplifies substantially many practical forming problems, providing results with acceptable level of precision, as the neglected components of elastic strain constitute here only a tiny fraction of the total strain. The same reason is behind the effort to formulate and use a rigid-plastic algorithm in finite element codes, which are specialized in the area of forming simulation.

One of such algorithms was in the last time formulated at the department of Solid Mechanics TU Brno. Its objective was to enable analysis of practical forming problems on a standard PC 386/486 computer. Basic constitutive relation of our formulation is the Levy-Mises equation of rigid-plastic flow, which relates the deviatoric stress \( s_{ij} \) to strain rate \( \dot{\varepsilon}_{ij} \) according to

\[
s_{ij} = \frac{2\sigma}{3\dot{\varepsilon}} \dot{\varepsilon}_{ij}
\]

where \( \sigma \) and \( \dot{\varepsilon} \) are equivalent stress and strain rate. Several types of flow stress curve \( \sigma = f(\varepsilon, \dot{\varepsilon}, T) \) can be prescribed: strain hardening material, viscoplastic or thermo-viscoplastic one. The last model is the most demanding one as it requires simultaneous solution of a coupled problem of unsteady thermal conduction in the material. Nevertheless, for 2D problems, even this coupled thermal-deformational analysis can be run on the PC.

Besides the constitutive equation, appropriate kinematic relations, incompressibility condition and principle of virtual power present the set of field equations constituting the basis of so called flow formulation, for which the primary unknown variable is the velocity. The incompressibility condition is introduced by the penalty method via parameter \( \lambda \), in this case the virtual power principle reads

\[
\int_v s_{ij} \delta \dot{\varepsilon}_{ij} dv + \lambda \int_v \dot{\varepsilon}_{ij} \delta \dot{\varepsilon}_{ij} dv - \int_s p_i \delta v_i ds = 0
\]

where \( v_i, p_i \) are velocity and external surface load. Standard finite element discretization of the presented relations leads to a set of algebraic equations

\[
K \cdot V = F
\]
solved with respect to the nodal velocity matrix $V$. General solution strategy is the incremental-iterative Newton-Raphson procedure with geometry updating at the end of each increment.

Programs using the presented algorithm are generally applicable in many areas of forming. Of course, there are also some limitations. Neglecting the elastic part of deformation, the solution is not able to provide the information concerning residual stress at the end of the simulated process. That is why the flow formulation is more frequently used in the area of bulk forming than sheet metal forming, where the elastic spring back represents an important aspect of the simulation. Also the correct prediction of boundary between the elastic and plastic zone can be difficult in situations, where only a part of the body is plastically deformed.

Applicability of the algorithm will be illustrated on the simulation of flat products rolling, modelled as two dimensional (plane strain) or three dimensional case. Created programs ROL2D and ROL3D can solve such problems on PC as nonstationary ones, i.e. including the end effects of material entering/leaving the roll gap. The rolls are supposed to be rigid with friction between roll and material. The two dimensional model can be solved as a coupled thermal-deformational one, with dissipated deformational energy entering the heat balance equation and appropriate boundary conditions: convection in contact with the roll and convection with radiation on the free surface. Reliability of the programs was verified by a number of hot rolling simulations. Some will be presented at the Workshop, among them for instance the edge rolling simulation with successive vertical and horizontal mill passes.

References:


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MODEL OF INTERACTION BETWEEN FLEXIBLE STRUCTURE AND FLUID

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Key words: elastoacoustics, interaction

Model of interaction between flexible plate and closed rectangular acoustic space is analysed in the paper. The solution is done under presumption that the flexible plate is isotropic, according to the Kirchoff's hypothesis, and is thrust on its edges. The walls of the acoustic space are considered perfectly reflected (Fig. 1.).

The analysis is focused on investigation of the acoustic space size on eigenfrequency magnitudes of the analysed model. The eigenfrequency magnitudes relevant to the interaction model were compared with eigenfrequency magnitudes relevant to the in vacuo structural normal modes of a flexible plate and also compared with eigenfrequency magnitudes relevant to the rigid-walled acoustic space. The finite element system ANSYS was used for the numerical solution.

Fig. 1:

The measures of the analysed model are:

a) the plate: $a = 416$ mm, $b = 330$ mm, the thickness of the plate $h = 1.2$ mm,
the plate is made from dural;
b) the acoustic space: $a = 416$ mm, $b = 330$ mm, $d = 350$ mm, $200$ mm and $150$ mm.
The results of numerical solution are presented on Fig. 2.

The results of numerical solution are following. Eigenfrequency magnitudes of the interaction model relevant to the first structural mode \((m_r = m_p = 1)\) are greater than the eigenfrequency magnitudes corresponding to the first in vacuo structural mode of a plate. The scope of eigenfrequency magnitudes is from 9.36 % for \(d = 0.35\) m to 12.34 % for \(d = 0.15\) m. For higher structural modes differences of eigenfrequency magnitudes relevant to the interaction model and in vacuo structural modes of the plate are less than 4 %.

Analogous to the structural modes of the interaction model, the eigenfrequency magnitudes relevant to the acoustical modes of the interaction model were compared with the values of eigenfrequency magnitudes corresponding to the rectangular acoustic space with perfectly reflected walls. Differences of the eigenfrequency magnitudes not exceed the value of 4 % in the solved cases.

References:


This research has been conducted at the Department of Mechanics as part of the research project "Acoustic-Structural Couplings of Vibration Elastic Bodies in Interaction with Acoustical Medium in a Confined Region" and has been supported by Grant Agency of the Czech Republic grant No. 101/95/1424.
ACOUSTICAL INTERACTION OF A PLATE WITH FLUID

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Key words: vibration, plate, compressible fluid, coupling, natural frequency

An aeroelastic system consisting of a thin elastic plate that is supported by an array of springs \((k_f)\) and subjected to a longitudinal tension \(N_x > 0\) along with flowing compressible inviscid fluid limited by rigid wall is studied. The equation describing natural vibrations of a plate of thickness \(h\) and material properties \(E, \rho_s, \nu\) and fluid of density \(\rho_t\) and sound velocity \(c_o\) for its coupling in 2D channel of height \(H_o\) could be written (according [1, 2, 4]) in the form

\[
D \frac{\partial^4 w}{\partial x^4} - N_x \frac{\partial^2 w}{\partial x^2} + k_f w + \rho_s h \frac{\partial^2 w}{\partial t^2} + p = 0.
\]

The linear potential flow theory for inviscid fluid is used. Then the perturbation fluid pressure \(p(z)\) is related to the velocity potential \(\Phi\) by means of \(p(z) = -\rho_t \frac{\partial \Phi}{\partial t}\). The velocity potential of the fluid is to satisfy the following set of conditions on the surface of the elastic plate: \(\frac{\partial \Phi}{\partial t}|_{z = 0} = \frac{\partial w}{\partial t}\) and on the rigid wall: \(\frac{\partial \Phi}{\partial x}|_{z = H_0} = 0\).

We can get the characteristic equation for natural frequencies \(\omega\) of the coupled plate-fluid system ([2, 3, 5])

\[
D \bar{\alpha}^4 + N_x \bar{\alpha}^2 + k_f - \rho_s h \omega^2 - \rho_t \omega^2 \cdot \Psi(\beta) = 0,
\]

where \(\Psi(\beta)\) denoted the function

\[
\Psi(\beta) = \begin{cases} \frac{\cosh(\alpha \bar{H}_o)}{\beta} & \text{for } \bar{\alpha} > \frac{\alpha}{c_o}, \\ \frac{\sinh(\alpha \bar{H}_o)}{\beta} & \text{for } \bar{\alpha} < \frac{\alpha}{c_o}. \end{cases}
\]

Dispersion characteristic of simply supported still plate (\(L_o\) length of plate) interacting with air in channel for dimensionless parameters of system: \(\rho = 0.128 \cdot 10^{-3}; c = 0.066; \nu = 0.34; H = 10; L = L_o/h = \pi/\alpha\) was studied by using ANSYS finite element code. As a result of this calculation some dispersion characteristics and fluid pressure distribution in the channel were obtained. A sample of these calculations is presented in the Fig. a) and b). The curves corresponding to the structural (plate) modes of vibration and those related to the acoustical resonance of air in the channel could be observed and distinguished.

A sample of the dimensionless frequencies \(\Omega\) of the pre-stressed plate interacting with the compressed air contained in the channel was calculated for the following parameters: \(\rho = 0.01; c = 0.066; \nu = 0.34; H = 10; N_x = 0.5; K = 15.6 \cdot 10^{-5}\). The first three branches of the solution \(\Omega\) for the coupled system are depicted in part c). The solutions \(\Omega_o\) and \(\Omega_{a,0}\) for the uncoupled systems (\(\rho = 0\)) are plotted in the same figure as dashed lines. We can see the region of strong acoustic-structural coupling, i.e. the field where the structural natural frequencies \(\Omega_o\) and acoustic resonance frequencies \(\Omega_{a,0}\) are very close (for \(\alpha = 0.14\) and
\( \Omega = 0.035 \). The characteristics \( P_a \) are plotted in d) for the first three natural frequencies \( \Omega \) from part c). The results show that if the mode is predominantly structural \( \Omega \to \Omega_s \) the amplitude of the pressure is very small \( (P_a \to 0) \) e.g. for the branch 2 and \( \alpha > 0.1 \). For predominantly acoustic modes \( (\Omega \to \Omega_a) \) the pressure amplitudes \( P_a \) is much higher, e.g., for the branch 3 and \( \alpha < 0.1 \). If the acoustic and structural modes are strongly coupled (near \( \alpha = 0.14 \)), the pressure amplitudes \( P_a \) in absolute values for these two modes of vibration are comparable, and the difference between the two modes is only in the opposite phase of the plate deflection and the pressure. We cannot distinguish the acoustic modes from the structural ones. In terms of free vibration of the plate in vacuo one mode of vibration in the region of strong acoustic structural coupling \( (\alpha \approx 0.14) \) is split into two separate modes.

References:


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SIMULATION OF SYSTEMS WITH n-DEGREE OF FREEDOM

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Key words: modelling of dynamic systems, n-degree of freedom

The Department of Mechanics and Materials Science of Electrical Engineering of the CTU in Prague is interested in the modelling of concrete systems of different physical characters with n-degree of freedom (machine aggregates, mechanisms, hydromechanical systems etc.) [1, 2]. The concrete system of different physical characters with n-degree of freedom is simulated by a model for which equations of motion are compiled. The equations of motions are systems of non-linear differential equation. The parameters of system, the physical characters and the initial conditions have an influence on their the final solution.

To evaluate these influences and to describe the experience with the transformation of the model into practice a report about exemplary solution models was established [1, 2]. The computer system, Famulus SW, uses the numerical solution in order to solve model. SW Famulus allows the application of differential equations libraries, tabular and graphical outputs and animation of movement of the model.

In the report 30 examples of mechanical systems with 2-degree of freedom q1, q2 are examples similar to example 1 (Fig. 1). It is possible to change mass m, moment of inertia I, geometrical quantities r, R, l0 and initial conditions q1(0), q2(0), q'1(0), q'2(0).

Fig. 1: Model and solution of the system with two-degree of freedom f11, f12
In the report 20 other examples of similar examples 2, 3 (Fig. 2, 3) demonstrate the influences of dissipative energies, circular frequencies, external driving force or external driving moment.

Fig. 2: Model and solution of the system with three-degree of freedom

Fig. 3: Hydrodynamical model of the system with two-degree of freedom $y_1, y_2$

References:

This research has been conducted at the Department of Mechanics and Materials Science and has not been supported by any grant.
IDENTIFICATION OF FEM AND EXPERIMENTAL DYNAMIC MODELS

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Key words: identification, mode shapes, FEM

Machine tool structure design is nowadays often preceded with FEM modeling. If a prototype is available it is possible to compare (identify) FEM model and experimental modal model. A FEM model, however, does not represent a structure fully, because of necessary simplifications due to economic and technical capacities. As an example the structure is assumed to be linear and undamped, which is far from reality dealing with complicated structures with joints or shells. Apart from that, geometric simplifications are also necessary. It is not, for instance, possible to include all details as holes, radii etc. These simplifications result in differences between computational analytical experimental models.

The goal of identification is to update the analytical model to match the reality. If the modal parameters of both models are at the end of the process close, the models are referred to as identified. Only identified analytical model can be used for further computations as simulation of various configurations etc.

Serious problems in FEM modeling present various types of joints. In this project, simple structures are identified at the beginning (plate, beam) step-by-step moving to more complicated parts and finally complete machine structures.

An example of a more complicated part (but still monolithic) is a "brake drum". It consists of a grooved hub, a big operation ring and a connecting "bottom" with holes.

In order to obtain mode shapes and natural frequencies, impact hammer, dual channel FFT analyser B&K 2034 and modal software VTK ADASH have been used. Experimental model consists of 168 excited DOFs. A response reference pick-up has been situated on the inner surface of the ring in radial direction. The structure has been suspended on a foam rubber block. The analytical model has been created in an FEM program LUSAS. It consists of 846 thin-shell-type parabolic elements producing 2612 nodes. "Free" suspension has been assumed also.

Natural frequencies of both models are for the identified mode shapes listed in the table below. Having considered the relative simplicity of the structure and low mode coupling, it has not been necessary to compute the correlation numbers. The identification has been performed visually in mode shape animation. The deviations (listed in the table) are relative to the experimental model. Due to the fact that the structure can be considered as rotation symmetric shell, most natural frequencies are double, which means that two orthogonal mode shapes have the same natural frequency. Both mode shapes have been found in the analytical model, only one in the experiment. Shell type elements perform double frequency split due to discrepancies in symmetry. The frequencies are very close, though. These close frequencies are also listed in the table.

In both models the vibrations of 3 fundamental substructures of the drum have been observed: big operation ring, hub and bottom. Individual mode shapes performed oscillations
of one of the substructures. Only exceptionally, coupled mode shapes in 2 or 3 substructures simultaneously occurred. The oscillation has been observed mainly in the radial direction typical for shells with 4, 6, 8, ... nodes.

<table>
<thead>
<tr>
<th>mode shape number</th>
<th>mode shape</th>
<th>experiment f [Hz]</th>
<th>Lusas f [Hz]</th>
<th>deviation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>rad. vib. of ring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 nodes</td>
<td>296</td>
<td>291</td>
<td>-1,7</td>
</tr>
<tr>
<td>2.</td>
<td>rad. vib. of ring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 nodes</td>
<td>744</td>
<td>672</td>
<td>-9,1</td>
</tr>
<tr>
<td>3.</td>
<td>rad. vib. of ring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 nodes</td>
<td>1352</td>
<td>1194</td>
<td>-11,7</td>
</tr>
<tr>
<td>4.</td>
<td>rad. vib. of ring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 nodes</td>
<td>2112</td>
<td>1853</td>
<td>-12,3</td>
</tr>
<tr>
<td>5.</td>
<td>rad. vib. of hub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 nodes</td>
<td>2008</td>
<td>2027</td>
<td>0,9</td>
</tr>
<tr>
<td>6.</td>
<td>rad. vib. of ring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12 nodes</td>
<td>3000</td>
<td>2639</td>
<td>-11,9</td>
</tr>
<tr>
<td>7.</td>
<td>rad. vib. of bottom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 nodes</td>
<td>3424</td>
<td>2943</td>
<td>-14,0</td>
</tr>
</tbody>
</table>

The deviations (in the table) may be due to incorrect values of material properties in the analytical model. This is easy to fix. The natural frequencies deviations are the same (percentually) in the observed frequency range. The model error, on the other hand, is manifested by increasing deviations in higher modes. Other errors might have been caused by nonlinear behavior due to large displacements of the shell.

The brake drum models can be considered as identified and the experience will be used in further indentifications of more complicated parts and machines.

References:

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GROUND HOOK FOR SEMI-ACTIVE DAMPING OF TRUCK’S SUSPENSION

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Key words: semi-active damping, truck, road forces, road damage

Semi-active damping of vehicles has been studied for a long time. It is a classical example of application of mechatronic concept towards vehicle dynamics. However, the semi-active damping has been usually studied from the point of view of ride comfort. Only recently the possibility of application of semi-active damping of truck’s suspension for decrease of road damage by increase of dynamic part of road forces has been started to be investigated.

Classical principle of “sky-hook” control concept [1] is used for design or comparison of ride comfort control. Analogical principle of “ground hook” control concept for the design or comparison of road force control has been developed by the authors. And even more, a combination of sky-hook and ground hook for both decrease of road forces and increase of ride comfort has been proposed and investigated.

Ground Hook. Let us investigate a quarter car model (Fig. 1). Its behaviour is described by equations

\[
\begin{align*}
\frac{d^2 z_1}{dt^2} &= -k_{12}(z_1 - z_2) - F_d \\
\frac{d^2 z_2}{dt^2} &= k_{12}(z_1 - z_2) + F_d - k_{20}(z_2 - z_0)
\end{align*}
\]

where \(m_1\) is the sprung mass with the coordinate \(z_1\), \(m_2\) is the unsprung mass with the coordinate \(z_2\), \(k_{12}\) the stiffness of the spring, \(k_{20}\) the stiffness of the tyre, \(z_0\) the coordinate of the road, \(F_d\) is the force of the active or semi-active damping element. By classical damping it is the force of the passive damper

\[
F_d = b_{12}(\dot{z}_1 - \dot{z}_2)
\]
The principle of ground hook is to introduce the force like a damper between unsprung mass and the ground – road. Then the behaviour of the unsprung mass will be described

\[ m_2 \ddot{z}_2 = k_{12}(z_1 - z_2) + b_{12}(\dot{z}_1 - \dot{z}_2) - k_{20}(z_2 - z_0) - b_{20}(\dot{z}_2 - \dot{z}_0) \]  

(3)

Combination of sky and ground hooks. The sky hook improves the ride comfort, the ground hook improves the road forces, their combination improves both. It is described by the equations

\[ m_1 \ddot{z}_1 = -k_{12}(z_1 - z_2) - b_{12}(\dot{z}_1 - \dot{z}_2) - b_1 \dot{z}_1 \]

\[ m_2 \ddot{z}_2 = k_{12}(z_1 - z_2) + b_{12}(\dot{z}_1 - \dot{z}_2) - k_{20}(z_2 - z_0) - b_{20}(\dot{z}_2 - \dot{z}_0) \]  

(4)

The resulting influence is described on the Fig. 2.

![Fig. 2: Classical and semi-active damping by sky-ground hook](image)

Certainly it is the ideal control law. This law must be modified by the semi-active principle for the application by a controlled (variable) damper.

**Conclusion.** A new control principle of ground hook for semi-active damping of truck's suspension and its combination with classical principle of sky-hook have been proposed. This combination is advantageous because it improves both road forces and ride comfort within important interval of input frequencies.

**References:**


This research has been conducted at the Department of Mechanics FME CTU Prague as part of the research project “Optimization of Motion of Flexible Mechatronic Systems” and has been supported by GACR grant No. 101/95/0728.
INVESTIGATION OF THE RAIL VEHICLE GUIDING PROPERTIES

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Key words: rail vehicle, truck, wheelset, track, riding safety, mathematical model, roller rig (testing stand), vehicle-track interaction

Vehicle guiding properties as a theoretical problem consists in two concurrent areas – operation in straight and/or curved parts of track. While in the first case problems of truck motion stability are investigated, in the second case antiderailment safety, track geometry stability and wear of wheel and rails are the main viewpoints.

The present state of the theory of rail vehicle guiding characteristics makes it possible to determine the basic property of behaviour of conventional truck types in usual operation conditions. Linearised mathematical models are mostly used to describe those cases; in fact the principle of these processes is deeply non-linear and even main parameters are stochastical.

Therefore it is not possible to extrapolate the used mathematical models and their results to the new unconventional types of trucks. For that reason some significant nonlinear connections have been analysed within the framework of the project (relations between creep characteristics and geometry of rail-wheel contact, real conditions – both of truck and track parts.)

Recently some of these partial influences (creep characteristics, geometry of wheel-rail contact, real wheel and rail properties) were evaluated, basic models of the unconventional truck types were created (self steered axle bogies with the passive and active control elements). Problems connected with the questions of the train operation speed increase were especially investigated. The antiderailment safety and the passenger comfort improved by means of tilting car body are the most important of them. These results have been referred to at the recent Workshop discussions.

Layout, design and construction of the 1/3-scale roller testing rig (Fig. 1) are the principal content of the present stage of the project. The aim of the roller rig is to verify and demonstrate the results of theoretical investigations. The testing equipment consists of the main parts – four rollers and the investigated two-axle bogie model. The roller rig is driven by two DC electric motors (drive units MEZOMATIC-K). A pair of rollers at one side is driven by one motor by means of the toothed belt FLENNOR. Distance between roller axes may be changed. Each motor is independently fed from its own converter. Motor speeds are independently controlled. While during the straigt track simulation the speed of both motors must be controlled at the identical constant value, during the curving simulation, the different speeds have to be controled with high accuracy. Theoretically, it is also possible to simulate passing transient curve by means of time-variable speed difference. Two air springs between the rigid cross beam (part of the main frame) and the bogie model produce vertical load.
The test program includes following investigations
- straight and constant radius curved track simulation with different running speed
- parameter studies - influence of wheelbase, axle load, wheel tread profile, rail profile and rail cant, primary suspension stiffness
- the risk limit situations (e.g. derailment during the higher speed operation) seem to be the most important tests as there is naturally impossible to realize them in real operational conditions.

The measuring device consists of two counters (precise revolution indicator), accelerometers and a PC controlled measuring amplifier.

![Testing Stand](image.png)

Fig. 1: Testing Stand

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[1] AKNIN - AYASSE - CHOLLET - MAUPU: Quasi static Derailment of a Railway Vehicle, Comparison between Experimental and Simulation Results, Dynamics of Vehicles on Road and on Trucks Supplement to Vehicle System Dynamics, Volume 23, 1994


This research has been conducted at the Department of Automobiles, ICE & Rail Vehicles as part of the research project “Theoretical Solutions of Problems of Rail Vehicle - Track Interaction” and has been supported by GA CR grant No. 101/94/1841.
Section 8

THEORY OF CONSTRUCTION
In the living rooms of permanently used dwelling houses, the indoor temperature \( t_i = 20 \, ^\circ C \) is considered to be optimum. Applicability of this temperature will be analyzed with regard to proposed outdoor temperature \( t_a = -15 \, ^\circ C \), person's energy consumption \( M = 65 \, W.m^{-2} \), heat resistance of clothing \( R_{cl} = 0.078 \, m^2.K.W^{-1} = 0.5 \text{clo} \), or \( R_{cl} = 0.154 \, m^2.K.W^{-1} = 1 \text{clo} \), indoor air temperature \( t_{ai} \), average temperature on building constructions' inner surfaces \( t_{sim} \), velocity of interior air flow \( v_{ai} = 0.1 \, m.s^{-1} \), partial steam pressure \( p_{ai} = 1402 \, Pa \). The conditions of indoor environment will be judged using the well-known Fangerer's relations which lead us to PPD - predicted percentage of dissatisfied people and PMV - predicted mean vote. Analysis will be made upon a characteristic room placed in a corner position, under the roof, with one window in the peripheral wall. In all the cases walls' constructions are made of ceramic elements, ceiling are of reinforced concrete.

The development of requirements on the thermal-technical protection of buildings can be devided into four generation levels. The criteria applied on the individual levels are shown in Tab. 1.

It is known that temperature \( t_i = 0.5(t_{ai} + t_{sim}) \); the lesser effective are the constructions the room is made of, in the thermal-technical point of view, the larger is the difference between the temperature \( t_{ai} \) and \( t_{sim} \).

What quality of the temperature environment does the temperature \( t_i = 20 \, ^\circ C \) provide? It was find out that less than 10% of people dressed in common office clothes with a shirt, trousers and a jacket with \( R_{cl} = 1 \text{clo} \), feel temperature discomfort. While it is thermally acceptable when max. 15% of people express their disagreement with the thermal quality of the environment. At home the clothes with \( R_{cl} = 1 \text{clo} \) are worn only exceptionally. More common are the light clothes with \( R_{cl} = 0.5 \text{clo} \): light trousers, thin shirt, thin socks and light shoes. Such a dressed person with energy emission of \( M = 65 \, W.m^{-2} \) working in the sitting position at the temperature \( t_i = 20 \, ^\circ C \) is in the zone of thermal discomfort (see Tab. 1). Under these conditions more than 55% of people complain of discomfort. As a consequence of this, the temperature \( t_i = 20 \, ^\circ C \) is suitable only for people commonly dressed in clothes with \( R_{cl} = 1 \text{clo} \) while using any kind of building constructions.

With the thermal comfort requirement for people dressed in light clothes complies the temperature \( t_i = 23 \, ^\circ C \). In this example is the air temperature \( t_{ai} = 23.34 \, ^\circ C \) and average surface temperature \( t_{sim} = 22.65 \, ^\circ C \). The number of dissatisfied is then 15.61% that is slightly above the optimum level. While using the clothes with \( R_{cl} = 1 \text{clo} \), 5.98% of people will be dissatisfied because of the high temperature influence. It is an objective reality that the temperature \( t_i = 23 \, ^\circ C \) causes an increase of heat losses. However, the growth is
only 8.6%. The application of constructions with high heat resistance allows for the increase of temperatures \( t_i \) without the rise of larger energy demands.

In flats there is possible to apply temperature increase from \( t_i = 20^\circ C \) to \( t_i = 23^\circ C \) only in such a place where a person proves lower or restricted movement activity, for instance in sitting room while reading, watching TV, resting in a sitting position, writing etc. It does not refer to a kitchen, bedroom or corridors.

<table>
<thead>
<tr>
<th>Generation of construction</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor temperature ( t_i ) (°C)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>Roof heat resistance ( R_D ) (m².K.W⁻¹)</td>
<td>0.91</td>
<td>1.80</td>
<td>3.00</td>
<td>4.35</td>
<td>3.00</td>
</tr>
<tr>
<td>Walls heat resistance ( R_W ) (m².K.W⁻¹)</td>
<td>0.55</td>
<td>0.95</td>
<td>2.00</td>
<td>2.90</td>
<td>2.00</td>
</tr>
<tr>
<td>Windows heat permeability ( k_{OK} ) (W.m⁻².K⁻¹)</td>
<td>3.70</td>
<td>3.70</td>
<td>2.90</td>
<td>2.00</td>
<td>2.90</td>
</tr>
<tr>
<td>Person’s energy emission ( M ) (W.m⁻²)</td>
<td>65</td>
<td>65</td>
<td>65</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>Transfer heat loss ( Q_o ) (W)</td>
<td>2325</td>
<td>1575</td>
<td>985</td>
<td>690</td>
<td>1070</td>
</tr>
<tr>
<td>Indoor air temperature ( t_{ai} ) (°C)</td>
<td>23.52</td>
<td>22.42</td>
<td>21.47</td>
<td>21.05</td>
<td>23.34</td>
</tr>
<tr>
<td>Temperature on inner surfaces ( t_{sim} ) (°C)</td>
<td>16.48</td>
<td>17.58</td>
<td>18.53</td>
<td>18.95</td>
<td>22.65</td>
</tr>
<tr>
<td>PPD (%) at ( R_d = 1 ) clo</td>
<td>9.75</td>
<td>9.84</td>
<td>9.94</td>
<td>9.98</td>
<td>5.98</td>
</tr>
<tr>
<td>PPD (%) at ( R_d = 0.5 ) clo</td>
<td>56.77</td>
<td>56.99</td>
<td>57.33</td>
<td>59.70</td>
<td>15.61</td>
</tr>
</tbody>
</table>

Tab. 1: Summary of results gathered by the analysis of the temperature \( t_i = 20^\circ C \) and \( t_i = 23^\circ C \)

References:
LONG-TERM BEHAVIOUR OF ONE-WAY COMPOSITE REINFORCED CONCRETE SLABS

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Key words: composite, structure, concrete, creep, shrinkage, experiment, analysis, design

Composite construction in which the precast concrete slabs are combined with cast-in-place slab is frequently used in practice. The precast concrete slabs are designed both to act as permanent formwork and to behave compositely with the cast-in-place slab for service load. This type of construction has become very favourite and it is being used for various types of floor structural systems. Inconsistently with this trend, the methods of static analysis used presently in design practice are simplified to the highest degree.

A detailed experimental and analytical investigation of a fragment of the composite structure has been performed at the Department of Concrete and Masonry Structures TU of Brno. The experimental fragment consists of a precast flat plate slab reinforced with bottom bars of a spatial welded wire truss and cast-in-place concrete topping. The width of the fragment is 300 mm, the depth of precast slab is 50 mm and the depth of concrete topping is 80 mm. Precast slab was shored by temporary supports during the first construction stage. The weight of both slab and the concrete topping was carried by the welded wire truss, depth of which was 90 mm. The composite cross-section has been exposed to the effect of removing the shore and to the additional superimposed dead load. The wire truss serves as the main tensile reinforcement for the whole slab, which was made continuous after the concrete topping has hardened. The change of structural system together with differential shrinkage and creep of old and new concretes were supposed to cause the stress redistribution in the structure. The creep of concrete together with crack development were expected to increase the deflection.

The experimental program followed the construction steps at building site:

- manufacturing of precast slabs, curing for 3 days,
- removing of the formwork at age of 7 days,
- introducing of temporary supports at age of 11 days, their adjustment at 20 days,
- casting of concrete topping, curing for 7 days,
- removing of temporary supports 42 days after casting of precast slabs,
- application of superimposed dead load at 56 days.

The long-term experiment is planned for duration of 360 days and it is accompanied by laboratory tests of both short- and long-term material properties, see [1, 4].

A combination of time-discretization and finite-element methods has been applied in this research for the analysis of long-term behaviour of the structure, see [2]. The theory of viscoelasticity is used for step-by-step creep analysis. The average properties of the
cross-section with respect to drying are considered for creep and shrinkage calculations. A sophisticated creep model "B3", see [3], is used, including updating creep and shrinkage predictions based on short-time measurements. The reduction of the stiffness of experimental fragment caused by cracks is modelled in a simplified way using reduced modulus of elasticity. The finite-element analysis is performed at each time step. Various parts of the cross-section are modelled using eccentric frame elements, e.g. precast slab, cast in place topping, and reinforcement. The history of construction steps is fully respected. The methods used for the analysis are compared with the methods traditionally used in practice and they are verified by results of the experiment.

Based on the results obtained till present time we may conclude:

- There is no reliable relationship between the strength and elastic modulus of concrete.
- Modulus of elasticity of cast-in-place concrete is usually lower than expected.
- The application of compliance function describing total deformation is strongly recommended with the possibility of updating of the predictions based on short-time measurements.
- The simplification in reduction of stiffness due to cracks is doubtful and it is not applicable in general case.
- The research contributed to the verification of the methods.
- The methods traditionally used in practice for the analysis of relevant problem are insufficient.
- The behaviour of temporary timber supports (drying up, creeping) is of decisive importance for the total deflection of the structure.

References:


This research has been conducted at the Department of Concrete and Masonry Structures as part of the research project “Structural Analysis of Composite Reinforced Concrete Slabs with Respect to Shrinkage and Creep of Concrete” and has been jointly funded by the Technical University of Brno under Grant No. B 17/94 and FU 250005, by Stamont Brno JSC, and by Hottinger Baldwin Messtechnik VUT-FS centre.
STRESS DEVELOPMENT IN SEQUENTIALLY CONSTRUCTED HIGH-RISE BUILDINGS

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Key words: concrete, building, creep, shrinkage, construction process, nonlinear analysis

The sequential construction is the commonly-used method for erection of moderate to high-rise buildings. Various operations used in construction, such as gradual addition of individual parts, possible changing of support boundary conditions of structural members, application or removal of construction loads and prescribed displacements, are causes of unavoidable changes of stress. The structure typically consists of parts, which are erected in the first phases of the construction process (e.g. continuously erected concrete cores or shear walls) and the parts, which are joined to the first ones later, with some time delay and which are typically of materials of different properties (e.g. concrete frame members of different ages and different creep and shrinkage characteristics, or steel parts). It is characteristic that the structure changes the structural system many times during the construction process and effects of creep and shrinkage of concrete are very significant. The behaviour of the structure is highly time dependent and much more complex than at the simple case, when a building would be considered to be erected at once and from a material exhibiting neither creep, nor shrinkage. However, not only the stress variations are significant – also the prediction of the development of deformations plays very important role because these can make problems to maintain horizontality of floors, to avoid appearance of additional stresses in dividing walls and in large glass panels, etc. For these reasons, the adequate analysis taking into account the gradual construction process, changes in the structural system and creep and shrinkage is a condition of a reliable and economical design.

There are several factors influencing the development of internal forces and displacements in building structures. The sequential growth of the structures means that the non-deformed and nonstressed elements are connected to the older already deformed and loaded elements. The individual parts are subjected to loading for a different period of time and also the initial position is not the same for older and newer elements. This fact have to be taken into account in order to get the correct development of internal forces, even if the structure is made of a material showing no time dependent behaviour.

The creep effects depend on the age of concrete at loading and on the length of the time period, when the elements are subjected to loading. The sequential loading is thus of a primar importance. The change of the structural system due to progressive growth of the structure also affects the loading of elements and their creep effects.

The different age of concrete of individual vertical elements (core or columns) together with different stress levels results in different creep effects. Nonuniform settlement of the core and columns leads often to the additional stresses in floor slabs and beams. The different environmental conditions of columns inside and outside the building lead also to a different
creep and shrinkage due to variable environmental conditions (humidity and temperature changes).

Shrinkage of concrete may induce unfavourable stresses in the stiff structural systems. Some of the stresses can be avoided, if a reasonable system of expansion joints is designed. However, sometimes it is not possible to provide sufficient degree of freedom and the induced forces have to be carried by structural elements. It is extremely important to keep the shrinkage values as small as possible. A suitable concrete mix and proper curing can help to limit shrinkage strains.

As an example, the 16 floors building with stiff cast in situ core was analysed. The simplified model included a typical plane frame with two columns, part of the core and floor slabs. The effect of sequential construction as well as the effects of the creep and shrinkage has been investigated. It has been shown that the redistribution of internal forces is rather significant. The detailed results were published in [2]. The shrinkage effects and the redistribution of bending moments within 20 years after completion of the structure in the bottom floors are plotted in Fig. 1. Due to shrinkage of the floor slabs in lower floors, the bending moments developed in the column of the first floor.

The analysis showed that the deformation of the building is dependent on the construction sequence. No loading of completed structures can approximate the actual deformation of the building. The creep effects increase the differences in settlement of individual columns, which results in redistribution of stress in horizontal elements. The redistribution is higher in top floors than in bottom floors. The unfavourable effect of shrinkage is observed particularly at the bottom columns, if a horizontal movement is not allowed.

References:


This research has been carried out as part of the research project supported by the Grant Agency of the Czech Republic, Grant No. 103/94/0930
STIFFNESS AND DEFLECTIONS OF STIFFENING CORES OF HIGH-RISE BUILDINGS

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Key words: shear lag, negative shear lag, stiffening cores

Modern high-rise buildings are often composed of shear walls combined with stiffening cores regularly tied together by floor slabs spaced at intervals of story heights. Such structures are sufficiently efficient in resisting the lateral forces imposed by wind or earthquakes. It is common in design practice when calculating the stress distribution in cores and the stiffnesses and deflections of cores to neglect the shear lag effects in cores and often also the shear deformations of core walls (the webs) parallel with the plane of loading. This leads to an overestimation of the core stiffness and to underestimation of the peak values of stresses and deflections which may be unsafe. Also the load distribution into individual cores and shear walls can be seriously affected by the shear lag effects and shear wall deformations. It has been proved [1] that the shear lag can dramatically change the stress distribution in cross sections of cores. The shear lag, in its classical meaning, results in an increase of the vertical stress in the regions of the core walls close to the cross section corners when compared to those near the midpoint of the transverse wall. This classical shear lag is particularly significant in regions adjacent to the core bottom. The negative shear lag, where the vertical stresses at the middle of the transverse wall exceed those nearer the corners, occurs along a considerable portion of the height of the core [1]. To evaluate the real stress distributions and the deflections, stiffnesses and to predict real load distribution into the individual structural parts, it is necessary to use adequate methods of structural analysis. The folded-plate theory is a technique ideally suited to predicting shear lag effects [2]. Fig. 1 shows typical results of analysis of distribution of vertical stresses in a cross section of a core, situated at its midheight, due to a horizontal loading - effects of the negative shear lag are clearly seen. Both, the non-uniformity of the stress distribution as well as the increase of deflections of the core depends very strongly on the width/height ratio \( b/h \) of the cross section - for cores that are wide or short, the shear lag becomes very significant. Fig. 2 presents results of comparison of shapes and magnitudes of deflection lines of cores evaluated by various methods: (i) a simple engineering calculation neglecting the shear effects (the full line) (ii) an improved calculation taking into account the shear deformations of walls, but neglecting the shear lag (the dashed line) (iii) an accurate analysis (the dotted line) Results belonging to different width/height ratio are shown in Fig. 2: from \( b/h = 0.32 \) (narrow, tall core) - Fig. 2a, to \( b/h = 1.279 \) (wide, low core) - Fig. 2d. Relatively slight difference between results of the simplified methods and the exact deflection values (8.4 or 5.8 % respectively) is seen at the top of the narrow core but this difference increases to 30 or 20% respectively at the level of 20% of the core height. On the other hand, very significant differences are seen at the top of a wide core, and particularly in the bottom region of the
core (Fig. 2d). The study has covered also the structural performance of cores with vertical bands of openings situated in various positions. The findings concerning the significance of the shear lag effects on the stress distributions, deflections and stiffness conditions were of a similar character as those belonging to the cores without openings. It may be concluded that not only the stress distributions but also deflections and stiffness conditions in cores of high-rise buildings are very significantly affected by the shear lag and therefore this phenomenon should be taken into account when analysing high-rise structural systems.

References:

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FAILURE OF CONNECTION
OF COMPOSITE BEAMS

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Key words: composite beam, partial connection, failure, stress, stud, concrete, steel

Steel beam and concrete slab of composite beams are usually connected by means of shear connectors. The welded studs are often used due to easy construction. The cost of studs can be reduced in the beams with partial interaction. The connection may then fail as the first part of the system composed of the steel beam, concrete slab and connection. The studs may fail due to the cracking of concrete surrounding the stud or due to the failure of the shank of the stud. In the following study the failure of concrete is assumed.

The load-slip diagram of the stud is assumed in the quadrilinear form plotted in Fig. 1. The first vertical part represents the development of a shear force before the slip occurs. The second part shows an active performance of the stud, the increasing force due to the growing slip. The post peak part of the diagram is composed of the softening linear branch and of the residual horizontal part, representing friction after the total failure of the stud.

The behaviour of the simply supported composite beam has been investigated, if stud connectors fail progressively. The smeared approach has been accepted. The diagram (Fig. 1) shows the force carried by studs over the unit length. The steel and concrete are assumed to be linear. The analytical method [1] has been developed in order to get the distribution of internal forces and deflections. Although the equations are derived analytically, due to the nonlinear load-displacement diagram of the stud behaviour, a numerical solution was necessary. In the symmetrical case of the beam subjected to a uniformly distributed load, the half span can be divided into one to four regions in dependence on the load value. If the load is small no slip occurs and the maximum shear flow carried by studs is smaller than $F_1$ (Fig. 1). If the load increases the slip occurs at the end of the beam, where the extreme shear flow $F$ lies in the interval $F_1 < F < F_0$. For higher loading the studs at the end of the beam start to fail. The end studs carry the shear force corresponding to the slip bigger than $v_0$. If the load becomes even bigger, the studs at the end of the beam fail totally and they carry only the shear due to friction between the steel beam and concrete slab. The distributions of stress in concrete slab at the top and bottom surfaces and the distributions of stress in the steel beam in the top and bottom flanges along the half span are plotted in Fig. 2.

The figures show that the extreme stresses are not always in the middle of the beam. The progressively failing connection between steel and concrete results in redistribution of bending moments and axial forces. In the central part of the beam no slip occurs and a major portion of the load is carried by the couple of axial forces (compression in concrete and tension in steel). Farther from the midspan, the axial forces are lower and large bending moments develop in concrete and steel. Their action is dominant and a contribution of axial forces becomes lower. The extreme stresses in steel move from the center of the beam. Extreme tensile stress in concrete is in the region of the decreasing shear force in connection.
The results presented here show the importance to investigate the progressive failure of structural elements and structures. As it is shown here, the distribution of stresses may be different from that, which is usual, if the structure works in elastic region.

![Shear flow vs. slip diagram of welded studs](image)

**Fig. 1:** Shear flow vs. slip diagram of welded studs

![Stress distribution in concrete and steel along the half of the span](image)

**Fig. 2:** Stress distribution in concrete and steel along the half of the span

References:


This research has been conducted at the Department of Concrete Structures and Bridges in cooperation with Northwestern University, Evanston, Illinois (Prof. Z. P. Bažant), as part of the research project “Structural Performance and Damage of Composite Structures” and has been supported by the Grant Agency of the Czech Republic Grant No. 103/95/1644, and by the CTU project “Safety and Serviceability Analysis of Concrete Structures”, grant No. 10018164.
MODELLING OF THE BEHAVIOUR OF CONCRETE – INFLUENCE OF CRACKS

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Key words: concrete structures, structural design, cracks, crack types, crack width, durability, load-bearing capacity, impermeability, static behaviour, prevention of crack, limitation of crack, crack repair

The question of the significance of cracks on the durability and function of concrete structures has in certain cases led to many discussions and sometimes to expensive remedial actions. The research team came to the conclusion, that there is a necessity to write a handbook on crack problems in concrete structures. In this handbook there are results received in this research program. The theses of this handbook are presented in this paper.

Structural cracks are caused by dead loads, applied forces and other external influences. Intrinsic cracks are more important than structural cracks (see [1, 2]), therefore there are given: the classification of the various type of intrinsic cracks (three main types: plastic – appear in first hours; early thermal contraction – appear one day to two/three weeks; long-term drying shrinkage – appears after several weeks or even months); the description of their symptoms and discussing the main influences. Some cracking may involve combinations of various types. Knowledge of this should enable designers and contractors to take measures which will either prevent or control intrinsic cracks. Cracks which are caused e.g. excessive use of calcium chloride, microcracking, etc. are mentioned briefly. Principles which govern the formation of crack in plastic and hardened concrete are very important.

Guidance about the circumstances under which some form of crack-limitation requirements need be stipulated at the design stage. The requirements differ depending on the environment and load type. Furthermore, crack-limitation requirements must sometimes be stipulated to limit deformations and wear, to achieve an adequate impermeability and sound insulation and, in certain cases, to satisfy hygienic and aesthetic requirements. Recommended principles on the crack width that may be accepted from the durability point of view in cases in which a concrete structure has cracked in an undesirable way. However, apart from complexity, there are in some cases reasons why it is not always realistic to determine crack widths rigorously. Intrinsic cracks are sometimes unpredictable, but they can be minimised and controlled by careful attention to design details and construction techniques.

Failure mechanism and failure theories are described. The width of the crack are influenced by the geometry and fixity of the part of the structure affected and by the concrete quality and reinforcement. There is no reliable methods for calculating crack widths in unreinforced concrete (see [3]). Various relationships for crack width were proposed based on an inventory of cracks. The crack distributing properties of the reinforcement are modelled using empirical formulae. The quantity of reinforcement that achieves the crack distribution
shall have the tensile force capacity that is as large as the concrete's capacity immediately before the crack occurs.

The significance of crack on the durability of reinforcement is discussed in detail. The durability could be affected by frost, aggregate reactions, lime leaching. Impermeability drops with increasing crack width. If the flow through a crack is assumed to be laminar, it increases as the cube of the crack width.

For practice there are important prevention and limitation of cracks. Non-structural cracks: - prevention of plastic settlement cracks: reduction of settlement, reduction of restraint, vibration, of plastic shrinkage cracks – curing, mix design, use fibres; – prevention of early thermal contraction cracks: aggregate with lower coefficients of thermal expansion, blended cements, distribution of reinforcement, no sudden changes of cross section, no high concentrations of reinforcement, providing movement joints, minimised delaying the removal of formwork, the use of insulation; prevention of long-term shrinkage cracks: concrete mix, temperature history, curing, relative humidity, ratio of volume to exposed surface. Structural cracks – prevention: strength class of concrete, reinforcement, thermal joints, etc.

Cracks may be separated into two classes for the purpose of deciding upon the type of repair. 1. Dormant cracks (open, close or extend further): fine, wide, fractures. 2. Live cracks (subjected to further movement). Cracks may be injected with various materials either to rebond the substrate or to act as void fillers. Dormant cracks: cement grouts, epoxy resin, polyester resin, synthetic latex; live cracks: polyurethane resin, acrylic gels, flexible epoxy resin.

In many cases it is possible to prevent cracking by the simple mentioned measurements. Cracking problem – balance between the function of the structure and the cost of limiting cracking. The handbook will be devoted to a wide range of civil engineers in research, in design and on the site.

References:

This research has been conducted at the Department of Concrete structures and bridges as part of the research project “Modelling of the structural performance” and has been supported by CTU grant No. 10018227.
STRESS-STRAIN DIAGRAM OF CONCRETE IN COMPRESSION

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Key words: compressive strength, deformation, stress-strain diagram, testing system stiffness, uniaxial testing

Concrete is a brittle material that exhibits a rapid loss in load carrying ability when deformed beyond a peak load.

The shape of the stress-strain diagram in uniaxial compression of concrete is strongly influenced by the structural properties of the specimen (size and shape), by boundary conditions (friction in the contact between the specimen and steel machine platen, caping, anti-friction layer, brush platens), by the degree of allowable rotation of the platen, by the servo-hydraulic system and feedback signal, by the stiffness ratio of the testing machine and specimen, and by the gauge length. Detailed analysis of the problem still needs to be carried out.

Deformations of concrete are usually determined on specimens in the shape of prisms or cylinders with a slenderness height-width ratio of 3-5.

The strength of concrete is affected by the size-effect phenomenon: as the dimensions of the specimen increase, the strength decreases. Increasing slenderness of the specimen leads to lower strength.

If the lateral deformation of the specimen is inhibited by lateral confinement, the peak load is increased and the rate of softening is decreased.

A closed-loop of the servo-hydraulic system should reflect the changes of axial strain, fast transient response and absence of residual noise conditions for successful post-peak control of failing material. The load frame of the testing system should be stiff enough in relation to the failing specimen for post-failure deformation to be reached in a stable state.

The base of the gauge and its ratio to the gravel grain of the concrete aggregates affects the variation of the strains measured.

In the laboratories of the Klokner Institute, specimens with a constant cross-section of 100 × 100 mm (prisms) and with a diameter of 100 mm (cylinders) were tested. The lengths of the specimens were 50, 100 and 200 mm. After casting, the specimens were cured in the prescribed way.

The experimental investigations were checked in two testing machines: in the MTS system with a loading capacity of 500 kN and in a modernized Amsler machine with a range of 5000 kN.

The specimens were loaded under a moderate loading rate of 1 μm/s. The deformations were measured with inductive transducers (LVDT) during the test, and a data acquisition system was applied.
It had earlier been proved, following Karpenko that the stress-strain diagram can be approximated by most lifelike numerical expression.

Fig. 1: Specimen in the testing machine

References:


This research has been conducted at the Department of Engineering Structures of Klokner Institute as part of the research project “Experimental Analysis of Compressive Strain-Softening in Concrete” and has been supported by CTU grant No. 10148151.
INFLUENCE OF DIFFERENT KINDS OF STEEL FIBRES ON SOME PROPERTIES OF CONCRETE

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Key words: fibre concrete, flexural strength, compressive strength, tensile strength, load-deflection curve, aspect ratio

The aim of this research is to compare the mechanical properties of concrete reinforced with different kinds of steel fibres and plain concrete. Hence sixteen series of concrete reinforced with steel fiber and one series of plain concrete were produced. The contents of concrete in all series were constant as shown in the following table:

Weight of contents per one cubic meter of concrete:

<table>
<thead>
<tr>
<th>CEMENT</th>
<th>WATER</th>
<th>AGREGGATE [kg]</th>
<th>SUPER-PLASTICIZER</th>
<th>FILLER FRACTION</th>
<th>STEEL FIBRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[kg]</td>
<td>[l]</td>
<td>0-4</td>
<td>4-8</td>
<td>8-16</td>
<td>[kg]</td>
</tr>
<tr>
<td>495</td>
<td>198</td>
<td>743.4</td>
<td>259.4</td>
<td>649.3</td>
<td>4.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45.4</td>
</tr>
</tbody>
</table>

The mechanical properties of concrete were tested on beam specimens of (100, 100, 400 mm).

The flexural strength of fiber concrete specimens was tested using computer program AD GRAF1, which was conducted with testing machine type VEB TIW RAUENSTEIN.

Compressive strength and splitting tensile strength were tested by conventional machine type VEB LEIPZIG on the rests of beams.

Loading speed – constant increment of deformation in time.

Toughness index was computed from load deflection curve.

The purpose of the presented work, which has been done according to the grant tasks was to realize the experimental programme, which will be evaluated in the thesis by the main researcher of the grant.

In the present time the measurements are carried out, and the first results will be presented in the workshop 1996.

References:
This research has been conducted at the Department of Concrete Structures and Bridges as part of the research project “Influence of Different Kinds of Steel Fibre on Some Properties of Concrete” and has been supported by CTU grant No. 10018228.
REINFORCEMENT BEAMS STRENGTHENED BY UNBONDED REINFORCEMENT

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Key words: analysis, concrete, reinforcement, prestressing, strengthening, failure, rolled section

Strengthening of reinforced concrete beams in reconstructed buildings has become very actual and this trend is going to continue for many years. For a wider practical use it is necessary to develop and verify the new methods of strengthening of reinforced concrete beams. One of the possibilities to increase the load carrying capacity is to strengthen them by unbonded reinforcement. The reinforcement rolled sections or prestressed reinforcement is placed on the bottom side or on the bottom part of the web.

For the thesis five alternatives of strengthening by unbonded reinforcement were selected and tested at the CTU laboratories. The alternatives differ in the way of strengthening of the bottom part of the beam. In 1995 alternative A was tested. The scheme of the strengthened beam and the cross section are in the Fig. 1. The beam, that has been tested and was already used, was strengthened by rolled section (angles at each edge of the beam). Anchoring of these profiles is easily provided by welding them to steel plates fixed at the ends of the beam. The shear is carried by skew steel strips on the right side. On the left side the shear is carried by vertical steel strips that replace the stirrups Fig. 1.

Each alternative was tested on three identical beams that were loaded up to the total failure. The measurements values were compared with the calculated results using the program VOK 2 (for prestressed structures) developed at the Department of Concrete Structures and Bridges (prof. Křížek, doc. Vitek, dr. Ing. Vítek) Fig. 2. In the program the beam is divided into several layers and the ordinary and both the prestressed reinforcement with bond and without bond are considered. The difference between the theoretical and experimental results is very small.

Due to restricted financial means only the alternative A was tested and calculated in this year. The additional reinforcement can be free or covered by mortar.

By now four alternatives have been tested and calculated. The last one will be tested next year. The particulars of the design, testing and experience gained in practice will be written in the thesis Ing. L. Podolka.

References:


This research has been conducted at the Department of Concrete Structures and Bridges as part of the research project "Reconstruction Concrete and Masonry Structures" and has been supported by CTU grant No. 10018229.

Fig. 1: Scheme of the strengthened beam VARIANT A.

Fig. 2: Compared the measurements values with the calculated results.
EXCESSIVE DEFLECTIONS OF PRESTRESSED CONCRETE BRIDGES

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Key words: concrete, cracking, creep, shrinkage, prestressing, load, bridge, humidity, temperature

Long-span prestressed concrete bridges were built since 50th and 60th. The first bridges erected by cantilever method had usually hinges at the midspans. This arrangement was used so that the clear structural performance guaranteed the reliable transfer of prestressing into the superstructure. However, the discontinuity at the midspan led to the unfavourable shape of the deflection line and large deflections. The unstabilized development of deflections within the first decades resulted in many reconstructions of these structures. The newer bridges were continuous. The deflections became significantly lower, but the growing deflections are observed many years after completion of the bridges. The analyses carried out as a part of the design or after the construction give lower values than those obtained by the field measurements. This discrepancy led to the decision to investigate the mechanism leading to the deformation of the prestressed concrete bridges.

The first step of the research was to collect the measurements available at existing bridges. Within the activity of the CEB task group 2.4, the data of 25 bridges have been collected and the time-deflection diagrams have been plotted. The general trends of the development of deflections are very similar at bridges in Sweden, in Switzerland, in the Netherlands and in Czech Republic. Based on the results, it can be concluded that the excessive deflections are not dependent on the specific concrete used in particular countries or on local conditions, but they may be considered as a general feature typical for specific structural systems.

The collected data contain 25 bridges. The hinges at the midspan are at 10 bridges, 11 bridges are continuous structures cast in situ, 4 bridges are assembled of precast segments. 7 bridges were built in Czech Republic and 18 are mostly from western Europe. The typical measurement of deflections covers a period of two to three decades. The typical deflection-time curve is plotted in Fig. 1. The increasing deformation shows no tendency to approach any final value.

The second objective of the research was to specify possible reasons why the deflections do not follow the assumed trends. The influencing factors cover the structural properties, material behaviour, environmental effects and loading conditions.

The deflection of the large prestressed concrete bridge is obtained as a difference of the action of the dead load and of the opposite action due to prestressing. The difference of the two large effects is extremely sensitive to the value of each of them. Any error leads to significant change of the resulting deflection.

The modulus of elasticity represents the basic material parameter. Its value used in analysis should be based rather on measured values than on code recommendations.
Creep and shrinkage of concrete are also uncertain material parameters. The values measured on small specimens cannot be simply used without adjustment for the large sections of the bridge superstructure. The transforming relations need to be developed.

The reinforcement of prestressed concrete bridge sections may significantly influence its stiffness in the support areas, where the number of tendons is high due to the construction procedure. The correct calculation of the excentricity of prestressing in those sections is important for the realistic analysis of deformations.

The progressive drying of cross-sections results in differential shrinkage of their surface layers and inside layers. The selfbalanced stresses vary during the time and their effect may cause a decrease of the stiffness under the short-term as well as long-term loadings.

The shear lag at wide thin-walled sections appears particularly at the support areas as well as due to concentrated forces induced at anchors of prestressing cables. The nonuniform stress distribution at the flanges also affects the stiffness of the structure.

The prestressing cables are placed into the ducts and before their grouting, the tendons in the ducts may move. During the construction process some settlement of tendons in the ducts may occur, which can result in change of the original prestressing forces.

Particularly the bridges cast by cantilever method are loaded at the early age of concrete. Also the loading by dead load and by prestressing of cantilever tendons results in deflections of the opposite sign. This procedure repeats at the time of casting each segment. In the usual analysis, the principle of superposition is applied. Its validity for the strain development at those bridges is at least questionable.

The last but not least reason of the discrepancy between calculated and measured values of deflections can be the effect of supplementary parts on the stiffness of the bridge. The asphalt layers, coping, safety walls and other parts contribute to the stiffness of the bridge. The contribution differs if the load is short-term or long-term.

This review of the possible reasons of the excessive deflections need not to be complete. However, their consideration in the analysis may increase the precision of calculations, and thus make the construction process easier and finally improve the quality of large span prestressed concrete bridges.

References:


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ENVIRONMENTAL EFFECTS
ON CONCRETE ELEMENTS

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Key words: concrete, creep, humidity, cracking, temperature, softening, nonlinear analysis, shrinkage

Concrete elements are usually subjected to progressive drying. After casting the concrete element is wet and the pores are filled with water. If the surface is exposed to drying, the thin surface layer dries rather fast, but the inside portions of the section dry much slower. The nonuniform drying results in differential shrinkage in the surface layers and inside the section. In the initial stage (in dependence on the drying conditions and on the size of the element), the surface layers tend to shrink more than the core of the section. However, the compatibility of the section have to be maintained, which results in the development of stress, although the specimen is not loaded. The tensile stress at the surface is balanced by the compression in the core. If the drying is significant the tensile stresses exceed the strength of concrete and cracks appear on the surface of the specimen.

After some period the compression stress inside the section causes the shortening of concrete, while the tensile stress causes the elongation of surface areas. The stress distribution changes so that the core is subjected to tension and surface areas are compressed. If there are cracks on the surface, they close. If they cannot close fully, the nonuniform distribution of the stress becomes more pronounced.

If an element is subjected to temperature changes, additional stresses due to the nonuniform thermal expansion across the thickness of the element originate and then they can significantly influence the stress distribution induced by nonuniform shrinkage.

Drying process is rather slow. It takes some months or years, until the slab element dries completely. The development of strain is therefore also slow and creep effects can reduce the stresses. On the other hand the temperature changes are much faster. The complete heating or cooling of the slab elements takes place within days. The reduction of stresses due to creep becomes much smaller. The most important phenomena influencing the stress development are cracking and the modulus of elasticity. The elastic modulus should be replaced by compliance function, which can much better express the stiffness of concrete at short-term (and long-term) loading.

The stresses are in equilibrium, however, due to the nonlinearity in tension (and due to cracking), they cannot be simply superimposed to the stresses induced by loading of the element. The complete analysis taking into account the environmental effects and external loading is necessary, if the correct stresses are to be calculated. Such process is usually too complex for the use in design practice. However, also if an usual analysis is applied the designers have to bear in mind, that the stress distribution may differ from that, that they obtained from their design calculations. The additional reinforcement should be added, to get a reserve capable to carry the mentioned stresses.
The stresses induced by nonuniform shrinkage and by temperature changes, also influence the stiffness of structural elements. As an example, the environmental effects on stiffness of the prestressed slab have been investigated. The slab 200 mm thick, is prestressed by pretensioning in the bottom part of the cross-section. The slab is subjected to drying at the age of concrete 3 days. During one week the surface dries to the relative humidity of the environment (60%), which is considered to be constant. At the age of concrete 28 days, the slab is loaded by bending moment 60 kNm. The stress distributions are plotted in Fig. 1. The thin full line shows the stress distribution before loading. Due to prestressing the main compression zone is in the bottom part of the section. The thick line illustrates the stress distribution after loading, and the dashed line the stress distribution after loading, if the shrinkage induced stresses are neglected (usual linear approach used in design practice). Although the dashed line shows that the complete section is compressed, the tensile stresses and even cracking appear in at the bottom surface of the slab. The stiffness reduction (short-term loading only) is in this case about 10% in comparison with the case, that no shrinkage induced stresses are considered.

The small example shows that the effects of environment (humidity and temperature changes in particular) have a nonnegligible influence on the stiffness and deformations of concrete structures. Further research in this field is planned for the next year.

Fig. 1: Stress distribution accross the thickness of the prestressed concrete slab

References:

This research has been conducted at the Department of Concrete Structures and Bridges and has been supported by the Grant Agency of the Czech Republic, grant No. 103/99/1175
DESIGN TOOL FOR RC STRUCTURES: OBJECT-ORIENTED APPROACH

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Key words: concrete, plasticity, sensitivity analysis, object-oriented methods.

The state of computerization of the structural design process is characterized by a disturbing disparity between analysis proper and the full design process. Most of the present specifications and codes have been historically calibrated in a manual design environment in which reanalysis was prohibitively expensive. In such environment the design was considered satisfactory when a few key members were at their allowable limit in one loading condition. The position of the analysis in the design process has changed considerably in the last decade. The analysis time and error have been drastically reduced. This increasingly motivates the research in the area of computerizing the design-oriented activities.

The developed design tool for RC framed structure is an example of the extended computer support throughout the development of the structure. The salient features of the system include:

- Easy transition of the structure model between the evaluation schemes (represented by both analysis and design algorithms) which are applicable in different stages of the design process and for different design members.
- Simple insertion of the new type of the design member into the system by providing suitable interface for the inclusion of design related objects.
- Support for preliminary design stages. For RC framed structures the rigid-plastic optimization scheme is a suitable tool for this task.
- Efficient algorithm for sensitivity calculation of the history-dependent response of RC framed structure. This item is necessary to provide the support for redesign decisions by identifying portions of the structure that need to be modified to achieve the intended function.
- Optional decomposition of the environment into several modules with an automated definition of the communication protocols.

The program represents the pilot application focused on the narrowed area of the problem domain. The use the conceptual support of the object-oriented paradigm for a small scale problem alleviates the difficulties with future extensions of the system. If the directions in which the system is expected to grow are concerned and enforced through corresponding abstractions during the object-oriented analysis, the support for these extensions is preserved in the produced system. As a result, the pilot application may be constructed for a narrow region of the considered problem domain. Once the overall system architecture is established and examined on a narrowed problem domain involving also the structure design activities, further functionality may be included at relatively low implementation cost.
The global view of the design tool in terms of the Coad-Yourdon model is presented in the figure. The displayed subjects conceptually delimit the subdomains of the problem. The borders of these subproblems must be maximally flexible to allow possibly independent development in the subdomains. In particular, the abstract classes \textit{ElemDesParam} and \textit{Response} intermediate the communication between the design and analysis.

The resulting processing allows to mature the design of design members by applying several mathematical models, i.e. rigid-plastic optimization, elasto-plastic analysis and its sensitivity analysis. The design member gathers the information throughout the design process which is used for gradual classification within the design standard hierarchy. In every reclassification step the provisions that apply are identified and the corresponding mathematical model is created. The details of the described processing are presented in [1].

References:


This research has been conducted at the Department of Structural Mechanics as part of the research project "Material models for concrete..." and has been supported by GACR grant No. 103/93/1175.
ULTIMATE LIMIT STATE
OF PRESTRESSED CONCRETE
BEAMS – COMPUTER CODE

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Key words: analysis, concrete, bond, tendon, failure, reinforcement, numerical solution, ultimate limit state

The safety of structures is assumed to be proven, if the cross-sections show higher load carrying capacity than the load effects calculated mostly under the assumption of the elasticity. The possible redistribution of internal forces due to softening of cross-sections at a high stress level is often neglected or assumed in a very simple way. At prestressed structures, particularly if the unbonded tendons are used, the nonlinear behaviour of concrete and steel should be taken into account, so that the more realistic view of the failure in ultimate limit state would be obtained. In order to make the nonlinear analysis of continuous beams easier, the computer code VOK-2 has been written by the authors of the paper.

The program is based on the finite element method. The beam elements are connected in nodes. The nodes are placed in the locations of supports, under the point loads and at the points, where the prestressing tendons change their shape. The elements are divided into concrete layers. Mild reinforcement is also included as a part of the cross-section.

The material behaviour of concrete, steel and prestressing steel is described by nonlinear stress-strain diagrams. Concrete in compression has curved loading branch and straight unloading branch. Concrete in tension has linear loading branch and linear softening branch. Unloading is simplified by a straight line connecting the unloading point with the origin of coordinates. The concrete stress-strain diagram may be modified so that it is suitable as well as for modelling of fibre reinforced concrete. The softening branch is then composed of the two lines. Mild steel behaviour is modelled by elastic-plastic diagram with or without hardening. Unloading branch is again linear. Prestressing steel has only curved branch in tension with linear unloading.

Bonded tendons are approximated by a polygon. They are connected with the concrete beam at all nodes along their length. The prestressing can vary in each segment of the tendon. The bonded prestressing can be assumed as pretensioned or posttensioned.

Unbonded tendons are again of a polygonal shape. However, they are connected to the concrete beam only in specific points. Their connection at deviators can be either free, i.e. no friction is assumed, or fixed, i.e. infinite friction does not allow the tendon to move at the deviator. These cases represent the boundaries of the realistic behaviour. In the serviceability limit state no movement appears at deviators, but in the ultimate limit state a movement may be expected. To model the movement at the deviators would be a significant complication of the analysis. During the loading process, the slips might occur in a sequence, which is dependent on the loading process. An increase of the precision seems...
to be inadequate to the effort necessary for the development of a sophisticated numerical procedure.

Loading of the beam is assumed in different stages. In the first stage the beam is subjected to dead load and prestressing by bonded tendons. This takes into account the initial stage if the prestressing starts to act on the undeformed beam.

In the second stage, the unbonded tendons are prestressed on the beam, which has already been deformed. It makes it possible to model the construction of precast bridges, where the tendons are stressed after the assembly of beam elements. If necessary, the prestressing can be activated in one stage by omitting of the first stage.

In the third stage the beam is loaded by a set of forces representing the live load or by the imposed displacement of the node. If the beam is loaded in the serviceability limit state, the stresses obtained after the third stage of loading may be compared with allowable values.

The ultimate limit state is reached, if the set of forces representing live load in the third stage is increased, until the failure of the beam at any section occurs. The Newton Raphson method is used in order to approximate the behaviour of the beam until failure is reached. The failure occurs due to crushing of concrete in compression or due to exceeding of the limit tensile strain in steel. The load is automatically adjusted, so that it corresponds to its maximum value at the failure. If the displacement of the node is assumed as a control parameter, the load is increased up to the peak load and then decreased due to softening of the beam. More than one section may fail, until the kinematic mechanism is created.

The general procedure gives a good opportunity of establishing the ultimate load carrying capacity of continuous beams. The question under discussion is, what parameters should be taken as an input for the diagrams describing the material behaviour. It may be expected that the values recommended by codes based on limit states would provide too small stiffnesses and load carrying capacity of the beam. The other opinion, which seems to be more realistic, suggests to use the average strengths of materials. The problems are connected with the design philosophy and the safety concepts. They are under discussion in international associations like CEB or RILEM, but the final decision has not still been adopted.

References:


This research has been conducted at the Department of Concrete Structures and bridges as part of the research project "The effects of random initial imperfections" and has been supported by Grant Agency of the Czech Republic, grant No. 103/99/0057 and by CTU grant No. 10018164
COMPARING PREDICTED AND MEASURED INDOOR AIR TEMPERATURE

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Key words: computer simulation, unsteady process, thermal network

Using computer simulation by means of thermal node models as a design tool depends on the results from comparing predictions with experimental results from actual buildings. There are some problems including determination of the thermophysical properties of the building elements, lack of adequate climatic data and the difficulties of measuring different variables.

For simulation of internal temperature, computer program ANSYN has been used, which allows to solve problems of unsteady processes in buildings and energy systems [1]. This program makes it possible to assess changes of internal temperature evoked by changes of external temperature.

Measurement was done in a room of a small house with heavyweight walls. The room was placed in the north part with the floor directly in contact with ground. The roof and walls of the building were exposed to the outdoor environment except for the south wall.

The simplified thermal network with lumped parameters representing the construction is shown in Fig. 1 where $R$, $R_w$, $R_f$ are thermal resistivities of building shell, windows and infiltration. Resistivities $R_i$, $R_o$ describe the transfer from building shell to interior and from interior to internal wall. $C$, $C_i$, $C_o$ are thermal capacities of building shell, interior with furniture, internal wall and ground.

![Fig. 1: Thermal network of the room](image-url)
During winter period twelve measurements were done for seven consecutive days. Eight cases were chosen when sunshine was insignificant, it means solar radiation did not influence the temperature in the interior. One case is shown in Fig. 2 where forced (external), measured and simulated internal temperatures are drawn. The difference between maximum and minimum temperature of the thermal swing for predicted and measured temperatures was lower than 0.5°C for 54% of cases, 0.5-1.0°C for 35% and higher than 1°C for 11%.

Inaccuracies were caused by infiltration which is very difficult to assess precisely (due to old windows air movement in the room is unpredictable) and by estimated thermal capacity of floor with the ground. Results are very sensitive to these parameters [2].

References:

This research has been conducted at the Department of Applied Informatics as part of the research project “Model of Dynamic Behaviour of Building Construction and Energy Systems” and has been supported by Faculty of Civil Engineering (CTU) grant No. 12812.
SOIL IMPROVEMENT BY GRAVEL PILES

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Key words: piles, UNIT CELL model, hypoelastic solution

This article deals with an improvement of subsoil by the placement of gravel columns or sand piles. The solution of the problem is based on UNIT CELL model (UCM) analysis. The assumptions of UCM are:

1. A relatively thin (with respect to wide spread load) layer based on uncompressible stratum.
2. Uniformly distributed gravel columns penetrate through the whole thickness of improved layer.
3. Load is applied by widespread ideal rigid plate.

Due to these assumptions the only axisymmetric problem is solved. Characteristics of UCM including boundary condition are shown in Fig. 1.

An elastic analytical solution of this problem is presented in [1]. In the case of a hypoelastic analysis, stable state inside the subsoil is required. It can be seen than for arbitrary material parameters the gravel pile is occasionally in the critical state. As the stress state of the pile is rather similar to triaxial test, Mohr-Coulomb yield criterion is adopted. Using this criterion we are able to compute ultimate value of Young's modulus of the pile material E1. Example of dependence is presented in Fig. 2.
Fig. 2: Ultimate value of the gravel Young's modulus

$E_1$ and $n_1$ describe Young's Modulus and Poisson ratio of the gravel respectively, $\phi$ is effective friction angle of the gravel; $E_2$ and $n_2$ is Young's Modulus and Poisson ratio of the improved soil.

References:


This research has been conducted at the Department of Structural Mechanics as part of the research project "Fuzzy-probability concept of time dependent of structures reliability" and has been supported by GA 103/94/0137
ON THE CALIBRATION OF THE NEW CZECH PAVEMENT DESIGN METHOD

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Key words: flexible pavement, deflection testing, deflectograph, reliability of pavement design, calibration

The new Czech design procedure for flexible pavements is based on principles and requirements for safety and serviceability of road structures. The fundamental structural criterion of the method makes use of the Miner law for pavement damage accumulation. By applying results of the Eurocode discussion on fatigue phenomenon [2], the pavement fatigue criterion may be formulated as

\[ S_f(a, B, n_s, \varepsilon_s) \leq S_0(\gamma, D_0) \]

with the quantity \( S_f \) representing a measure of the pavement damage accumulated during the "model" fatigue process

\[ S_f(a, B, n_s, \varepsilon_s) = n_s \sum_{j=1}^{4} (10^{a_j} \varepsilon_{sj})^B \]

that distinguishes four seasons of the year with relative durations \( \tau_j \) and corresponding fatigue material parameters \( a_j \), the additional fatigue parameter \( B \) being thermally independent. The traffic induced pavement loading process is modelled here as a standard axle load application repetitive process, \( n_s \) denoting the total number of load applications, each load application causing the pavement strains \( \varepsilon_{sj} \).

The expression \( S_0(\gamma, D_0) \) from the right side of (1) comprises partial factors to assess different aspects of the reliability of our pavement modelling effort

\[ S_0(\gamma, D_0) = D_0 \gamma_d \gamma_D \]

with \( \gamma_d \) being the partial factor of the pavement mathematical response model reliability (indicating the accuracy of the pavement strains \( \varepsilon_{sj} \) calculation). The \( D_0 \) factor represents the critical value for the damage ratio, it describes in a quantitative way the fact that the Miner rule does not take "sequence" effect of the traffic load into account. Finally, the \( \gamma_D \) factor deals with the consequences of pavement failure (in terms of riding comfort levels). The factors \( D_0, \gamma_d, \gamma_D \) form a set of control parameters to be determined in such a way that the desired level of the pavement structure reliability is reached under all design situations.

In order to calibrate the design procedure, the outcome of its application to the pavement structures, that are representative of construction tradition, should be analysed. Tab. 1 presents \( S_f(a, B, n_s, \varepsilon_s) \) values pertaining to the selected catalogue pavement structures [3] (taken from the catalogue pages NN 1-1 and NN 1-2 with \( \gamma_D = 1 \)). In calculating \( S_f(a, B, n_s, \varepsilon_s) \), the values of parameters \( a_j, B \) were taken from [1] and \( n_s \) was set to 2.5·10^7.
The results presented in Tab. 1 indicate considerable inhomogeneity of the structural criterion (1) outcome with respect to different types of pavement structures. It is, therefore, impossible to select parameters $D_0$ and $\gamma_d$ in such a way as to fulfill the criterion (1) with the same reliability for all considered types of pavements.

<table>
<thead>
<tr>
<th>pavem.</th>
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<th>S (18.8)</th>
<th>KSC (19.9)</th>
<th>MZK</th>
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</tr>
<tr>
<td>b</td>
<td>KSC</td>
<td>18.0</td>
<td>2.76 (17.8)</td>
<td>0.45 (23.9)</td>
<td>14.2</td>
</tr>
<tr>
<td>c</td>
<td>KZK</td>
<td>19.8</td>
<td>2.87 (18.2)</td>
<td>0.47 (24.5)</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Tab. 2: Values of $S_f(a, B, n, e)$ for pavements with subbase:

OK – bituminous,
S – cement stabilized,
KSC – cement treated aggregate,
MZK – mechanically stabilized aggregate

There are two ways out of this intricate situation:

1. to define different values of the mathematical model reliability $\gamma_d$ for each basic type of pavement structures
2. to modify mathematical model by considering incomplete layer bonding at the subbase level.

Tab. 1 shows that for pavements with S and KSC subbases the assumption of incomplete bonding may rise values of $S_f(a, B, n, e)$ (values presented in the parenthesis) to the level of those pertaining to pavements with OK subbases.

References:


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DESIGN AND MANUFACTURING OF AN ULTRALIGHT AEROPLANE

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Key words: aircraft design, aircraft manufacturing, very light aeroplane, ultralight aeroplane

The current period in aviation of Czech Republic can be characterised by a certain decrease in production amounts caused by the new economic conditions after November 1989 and by changes in the former traditional markets. In the field of sports flying on the contrary the activities have risen significantly which has brought a production boom in the "ultralight" aeroplane category. In Czech Republic more than 450 such aeroplanes were produced within few years and their total number is still increasing.

The Institute of Aerospace Engineering (IAE) of the Faculty of Mechanical Engineering at Technical University Brno has always been involved in any actual activity — at aircraft industry and design offices as well as at the Czech Amateur Flight Association, private or amateur producers. The professional level of IAE staff supported by its hardware and software equipment brought an idea to design and manufacture own ultralight aeroplane. The design stage should enable the students to apply their knowledge of lectures and practical courses in framework of aircraft design. In the production stage the students should directly participate in manufacturing and in testing of the aeroplane in the Aircraft Test Laboratory. The design and development work at the project of ultralight aeroplane should result in an aeroplane for amateur flying of the students of the IAE.

The manufacturing costs of a modern ultralight aeroplane are very high and cannot be covered either from the budget of the IAE or the Faculty alone. A partner was searched for to assist the IAE — an agreement was finally signed with the company KAPPA Jihlava which agreed to cover production costs. To have additional support for the project, a grant application was submitted at the Faculty of Mechanical Engineering TU Brno. The objective was to support the project in area of theoretical analysis, material tests, structure design as well as the verification of the flight characteristics and design conception by a precisely scaled radio-controlled model.

A modern conception of the aeroplane has been chosen. The result is the aeroplane which get over the standard design practices in many aspects. The aeroplane has been designed in accordance with the European Aviation Requirements for very light aeroplanes JAR-VLA and the Czech ones L8/S and UL-2. It is a two-seat, low-wing, all-metal aeroplane with a retractable undercarriage. The power plant is the ROTAX 618 engine with a propeller designed at the IAE. The airfoil of the wing and the tail were optimised with respect to the maximum performance of the aeroplane and the minimum stalling speed.

The most important designs features are as follows: The aeroplane is equipped with a retractable undercarriage enabling to increase the maximum speed. In order to provide more comfort while decreasing the maximum width of the fuselage, the seats are set over in the longitudinal direction. The aeroplane has integral fuel tanks enabling the flight range over

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1000 km. The maximum level speed with a retracted undercarriage is higher than 200 km/h. The special type of riveting was used. The stalling speed is less than 55 km/h thanks to the Fowler flaps. The main specifications and performance data see Tab. 1.

The radio-controlled model of the aeroplane was built in scale 1:6 holding the airfoils and other geometric characteristics of the real aeroplane. Five functions were controlled – the elevator and the rudder, the ailerons, the landing flaps and the throttle of engine. The model served mainly for the verification of manoeuvrability and currently shows very realistic and favourable flight characteristics. Verification of the spin characteristics on the model which would help to determine behaviour of the real aeroplane is scheduled next.

The real aeroplane is in final stage of assembly and the maiden flight of a prototype is scheduled to the end 1995. The first flight will be preceded by a complete strength test in the Aircraft Test Laboratory of the IAE and by check-up of all functions, according to requirements valid for a new aeroplane. Results will be presented to both the professional and the amateur public. The development of the aeroplane will proceed further towards the JAR-VLA regulations. The radio-controlled model of the high-wing variant of the aeroplane (1:4) is in build. The model will enable further measurements of aerodynamic characteristics for the IAE research. The production of the high-wing variant seems to be very realistic.

| Wing span | 9.9 m |
| Wing area | 11.85 qm |
| Empty weight | 250 kg |
| Max. takeoff weight | 450 kg |
| Maximum speed | 220 km/h |
| Stall speed | 55 km/h |

Tab. 3: Main specifications and performances.

The most important student and staff works:

- Tests in the IAE Aircraft Test Laboratory: Outer wing tests. Undercarriage static tests. Wing hinges tests.

This research has been conducted at the Institute of Aerospace Engineering as part of the research project "Design and Manufacturing of an Ultralight Aeroplane" and has been supported by TU grant No. F-92-94.
BOUNDARY LAYER WIND TUNNEL
AT VZLÚ LETŇANY – PROGRESS
REPORT

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Key words: boundary layer wind tunnel, wind engineering

A boundary layer wind tunnel has been under construction by KÚ ČVUT and VZLÚ since October 1993. This project is supported by a GA ČR grant. ÚTAM AV ČR is participating in the project as a consultant.

A description of the project can be found in [1, 2]. The outlet parts of the tunnel behind the test section, including a fan, were assembled and set in operation at the end of 1994.

In 1995, production and assembly of the 13.6 m long development part (in which the boundary layer is developed) was completed. The inlet part of the tunnel – consisting of a dust filter, an input segment and a nozzle – has been designed, manufactured and assembled. The inlet part is detachable. It can be moved to a special place in the tunnel hall, where it will have no influence on the return air flow in the case of the operation of a second wind tunnel. Because elements of dust can damage wire anemometers, a dust filter is used. This filter is in front of the input segment, which an air flow turns by 45 degrees to the horizontal direction by two cascades of the blades. Then the air flow cross section is reduced by 2.6 times in the nozzle.

A test section was completed in November 1995. Parts of the construction of a small room for staff have been prepared. The room will be completed after installation of a test section at VZLÚ. The production of adjustable ceiling panels and mechanisms for the development and testing sections are nearing completion. The assembly of all these parts should be completed by the end of 1995.

A first version of a field of blocks (more than 12 m long) for developing an "open terrain" boundary layer type has been installed in the tunnel. The remaining parts of the development equipment (spires) are in production.

Some problems that have arisen have been discussed with specialists in Germany. Two important changes in the tunnel design were made on the basis of joint discussions. Firstly, one segment of the development section was installed behind the test section to reduce pressure fluctuations. The spectra of the pressure fluctuations were analysed for different fan speeds. To remove undesirable peaks of the spectra, modifications were made to the shape of the motor frame parts. Pressure fluctuation spectra were analysed again, and new modifications were made. These tests are being continued.

Secondly, we decided to install an adjustable ceiling along the development and testing sections. Some ceiling panels are made of wood, the others of hard aluminium sheets.
The rigid wooden panels are lightweight and will be installed in the development part. They will be adjustable in the vertical direction by a mechanism driven by a transportable electrical adapter. Metal panels will be installed in the test section. The elasticity of these panels is utilized for smoothing cross section changes. The vertical position of the panels is remote controlled. Panel couplings involve axial movement and angular displacement between the panels. This equipment should form a boundary layer flow with constant static pressure.

The test section is a complicated part of the tunnel. It is separated from the tunnel sections to reduce undesirable vibration. It can be fixed to the ground or separated by vibration dampers. The turntable with a diameter of 1.5 m has a ball bearing.

A 3D positioner is prepared for production. The positioner will be remote controlled by PC. Because of long delivery times for some parts, the positioner will not be ready for use before January 1996.

New measurement equipment for differential pressure measurements is being tested. It consists of 32 small pressure sensors with amplifiers, an I/O card for PC, and universal software for measurement control and analysis of results.

We would like to thank all co-workers from VZLÚ and KÚ ČVUT for their inventive collaboration during boundary layer wind tunnel design, production and assembly.

References:


This research has been conducted at the Klokner Institute ČVUT as part of the research project "Boundary Layer Wind Tunnel Building up for Testing Dynamic Effects on Buildings and Structures" and has been supported by GA ČR grant No. 103/93/0765.
STIFFNESS OPTIMIZATION OF MACHINE STRUCTURES

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Key words: optimum structure design

When modernizing of machines the designer is often limited, in consequence of original conception, by requirement that some machine parts may or must remain unchangeable as they must fit to the present design.

Fig. 1 shows a part of a machine designated to an innovation. This is the arm of an X-radiator rotating around its horizontal axis being supported with the bearings Z. The radiator itself is located in the protective covering having the big mass and connected with the arm in the position C where it can further rotate, supported with the bearings H. A basic constructional limitation appears to be the determined footing with the bearings Z; the original design of the radiator covering attachment C; the modification of the arm manufacturing technology (from the casting to the welding process) and the maintaining of a free space between the radiator and the rotation axis Z. The arm stiffness in the point C related to the footing Z was chosen to be the principal optimization criterion because owing to the requirement of its multiple increase was the innovation of this subset carried out. Objective function and a set of constraints represent in the optimizing process very strict requirements with regard to computational systems. There had been necessary to applied calculations of the structure repeated many times using 3D FEM but such an approach was not bearable (profitable) both from time and financial standpoints. From that reason an computational difference of less accurate models of the structure in 1D (in respect to 3D) were estimated and the optimizing, many times repeated, calculations were applied to the 1D models of the structure. A detailed stiffness analysis showed that the demanded stiffness parameters can not be attained in the original design and thus the optimizing model of the structure was extended by using further possible design variations. First of all, the lengths x, y were gradually changed using the cross section A = const and finally the support H was altered as well. The resulting structure shape in Fig. 2 was, after the computational analysis executed in 1D, verified by applying the 3D model at several loading variations when rotating in the gravitational field. It appeared that according to obtained experience it was possible to estimate the computational difference of the 1D model compared with the 3D model with a high accuracy and in this manner carry out the optimizing process. Necessary design alternations of the decisive component led to new proposals of other original apparatuses that had not been originally taken into account. In order to obtain the innovation optimum, i.e. objective function of the stiffness, the alternations, representing the optimizing constraint reduction in the solution process, were necessary.
Fig. 1:

Fig. 2:
OPERATING RELIABILITY OF HARMONIC DRIVE UNITS

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Key words: harmonic drive unit, design, testing, reliability

The research project has been aimed at further improvements of HDU (Harmonic Drive Unit) service properties. The theoretical and experimental activities were realized at two basic types of HDU. Firstly, at standard type PII 80-100 with unshortened Flexspline (gear cup) and simple Wave Generator (external diameter 80 mm), and secondly, at flat type PHD 96-96 with shortened Flexspline (gear ring) and duplex Wave Generator (external diameter 96 mm), as they are shown in Fig. 1. The both HDU rank among the series of these transmissions developed in the laboratories of our department.

HDU: PII 80-100
HDU: PHD 96-96

Fig. 1: Structural diagram of HDU component set (Wave Generator: 1 - hub, 2 - segment, 3 - flexible bearing, 4 - distance ring; 5 - Circular Spline, 6 - Dynamic Spline, 7 - Flexspline, 8 - tensometers).

The experimental research programme was realized on especially designed testing stands and comprised the following kind of measuring, obtained in the course of during:

1) short-run test – kinematic accuracy (was measured in cooperation with the firm Strojírny Čelákovice, CR), intermesh of HDU gears (a zone of full gear mesh and a throwing into and out of gear mesh), state of Flexspline stress by means of a tensometer’s measuring,
2) long-run test – operating capacity, thermal state, operating efficiency, loading capacity, vibration, service life,
3) static test – torsional characteristic, lost motion.

The results of this research project brought a next increase of knowledge about HDU service behaviour, verified an adequate reliability of our theoretical analysis and led us to a definite improvement of HDU service properties by means of the real proposed modification of HDU design, production technology, maintenance and repair. The proposed computerized modification of HDU toothing – for example, shown in Fig. 2, considerably reduce the wear in different from unmodified toothing.

Fig. 2: HDU toothing (1 – Dynamic Spline, 2 – Flexspline); a) wear of unmodified HDU toothing (--- before and —— after long-run test), b) computerized modification of HDU toothing.

References:


This research has been conducted at the Department of Machine Elements and Mechanisms as part of the research project “Improvement of Harmonic Drive’s Service Properties” and has been supported by CTU grant No. 10028171.
EMBEDDED COLUMN BASE EXPERIMENTS

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Key words: Embedded, Structural design, column base, steel concrete connection, experiments

This paper presents an experimental research concerning embedded column bases. The preliminary analytical research is also included.

The main advantage of an embedded column base is the high stiffness of its steel-concrete connection. Compared to the base plate with anchor bolts, during the construction of an embedded column base there are not difficulties with the accuracy of the anchor bolt placements and assuring of the contact surface between the base plate and the concrete base. One disadvantage of this column base can be the difficulties involved in erection of the column, for it is necessary to fix the column into its final position until the concrete of the base begins to support the column's weight.

Nine specimens were tested in the laboratory of Czech Technical University, Civil Engineering Faculty during the year 1995. The experiments could be sorted into three sets. Each set was designed to separate the basic responses of the column base to the load. The vertical and horizontal displacement of the specimens were measured with respect to the increasing axial force, sheer force and bending moment.

On the first set of experiments (see Fig. 1b) the bonding between the steel column (web and the flanges) and the concrete was measured.

To contrast, the bonding was excluded by use of oil on the second set of specimens (see Fig. 1c). The resistance of the bottom of the concrete block against punching was examined.

The third set of specimens (see Fig. 1a) was loaded by a moment only, with the normal force excluded. The deformation of the surface was measured (using strain gauges), as well as the horizontal displacement of the column and the concrete base.

The design bending resistance model of the embedded column in the concrete foundation can be calculated from the equilibrium between the internal concrete forces and the external loading forces. A simplified plastic stress distribution in concrete of approximated height of 0.8\(z\) is taken into account.

The collapse can occur by steel failure in shear or by concrete failure in bending. The experiments show the ways of improving a prediction model. The internal column flange is contributing highly to the transmission of stress from steel to concrete. This occurs due to the existence of the concrete cantilever closed between the column flanges and the column web. For a calculation of the concrete bearing strength in the horizontal direction, the concentration factor could be estimated as 1.3.

A numerical simulation using the Finite Element Method is being made in progress to provide a wide sensitivity study of the main parameters of influence. The final finding should lead to the production of a simplified method of prediction of the necessary embedded depth.
Fig. 1: a – Experiments designed to obtain bending resistance; b – Experiments designed to obtain bonding resistance; c – Experiments designed to obtain bearing resistance.

References:


This research has been conducted at the Department of Steel Structures as part of the research project “Modelling of Steel-Concrete Joint” and has been supported by CTU grant No. 10018234.
MATHEMATICAL MODELLING OF BUCKLING BEHAVIOR OF SLENDER STEEL WEBS

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Key words: post-buckling, repeated loading, numerical simulation, fatigue crack, patch load, FEM computer system FEAT, shape mode, imperfections

The objective of this investigation is to determine the stress state of webs subjected to shear and operating in the post-buckled range. The study has been performed in the framework of Prague research on the "breathing" of slender webs under repeated loading.

It is well known that the post-buckling capacity of plated structures is very remarkable, and the exploitation of this feature is quite important from the point of view of the cost of structures. Studies of buckling and post-buckling behavior under monotonic loading have been performed for years in many laboratories. However, the task is far more complicated if the loading is not monotonic. The aim of the numerical analysis was:

a) to study buckling shapes,
b) to make a numerical simulation of structural response during the experiment, in order to determine
   - the stress state, in the case of monotonic loading, and
   - the stress conditions in the zones of expected fatigue cracks.

Testing Specimens and Mathematical model. The investigations concerned steel girders, as shown in Fig. 1. The web was modelled by triangular shell elements, the flanges and stiffeners by means of beams. The finite element computer system FEAT was used. Special improvements to its geometrically nonlinear analysis part were made in order to achieve better convergency properties and accuracy. The principal features of the calculations are as follows:

Triangular three node shell finite element with 3 displacements and 3 rotations in each node. DKT (Discrete Kirchhoff Theory) finite element for the plate, special finite wall element with rotation around the axis perpendicular to the element plane (Fajman [2]).

Beam element with the same degrees of freedom in the node as the shell element.

Combination of the Newton-Raphson and Arc-Length methods for the nonlinear solution procedure.

Calculation of the initial stress matrix from membrane stress and axial forces in each iteration for determination of unbalanced forces.

Numerical results. Linear buckling shape modes were computed as essential results. The critical value of the loading provides an estimation of the beginning of the "post-critical" state of the structure. In our case this first shape mode was between 41 % and
48% of the experimentally obtained bearing capacity. In the numerical modelling, the main problem came – as usual – from the imperfections. They influence the behavior of the structure very strongly, namely at low levels of loading. The shape of the imperfection is also very important. Because the displacements in the post-critical state are larger than the imperfections, the structure behaves "ordinarily" if the shape of the imperfection is smooth. However, in the case of an imperfection of complicated shape, the structural response is completely different and bifurcation points can be found. Local imperfections, though not leading to buckling of the web as a whole, produce local gradients of stresses and initiate cracks or plastic zones.

In order to gain more information about these phenomena, the response of the structure to various shapes of imperfection has been modelled. The comparison of the load-displacement diagrams is shown in Fig. 2.

Fig. 1: FEM model

Fig. 2: Load-perpendicular displacement diagram

References:


This research has been conducted at the Department of Engineering Structures, Klokner Institute CTU as part of the research project "Limit States of Steel Plate Elements Subject to Various Regimes of Loading" and has been supported by GAČR grant No. 1314/2005.
DESIGNING STEEL CONSTRUCTIONS
BY FEM METHOD

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Key words: FEM method, ANSYS, modelling

In building construction and water management practice some constructions occur whose design represents certain problems. This applies to namely designing details with increased spatial complexity and solution of constructions which are exposed to dynamic loads. In some cases impact load is in question, e.g. by a falling load. By applying classical theoretic mechanics such tasks may be solved only with difficulties. Then, there are two possibilities left: either to construct a physical model acquiring results for the real construction on the basis of mechanical similarity or to create a mathematical model. Mathematical modelling of constructions has gone through a marked development lately mainly because of its relatively fast solutions available and for economical reasons. From mathematical models the most common one has become that of modelling by using a method of finalized elements. One of the largest programme systems for the solution of these problems is represented by ANSYS system which has now reached its 5.2 version. ANSYS programme is built on a module basis consisting of three basic modules. These are a preprocessor by which the construction set-up data is developed, the proper processor with computation modules (SOLVERS) and a postprocessor; on these components a complete modern computer system is based.

For solving dynamically loaded constructions a DYNA 3D module is applied, where 3D stands for three dimensional modelling by using three dimensional finalized elements. The system allows to solve contact problems with mutual interaction of two structural elements, e.g. two or more walls.

By using a system with DYNA 3D module Ls tasks may be solved as well in which the construction has suffered a rupture and it is necessary to deal with a state which will occur after the slip limit has been exhausted.

Within the framework of a grant project we have dealt with problems of contact between two or three walls and of impact stress of constructions. This problem consisted in impact load affecting a simple beam by a falling load and the impact of the fall on this load. To make the conditions for solving the task more difficult, the body was modelled in a shape of a hollow vessel with several lids. The lids were screwed to the vessel's jacket. The subject of the solution was to establish the ultimate strength of screw connections when subjected to dynamic stress during the fall of the vessel first on a solid base, later on an elastic cushion. The reaction of the elastic cushion was modelled as well by using a FED method.

The result of the modelling is the determination of ultimate load of an elastic beam subjected to stress by a falling load and the impact of the reaction of base on the deformation of the vessel. The design also resulted in the determination of ultimate load of the dynamically stressed screw connections between the solid boards of the vessel's lid and its jacket.
The most interesting result is the solution of the contact of three lids. Theoretically this represents a contact problem where it is necessary to change the density and the distribution of finalized elements in the contact area. During modelling of this problem such promising results have been obtained which confirm a possibility of finding a solution to this or similar contact problems as well.

This research has been conducted at the Department of Hydrotechnics and has been supported by CTU grant No. 10018238
COMPOSITE STRUCTURES:  
THE PERFORATED BAND  
AS A SHEAR CONNECTOR

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Key words: concrete, composite girder, perforated band, push test, shear connector, shear strength, steel

The new type of a shear connector for composite steel-concrete floor or bridge girders was developed in Germany some time ago [1]. The connector is formed by a perforated steel band which is welded to the steel girder. A transverse steel reinforcement of the concrete plate goes through the band (Fig. 1) and increases rapidly the shear strength of the connector. After some discussions with producers of steel structures a simple modification of the original perforated band was proposed by the authors (Fig. 1).

Fig. 1: General view of a perforated band and the band proposed by the authors.

To determine the basic shear strength of the connector the standard push tests in accordance with Eurocode 4 [2] were carried out. In this abstract the results of three series of tests are described. The nominal concrete of C30/37 ($f_{ck} = 30\,\text{MPa}$) and the reinforcement steel 10425 ($f_{y} = 410\,\text{MPa}$) of diameter 10 mm were used throughout the tests. Each series included three identical test samples.

- The first series had no transverse reinforcement inside the holes of the band. The only shear was transferred by the concrete pins going through the holes.
- The second series had few reinforcement steel bars inside the holes ($A_{st} = 249\,\text{mm}^2$ per one meter of the band).
- The third series had heavy transverse reinforcement ($A_{st} = 582\,\text{mm}^2$ per one meter of the band).
The testing procedure, modes of collapse and statistical evaluation of the tests are given in [3]. Some typical shear-force deflection curves are shown in Fig. 2. Here only the values of shear characteristic strength per one band hole in accordance with [2] are presented:

- Series 1 (non-reinforced perforated band) : \( P_{Rk} = 13.5 \text{kN} \)
- Series 2 (slightly reinforced perforated band) : \( P_{Rk} = 26.3 \text{kN} \)
- Series 3 (heavy reinforced perforated band) : \( P_{Rk} = 38.3 \text{kN} \)

![Fig. 2: Typical force-deflection curves.](image)

The most important strength parameter seems to be the amount of transverse reinforcement. Its influence is not fully recognized in the formula given in [1]:

\[ P_{Rk} = p^2 \beta_{un} \]  
(\( \beta_{un} \) being the concrete strength due to German Standard).

The authors proposal for the shear strength per one hole at this stage of investigation is given by formula:

\[ P_{Rk} = (p/650)f_{ck}\sqrt{A_{st}} \]  
(see above for the symbols).

The formula is conservative for low reinforced bands and is being verified by another push tests at present, with respect to strength of concrete as the formula variable. Finally, the real composite girders will be tested to confirm the shear strength results in the bending beam behaviour.

The described new type of shear connector seems to be very powerful element, suitable in particular for girders of big strength (large spans of girders and/or their associate concrete plates).

References:


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Section 9

MATERIALS SCIENCE
IN MECHANICAL ENGINEERING
APPLICATION OF IMAGE ANALYSIS ON THE EVALUATION OF STRUCTURES OF Ni-SUPERALLOYS, STEEL AND CERAMICS


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Key words: image analysis, structure, Ni, superalloys, steel, ceramics

The project was proposed for one year with the aim to introduce the image analysis as a valuable tool in structure evaluation and measurement. The materials and procedures were chosen so that the results can be used in other research projects and teaching. The software used was the ScreenMeasurement provided by LIM.

The materials used were Ni-Cr-Al alloys, Ni-Cr plasma coatings on Al substrate, Ni20Cr powder used for plasma spraying, Ni based superalloys CMSX-3, and various ceramic coatings plasma sprayed on steel substrates. The study of the structures of ferritic steels is anticipated. Both, on-line evaluation from light microscope Zeiss Neophot 32 and off-line evaluation from micrographs obtained in SEM and TEM, were employed. The application of image analysis for assessment of selected area electron diffraction patterns is being developed. The image analysis is also used to measure the shape change of Taylor test specimens. These specimens are impacted onto the rigid anvil and their final dimensions and shape are used to determine the dynamic mechanical properties. Common problem accompanying the application of image analysis regardless of material, is specimen preparation. Especially, when different materials comprise one specimen, metallography preparation is crucial. The preparation of metallography specimens from plasma sprayed coatings require special procedure for each pair of materials. [1]. Some material combinations cannot be manually, and testing different condition for automatic specimen preparation is time consuming. Nonetheless, relatively “easy” materials like Ni-based superalloy or Ni-Cr-Al alloys may also pose some problems. Transmission electron micrographs of the structure containing $\gamma$ and $\gamma'$ phases are difficult to obtain with uniform contrast. In some cases, $\gamma - \gamma'$ interface cannot be resolved under ordinary imaging conditions, and suitable dark field must be find.

In all instances, evaluated recently, both manual count and semi — or full automatic image analysis were used. The aim was to compare results and find the limits were image automatic analysis could be treacherous. We are glad to report that all results coincide within the experimental errors. The measurement was done on $\gamma'$ phase particles in superalloy, $\gamma'$ phase particles in Ni-Cr-Al alloy with varying size and shape (subjected to different heat
treatments), porosity in thermal spray coatings (NiCr, Mo, hydroxyapatite, Ni etc. on steel substrates), and NiCr powder used for plasma spraying. Electron diffraction patterns could be evaluated in two ways, namely, by the direct measurement of length (spot position) and angles, or by comparison with previously indexed patterns. The second method requires gradual building of the library of typical diffraction patterns. The length changes and shape of impacted specimens (Taylor test) are basic data necessary for determination of dynamic yield stress. The final shape of specimen is mushroom-like and usually is determined by manual measurement. The software makes possible not only the measurement on the screen but also the suitable image storage and transfer of the results to other software packages. The results acquired in the frame of the project are used for teaching and in many other research projects.

References:


This research has been conducted at the Institute of Material Engineering as part of the research project “Application of Image Analysis on the Evaluation of Structures of Ni Superalloys, Steels, and Ceramics” and has been supported by TU grant No. FME959577.
THE PREPARATION OF THIN FOILS FOR TRANSMISSION ELECTRON MICROSCOPY BY ION MILLING

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Key words: thin foils, ion gun, phase identification, specimen preparation, ion sputtering, ion source, incident angle, transmission electron microscopy

Transmission electron microscopy is powerful tool of material science. It allows the structure studies, phase identification, microanalysis, etc. The specimen preparation is essential for reliable results. It has to satisfy to requirements: transparency and unchanging of structure originally present in the material. For metals and alloys electrolytic thinning is most popular method. For nonconductive materials, many techniques were tried (ultramicrotome, cleavage, etc) but it seems that only ion bombardment meet both conditions. Even when conductive materials are concerned, there are many instances when electrolytic thinning is not suitable. For example composite materials, specimens containing two different materials joined. The difficulties always arise when we attempt to thin material containing constituents differing considerably in conductivity, hardness, chemical properties etc. Thus for some materials (ceramics, composites, high speed steels, gray cast irons, especially with nodular graphite, explosive weldments, thermal spray coatings) the ion sputtering is the only possible method for the last stage of foil preparation. The objective of the project has been the development of methods for thin foil preparation these materials with ion gun IV3.

The process of thinning in the ion gun depend on a number of parameters: accelerating voltage, vacuum quality, current, gas pressure, angle of ion beam incidence etc. It showed it is impossible to operate relatively obsolete apparatus IV3 so that it can be used for routine thin foil preparation. During the second year of the project, necessary fixing and modifications of the apparatus were performed. The vacuum system was checked and sealed and the apparatus became at last operational. Nevertheless, the apparatus embody vacuum system with pumping speed around 35 l/s and this capacity showed insufficient for our purposes. For full operation, the ion milling apparatus would require around 150 l/s. The results, therefore, were not satisfactory although experiments were extensive. Other applications, like cleaning of the surface of ceramics yielded satisfying results. To gain some experience and to start to produce transparent thin foils for other research projects, experiments have been done simultaneously on new equipment (Edwards) installed at the Institute of Physics of Materials. Two types of specimens were used. First we prepared thin foils from explosive weldment of copper and carbon steel. After some labouring the optimal conditions were found to be: ion source voltage: 6 kV; ion source current: 1 mA; specimen current: 50 μA; incident angle 20° (5 hours) and 5° (1.5 hour). These foils were examined in a Philips CM12 STEM with EDAX 9900 ultra thin window X-ray microanalyzer. An example of the structure in mixed zone is in Fig. 1. This micrograph correspond to the region containing nonequilibrium alloy Cu+Fe (Fig. 2)
Fig. 1: TEM of explosive weldment carbon steel–copper. Magn. 100 000 x.

Fig. 2: Microanalysis across the mixed region of carbon steel–copper weldment.

References:

This research has been conducted at the Department of Structure and Phase Analysis of the Institute of Materials Science as part of the research project “The Preparation of Thin Foils for Transmission Electron Microscopy by Ion Milling” and has been supported by TU grant No. F-64-94.
CONTRIBUTION TO THE STUDY OF GUINIER–PRESTON ZONES BY MEANS OF HIGH RESOLUTION ELECTRON MICROSCOPY

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Key words: Al–Cu alloy, Al–Cu–Mg–Mn alloy, GP zones, electron microscopy, contrast, multislice simulations, tomographic atom probe, solid solution

Guinier–Preston (GP1) zones, small clusters of alloying elements, are known to form in the first stages of the decomposition of solid solution. They are disc shaped in the Al–Cu based alloys, being only one atomic layer thick in the majority of cases.

We studied these GP1 zones in the model alloy Al–Cu 4wt.% and in the industrial alloy Al–Cu 4.4–Mg 1.5–Mn 0.6 wt.% (AA 2024) by means of high resolution electron microscopy. The experimental images in [100] and [110] crystal axes are interpreted using multislice simulations [1].

A local analysis of the Cu content in the GP1 zones by means of X ray emission excited by a nanoprobe of electrons from field emission gun was made. We used a simple model to interpret the results. The copper concentration turned out to be 50–100%. A three-dimensional cartography of the distribution of copper atoms in the binary alloy has been obtained by means of the tomographic atom probe [2].

The majority of the GP1 zones in the Al–Cu 4wt.% alloy aged at 373 K for 10 hours consist of atomic monolayers, the disc diameter ranging from 4 to 10 nm. In the same alloy we found also double layer GP1 zones. The GP1 zones in the industrial alloy Al–Cu–Mg–Mn (AA 2024) in the T3 temper (solution annealed, quenched, pre-strained 2% and naturally aged for more than 2 years) have the same form as those observed in the binary alloy.

The contrast of the GP1 zones is strongly dependent on their size, on the foil thickness, on the defocus of the objective lens (Fig. 1) and less sensitive to their internal structure (Cu content) and to the position of the GP1 zone in the depth of the foil. In certain conditions, we observed also a very strong contrast of the GP1 zones. This contrast is explained by the channelling of electrons along the copper rich columns in the GP1 zone. The heavy copper atoms collect, due to their stronger electrostatical potential, more electrons from the incident beam than the light aluminum atoms in the adjacent matrix.

We observed, in the [110] zone axis orientation, shearing of a GP1 zone by a dislocation. We propose a simple model of strengthening by the GP1 zones, related to the yield stress.

The results obtained by means of the tomographic atom probe show that the matrix surrounding GP1 zones is still rich in copper. The distribution of Cu atoms in the solution is not homogeneous. In the vicinity of the GP1 zones (several angstroms), the matrix is...
depleted and the copper concentration seems to be zero. The GP1 zones nucleate and grow on the expense of their copper environs.

According to the contrast analysis of throughfocus series of experimental images, the Cu content within several GP1 zones is 100%. One of the images is better interpreted using a model of 50% Cu/50% Al. Consequently it is possible that GP1 zones composed of 100% Cu and 50% Cu/50% Al coexist.

Fig. 1: Contrast changes of GP1 zones with defocus; Al–4 wt.% Cu alloy, [110] zone axis, foil thickness 26.9 nm. The micrograph with relative defocus of -39.6 nm represents structure image.

References:

This research has been conducted at the Laboratory of Mechanics, Structures, Soils and Materials of Ecole Centrale Paris and has been supported by a grant of the Foreign Affairs Ministry of the French Government.
The project "Increase of exploitability of the SEM analytic complex JXA 840 A" was aimed generally at improving the measurement data analysis by providing a link between the microscopic complex and a PC-type computer and at applying modern numerical data processing methods. The main problems met and solved in frame of the project were: 1) format conversion of data from the LINK format used by the measuring complex into the MS-DOS format, 2) hardware configuration selection and installation, 3) program development or selection of suitable software packages for analysis and presentation of the particular types of measurement data, 4) routinely usable implementation of the surface calculation, based on couples of stereo images.

As for providing the link between the measuring complex and the PC computer, the only feasible way turned out to be the data transfer via external media. Nevertheless, the LINK data format is not compatible with MS-DOS format; after consulting many different sources, a functioning data conversion program has been provided [4].

The initial equipment available consisted of a 386/20 MHz/4 Mbyte computer in 1994. A substantial upgrade was made in frame of cooperation with the Faculty of El. Eng. and Comp. Sci. [9] turning the computer into a 486/66 MHz/20 Mbyte machine and providing a high resolution HP-LJ4P laser printer. This equipment provided sufficient power to solve some data processing tasks as needed e.g. in the projects [5-8] as well as to implement a simpler version of stereo analysis programmed in the Borland PASCAL language. Nevertheless, implementing the stereo analysis package in MATLAB environment was at the edge of possibilities of the system without providing sufficient space for further development. The price/performance analysis showed that the PC-based hardware is for the given purpose presently advantageous over workstations; joining the means of this and other projects, it was possible to exchange the hardware for a new Pentium/90 MHz/32 Mbyte system in 1995.

The initial program development in frame of the project has been done in the Borland PASCAL environment. In 1994 it has been decided to switch to the MATLAB environment utilizing both its general purpose core and the available specialized toolboxes. So far, the core MATLAB package has been provided. Concerning the hardcopy presentation of images, a way [10] of a reasonable quality image print has been verified.

The main part of the work in frame of the project has been devoted to implementing the original approach to stereo analysis, as described in [1, 2], enabling to calculate the
surface of microscopic samples on the basis of stereo couples of images. Nine versions of the PASCAL based program systems have been worked out, gradually improving both the speed and reliability of surface determination as well as the friendliness of the user interface. The last version includes also the automatic measurement geometry identification in a simplified form. All the versions worked with image data matrices of 256 × 256 pixels obtained by decimating the original data. The height data provided are substantially more reliable than the results of the firmware that provides totally chaotic results under common conditions.

In 1995, most of the work on this implementation was devoted to switching to MATLAB environment which enabled working with the original image matrices 512 × 512 pixels. In this frame, a set of specialized procedures has been developed, namely for testing different types and modifications of disparity analysis (5 versions), for deriving parametric images, procedures for surface calculation and for statistical identification of the measurement geometry based on histogram of the directional disparity field. Even difficult images with large areas of low variance could be successfully analyzed. Presently, a user friendly version of the program package is being prepared.

References:


[5] Project COST No. 504


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DEVELOPMENTS IN ROBUST SURFACE RECONSTRUCTION FROM STEREO SEM IMAGES

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Key words: scanning electron microscopy, stereo vision, disparity analysis, surface reconstruction

The last year developments in a robust method providing quantitative surface description of microscopic samples from scanning electron microscope based on disparity analysis in stereoscopic couples of microscopic images are described. The new contributions are: disparity analysis using vector grey level registration based on vector angle minimisation (rather than on correlation or distance minimisation) in comparison with a feature matching approach, the effective implementation of the disparity map calculation and the identification of measuring geometry based on statistical processing of the disparity matrices. The presented approach is distinguished from most current stereo work by not imposing any constraints concerning the computed surface while still keeping the computational demands at a reasonable level for the application.

After the previous work, there remained two main problems in SEM stereo analysis. The disparity analysis had to be sufficiently robust to cope with often unfavourable conditions in SEM imaging. With respect to the high variety of the analysed scenes, it was undesirable to impose any a priori constraints to the calculated surface shapes which excluded many otherwise useful simplifications. The second problem concerned the real geometry of a particular measurement which can only be based on noisy disparity matrices as the real situation differs substantially from the expected one due to mechanical imperfections of the support working in micrometer domain.

An extensive experimental comparison of different criteria, as applied to SEM stereo images, has been made. Both basic groups of the criteria, i.e. grey level and feature based matching were tried. No better criterion has been found in the first group comparing defined image areas than to minimise the angle between the multidimensional vectors \( \mathbf{a} \) and \( \mathbf{b} \), describing the two areas by ordered sets of pixel values, or to maximise its cosine

\[
\frac{\mathbf{a} \cdot \mathbf{b}}{||\mathbf{a}||||\mathbf{b}||}.
\]

(1)

The advantage of the criterion is its insensitivity to different intensity and contrast of both images but even in well exposed couples it gave definitely the least error rate among all the more common criteria including correlation and covariance or Euclidean and other distances.
In the group of feature based criteria, particular attention has been devoted to the combined criterion described in [1] that obviously worked well in practical tasks and is substantially less demanding computationally but until now the achieved error rate was too high.

Unfortunately, the criterion (1) is rather demanding so that a well organized computation is needed to achieve reasonable computing times. The basic idea is to start with a sparse “layer” of possibly not too precise but reliable pairs of points and to proceed to more dense “layers” based on the previous ones as estimates. The influence of sequences of the layer parameters was in a greater detail estimated in [3]. There is unfortunately no formalised clue to an optimum design so that only intuitive experimental approach was used to determine a reasonable sequence of the “layers” with appropriate parameters. In this way determined sequence has led to cutting the computing time by more than one decimal order.

As already mentioned, the tilt axis is both shifted and rotated with respect to its expected position. There are no direct means to determine the real axis position so that it must be estimated from the vector field of disparity. In the previous work [2] the axis was interactively placed to the line with maximum zero disparity vectors. In practical cases such an estimate may be unreliable; therefore a new formalized method to identify the measurement geometry has been introduced. It is based on statistical analysis of 2-D field of “rectified” disparity direction as described in detail in [5].

After implementing the mentioned improvements, the analysis became usable routinely and its processing time is already in the acceptable range comparable with the time required to gather the microscopic image data. Also, the location of the tilt axis is determined fully automatically thus removing the last interactive step.

References:


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DIFFRACTION ANALYSIS OF MATRIX PHASES IN ELECTRON BEAM WELDS OF A STAINLESS MARAGING STEEL

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Key words: neutron diffraction, maraging steel, austenite content, dislocation density

The diffraction techniques enable both quantitative phase analysis and determination of internal strains in polycrystalline metallic materials. The plastic strains are related to stress fields resulting from microstructural defects which cause the broadening of diffraction peaks. Various shape analysis procedures can be applied to quantify the latter effect [1]. The instrumentation for neutron diffraction measurements was considerably improved by original set up of monochromator and analyzer at the LWR-15 reactor in Rez [2].

The purpose of the present work was to determine the volume fraction of matrix phases and their dislocation densities as derived mostly from neutron diffraction spectra, in a martensitic-austenitic age-hardenable stainless Cr-Ni-Mo-Ti-Al steel after electron beam welding followed by different post-weld heat treatments.

The chemical composition and heat treatment of the investigated steel are given in [3]. Neutron diffraction profiles from the martensite (110 reflection) and from the austenite (111 reflection) were measured only in weld metal (WM) and in base metal (BM) 1 cm apart from the weld axis, since heat affected zones of the weld joints were very narrow. The neutron wavelength was 0.16 nm. The instrumental profile was approximated by the measured diffraction line (110) from well annealed pure α-Fe standard sample where the grain size contribution is supposed to be negligible. This line (FWHM=8.7') was used for deconvolution of all experimentally obtained diffraction profiles by means of indirect deconvolution method [4, 5]. The volume fraction of austenite was obtained by comparing the integrated intensities of 110m and 111a reflections. In order to check neutron diffraction (ND) results, the quantitative X-ray diffraction (XRD) method using CrKα characteristic radiation was also employed.

Experimentally measured neutron diffraction profiles are shown in Fig. 1 whereas Tab. 1 summarizes the values of < ε > obtained by both Mignot-Rondot approximation (index MR) and deKeijser method (index K). Both methods used for the line-broadening analysis have yielded very close values of the mean-square microstrain and, consequently, close dislocation densities ρc. Despite of the relatively rough model [6], presented dislocation densities ρc (Tab. 1) are in very good agreement with those measured by means of electrical resistivity in lath martensite [7].

Similarly like volume fraction of austenite, the dislocation densities of both matrix phases are also maximum in welds which were quenched and intercritically annealed. The
dislocation densities of martensite in the as-quenched state or just air-cooled state are also relatively high ($3-4\times10^{11}\text{ cm}^{-2}$). With increasing ageing temperature, the dislocation density decreases and a minimum is attained in the overaged condition (Fig. 2). However, it increases again during intercritical annealing, apparently due to higher austenite content.

<table>
<thead>
<tr>
<th>sample</th>
<th>phase</th>
<th>$&lt;\epsilon&gt;_{MR}.10^3$</th>
<th>$&lt;\epsilon&gt;_{K}.10^3$</th>
<th>$v_a$</th>
<th>$\rho_{\epsilon}^{MR}.10^{11}$</th>
<th>$\rho_{\epsilon}^{K}.10^{11}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>QA 560</td>
<td>WM mart.</td>
<td>3.3±0.1</td>
<td>2.38±0.04</td>
<td>12.4</td>
<td>3.2±0.1</td>
<td>1.73±0.05</td>
</tr>
<tr>
<td></td>
<td>WM aust.</td>
<td>2.4±0.3</td>
<td>1.8±0.2</td>
<td>1.8±0.3</td>
<td>0.9±0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BM mart.</td>
<td>3.5±0.1</td>
<td>2.42±0.03</td>
<td>17.0</td>
<td>3.7±0.2</td>
<td>1.78±0.04</td>
</tr>
<tr>
<td></td>
<td>BM aust.</td>
<td>2.9±0.3</td>
<td>2.1±0.2</td>
<td>2.7±0.4</td>
<td>1.3±0.7</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 4: Mean microstrain $<\epsilon>$ of martensite and austenite crystals, volume fraction $v_a$ (in vol.%) of austenite and dislocation densities $\rho_{\epsilon}$ in martensite and austenite.

Fig. 1: Neutron diffraction profiles

Fig. 2: Dislocation density vs. temperature of post-weld heat treatment

Present investigations resulted in the following conclusions. The volume fraction of austenite is lowest in as quenched condition and reaches maximum value after intercritical annealing. Dislocation densities computed on the base of mean-square microstrain yielded values of $10^{11}\text{ cm}^{-2}$, which were systematically higher in martensite than in austenite with very small differences between weld metal and base metal.

References:

This research has been conducted at the Department of Material Science as part of the research project "Structure and properties of welds in IISS steel" and has been supported by CTU grant No. 8087.
COMPUTER PROCESSING
OF NDT INDICATION

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Key words: something, anything, nothing

The development of radiological methods in the field of NDT is greatly affected by
efforts to limit as much as possible the application of radiographic methods and to replace
X-ray indication (on a film) by a new, qualitatively higher form of recording. Doing away
with the film recording of an X-Ray image brings some important advantages:

1. There is no lengthy negative process or defects that may appear in the course of the
   negative process (artefacts in radiographs).
2. The possibility of real-time radiological testing.
3. A marked improvement in the economy of testing (there are no expenses on films,
   baths, dark-room operator, documentation and storing of test results are simpler).
4. The process of testing is made faster.

Most promising in the development of film-free indication seem to be skiascopic methods
with a highly sensitive system of recording. It should be noted that such facilities are
commercially available from leading manufacturers of X-ray devices, mostly supplied in
the form of single-purpose units. The skiascopic image is taken, amplified, converted to
electronic form and either recorded by means of a TV monitor or processed by a CCD
matrix [1], or digitalized and processed on a powerful computer.

Solution of assigned project Project F-60-94 was divided into two tasks:

1. To set up a radioscopic device assembly with digital output (digital image processor,
   image memory, control unit)
2. To write a (or adapt an existing) program for quantitative analysis of radioscopic
   image that would make it possible to solve problems of testing various machine parts
   (metals, ceramics, plastics).

The aim of the present work is to introduce methods of computer-processing a radiosco-
pic image in order to enhance the sensitivity of the method, resolvability and overall
assessibility of material defects. It can be expected that the quality of an X-ray signal eval-
uated in this way will exceed the quality of radiographic methods, especially in cases when
very thick walls are to be X-rayed.
Device assembly and its function. The device assembly was proposed and implemented in keeping with the schematic diagram. The X-ray source releases a homogeneous beam of radiation which will pass through the object under irradiation. Due to the interaction between radiation and substance an intensive relief is formed in the beam. This modified (no longer homogeneous) beam impinges on a fluorescent screen, where the X-ray radiation gets modulated to the region of visible spectrum. Subsequently the radiation intensity can be amplified as much as 10 000 times in a two-stage brightness amplifier. This amplified visible image is taken by a camera and converted to an electric signal. The electric signal is applied to the input of a computer (486 DX 40), where it is digitalized to be ready for further processing (a VIDEO PLUS digitalization card is used). The evaluation program is based on the DIPS 4.0 program of the SOFO Company, which is used e.g. for image analysis in metallography or in astronomy. Scanning the X-ray image is done by SLOWSCAN, which provides for slow scanning of static images and thus ensures their high quality. It can also be used for scanning at extremely low illumination levels or in the photometric analysis of images.

The DIPS program enables:

- photometric analysis
- combining images (algebraic, statistical and logical operations)
- filtering the image by using matrix convolutions
- generating the image, magnifying its parts and adjusting the pseudocolours
- measuring in the image (coordinates of objects, distances and angles between them)
- counting the objects
- analyzing the shape of objects
- classifying the objects.

The two-monitor version makes it possible to follow continuously on one (black and white) monitor the image scanned, and to carry out the analysis on the other (colour) monitor. DIPS's internal programming language makes it possible for DIPS to adapt to the needs of evaluating radiograms, writing an algorithm of image analysis, and comparing the results of analysis with the classification conditions as set by evaluating standards. An important advantage consists in the possibility of storing the results (both the image and the record of its evaluation) on a magnetic or optical disc, which provides for an easy and cheap method of keeping records of the results of testing.

References:


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USE OF SCANNING TUNNELING MICROSCOPY IN MATERIALS SCIENCE AND ENGINEERING

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Key words: scanning tunneling microscopy, surface topography, fatigue, thin solid films

Due to its parameters, especially its very high lateral and vertical resolution, scanning tunneling microscopy (STM) is an outstanding experimental instrument. Until now, most of the published information refers to its applications in theoretical and applied physics, especially surface science. STM can, however, be also very useful for solving problems that are of "engineering nature". These STM applications often do not utilize fully the limits of its possibilities. In material science and engineering (MSE), it is used when required information cannot be obtained by other techniques. Frequently, lower magnifications are used, with STM only complementing or substituting traditional methods such as optical microscopy, scanning and transmission electron microscopy when these methods fail or when they must be stretched to their limits. Unfortunately, STM can be usually used in the microstructure evaluation of several metals and alloys only [1, 2]. Due to the serious absorption and surface oxidation, it is difficult to investigate easily oxidizing materials. It is almost impossible to study the microstructure of industrial alloys, such as steels, with STM unless proper surface protection is applied. Very nice examples of such surface protection (by covering it with a layer of glycerol) during the study of bainitic microstructure of an austempered Fe-1C-4Cr-2Si steel have been published recently [2].

Excellent examples of these STM applications are given, e.g., by Opielka et al. [3], who studied the morphology of γ'-phase in a nickel alloy. He used STM to determine the volume fraction of γ'-phase when conventional metallographic examination yields erroneous results due to inaccurate image representation of the phase. Similar examples is the study of dispersed particles and carbides in Ni- and Fe-base alloys, the study of PVD layer of TiN on high-speed steel, etc. Pischow et al. [4], studied, among other, carbonitrides in steel. They also a comparison of the laboriousness and reliability of conventional techniques (such as carbon replicas in TEM) and of STM, revealing the advantages and great possibilities of STM. Several examples of our own results obtained on STM 3130 (TESCAN) built into SEM 2SS (JEOL), follow.

One of our first attempts was the study of the "just-initiated" fatigue cracks in the earliest stage of the fatigue process. Cylindrical specimens of stainless austenitic steel 316L THYSSEN were. Small area of the surface was electrolytically polished. After short loading
(\(N = 7500\) cycles, which represents cca 5% of fatigue life) a slab containing the polished area was cut out and sputtered with Au. These specimens were examined in STM. Cyclic-plastic deformation is revealed in surface extrusions and intrusions created by persistent slip bands.

Another issue is the analysis of Pd coatings with different thicknesses (250–2200 nm) formed by reactive diode sputtering on various substrates (single crystal Si(111), Si(100), glass). The subject of study was the effect of the coating thickness and the type of substrate on the surface quality of a sputtered layer. It showed, for example, that the layer on Si(100) has a tendency to copy the morphology of a substrate surface [1].

The last example refers to nanostructural and amorphous thin coatings, namely Ti, Ti-14% Cr, Ti-50% Cu, prepared by magnetron sputtering on a glass substrate. Both STM and TEM allowed to verify the proposed model. The structure of both surfaces of PVD coating (i.e., free surface and surface adjacent to glass), and the coating fracture were studied by means of STM. It was found that the microstructure of specimens was in good agreement with the Thornton model [5], that takes into account the effect of substrate temperature and argon pressure on the coating microstructure. The surfaces images clearly show the columnar growth structures, that are characteristic for low thermal mobility of ions and low mobility of particles growing perpendicular to the substrate surface. At greater magnification, the micrographs of coating fracture surfaces show columnar structure of the individual fibres. Image of the free surface confirm a very low roughness but show a well-defined crystalline structure, while the “glass” side exhibit nanostructure of the first deposited layer. Nanostructure can be attributed to the cooling rate of impinging particles, and to the transfer of heat after the impingement.

References:

This research has been conducted at the Institute of Material Engineering as part of the research project “Application of Scanning Tunneling Microscopy” and has been supported by TU grant No. C 26/94.
DEGRADATIONS ACTING DURING SERVICE EXPOSURE OF STEAM TURBINE PARTS AND THEIR INFLUENCE ON REMAINING LIFE

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Key words: low-alloyed, heat-resistant CrMoV and CrMoVW steels, long-time service, degradation mechanisms, stability of microstructure, carbide reactions, remaining life

The influence of long-term service on the microstructure and mechanical properties of twenty-five steam turbine casings, which were cast from steels of grades 42 2740, 42 2745, 42 2747 and 42 2834, has been described in [1] and [2]. The results of these works can be summarised as follows:

• Long-term service resulted in the embrittlement of casings, which was linked with a decrease in relative notch toughness and yield stress in more than 50% of casings.
• An enrichment of the coexisting carbides (M₄C₃, M₇C₆, M₃C₃ and M₅C) by Cr, Mo, V and W was observed and it was more pronounced at the hot end of the casings and after a longer period of exposure. The thermodynamic stability of carbides, which was evaluated by the quasi-equilibrium constant K of the carbidic reactions of the "integral" carbide M₄C [2], was greater at the hot end.

The results of the subsequent more detailed experimental work (ATEM, SEM, AES, EDS and XRD; microchemical and phase analysis of all carbides were realized in carbon extraction replicas and on carbides prepared by anodic isolation), which has partly been described in [3], [4] and [5], can be summarised as follows:

• The embrittlement of especially the hot end of casings was proportional to the intergranular decohesion (ID) mode fracture followed austenite (steels 42 2740, 42 2747 - bainite) or ferrite (steel 42 2834 - ferrite) grain boundaries. Casings with the ID fracture mode greater than 50% of fracture surfaces had the transition temperature tₐ above the room temperature.
• Carbide coarsening contributes to the to the embrittlement at the hot end of casings – carbide-induced embrittlement.
• One of the degradation mechanisms leading to the embrittlement of casings is temper or segregation embrittlement due to the segregation of P, Sn and Cu to austenitic or ferritic grain boundaries [3]. This type of segregation embrittlement probably fits the model proposed by Qu and McMahon [6].
• Changes in types of carbides can be observed during long-time service (dissolution of carbides \( M_3C \), \( M_{23}C_6 \) in grade 42 2740 steel and precipitation of carbides \( M_2C \) and \( M_6C \); precipitation sequences were found to be in general agreement with that of Senior [7]).

• Increasing time and temperature of service had little effect on the chemical composition of carbides \( M_4C_3 \), \( M_2C \) and \( M_6C \), but in type \( M_3C \), \( M_{23}C_6 \) and \( M_7C_3 \) carbides an increasing content of \( Cr \), \( Mo \) and \( V \) was observed.

• Phase and chemical composition of coexisting carbides, or changes in their thermodynamical stability quantified by their quasi-equilibrium constant \( K \), can be used to estimate the time-temperature history of important steam turbine parts.

• The degradation of microstructure (particle coarsening, precipitation sequence, redistribution of alloying elements between carbides and ferritic matrix, segregation of impurities) is rather more difficult to quantify. At present it is not clear, whether these “metallographic methods” will be sufficiently sensitive and reproducible. These methods are useful for preliminary assessment of life in that they supply supporting evidence for other methods.

References:


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REMAINING STRENGTH OF CORRODED TRANSIT GAS PIPELINES

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Key words: gas pipeline, corrosion defects, limit analysis

Gas transmission pipelines can be affected by a range of corrosion mechanisms which may lead to reduction in structural integrity and eventual failure. The economic consequences of reduced operating pressure, or lost production, repair or replacement are severe. Engineering assessment methods are therefore applied to assess the fitness-for-purpose of operating pipelines containing corrosion. The existing widely accepted criterion, the 'B31G Criterion', is semi-empirical, and is conservative mainly when being applied on higher grade material. At the Dept. of Elasticity & Strength of Materials, CTU - Fac. of Mech. Eng., research was designed ten years ago to assess a guidance derived from theoretical analysis, validated through a carefully designed programme of experimental analysis enabling the continued safe and economic operation of corroded pipelines. In 1995 the research programme continued focusing on two main objectives: 1) The continuation of the theoretical and experimental analysis of the problem; and 2) the application of results achieved to date focused on urgent problems arising from the transit gas pipelines operation.

First of all, carried out was evaluation of the theoretical and experimental results obtained so far, concerning machined (determined) defects of the surface corrosion type. A new programme was designed aiming at the assessment of the residual life, reliability and safety of gas pipelines having natural defects.

The theoretical approach has been amplified by taking into account a geometrically nonlinear formulation of the problem. However, this more accurate mathematical approach has thrown up the necessity to define new state parameters for the assessment of the corroded pipe limit load carrying capacity (LLCC). Observing an interesting phenomenon, which being the conservation of the location of the extreme local values of the pipe radial displacement, the relative plastic area length (with respect to the pipe parameters) based on that extreme, is used for this purpose. From the experimental standpoint, we set out, subsequent upon newly encountered problems, to assess the limit state of pipe having natural defects and also to simulate the corrosion process propagation and its influence on the pipe LLCC over an interval of two years, i.e. the regular inspection period. A methodology serving for the surface corrosion defect assessment based on both the numerical and experimental analyses was projected. Substantial progress has been achieved in this field. The proposed methodology has been gradually compared and validated with international standards. For the next two years an extensive programme concerning both the theoretical and experimental analyses has been proposed. This will be focused on the numerical assessment of natural defect topology using optical methods directly enabling their applications in the field. Based on this, a preparation of the project on the automatic FEM meshing of natural defects has been in progress. Finally, the creation of the link between the numerical
topology of the natural corrosion defect surface; FEM meshing; FEM numerical analysis and the evaluation of the discovered stress and strain distribution and the assessment of the pipeline LLCC will be the next (two-year) research aim. For verification of the theoretical conclusions an extensive experimental programme has been scheduled.

References:


This research has been conducted at the Department of Elasticity & Strength of Materials as part of the research project "Limit load - carrying capacity of transit gas pipelines with areal corrosion defects" and has been supported by GAČR grant No. 106/95/0869 (13022107).
CREEP RUPTURE STRENGTH OF A STAINLESS MARAGING STEEL

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Key words: creep, rupture strength, stainless maraging steel, Larson-Miller parameter

Mechanical properties particularly the yield strength and ultimate strength at room temperature of the stainless martensitic-austenitic age hardenable steel 10%Cr-10%Ni-2%Mo-Ti-Al do not attain corresponding properties of the classical ultra-high strength maraging steels. However, the former steel has excellent corrosion resistance and also better preserves its strength at elevated temperatures (up to 550°C) due to higher reaustenitization temperature [1] as compared with the latter steels.

Previous investigations [2] were focused on the mechanical behaviour of the steel 10-10-2 at elevated temperatures in dependence on its heat treatment. It has been pointed out that the influence of heat treatment on short-time tensile strength decreases with increasing testing temperature. The values of yield strength and ultimate strength at the highest testing temperature 480°C were nearly independent on the temperature of preceding heat treatment (from 520°C to 650°C). The influence of the temperature of heat treatment may be illustrated in the following way: after ageing at 520°C in order to obtain the peak-hardened state, both the high hardness and strength decreased with increasing temperature of the short-time tensile test, whereas after intercritical annealing at 650°C both the low hardness and strength were almost unaffected by the testing temperature within the range of 400-480°C.

The present paper reports a further study of the effect of prior heat treatment on creep rupture tensile strength of wrought steel of the type 10-10-2.

Two heats No. 25 and No. 26 of the steel were used for these experiments. Chemical composition of the heat No. 25 was as follows (in wt. %): 0.011 % C-0.21 % Mn-0.16 % Si-0.016 % P-0.014 % S-10.41 % Cr-9.96 % Ni-2.32 % Mo-1.03 % Ti-0.47 % Al-0.026 % Co-0.06 % Cu-0.007 % N-0.003 % O. The heats were produced in a vacuum induction furnace and cast into ingots of 11 weight. The ingots were forged and rolled into rods of 20 mm in diameter. Specimens of 6 mm in diameter with threaded ends were turned from test blanks quenched from 930°C, 1 h in water. Then the specimens were either aged for 3 h at 520°C or 560°C, or intercritically annealed at 650°C and air cooled. Creep rupture tests were carried out in electrical resistance furnaces on air, where the temperatures were measured using chromel-alumel thermocouples. The testing temperatures ranged between 500 and 540°C. The testing procedure met the standardized requirements according to CSN 42 0351. The microrstructures were investigated by means of light or transmission electron microscopy of plastic replicas in the longitudinal sections both in the threated ends and in the vicinity of fracture of the tested specimen.

The results of creep tests were evaluated using Larson-Miller's parameter

\[ LM = T(C + \log t) = f(R_{mT}) \] (1)
For the groups of specimens with the same heat treatment for a given stress but for different temperatures, the constant $C$ in the relation (1) was computed by use of the least square method. The functions $f(R_{mt})$ was supposed to be linear in the form

$$LM = a_1 + b_1 R_{mt}$$  \hspace{1cm} (2)

$$LM = a_2 + b_2 \log R_{mt}$$  \hspace{1cm} (3)

Also quadratic functions were considered either in the $LM - R_{mt}$ plot or in the $LM - \log R_{mt}$ plot. However, these quadratics did not yield good results. The constants $a_1, a_2, b_1$ and $b_2$ in relations (2), (3) were computed separately for each kind of heat treatment. Since there was no obvious dependence between the linear terms $b$ and the temperatures of ageing (annealing), only the linear terms $a$ were considered as dependent on the temperature of heat treatment (Fig. 1). For the different $a$-values we obtained the empirical distribution curves from which 10% and 90% quantiles were derived. These results were compared to the last year investigations on the same type 10-10-2 of steel. This comparison led to the conclusion that relation (2) fits better than the others (Fig. 2).

Examinations of microstructures in the crept specimens revealed the metallographic texture that has higher degree of orientation in the necked area. In the vicinity of fracture, there were also observed large grains of austenit and more coagulated particles of intermetallic phases of the type $A_3B$ and $A_2B$.

It may be concluded that the creep rupture strength within the temperature range 400 to 540°C of the steel investigated depends pronouncedly on the prior ageing or intercritical annealing between 520°C and 650°C. In the necked region of tensile specimen more advanced reaustenitization and coagulation processes were observed.

References:


This research has been conducted at the Department of Materials Science as part of the research project “Structure and Properties of Welds in 11SS Maraging Steels” and has been partially supported by CTU grant No. 8087.
PHASE TRANSITIONS IN Ni–Cr–Al ALLOYS AND NiCr–Al COUPLE

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Key words: phase transformations, structure, order, TEM, microanalysis

The interest in Ni–Cr–Al ternary system increases due to new technologies and applications. Ni–Cr-based thermal barrier coatings, functionally graded materials, intermetallic matrix composites [2], resistors, etc., add to the primary interest in Ni-based superalloys where these three elements play essential role. The Ni–Cr–Al system was used as a model to simplify the complex chemistry of most Ni-base superalloys. Although more than 40 years elapsed since first comprehensive study of the Ni–Cr–Al system was undertaken [1], the ternary phase diagram is not yet known in detail. The experimental data are limited both in concentrations and temperatures; sometimes the published results are confusing. The phases appearing in the ternary diagram [1] are: 7 - Ni rich primary solid solution (FCC), 7' ordered intermetallic phase Ni2Al (based on FCC), 8 - Cr rich primary solid solution (BCC) and 8' ordered intermetallic phase NiAl (B2, CsCl type). Ni-rich region of the phase diagram contains single phase 7 field (higher temperatures) or 7 and 7 + 7' fields (lower temperatures). Alloys containing 13 at.%Cr and 11 at.% Al exhibited in as quenched and 850 °C annealing condition cuboidal particles of Ni2Al. Authors found near the 1000 °C four-phase plane (β + γ <=> α + γ'). Recent compendium on ternary phase diagrams [2] make mainly use of these results with some minor correction. The experimental data should be therefore supplied including the medium annealing temperatures as the final products pass through this temperature range repeatedly. Other problems are the grain boundary instigated phase transformation and the influence of interstitial impurity atoms, especially frequently present carbon.

Ni20Cr13Al alloys with 0.02 wt. %C and without (very low content of) carbon were chosen for experiments because 13 at. %Al are “safely” in the 7'+ γ phase field and total alloying element content correspond to earlier experiments [3, 4] on Ni–Cr binary system around the Ni3Cr superstructure stoichiometry. Melting under Ar atmosphere was followed by chill cast (cooling rate ≈500 °C/s). The slabs were annealed for 10, 100 and 500 hrs at 800 °C and 600 °C in evacuated silica ampoules. Annealing was terminated by water quenching. Annealed slabs were prepared in usual manner for light, scanning and transmission electron microscopy. These specimens were also used for X-ray phase analysis. In due course, the layered specimens containing Al 99.999 % substrate and Ni20Cr plasma sprayed coating were prepared. These specimens were studied, after annealing at 600 °C, by light and scanning electron microscopy. The preparation of thin foils for transmission electron microscopy from coated specimens is under way.
All literature data assume the presence of only two phases, \( \gamma \) and \( \gamma' \), at temperature and composition used in our experiments. At high temperatures only \( \gamma \) phase is considered to be in thermodynamic equilibrium. Nevertheless, we encountered \( \gamma' \) phase in as cast specimens. Its volume fraction, size, shape and composition change during the annealing at 800 °C. The volume fraction decreases while the particle size increases. The shape changes from almost circular to rectangular with aspect ratio 2:1. Majority of these changes takes place in the first 10 hours of annealing. The Al content in \( \gamma' \) particles gradually increases with annealing time from \( \approx 13\% \) in as cast specimens to \( \approx 17\% \). These values are valid for in-grain particles. Grain boundaries (GB) are a different story. Irregular angular \( \gamma' \) particles appear on GB during the annealing, their Al content is \( \approx 25\% \). Contrary to the literature data, BCC \( \alpha \)-phase Cr rich particles show at grain boundaries (Cr content 90 % and more) after short annealing. These particles appear usually close to the coarse \( \gamma' \). Longer annealing leads to the precipitation of needle-like a phase inside the grains as well. The sum of Al and Cr nominal contents is higher than 25 at.%, and despite the precipitation of Cr-rich phase, the Cr atoms enter both sublattices. Therefore, with exception of GB particles, the Al content in \( \gamma' \) phase is relatively low, although the degree of long range order increases with annealing time as proved by X-ray and electron diffractions. In as-cast specimens, the interface between matrix and circular \( \gamma' \) particles is not well defined and the particles are far off the equilibrium as they change after short annealing. \( \text{Ni}_3\text{Al} \) particles attain rectangular shape similar to that in Ni based superalloys, with sides parallel to (100) planes. This shape does not change during the further annealing and suggest that the misfit (i.e., strain energy) between lattice parameters is decisive factor. The presence of carbon is apparent after long annealing times when Cr carbides nucleate at grain boundaries or Cr rich particles. Their volume fraction is very low and they were observed only in TEM (X-ray diffraction did not show their presence) [5]. The coated specimen preparation posed some problems. These problems include adhesion of coating, diffusion across the interface, metallography preparation of specimen containing two very different materials. Preliminary assessments of structures on coated couples were then done. The examination of the coated specimens revealed that no mixing of elements takes place during the plasma spraying, while annealing at 600 °C starts the diffusion of Al and Cr.

References:


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METALLURGY OF Mg–Li ALLOYS

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Key words: something, anything, nothing

Magnesium alloys are extremely light alloys with a very favourable strength-to-density ratio. They are therefore specially suited for the construction of means of transport, especially aircraft and rockets. The density of these alloys can be further reduced by additions of lithium. An unfavourable property of magnesium is its easy inflammability in air. The inflammability of magnesium alloys in molten state poses some special metallurgical problems. The melt must be covered permanently with suitable slag or it must be protected with a protective atmosphere. The melting of Mg-Li alloys is further complicated by lithium reacting with oxygen, nitrogen and hydrogen, as well as by the great differences in melting temperature and density of the two metals. Both metals are also characterized by comparatively low boiling temperatures. Mg-Li alloys are prone to explosion when the melt gets into contact with water or moisture. Type IS2/I HERAUS vacuum induction furnace was used for the preparation of Mg–Li alloys, which solved the problem of Mg ignition, and the possibility of explosion in case lithium got into contact with moisture was excluded. The melting of Mg alloys in vacuum is rendered difficult by the high pressure of saturated vapours of the base metal, which at the melting temperature amounts to 359 Pa. With the pressure in the furnace space at 1 Pa, the melt might start boiling and incontrollable changes in the composition of molten alloys might set in. Thus after evacuation the furnace was filled with argon to a pressure of 5 000 Pa in order to suppress the boiling reliably even in the case the melt got overheated in the course of melting. Several heats of Mg–Li alloys with different Li contents were prepared in this way. Chemical composition of these experimental heats is given in Table 1.

Tab. 1: Chemical composition of experimental heats [weight %]

<table>
<thead>
<tr>
<th>Heat No.</th>
<th>Al</th>
<th>Mn</th>
<th>Fe</th>
<th>Zn</th>
<th>Li</th>
</tr>
</thead>
<tbody>
<tr>
<td>951</td>
<td>5.40</td>
<td>0.139</td>
<td>0.008</td>
<td>2.58</td>
<td>12.6</td>
</tr>
<tr>
<td>952</td>
<td>5.25</td>
<td>0.161</td>
<td>0.008</td>
<td>2.55</td>
<td>14.3</td>
</tr>
<tr>
<td>9521</td>
<td>5.22</td>
<td>0.104</td>
<td>0.049</td>
<td>2.48</td>
<td>12.6</td>
</tr>
<tr>
<td>9522</td>
<td>5.33</td>
<td>0.133</td>
<td>0.016</td>
<td>2.55</td>
<td>12.9</td>
</tr>
</tbody>
</table>

As part of experimental work the application of protective gas SF₆ (sulphur hexafluoride) was verified in suppressing the ignition of Mg alloys during the melting and pouring in air. An electric resistance furnace was used for melting. The alloy was melted in a crucible of type 18/8 chrome-nickel steel. Prior to melting the crucible was rinsed and filled with protective gas. This gas is of ca six times the density of air, it falls to the bottom of crucible
and drives air out of the crucible. According to [1, 2] the protective effect of this gas is present even at concentrations of 0.5-1.5% in a mixture with air. After melting the melt was poured into a cast-iron mould which had been rinsed with protective gas. The chemical composition of remelted heats is given in Table 1 under No 9521, 9522. It turned out that the protective gas SF₆ was reliable in protecting the Mg-Li alloys from ignition during both melting and pouring. The surface of the specimens cast was smooth and of metallic lustre. Thanks to their specific properties, especially the favourable rigidity-to-density ratio, Mg-Li alloys can be used with advantage as matrices in composite materials with metallic matrix. The production of composites by way of casting was tested experimentally. Used as strengthening phases were SiC whiskers. With regard to the reactivity of Mg and especially Li the compatibility of the hardening phase and the matrix Mg-Li alloy deserves attention. Several methods of introducing SiC whiskers into the melt were proposed and tested. It is evident from the metallographic analysis that the hardening phase used is compatible with the matrix Mg-Li alloy. These favourable results point to a possible direction of further development.

The same as the metallurgy, the preparation of metallurgical specimens from Mg-Li alloys, too, is rendered complicated due to the properties of the two elements. Complications appear already while taking (cutting) samples when, in the absence of intensive cooling at the point of cutting, burning develops. Etching the samples presents another complication. A number of etching agents and methods were tested on alloy specimens for light microscopy. When the FUSS etching agent was used, the specimen of Mg+14% Li showed signs of overetching after a short period. The procedure given in [4] (etching by the Vilella-Bain solution, i.e. 50 ml HCL, 1 g picric acid, 100 ml water) was tested but with negative result. A more favourable result was obtained when using a solution of oxalic acid. It is clear, however, that this solution will not be final.

References:

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INTERMETALLIC PHASES
IN AN Al–Li–Cu–Zr ALLOY

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Key words: electron probe, microanalysis, Al-Li alloys, primary and secondary phases

Electron Probe X-ray Microanalysis (EPMA) is a method which makes it possible to
connect the direct definition of chemical composition to the electron microscopical image
in a given place in the sample. In recent years, EPMA has been widely used in material
science. The principles of the method, i.e. analysis in a very small interaction volume, make
local chemical analysis possible. The main application has thus been in the study of volume
(lateral and depth) inhomogeneities. This study concerns the chemical composition and
size distribution of primary and secondary particles of intermetallic phases in Al–Cu–Li–Zr
alloys.

EPMA measurement was carried out at SEM (TESLA BS 300) equipped with an EDS
detector (Be window) and LINK system AN10/85S. The average chemical composition (in
wt.%) of the investigated aluminium alloy was 3.3% Cu, 1.9% Li, 0.1% Zr and low level
traces of Mg, Fe, Mn, Na, Si, Ti and Ca [1]. We studied two types of sample: the first was
in as cast condition (only low temperature annealing was used), the second was prepared
by extrusion at 460°C followed by thermal treatment. The surface was polished in the
standard way (finally using a diamond size 1/0). Optical microscopy showed several phases
at the grain boundaries and some phase inside the grains. The complete results of optical
microscopy analysis are given in [2]. For approximate quantitative analysis we used LINK
ZAF. Size distribution and the simultaneous chemical composition was quantified by LINK
programs DIGISCAN and DIGIPAD.

By the scanning electron microscopy, basically two types of particles (bright ones (BR)
and dark ones (DK)) were revealed in the image. The dark and the bright particles are
assumed to contain Li and heavier elements, respectively. We divided them into classes
according to their composition: Cu(BR), Cu(DK), CuTi, CuFe, CuCaZr and CuCaSc. Of
course, all the particles contained Al; some of them may have contained Li, which is not
measureable by EPMA. In the cast sample, there are two groups, containing only Cu (in
addition to Al and possible Li) - the first group (BR) with a larger concentration of Cu,
the second group (DK) with a lower concentration of Cu. Moreover, it was also possible
to divide the particles according to their shape. The rod-shape particles (length 2-4 \( \mu \)m)
were bright and usually of Cu or CuFe type. The observed particle size was limited in
the program to about 0.1 \( \mu \)m. The size distributions of several types of the particles are
illustrated in Figs. 1 and 2.

In the literature, the soluble phases \( \text{Al}_3\text{Li}, \text{Al}_2\text{CuLi}, \text{Al}_2\text{Cu}, \text{Al}_2\text{CuMg} \) are reported, the
next possible phase is \( \text{Al}_2\text{Cu}_3\text{Fe} \) [3]. Insoluble particles such as \( \text{Al}_3(\text{Fe,Mn}) \) and \( \text{Al}_6(\text{Fe,Cu}) \)
are also mentioned [4]. In the cast sample, most of the extra elements were in the relatively
large areas (bright in the SEM image) at the boundaries of the dendrites. In the round-
shape particles with a large Cu content (probably \( \text{Al}_2\text{Cu} \)), Ca, Zr and Ti were relatively
rare. The only exception was Fe, which was usually present in the rod-like particles. In the treated sample, the Cu particles with a high concentration of Cu always contained some other element – not only Fe but also Ca, Zr or Sc. The bright particles as well as those containing Ti, were situated at grain boundaries, those of the so-called Cu(DK) type mostly inside of grains. Because they contain Li, they are probably of the type Al$_2$CuLi or Al$_3$Li; Cu could appear from the matrix. No particles with Mg were found. The composition is very approximate, due to the various size of particles – the ratio between the size of the particle and the interaction volume is unknown.

Fig. 1: The size distribution of Cu(DK) particles.

Fig. 2: The size distribution of CuTi particles.

In conclusion, we found that in the cast state the alloy contains areas (not particles) with a high content of impurity and modifying elements. These elements are not usually in particles, except for Fe (rod-shape particles) and Ti; the other particles with a greater or smaller amount of Cu are supposed as Al$_2$Cu and Al$_3$Li (or Al$_2$CuLi) types, respectively. In the extruded and aged alloy neither rod particles nor particles with a higher concentration of Cu were observed. At the grain boundaries we found mainly particles with complex composition and those containing Ti; inside the grains, those with low Cu concentration were found. Unfortunately, the concentration of elements in particles less than the interaction volume can only be roughly estimated – a method involving more exact concentration measurement in these particles needs to be developed and applied for this problem.

References:


This research has been conducted at the Department of Materials Science as part of the research project “Study of Structure Nonhomogeneity in Al-Li Systems” and has been supported by GA CR grant No. 106/93/2142.
DIFFRACTION ANALYSIS OF ALUMINIUM SPECIMENS AFTER PLASTIC EXTENSION

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Key words: aluminium, residual stress, plastic deformation, diffraction analysis

The aim of investigation was to identify residual stresses by diffraction methods in pure Al (99.85 %) samples after tensile deformation.

Samples investigated. a) Flat specimens with dimensions 10 × 150 × 2 mm³. Sample 1: strain value ε = 5%, strain rate v = 5 mm/min. Sample 2: ε = 5%, v = 2 mm/min.
b) Flat specimens with dimensions 10 × 50 × 2 mm³. Sample 3: ε = 5%, v = 0.5 mm/min. Sample 4: ε = 10%, v = 0.5 mm/min.

Experimental methods and techniques. 1. The Debye-Scherrer back-reflection method with photographic registration of CuKa radiation was used for qualitative visual estimation of crystallite size on samples 1, 2 and diffraction line {511}/{333} was analysed.
2. The X-ray tensometric "sin²ψ" method was applied on sections (10 × 22 × 2 mm³) of deformed specimens 1, 2. An ω-goniometer DRON UM-1 with scintillation detection of CuKa radiation was used to measure {422} diffraction line profile in step-scane mode (Δ2θ = 0.1°, const. time exposition 15 sec). The XEC l/2α² = 19.07 × 10⁻⁶ MPa⁻¹ [1] was used for stress evaluation. Powder standard Al was measured under the same conditions.
3. Line broadening analysis for microstrains estimation was carried out on samples 1, 2. Owing to spotty lines reversal motion (±5 mm) of specimens was applied.
4. Analysis of lattice strains by means of neutron diffraction methods was carried out on samples 3, 4.

Results of experiments.
a) The character of spotty lines for samples 1, 2 was qualitatively the same both before and after deformation.
b) 2θ vs sin²ψ plots obtained for sample 1 in longitudinal (1L) and transversal (1T) directions of measurements and for Al powder are given in Fig. 1 (including "maximum" error bar 2Δ2θ). The following values of macroscopic stresses σψ have been calculated:

sample 1: σL = -5.17 ± 5.35 MPa, σT = -0.47 ± 5.88 MPa;
sample 2: σL = -6.53 ± 5.73 MPa, σT = -3.32 ± 4.70 MPa.
c) Profiles of diffraction line {422} obtained at ψ = 0° for Al standard and deformed samples are shown in Fig. 2. From the comparable shapes of profiles (especially from the clearly resolved doublets Kα₁,₂) and the very small values of breadths for the
deformed samples 1, 2 ($\beta_1 = 0.01^\circ2\theta$, $\beta_2 = 0.02^\circ2\theta$) it follows that neither marked microstresses nor crystallite size refinement arise after samples deformation.

d) Results of neutron diffraction analyse show no effect of deformed state on lattice strains.

Conclusion. The deformation of Al samples as described above induces neither macroscopic nor microscopic residual stresses. It means that volume of sample responsible for the diffraction patterns has been subjected to plastic homogeneous deformation.

![Figure 1: $2\theta$ vs $\sin^2\psi$ for Al powder (a) and sample 1 in L-direction (b) and T-direction (c)](image)

![Figure 2: Diffraction profiles of {422} line for Al powder (a) and samples 1 (b), 2 (c)](image)

References:


This research has been conducted at the Department of Solid State Engineering as part of the research project “X-Ray Tensometry of Polycrystalline Materials” and has not been supported by any grant.
STRUCTURE OF 7010 Al-ALLOY
AND FATIGUE CRACK PROPAGATION

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Key words: fatigue, structure of material, aluminium alloy, macroscopic crack growth rate, quantitative fractography, striation spacing

Generally, the fatigue crack growth rate is a result of stochastic interaction between the stress field at the crack front and the structure of material. The main goal of research, the results of which are summarized in this paper, was to study the influence of AlZnMg alloy structure on its fatigue properties.

Alloy 7010-T7651, widely used in aircraft industry, was studied in two substantially different structure states: fibrous (denoted F), and recrystallized (denoted R).

In both the structure states, two crack/structure orientations were investigated:

a) TL/L - direction of fatigue crack growth was parallel to the lamination direction,
b) TL/TC - direction of fatigue crack growth was perpendicular to the lamination direction.

High-cycle fatigue tests of CCT specimens were performed at room temperature, constant stress range ($\Delta\sigma = 56$ or $40$ MPa), stress ratio $R = 0.1$, and load frequency $f = 7$ Hz with the aim to measure the macroscopic crack growth rate ($v = da/dN$) [1, 2]. By means of the computer aided quantitative fractography [3], striation spacing $s$ was measured on fracture surfaces of specimens. The experimental data $v$ and $s$, as functions of stress intensity factor range $\Delta K$, were fitted by multilinear regression functions [4], the parameters of which are presented in [1, 2] - see Figs. 1 and 2.

A comparison of fatigue crack growth data results in the following conclusions:

1. The macroscopic crack growth rate $v = da/dN$ in TL/TC orientation is slightly higher than in TL/L orientation for both the structures (fibrous and recrystallized) - see Fig.1. This difference is decreasing with increasing the $\Delta K$ and has no practical importance on the background of data variability.

2. The slope of regression line $s(\Delta K)$ is higher in TL/L orientation than in TL/TC orientation for both the structure states under study: in the range of low $\Delta K$, the striation spacings on specimens with TL/TC orientation are rather higher than on specimens with TL/L orientation, while in the range of higher $\Delta K$, the relation is opposite (see Fig. 2).

The differences between both the macroscopic crack growth rate and striation spacing in fibrous and recrystallized state are negligible for both the studied crack/structure orientations (TL/L and TL/TC). Experimental data analysis leads to the conclusion that in
the alloy under study, an influence of structure factors on the fatigue crack growth rate can be neglected for industry applications.

Fig. 1:

Fig. 2:

References:


This research has been conducted at the Department of Materials as part of the joint research project "Properties of Al-Alloy 7010" and has been supported by Pechiney Centre de Recherches de Voreppe (France).
THEORETICAL PREDICTION OF THE FATIGUE CRACK GROWTH RATE

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Key words: material damage, fatigue, fatigue crack, crack rate, fracture criteria, finite element method

Recently some special FEM techniques were developed for the mathematical modelling of cyclic plasticity around a growing fatigue crack [1]. An important question is: can such detailed numerical stress-strain analysis also provide a direct theoretical estimation of the crack growth rate? A series of FEM simulations of edge fatigue crack growth in specimens of Al alloys were described in reports [2-5]. The resulting theoretical crack rates are summarized in Tab. 1 together with the corresponding experimental values. The main conclusions drawn from these calculations are summarized below.

Let's assume a material element A in front of the fatigue crack tip in the small distance $\Delta a$. According to a critical strain-to-fracture model, the crack tip will extend to A during $\Delta N$ cycles satisfying the Manson-Coffin relation $\Delta e_p \Delta N^\beta = \varepsilon_c$ in A. Denote $\Delta e_p$ the plastic strain range in the loading direction. According to Sih's energetic hypothesis, the crack will extend by an amount $\Delta a$ after $\Delta N$ cycles, during which a critical amount of strain energy density $\Delta \varepsilon$ is reached in element A. Parameters $\beta$, $\varepsilon_c$ or $\lambda_c$ are obtained from common low-cycle fatigue tests and the immediate crack rate can be estimated as $\Delta a/\Delta N$. The results presented in Table 1 show that both "local low-cycle fatigue" criteria give very good results for thin-walled bodies (plane stress). In practice, the energetic criterion has proved to work better. It is not very sensitive to finite element mesh density around the crack tip.

The so called global/local theory [6] describes the fatigue crack propagation process at both continuum and micro-mechanics levels in terms of internal energy in static plastic zone. The fatigue crack rate is expressed as $(\lambda - \Phi)/(\Gamma - J)$ where $\lambda$ is the rate of plastic work, $\Phi$ is the heat generated during one cycle, $\Gamma$ is the increase in fracture energy within zone per unit crack advance and J is the well known J integral. As a first approximation for the term $(\lambda - \Phi)$ the plastic work dissipated in the cyclic plastic zone only was estimated from FEM solution [7]. From the experimentally obtained crack rate, in AlZn6Mg2Cu2-plate with a unit thickness $\Gamma = 16\, \text{mJ/mm}^2$. Further calculations, however, must be carried out in order to decide whether $\Gamma$ is a material constant and also whether the above presented general relationship is applicable for theoretical predictions of the real crack rate.

The theoretical estimation of the fatigue crack rate in thick-walled bodies remains an open question. It is mainly the real stress-strain state along the crack front that is not fully understood. If plane strain is assumed, the cyclic plasticity at the crack tip is mild and predicted crack mouth displacement as well as the crack rate are unrealistically low (see the last three rows in Tab. 1). On the other hand, if plane stress conditions are prescribed, the theoretical crack opening load is too high when compared with the experiment. The underlying cause of the contradiction might be in the different fracture mechanism under plane strain condition. In order for the local fracture criteria above to remain valid, the
The critical value of \( \lambda_c \) should decrease five times and \( \Gamma \) approximately twice. However, it is also possible that for thick-walled bodies, it will be necessary to look for an entirely new computation method based on a three-dimensional FEM solution.

<table>
<thead>
<tr>
<th>ref.</th>
<th>material</th>
<th>specimen type [mm]</th>
<th>( t ) [mm]</th>
<th>( a ) [mm]</th>
<th>( \Delta K ) [MPa√m]</th>
<th>( R )</th>
<th>crack rate [μm/cycle]</th>
<th>exp. theoretical prediction</th>
<th>( \Delta A )</th>
<th>( \Delta \epsilon_a )</th>
<th>Solution</th>
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<td>1,00</td>
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<td>I</td>
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<tr>
<td>4</td>
<td>3</td>
<td>260 x 50</td>
<td>5</td>
<td>12,0</td>
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<td>0,22</td>
<td>0,25</td>
<td>0,16</td>
<td>I, CT-25</td>
<td></td>
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<tr>
<td>4</td>
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<td>260 x 50</td>
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<td>3</td>
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<td>0,09</td>
<td>0,08</td>
<td>I, CT-25</td>
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<td>5</td>
<td>3</td>
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<td>5,7</td>
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</tr>
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<td>3</td>
<td>CT</td>
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<td>0,04</td>
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</tr>
<tr>
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<td>3</td>
<td>CT</td>
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</tr>
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<td>3</td>
<td>CT</td>
<td>25</td>
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<td>5,7</td>
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<td>( \frac{1}{10} )</td>
<td>0,09</td>
<td>0,01</td>
<td>0,01</td>
<td>II, CT-25</td>
</tr>
</tbody>
</table>

Tab. 5: Experimental and theoretical values of the fatigue crack rate. \( t \) - thickness, \( a \) - edge crack length, \( \Delta K \) - stress intensity factor range, \( R \) - stress ratio. Material: 1 - Al-clad, 2 - AlCu4Mg1, 3 - AlZn6Mg2Cu2. \( \Delta \lambda \) - Sih’s energetic hypothesis, \( \Delta \epsilon_a \) - critical strain-to-fracture model. I - Plane stress, II - Plane strain

References:


This research has been conducted at the Department of Materials as part of the research project “Computer Modeling of Fatigue Crack Growth in Aluminium Alloys” and has been supported by grant No. 106/94/0985 of Grant Agency of the Czech Republic.

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FATIGUE CRACK SURFACE PICTURES: 
A RANDOM FIELD ANALYSIS 
(COMPUTER AIDED FRACHTOGRAPHY)

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Key words: fatigue fracture, picture analysis, random field

For incorporating automatical computational methods into practical fractography, 1) image features correlated to the crack growth rate (magnitude and/or direction) must be defined, 2) computer procedures must be constructed for indentifying and analysing these features.

In the conservative fractographic practice the individual occurrences of the given fractographic feature are recognised and measured. To receive a representative information, a rather long time of both the operator and the scanning electron microscope must be inves-ted. A significant lowering of costs is expected from automatic methods through increase of the operational efficiency.

However, the most important contributon of picture processing in fractography consists in extending the information sources. The concept of fractographic feature is no more limited to localised, geometrically precisely defined structures, but also integral statistical characteristics of greater areas may be used.

A new fractographic feature has been looked for in connection with fatigue fracture surfaces affected by corrosion. The usual information source – striations – is damaged. The remaining surface relief can be studied under low magnification from 100 to 500. The picture resembles a mountain landscape: a significant part of information is contained in areas of continuously changing brightness. Image elements cannot be defined by using the usual geometrical structures as fibres or closed areas.

Several attempts have been made in the past to use the dimensions of striation patches as a new fractographic feature [1, 2] (in a striation patch the striations had been laid continuously before they were damaged). These patches are present in the picture mostly not as areas of constant brightness, but as "smooth slopes", often with a changing gradient. That is why no objective algorithm has been found yet to determine the striation patches borders.

The general nature of the picture is a random field with significant anisotropy. The relief is oriented along the crack growth direction. It is distinct in visual evaluation that characteristic dimensions of the random field change with the crack growth rate. While the dependence of “longitude" of the relief in the direction of crack growth is complicated, the “width" of the relief perpendicular to the crack growth direction is monotonously increasing with the crack growth rate. It follows that some characteristic of the random field correlation properties in this direction may be taken as the demanded fractographic feature.
A complex procedure has been developed to realize the idea proposed above:

1. Normalisation of the picture to avoid global trends in the mean value and the variance (compensation of large spots or slopes in the brightness and the contrast).
2. Transformation of the picture to "ideal" distribution of brightness (empirically found distribution with high contrast and distinction).
3. Analysis of image correlation properties in the direction perpendicular to the crack growth. Due to low organisation of the picture the generally used methods (Fourier transformation, correlation analysis) are not applicable. A special method has been developed. It results in a number parameter \( \gamma_x \) which reflects especially the width of the above striation patches. The correlation between \( \gamma_x \) and crack growth rate \( da/dN \) is presented in the Fig.1.

Fig. 1: Crack growth rate \( da/dN \) expressed as a function of image analysis parametr \( \gamma_x \). Three fracture surfaces created under different conditions are included. Material: Steel EDF6.

Conclusions: A random field analysis of fatigue fracture surface images

1. allows to exhaust information from fractographic features which cannot be or had not yet been exactly defined,
2. can offer information sufficient for the reconstitution of crack growth process.

References:
THE FATIGUE DURABILITY OF NITRIDED GEARS

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Key words: fatigue, durability, gears, fatigue testing methodology, fatigue crack propagation

Fatigue failure is the final result of degradation processes, taking place in metallic materials as a consequence of repeated, cyclic loadings with combination of several other effects. This way of loading is the principal one for practically all constructions, and especially for the automotive and power engineering equipments. One of the fatigue stages is the period of a fatigue crack propagation, which may produce a defect of the critical length, initiating a sudden, brittle fracture.

The reliability and operational ability of a gear are limited by loading capacity of gear, especially in bending. The most dangerous failure is the fracture of the tooth, usually as the result of cumulative fatigue degradation process, caused by a cyclic external loading.

The decisive stages of fatigue degradation process (initiation and short crack propagation) are situated into the surface (active) layer. This is why the technologies, that strengthen the surface layer of a machine part favourably influence its fatigue strength. Marked high effects have been found for nitriding or ion-nitriding technologies; many experiments have proved the significant increases in fatigue limits of nitrided specimens and machine parts as well.

The benefits of nitriding, however, are not conformable for the region of time limited fatigue strength. Explanation of these phenomena requires more detailed study of individual stages of fatigue process in nitrided materials, including the determination and the evaluation of external factors, which controls the fatigue mechanism.

The surface hardened, mainly nitrided spur gears were tested on hydraulic fatigue machine ZDM 10 Mp. Using the up and down testing procedure, the fatigue limits and durabilities for different applied loads were obtained and statistically evaluated and the equations of S-N curves were calculated for typical gear materials.

The nitriding CSN steel 15330 (comparable with DIN 30CrMoV9) was studied more in details. In addition to the above mentioned experiments, the fatigue crack propagation parameters, including the threshold values, were measured. The CT specimens and the methodology according ASTM E 647 Standard were used.

Conclusions, resulting from experiments are the following:

a) Experiments and theirs results (statistically evaluated values of fatigue limits, S-N curves) supply the principal material characteristics being necessary for the strength calculations of gears.

b) The fatigue durability and the ability of overloading of each material could be expressed by means of the slope coefficient of S-N curve.
c) The variance of fatigue limits of experimental materials, being treated with individual parameters of nitriding technology, as well as the different values of the slope coefficient express the important effect of internal factors (chemical composition, microstructure of material).

d) The location of fatigue fracture nucleation either under the nitrided layer or in its bottom part could explain the following facts:

- the higher level of fatigue crack propagation threshold value of nitrided layer with respect to the base material
- more effective role of fine, more dense segregated complex carbonitrides, that act as the barrier against the short fatigue crack growth
- the existence of microscopic and macroscopic internal stresses in the nitrided layer

The action of individual mentioned factors are complex and additive.

e) The analyses of fracturing process in nitrided parts and results of crack-rate experiments have enabled the approximative quantification of individual stages of fatigue process with the following conclusions:

- the stage of long fatigue crack propagation covers relatively short and constant period of the total life (up to 20%). This is valid both for tested specimens and gears.
- the different durability of individual tested specimens and teeth could be likely related to the duration of the nucleation and the short crack propagation stages.
- the exact analysis needs the better understanding to the physical nature of mentioned processes and more adequate quantification of the initial stages of fatigue process.

References:


This research has been conducted at the Department of Mechanics and Machine Design and at the Department of Materials and Technology of Production Constructions as part of the research project “Fatigue Strength and Durability of Nitrided Machine Parts” and has been supported by Military Academy in Brno by grant No. G9/93.
FATIGUE PROPERTIES OF UHSLA POLDI STEEL

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Key words: low cycle fatigue, cyclic creep, UHSLA steel, cyclic creep threshold curve

The ultra high strength low alloy (UHSLA) steel LDHA Poldi of the Czech provenience, an equivalent to the American 300M steel, should replace the HSLA steel ROL N in the Czech military aircraft industry. Chemical composition, heat treatments and basic fatigue properties of the Poldi steel as well as the low cycle fatigue (LCF) response of the high tempered specimens were published elsewhere [1, 2].

In this paper, the LCF and cyclic creep (CC) response of the standardly heat treated Poldi steel have been studied at ambient temperature. Structure of this steel consists of a refined martensite with homogeneously distributed carbides. The yield stress $\sigma_y = 1520$ MPa and the ultimate tensile strength $\sigma_u = 2180$ MPa were determined as a result of the tensile test. The servohydraulic DARTEC machine, standard strain gauge and smooth cylindrical specimens were used in load controlled push-pull tests. The stress ratio $P = \sigma_{\text{max}}/\sigma_{\text{a}} = 2/(1 - R)$ was varied in the range of $< 1.0, 2.0 >$. Fig. 1 illustrates the growth of both the plastic strain amplitude $\varepsilon_{\text{ap}}$ and the associated cumulative elongation $\Delta l_k$ with increasing relative number of cycles $n/N$ ($N$-number of cycles to failure). Two basic types of curves corresponding to the logarithmic- and the more pronounced cyclic softening behaviour are apparent. The negative peak of $\varepsilon_{\text{ap}}$ vs. $n/N$ dependence (specimen No. 21) is connected with intensive strain ageing which followed after 12 hours break in the fatigue test. Detailed examination of $\Delta l_k$ vs. $n/N$ curves shows that they exhibit a fine periodic wave-like structure superimposed on the main cumulative elongation coarse. This is, most probably, the well known "strain bursts" phenomenon [3].

In Fig. 2, plastic strain amplitudes $\varepsilon_{\text{ap}}$ related to the onset of CC are plotted against the parameter $P$ - the so called CC threshold curve (CCTC). This curve separates the region of CC appearance (full points) from that of CC absence (empty points).
In Fig. 3, the full line curve corresponding to the product of $\sigma_a P = \sigma_y$ in the $\sigma_a$ vs. $P$ plot separates the experimental points with nearly constant $N$ (no CC) from those with significantly lower $N$ (CC) - the so called stress ratio sensitivity threshold curve (SRSTC). Analogous CCTCs and SRSTCs were found in case of other cyclic softening steels [4].

For comparison, the CCTC and SRSTC for the high tempered modification are also plotted in Fig. 2 and 3. It is clearly seen that this curves lie substantially lower than those of the standard heat treatment. In this case, the above mentioned strain bursts phenomenon was not observed.

The most important results of the research can be summarized as follows:

1. The standard fatigue properties of both the 300M and UHSLA Poldi steels are well comparable.

2. The standardly heat treated specimens exhibit much higher resistance against the cyclic creep than those high tempered.

References:


*This research has been conducted at the Institute of Engineering Physics as part of the research project “Mechanical Properties of Advanced UHSLA 300 M Steel and their Structural Interpretation” and has been supported by TU grant No. FU 350003.*
HIGH AND LOW CYCLE FATIGUE OF AUSTEMPERED DUCTILE IRON

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Key words: austempered ductile cast iron – ADI, upper and lower bainite structure, mechanical fatigue properties, Woehler and Manson-Coffin curves, fatigue limit

Because of its good physical, technological and mechanical properties, ductile iron finds an ever wider range of application in a number of industries. Its main advantage is the very wide spectrum of possible heat treatment alternatives, which is conditional upon favourable graphite shape. One such possibility, which in technical practice is today often made use of, is austempering. The present paper deals with the effect of this type of heat treatment on the fatigue properties of ductile iron.

Used in the experiments were 2 heats of unalloyed and alloyed ductile cast irons. Isothermal heat treatment in order to obtain a bainitic structure was carried out in electric crucible furnaces with salt baths. In all the cases austenitization temperature was 900°C and the holding time at this temperature was 1 h. The time of isothermal transformation was for individual heats determined experimentally on the basis of optimum mechanical properties, characterized by maximum elongation, in intervals from 2 s to 25 h.

Haigh cycle fatigue properties were assessed on the basis of determining the Woehler curves and the fatigue limit values. Fatigue tests were carried out under symmetric loading cycle or under repeated tension on an Amsler high-frequency resonance pulsator at room temperature. The Woehler curves were determined on a set of 12 to 15 cylindrical test specimens with threaded heads, the working part of the specimen was of dia 7 mm.

The Woehler curves were evaluated mathematically by the least square method with the aid of three-parameter non-linear function. The fatigue limit values were determined for the basic number of cycles \( N = 10^7 \).

Low cycle fatigue tests were performed using cylindrical specimens with 8 mm in diameter. Specimens were cycled in a computer controlled electrohydraulic testing machine MTS. Constant total strain amplitude cycling with the strain rate \( 3 \cdot 10^{-3} \text{s}^{-1} \) was adopted. Hysteresis loops were digitally recorded for selected number of cycles and stress amplitude, strain amplitude, plastic strain amplitude and the area of the hysteresis loop were evaluated.

The fatigue life curves were plotted as Manson-Coffin curves and derived Woehler curves using values of the plastic strain amplitude and stress amplitude at half-life.

The surface of the gauge length after cycling and fracture surfaces were examined in a scanning electron microscope Philips 505.
The study of fatigue properties of austempered ductile cast irons has brought following results:

- In ADI the most favourable fatigue properties can be found with upper-bainite structures as opposed to transition bainite and, especially, lower-bainite structures. This behaviour is affected neither by the type of loading (tension-compression, tension, bending) nor by the loading cycle asymmetry.
- With bainitic structures the increase in ultimate strength due to changes in heat treatment conditions (lower transformation temperature) is not accompanied by an increase in fatigue limit; on the contrary, the fatigue limit decreases with increasing ultimate strength.
- With ADI the dependence of the loading cycle amplitude on the mean cycle stress during tension-compression loading is hyperbolic.
- Upper and lower bainite showed rapid initial hardening and saturated behaviour during the whole fatigue life.
- The fatigue resistance of the materials depends on the structure of the matrix but also on the criteria used for life evaluation and is different when stress amplitude or plastic strain amplitude is applied.
- When the crack is initiated from a large initial defect, the stage of short crack growth is diminished and the fatigue life is reduced.

References:


This research has been conducted at the Department of materials Engineering as part of the research project "High And Low Cycle Fatigue Of Austempered Ductile Iron" and has been supported by TU of Brno grant No. F-59-94.
INCREASING OF UTILITY PROPERTIES OF FERRITIC DUCTILE CAST IRON DETERMINED FOR WORK UNDER LOW TEMPERATURES

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Key words: ferritic cast iron, tension test, fracture toughness

Ferritic ductile cast iron is a perspective engineering material determined for castings of machine elements working under low temperatures. Its wider application is often limited by its low yield stress (up to 250 MPa) and a lack of objective basic data (first of all values of fracture toughness for the design of the casting structure from the point of view of ensuring its brittle fracture resistance under low temperatures). The aim of the experimental works was to verify the possibilities of increasing the yield stress and brittle fracture resistance of the ferritic ductile cast iron both by alloying with Nb and Ni and by optimization of the process of ferritic annealing.

As an experimental material, six melts of ferritic ductile cast iron of the weight of 100 kg were cast from arc and induction furnaces into Y2 keel blocks. The chemical composition of the melts was as follows:

<table>
<thead>
<tr>
<th>Melt No.</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Mg</th>
<th>Nb</th>
<th>Ni</th>
<th>Cr</th>
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<tr>
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<td>1.97</td>
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<td>0.011</td>
<td>0.048</td>
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<td>0.51</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>2</td>
<td>3.46</td>
<td>0.16</td>
<td>1.95</td>
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<td>0.03</td>
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<td>0.03</td>
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<td>2.27</td>
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<td>0.008</td>
<td>0.033</td>
<td>0.28</td>
<td>0.02</td>
<td>0.03</td>
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<tr>
<td>18</td>
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<td>0.035</td>
<td>0.010</td>
<td>0.040</td>
<td>0.16</td>
<td>0.50</td>
<td>0.03</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Heat treatment included austenitization at the temperature of 800°C, 825°C, 850°C, 900°C, 950°C, 1000°C and 1100°C at graduated dwells of 2, 5 and 20 hours, followed by cooling in the air and the ferritic annealing itself at the temperature of 700°C for the period of 14 to 16 hours.

All six melts, after various alternatives of heat treatment, besides metallographic analysis of the structure (particularly evaluation of the size of ferritic grains and the share of pearlite) [1], were subjected to tension tests at the temperature of +20°C and Charpy.
V-notch toughness tests at the temperature of 0°C to -40°C. For melts No. 1 and 2, dependences of the temperature and stress rate on the strength properties, reached at tension tests and the temperature dependences of the Charpy V-notch toughness and dynamic fracture toughness were found out in addition [2].

Optimization of the heat treatment showed that the smallest ferritic grain and therefore the most advantageous combination of mechanical properties was achieved for all the melts after the austenitization at the temperature of 825°C up to 850°C after the dwell of 2 and 5 hours. At lower austenitization temperatures a significant drop of the Charpy V-notch toughness due to the presence of the sub-grains boundary structure occurred. At austenitization at the temperatures above 850°C the size of austenitic and subsequently ferritic grain grows. It results in a significant drop of yield stress in particular. A similar influence to that of the high austenitizing temperature is caused also by a long time of austenitization (20 hours) [3].

After an optimum cycle of the heat treating the best brittle fracture resistance was achieved with the melt No. 8 (i.e. unalloyed) which had the Charpy V-notch toughness more than 22 J.cm\(^{-2}\) even at the temperature of -40°C, with the yield stress at the 20°C of approx. 300 MPa. The highest yield stress (350 MPa) was achieved with the ferritic ductile cast iron of the melt No. 14, alloyed by 0.23% Nb, but with Charpy V-notch toughness at the -20°C under 12 J.cm\(^{-2}\).

The most suitable combination of the strength properties (\(Re = 330\) MPa) and the Charpy V-notch toughness (at -40°C 18 J.cm\(^{-2}\)) was proved by the cast iron alloyed by a combination of Ni and Nb (melt No. 18), cast from an arc furnace. A similar cast iron (melt No. 1) from an inductive furnace, however, had rather worse mechanical properties, due to other structure after casting [3].

In addition to the optimalization of the heat treatment and the chemical composition, also the applicability of the Hall-Petch relation [2] and the possibility of mathematical expression of the dependence of the true stress on the true strain in the sphere of uniform plastic strain was proved with the ferritic ductile cast iron during the project solution [4]. The experimental works made showed the possibility of significant improvement of the mechanical properties of the ferritic ductile iron by the option of suitable chemical composition and the heat treatment process.

References:


This research has been conducted at the Department of Material Engineering as part of the research project “Increasing of Utility Properties of Ferritic Ductile Cast Iron Determined for Work under Low Temperatures” and has been supported by TU grant No. F 49-94.
STUDY OF PHASE TRANSFORMATIONS IN HEAT TREATED MODEL CAST STEEL Fe–C–Si–Ni–Nb

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Key words: nodular grey cast iron, low alloy silicon steel, chemical microheterogeneity, ferritic annealing, transitive behaviour

The long term research task was aimed at a more detailed study of the defined properties of the ferritic cast irons with nodular graphite, the materials designed for low temperature application. Because of the structurally intricate relationships of the low alloy cast iron brittle-fracture behaviour and their heterogeneity, the phase transformations and the precipitation processes, the attention was focussed at the study of model alloys. These alloys were the cast silicon steels with nickel and niobium additions, the chemical composition of which corresponded to the cast irons matrix but the alloys were structurally more simple.

The aim of the grant project was:

- to propose and optimize the chemical composition and the heat treatment regimes of steels,
- to study the influence of chemical heterogeneity in as cast state on phase transformations during heat treatment,
- to carry out the structural analyses of original states, the states after individual stages of treatment and of the final optimized structural states,
- to study the structural processes using anisothermal methods of annealing in the gamma-alpha region,
- to obtain the optimum combination of mechanical properties, that means yield strength and tensile strength as high as possible preserving the high level of brittle-fracture behaviour properties in the region of low temperature practical applications.

The solution of the grant project was performed on six experimental melts of silicon steels with graduated contents of niobium and of carbon. Initial work was aimed at the structural analyses of cast state and the study of chemical microheterogeneity. There were verified different heat treatment regimes consisting of annealing without phase changes of the cast states, normalizing with consequent annealing under temperatures $A_{c1}$ or quench hardening in combination with high temperature tempering. The aim of experiments was to get ferritic matrix of cast irons and to trace the kinetics of the passing phase transformations with special regard to precipitation processes and to obtaining of very fine grained homogeneous ferritic matrix.
The optimized structural states were used at the heat treatment of specimen for the determination of the basic mechanical properties and for the verification of transitive behaviour of cast silicon steels.

The study of phase transformations performed with model silicon steels has brought following results:

- Primary carbides with niobium content are present in the structure of all melts and are formed already in liquid steel. Directional segregation of silicon into the regions of grain boundaries of primary austenitic grains takes place during solidification.
- Pearlitic-ferritic structure of cast state is not possible to be transformed fully into ferrite and graphite by an annealing below $A_{c1}$ because the pearlitic cementite is stabilized by the carbide forming elements.

During austenitization the precipitation of carbides or niobium carbonitrides of the type of $\text{Nb}_x(C,N)_y$ takes place. The carbides are concentrated into the region of grain boundaries of secondary austenitic grains and prevent their coarsening. This process takes place also at lower niobium content in cast steel.

- The intensity of precipitation is influenced by the condition of austenitization and in less degree also by the tempering temperature at the decomposition of martensite. The original carbon content in steel determines the range of the graphitization process during annealing and in less degree also the amount of the present carbide precipitates.
- The degree of decomposition of the pearlitic cementite is determined by the transformation conditions and by the degree of cementite saturation especially by chromium.

The resulting grain size of ferrite at given melts, the substitutional strengthening of ferrite and the extent of precipitation process are the main reason of the reached values of the strength characteristics of the cast silicon steels. In comparison to the nodular grey cast irons the transitive curves are shifted to the right and to more higher temperatures.

References:


This research has been conducted at the Department of Materials Science of Píšek Institute of Materials Engineering as part of the research project “Study of Phase Transformations in Heat Treated Model Cast Steel Fe-C-Si-Ni-Nb” and has been supported by TU grant No. F-50-94.

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CAST MOLYBDENUM HIGH-SPEED STEELS FOR CUTTING TOOLS

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Key words: high speed steel, heat treatment, structure, hardness, fracture toughness, cutting property

The hardness, tempering resistance, fracture toughness, cutting property and microstructure of six high-carbon, high-molybdenum alloys were investigated in the as-cast condition and after heat treatment. The experimental samples were produced from molybdenum high-speed steels with based composition: N1 (5.4Mo-4Cr), N2 (5.7Mo-4Cr), N3 (4.9Mo-4Cr), N4 (4.5Mo-4Cr), N5 (6.1Mo-4Cr), N6 (6.2Mo-4Cr). The nominal carbon and vanadium contents for each base composition ranged from 0.9 %C, 1.5 %V up to 1.4 %C, 4.4 %V. The chemical composition of the alloys are presented in Tab. 1. Conventional foundry methods were used to melt and cast the alloys.

In the experimental alloys solidification began with the crystallization of austenite or MC carbide rather than d ferrite. The carbides in the microstructure often were present as discrete particles instead of the embrittling interdendritic eutectic characteristic of conventional cast high-speed steels. Simultaneously increasing the carbon and vanadium contents resulted in an increase in the amount of carbides and higher hardness in the as-cast condition.

<table>
<thead>
<tr>
<th>Steel</th>
<th>Nominal content</th>
<th>Optimum Austenitizing Temperature</th>
<th>Fracture toughness $K_{IC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C [%] Mo [%] V [%]</td>
<td>Temperature [°C]</td>
<td></td>
</tr>
<tr>
<td>N1</td>
<td>0.95 5.4 1.8</td>
<td>1210</td>
<td>19.2</td>
</tr>
<tr>
<td>N2</td>
<td>1.10 5.7 3.0</td>
<td>1230</td>
<td>21.2</td>
</tr>
<tr>
<td>N3</td>
<td>1.30 4.9 3.9</td>
<td>1210</td>
<td>21.8</td>
</tr>
<tr>
<td>N4</td>
<td>1.05 4.5 1.5</td>
<td>1190</td>
<td>-</td>
</tr>
<tr>
<td>N5</td>
<td>1.05 6.1 2.2</td>
<td>1230</td>
<td>-</td>
</tr>
<tr>
<td>N6</td>
<td>1.45 6.2 4.4</td>
<td>1240</td>
<td>22.9</td>
</tr>
<tr>
<td>19830</td>
<td>0.9 5.0 2.0</td>
<td>1200</td>
<td>19.0</td>
</tr>
</tbody>
</table>

Tab. 1:

Samples of all steels were heat-treated to produce a wide range of microstructure, hardness, and fracture toughness values. Samples were austenitized in an electric furnace at temperatures ranging from 1150-1250°C and oil quenched to room temperature. The increase in hardness with increasing austenitizing temperature can be attributed to an increase in hardness of the martensite formed upon quenching, a direct result of higher concentration of carbon and other alloying elements dissolved in the prior austenite. The gradual decrease
in hardness observed is due to an increase in retained austenite resulting from higher concentrations of carbon and other alloying elements in solution, and consequently, a reduction in $M_s$ temperature.

Double tempered at a temperature of about 550°C produced the maximum secondary hardening effect (HRC 65). These alloys have higher tempering resistance than forgeded high-speed steel ČSN 19 830.

The fracture toughness specimens used for the experiments were of the three-point bend type. The results of these experiments are given in Tab. 1. The morphologie of Vanadium-carbides in the high-speed steels have a direct effect on fracture toughness. As seen, values of fracture toughness of new steels are higher than forgeded high-speed steel ČSN 19 830.

The price of molybdenum cast high-speed steels is lower than that of the steel.

References:


This research has been conducted at the Department of Materials Engineering as part of the research project “Cast Molybdenum High-speed Steel for Cutting Tools” and has been supported by TU of Brno grant No. F-47-94.
The Laboratory of Ceramic Materials Mechanical Properties Testing

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Key words: ceramics, glass, mechanical testing, fracture, toughness

The aim of the project "Mechanical Properties and Fracture Behaviour of Advanced Ceramics" was to build the Laboratory that will make it possible to evaluate mechanical properties of ceramic materials. The realization of the project was planned for two years, namely 1994 and 1995.

During the first year, the measurement of two fundamental mechanical characteristics, strength and fracture toughness, was mastered. For fracture toughness measurement, we intended to find the method close to the ASTM E399 Standard. This standard requires the crack of defined shape to be introduced in the specimen. For three-point bending specimen we used the technique known as "bridge indentation". First experience shows that this method is relatively reliable but not universal. Some structures of aluminium oxide (corundum) ceramics and glasses defy the attempts to introduce a crack. Thus, for bending tests, it was necessary to modify the Chevron V-notch method (ASTM E1304). On aluminium oxide ceramics, where both methods could be used, the values of $K_{IC}$ measured by both methods were acquired; it was found that the differences between the methods of measurement are negligible [1, 2]. During the project first year, we also tried to unearth financial resources for modern testing machine suitable for test of ceramics, eventually of plastics.

Second year was dedicated to the solution of two problems:

a) the relation between mechanical properties and the structure of materials,

b) the surface preparation both for test specimen and for the microstructure evaluation (ceramography, thin foils for TEM).

In the course of the study of relationship between mechanical properties and structure, following publications were prepared:

- The methods for strength and fracture toughness measurement of ceramics were tested on aluminium oxide. Raw material for test pieces was prepared by injection moulding from powders of different origin. Data acquired during the measurement methods evaluation and results concerning the effects of grain size on strength and toughness were accepted for publication in the journal Kovové materiály [3]
The fracture behaviour of borosilicate glass hardened by vanadium and molybdenum particles was studied in collaboration with Institute of Physics of Materials ASCR and School of Metallurgy and Materials, University of Birmingham. The results were presented on International Conference in Plzeň [4] and they are being prepared for publication [5].

Mechanical properties of new generation zirconia ceramic material were compared for two ceramics production technologies. The technologies were isostatic pressing (CIP) in widespread use, and injection moulding. The experiments were completed, at present the results are evaluated. It is necessary to prove that the ceramics structure is that of tetragonal polycrystalline zirconia (TZP), and thus, the preparation of thin foils for TEM is under way.

In the first year, we had to rely on colleagues from DIAS Turnov for specimen surface preparation and ceramographic polishing for structure study. During the second year, we succeeded in fitting our metallographic laboratory for these purposes.

Due to financial support provided by Grant Agency of Ministry of Education and grant support of Faculty of Mechanical Engineering TU Brno, it was possible to equip the Laboratory with modern testing machine by ZWICK with loading up to 20 kN. The machine will be delivered at the end of 1995 year.

The Laboratory for Mechanical Testing and Structure Evaluation of advanced ceramic material was established at Faculty of Mechanical Engineering of TU Brno. It is used for research primarily by Department of Ceramics of the Institute of Material Engineering, of TU for study of advanced ceramic materials. In due course, it is utilized both by undergraduate and graduate students of the Material Engineering specialization.

References:

This research has been conducted at the Institute of Material Engineering as part of the research project "Mechanical Properties and Fracture Behaviour of Advanced Ceramics" and has been supported by TU grant No. C27/94.
THE INFLUENCE OF Cr AND Ti
ON THE ALUMINA SINGLE CRYSTAL
AT HIGH TEMPERATURES

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Key words: ceramics-metal interaction, chromium, titanium, alumina

The problems associated with the application of directional crystallization of modern heat resistant alloys stems from the reaction between the components of the alloy and the ceramic mould and core at high temperatures [1, 2]. Results from previous experiments [3, 4] confirmed that the attacking species were primarily chromium and titanium in nickel base superalloys.

Due to the lack of available thermodynamic data on real complex alloys, it is difficult to establish a theoretical description of the reaction processes involved in the system. For this reason, a simpler arrangement of the reaction model system was devised. This involved using single crystal alumina of defined crystal orientation and replacing the complex alloy with ternary and binary alloys of specific composition and with pure metals.

It was revealed that the initial step of the interaction between the alloys, Ni-20Cr and Ni-20Cr-5Ti, and the alumina ceramic is redox of the following type:

\[ 2\text{Cr} + \text{Al}_2\text{O}_3 \rightarrow 2\text{Al} + \text{Cr}_2\text{O}_3 \]

\[ 2\text{Ti} + \text{Al}_2\text{O}_3 \rightarrow 2\text{Al} + \text{Ti}_2\text{O}_3 \]

The structure of the reaction products are considerably different: the formation of a solid solution of Al\text{2}O\text{3}\times\text{Cr}_2\text{O}_3 against a sharply bordered layer of Ti\text{2}O\text{3}. The growth kinetics of the reaction layers is controlled by diffusion of trivalent metal cations through the product layers. The diffusion coefficient of Cr\text{3}+ through Al\text{2}O\text{3}\times\text{Cr}_2\text{O}_3 was calculated to be \(10^{-12}\) cm\textsuperscript{2}/s and the diffusion coefficient of Ti\text{3}+ was calculated to be \(10^{-9}\) cm\textsuperscript{2}/s at 1600 °C.

Activities of the reactive elements have a remarkable influence in the described mechanism. But the activities are not known in general even for binary or ternary alloys. The effect of the reaction is different when dealing with pure metallic constituents (activity = 1) and single crystal alumina. The reaction of the pure metallic elements (Cr and Ti) are possible in the liquid or solid state. Because of the high melting points of pure chromium and titanium (1857 °C and 1660 °C respectively) high temperatures are required to achieve the liquid state. The pure metals were superheated 50 °C above their corresponding melting points. Results from such experiments showed that even after a short period of time of interaction (25 mins) the reaction was very intensive leading to the destruction of the single crystal alumina such that determining kinetics parameters was very difficult.

The study of the reaction of pure metals with alumina was more conveniently done at 1600 °C, which is the highest temperature used during unidirectional solidification. Both metals are in the solid state at this temperature.
Perfect contact of the metal with the ceramic can be achieved by sputtering or steaming of the metal. The sputtering was preferred due to its higher purity. Thin layers (tenths of \( \mu m \)) of chromium and titanium were successfully sputtered on single crystal alumina by using of two broad beam Kaufman ion sources [5]. The study of kinetics required temperature dwells of the order of tens of hours. The performed experiment showed that for long temperature dwells, it is important to sputter thicker layers of the order of 10 or 100 \( \mu m \), thus compensating for the loss of metal due to evaporation at high temperatures even with the use of an inert gas over-pressure.

For completion of the interfacial behaviour between the Cr/Al\(_2\)O\(_3\) sandwich, interactions were also investigated between the Cr\(_2\)O\(_3\)/Al\(_2\)O\(_3\) sandwich.

References:


This research has been conducted at the Department of Ceramics as part of the research project “The study of high temperature processes involved between Cr resp. Ti and single crystal alumina” and has been supported by TU grant No. FU350038.
PRODUCTION TECHNOLOGY
VS. STRUCTURE
AND MECHANICAL PROPERTIES
OF ADVANCED PLASTICS

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Key words: composite, polypropylene, magnesium hydroxide, degree of filling, filler grain size, filler grains' surface modification, mechanical properties, impact toughness

In the modern macromolecular chemistry research a much greater effort is devoted to the improvement of the already existing material properties than to the development of completely new polymeric materials [1]. From this point of view an important way is to process composite materials filled with mineral grained particles [2]. One of the best fillers seems to be magnesium hydroxide, originally used as an agent capable to lower the flammability of plastics. In the addition to self-extinguishability or non-flammability the composite materials with polyolephine matrix filled with 40–60 % of magnesium hydroxide present excellent mechanical properties, especially toughness, as well [3]. For this reason the researchers struggle hard in order to optimize the constitution of these composites for different applications. This optimization is based on the scientific explanation of the relationship between structure and properties.

The aim of the grant project named “Relationship between Production Technology, Structure and Mechanical Properties of Advanced Plastics” which has been solved at the Faculty of Mechanical Engineering, Technical University Brno, in the years 1994 [4] and 1995 has been to improve the knowledge of the influence of two kinds of commercial magnesium hydroxide as filler on the structure and mechanical properties of the polymeric composite with polypropylen matrix, with special respect to the various filler grain size of the same shape, of the surface modification of the filler grains, and to the degree of filling. Having combined these factors we have obtained 10 kinds of experimental materials. The samples were manufactured by means of injection moulding machine BATTENFELD BA 750/220 in Polymer Institute, LTD, Brno.

All materials were subjected to tensile tests (ISO 527:1993) under the temperature from −50 °C to +110 °C and the speed of loading 50 mm.min⁻¹. Temperature dependences of Young’s modulus, yield stress, tensile strength and tensile strain at tensile strength have been obtained.

Moreover the dependences of the named stress and strain characteristics on the speed of loading under constant temperature +23 °C were examined. The speed of testing was from 0.1 mm.min⁻¹ to 100 mm.min⁻¹.
The resistance of materials to impact loading was examined by instrumented Charpy impact tester. The relevant samples notched with type A notch (ISO 179:1993) were tested under the temperature from -30°C to +70°C.

Our research results will be presented at the international conference in January 1996 and are prepared for publication.

During solving the project we have gained knowledge of methods for the evaluation of mechanical properties and structure of the plastics. This means a contribution to the further relevant research and to teaching the students in the under- and post-graduate degree.

References:


This research has been conducted at the Department of Materials Sciences as part of the research project "Relationship between Production Technology, Structure and Mechanical Properties of Advanced Plastics" and has been supported by TU of Brno grant No. F-94-95.
COLD-ROLLING OF POLYMERS
PART I: TENSILE PROPERTIES

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Key words: cold-rolling, engineering polymers, tensile deformation

Introduction. It is well known that orientation processes in polymeric materials can significantly enhance the mechanical properties of the final product. In the past, much effort has been directed to solid state deformation of polyethylene and polypropylene and respective technologies as drawing, extrusion, rolling and forging [1]. However, due to the low heat distortion temperature of these polymers, their practical use as highly oriented polymers is limited. Hence, particular focus has to be directed towards the polymer group designated as engineering polymers. This will push up the useful range for the oriented structures to higher temperatures, well beyond 100 °C. Furthermore, most of solid-state forming processes have been generally performed at relatively high temperatures. It requires additional heating of materials. On the other hand, little information is available about cold-rolling of engineering polymers at ambient temperature. Accordingly, selected types of engineering polymers have been tested with respect to cold-rolling ability and produced profiles have been characterized from the mechanical points of view.

Experimental. Based upon the foregoing examinations, two engineering polymers, substantially different in their structure and tensile behaviour, have been chosen for this study. The materials used were polycarbonate MAKROLON (Bayer) and polyoxymethylene KEMATAL (Hoechst). Polycarbonate has amorphous structure with the glass transition temperature of 150 °C. It is characterized by very good toughness, distinct and sharp yielding, typically initiated by shear band mechanism. More particularly, it exhibits relatively high drawability as a result of neck formation. It is, therefore, to be understood that polycarbonate can be considered as a model amorphous polymer for plasticity and orientation studies. Notably, some of the typical amorphous polymers exhibit crazing mechanism and brittle behaviour (PS). By contrast, polyoxymethylene is a highly crystalline polymer with the melting temperature of 180 °C. Polyoxymethylene used in the present work breaks in the stage of neck development and its tensile strain at break is low. At this point, it is also noted that the semicrystalline polymers usually achieve high draw ratio (PE, PP). Two-roll machine with different rolls speed (asymmetrical rolling) has been used for the cold-rolling of injection molded dumb-bell shaped standard ISO specimens. The temperature of the rolls was 20 °C. That is, due to the asymmetrical rolling, the shear plastic deformation was very intensive. The mechanical properties, in the tensile mode, were measured using conventional tensile tester at room temperature. The distance between the grips has been adjusted according to the draw ratio of rolled specimens.

Results. It is to be observed from Fig. 1 that the cold-rolling apparently changes the shape of the stress-strain curves. In general, both polymers examined behave in different manners. The tensile deformation of cold-rolled polycarbonate is homogenous up to break, necking does not occur as compared to the original material. Importantly, the stress-strain
curve demonstrates a significant strengthening just beyond the yield point. This part of the stress-strain dependence is practically linear up to break. On the other hand, the impact of cold-rolling on the mechanical properties of polyoxymethylene is quite different. It is evident from Fig. 1 that the cold-rolling causes rather toughening while the strength does not change remarkably.

![Graph](image)

**Fig. 1: Effect of cold-rolling on the tensile behaviour of selected polymers**

Conclusions.

1. Cold-rolling seems to be a very fast and simple process which can provide a polymeric material in the form of profiles with enhanced mechanical properties.
2. Material strengthening is the significant phenomena of cold-rolling by polycarbonate while toughening is the principal characteristic of cold-rolling by polyoxymethylene.
3. It is believed that polymeric profiles prepared by cold-rolling can be usable as a reinforcement for specific polymer-polymer composites.

References:


This research has been conducted at the Department of Materials as part of the research project “Adjusting Strength and Toughness of Polymeric and Composite Materials by Structural Transformations” and has been supported by grant No. 106/93/0198 of the Grant Agency CR.
PRELIMINARY TEM STUDY
OF CARBON/CARBON COMPOSITE

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Key words: C/C composites, microstructure, transmission electron microscopy

The outstanding features of carbon fibre reinforced carbon (CFRC) composites are their high temperature strength, chemical inertness, thermal shock resistance, low density and also compatibility with human tissue. The most important properties such as strength and fracture behaviour are controlled by microstructure (that of fibres, matrix and especially by the microstructure in the region of the fibre-matrix interface [1]). Fine details of the microstructure we obtained employing transmission electron microscopy (TEM) in conjunction with selected-area diffraction (SAD).

The samples were prepared as follows. The matrix precursor was the phenolformaldehyde resin “UMAFORM”, the fibres (IIT fibre T800) were laid unidirectionally. Samples were prepared firstly by carbonisation (at 950 °C/1h, the temperature growth rate was 10 °C/h between 250-500 °C and 20 °C/h else). In the next step the samples were graphitized at 2200 °C/1h in Ar at atmospheric pressure. For TEM, a specimen about 0.5 mm thick was sliced from the bulk composite using diamond saw. It was thinned to roughly 50 μm using alumina and diamond pastes. Finally, the Ion Beam Thinning Unit IV-3 (Technoorg–Linda, Budapest, Hungary) was employed. A beam current 3 mA at 4–5 keV and incident angle 30° was used for approximately 5 hours at each of the bombarded sides. The thin foils were examined in transmission electron microscope JEM-2000EX operated at 200 keV.

The results of TEM analysis are given in Figs. 1-6. Fig. 1 shows transverse section in bright field (BF) mode at small magnification – the typical morphology within a fibre bundle. The average diameter of the PAN fibres was 9 μm. Fig. 3 represents fibre core region. The microstructure is created by a great number of small crystallites, that produce 002 diffraction pattern (Fig. 4). The crystallites are randomly oriented, their c-axes lie within all angles in the plane of the section. Region A in Fig. 1 (intragranule matrix far from fibres) appears to have a fibrelke microstructure, but crystallites are much smaller and less graphitic than in the PAN fibre (Fig. 2). The crystallites near fibre surfaces or that between closed spaced fibres have better alignment (parallel to the fibre surface) than those far from fibres (Fig. 5). The microstructure in this region (region B in Fig. 1) is nonlamellar but with preferential orientations of the large graphitic crystallites. The associated SAD of region B (Fig. 6) confirms the observation from the BF image (Fig. 5). The formation of parallel oriented crystallites to the fibres in the immediate vicinity of the fibre surface resulting from biaxial tension develops as the matrix experiences restraint of shrinkage during pyrolysis and carbonisation [2]. The fibre matrix interface in the present composite is generally well bounded to the fibre, no microcracks along and near the fibre-matrix interface are visible.
Fig. 1: Transversal section structure of C/C composite at low magnification.

Fig. 2: Microstructure of interbundle matrix far from fibres.

Fig. 3: Microstructure of PAN fibre core, transverse section, BF.

Fig. 4: Microstructure of PAN fibre core, transverse section, SAD.

Fig. 5: Transverse section morphology between closed spaced fibres, BF.

Fig. 6: Transverse section morphology between closed spaced fibres, SAD.

References:


This research has been conducted at the Department of Materials Science as part of the research project “The Prospective Structural Biomaterials” and has been supported by GA CR grant No. 106/95/0359.
THE INFLUENCE OF HYGROTHERMAL AGING ON IMPACT PROPERTIES OF KEVLAR–EPoxy COMPOSITE

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Key words: composite materials, impact properties, hygrothermal aging

Para-aramide fibre reinforced epoxy resins are used for aircraft fuselage panels where both good impact resistance and radiotransparency are required. Our previous investigation has revealed that hygrothermal aging of para-aramide composite, manufactured from prepreg VICOTEX 913, results in irreversible increasing of water diffusivity and mechanical damping [1]. This abstract summarizes results of evaluation of composite impact behaviour influenced by the hygrothermal aging. The Charpy impact test was used to determine energy absorbing characteristics of the composite. Using an instrumented Charpy pendulum hammer, differences in load histories among original, wet and dried specimens were evaluated.

Experimental procedure. Composite panel was fabricated using VICOTEX 913/50/K120 prepreg manufactured by Brochier, France. The prepreg contains Kevlar 49 plain fabric impregnated with tetrafunctional epoxy resin (tetraglycidylmethyleneedianiline–TGDMA) cured with dicyandiamine (DICY) and substituted urea as an accelerator. A twelve-ply composite panel with a stacking sequence of plies [0]_12 treated using the standard vacuum-bagging procedure and a platen press molding proc. The rectangular un-notched specimens (1.6 x 10 x 55 mm) were machined from a composite panel. The first set of specimens was impact tested in the original condition. The second set of specimens was exposed to distilled water at a temperature of 65 °C until near complete water saturation (70 days) and then tested. The third set of specimens underwent the same treatment but was dried until achieving the initial weight prior to being tested.

The instrumented Charpy testing machine CEAST (impact velocity 3.7 m/s, energy 7.5 J, span between the specimen anvils 30 mm) has a strain gage attached to the striker which allows to record the load-time history. Load resolution is determined by the analog/digital converter Advantech with a 100 kHz frequency. Data collection is triggered by a photodetector. Collected signal can be digitally filtered to reduce high frequency oscillations (ringing) using a moving average procedure. Further analysis of load-time signals is made using a personal computer and a spreadsheet program.

Results. Fig. 1 shows load-deflection and energy-deflection curves obtained in an instrumented impact test of an original and a hygrothermally aged Kevlar 49-epoxy specimens. A comparison of total Charpy impact energies and ductility indexes for an original composite, a wet composite and a composite dried after hygrothermal exposure is shown in Figs. 2, 3.
Conclusion. Our results show that impact resistance of a Kevlar 49-epoxy composite is not negatively influenced by hygrothermal aging, contrary to tensile strength of the composite [2]. Irreversible changes in epoxy matrix and fibre-matrix interface which were previously confirmed from damping characteristics [1] result in additional energy absorption processes during the propagation phase of impact loading.

References:


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ADHESION STUDY BY SCRATCH TEST AND VIBRATIONAL SPECTROSCOPY

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Key words: adhesion measurement, scratch test, IR spectroscopy

Adhesion is a very significant nonelectric property of insulating coatings. It influences many other electric and nonelectric properties. Therefore the study of adhesion is very often joined with the study of electrical and nonelectrical properties of coatings. The substance of adhesion is given by physical, and/or chemical bonds created between a substrate and a coating.

There are many methods of adhesion measurement. According to the National standard the adhesion test is described as follows: a grating of mutually perpendicular lines (usually 5 x 5 lines) is scratched using a proper tip. The distance between neighboring lines is given by the standard. Then the number of squares in the grating which have dropped out during the scratching is calculated. The adhesion of the coating is evaluated with regard to this number. This test is good for an industrial use, however, its sensitivity is not sufficient for a deeper adhesion analysis. Therefore we have used a "scratch" test for the adhesion measurement. This test is based on the evaluation of a track after scratching of the coating by the tip of defined radius and is described elsewhere [1]. Using this type of test we have evaluated adhesion of different electric insulating varnishes.

We have found that the thickness of the coating that is recommended by producer of varnish is usually too thick for the scratch adhesion measurement (the maximum load of the tip has been 10 N, the tip radius has been 300 μm). Therefore the specimens have been prepared of a diluted varnish. The layer thickness proper for the measurement has been different for different varnishes. The coating have been prepared on Cu and Al substrates. The specimens have been aged thermally at the temperature higher than the temperature of the class (the varnishes of the classes B, F, H and C have been investigated). The scratch adhesion measurement is also influenced by the hardness, persistence and thickness of the layer. All these properties including adhesion change during the ageing. Therefore the value of adhesion force only (not adhesion) can be obtained as a result of the scratch measurement after measured data evaluation.

We have found that the adhesion decreases during the varnish ageing in the most cases. Results of adhesion investigation of the varnish S 1942 and the varnish Isola have been very interesting. The adhesion of layers prepared on the Al substrates has been very good during all the ageing time whereas the adhesion of layers prepared on the Cu substrates has decreased to the zero after three weeks of ageing and the varnish has been full destroyed. We suppose a chemical reaction between Cu and these types of varnishes. This reaction is probably accelerated by the temperature.

The adhesion investigation described previously makes the adhesion force measurement possible but it does not make the analysis of a cause of adhesion possible. This information is necessary for varnishes producers because they have to analyze the substance of adhesion.
forces with regard to the chemical composition of material. Therefore we have also tested
the possibilities of IR and IETS spectroscopies for this analysis. However, there is very
difficult to analyze the substance of adhesion forces because the spectra are given by many
bands that are caused by chemical bonds and groups in material. The number of these
bands is usually very high whereas the number of bonds that are given by the bonding of
the coating on the substrate is substantially lower. Therefore the intensity of spectral bands
causd by the adhesion is usually very low in comparison with the intensity of other bands
and often is smoothed by these bands.

A possible way how to analyze the adhesion bonds by the use of IR spectroscopy is
to prepare special specimens. These specimens are prepared by the dropping of the liquid
material of the prepared layer (an insulating layer is e.g. the layer of an electric insulating
varnish and therefore this form of layer preparation is the most usual) on the substrate.
The substrate is located on the separator and an excess of dropped material is spun off
immediately after dropping. Then the concentration of the dilution is decreased by an
adding of a proper thinner and the process is repeated. The line of specimens with the lower
and lower thickness of the layer is prepared by this way. The spectra of these specimens have
to be measured by an IR spectrometer with the good sensitivity. If the coating is bonded
on the substrate by the chemisorption the bands caused by chemical bonds could be usually
found in the spectra of layers with the thickness near to the monomolecular ones. A more
probable situation is that some spectral bands of the basic material will be shifted because
their vibrational frequency is influenced by the adhesion forces. We have used this method
for the study of principle of adhesion of insulating varnish S 5001. The new spectral bands
have not been found and the shift of bonds of basic coating material has been very low.

An other type of vibrational spectroscopy for the adhesion bonds analysis is IET spec-
troscopy. The preparation of specimens is more difficult in this case but the layer under test
is very thin and therefore the analysis of adhesion bonds is more convenient. The compar-
ison of IR spectra of the varnish and its IET spectra can also help in this analysis though
not only IR bands are presented in the tunnelling spectra. The results of adhesion analysis
of four different types of electric insulating varnishes will be presented.

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research project “Evaluation of Electric Insulating Varnishes” and has been supported by
GACR grant No. 102/94/1480.
COATINGS ON DEEPLY CURVATURED SURFACES

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Key words: internal stress, internal stress relaxation, coatings, thin films

The mechanical properties of coatings deposited on deeply curvatured surfaces are of great importance also in the design, fabrication and use of wear resistant coatings on the edges of cutting and forming tools. Stress computing for this type of coating using common methods and also the elastic constants values, which are valid for bulk materials, cannot provide the right conclusions concerning the behaviour of the coatings. The reason is that the coatings are growing on the edges under the conditions which are very far from the thermodynamic equilibrium. In particular, in the case of plasma assisted deposition methods, the edges are exposed to an intensive ion bombardment which brings a considerable amount of energy into the coating. Under this circumstances the relaxation of the growth induced stress cannot proceed and it shows in the high internal stress and in the fact that there are substantial differences in the elastic constants values in comparison both with the bulk material and with the coating deposited on the planar or only shallowly curvatured substrates.

In comparison with coatings deposited on planar substrates, for coatings on deeply curvatured surfaces the typical feature is the presence of the radial stress perpendicular to the coating-substrate interface. The direction of this stress is very important, because it can affect substantially the coating adhesion. It can be easily shown that:

- In the case of the tangential tensile stress in the coating on a convex surface, the radial compressive stress is present. In the opposite case, the compressive tangential stress generates a tensile stress, which tries to tear off the coating from the substrate.
- On the concave surfaces all stresses have the same sign, i.e. the tensile stresses act against the adhesion of the coating.

It is also important to consider the fact that the presence of a radial stress due to some external reasons (e.g. due to its rigidity, the substrates prevent the coating shrinkage during cooling) can induce the tangential stress, which affects the state of stress in the substrate-coating interface and also the coating adhesion.

The state of stress in the coatings depends on the ratio of coating thickness and radius of curvature. For shallow curvature, when the radius of curvature is substantially larger than the coating thickness, the influence of the substrate rigidity on the state of stress in the coating is negligible. For deep curvature, which is typical for the tools edges, when the radius of curvature and the coating thickness are comparable, the state of stress in the coating is complex and the radial stresses can play an important role. Simultaneously
also the substrate deformations could be significant, and the state of the system substrate-coating depends also on the ratios of Young's modules and Poisson's constants. Stress in the coating can also create some plastic deformations. Analytical solution is possible only in the case of spherical surfaces, in the remaining cases an experimental investigation is necessary.

The experimental evaluation of the internal stresses is usually performed by bend deflection measuring of a thin elastic cantilever beam with the coating deposited on one of its surfaces. The width and depth of the beam are comparable with the coating thickness. These micromachined structures are made by means of procedures common in microelectronics (masking, underetching etc.). That is why the beams are usually made on silicon wafers. The tests are performed by means of micromanipulators in vacuum chambers of scanning electron microscopes and both the spontaneous bending of the beam and the force versus deflection graphs are measured. Recently a new experimental procedure was developed [1] by which a complete elastoplastic stress-strain characterization of thin coatings on cantilever beams can be performed. Also the effects of residual stresses and stresses induced by external forces can be recognized. These experimental data provide important information about the state of stress in the coatings on tool edges and the results can be used for the optimization of the deposition process parameters.

References:


This research has been conducted at the Department of Physics, the Department of Machining and the Department of Material Sciences of the Faculty of Mechanical Engineering as part of the research project "Behaviour study of the PVD deposited metal coating on edges of machine parts" and has been supported by GA CR grant No. 106/95/1397.
PARTICLE SCATTERING  
ON SOLID SURFACES

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Key words: particle scattering, kinematical and dynamical theory of diffraction, surfaces, sputtering, TRIM

Physical processes taking place at bombardment of solid surfaces by electron and ion beams are interesting not only from the physical point of view, but they find growing application both in technological and analytical areas. Detailed understanding of these phenomena is thus vitally important for their application in surface and thin films engineering.

The primary physical process determining numerous secondary phenomena during bombardment of a solid surface is scattering of the particle on the target atom. The wavelength of the electrons within the energy range of $10^2$ eV falls into the interval of inter-atomic distances ($\approx 10^9$ Å). Therefore, the scattering event must be treated by quantum mechanical methods [1]. The direct consequence of the elastic scattering of electrons on the surface is for example diffraction of electrons on periodic solid surfaces. On the other hand, the wavelength of ions is at least in three orders of magnitude lower than in the case of electron of the same energy. Scattering of the ions with the energy higher than $10^2$ eV on surface atoms can thus be described as a collision of particles fully governed by the laws of classical physics. For the application purposes one of the most important phenomena induced by scattering of ions is sputtering of the target atoms.

Diffraction of electrons is used for determination of surface structure of solids. To find precise positions of the atoms in the crystal lattice, the experimental dependence of diffraction spot intensities on electron energy, obtained from the LEED experiment, is compared with that obtained theoretically for a supposed model of the structure. The theoretical dependence of the intensity is found using numerical calculations based on the dynamical theory of diffraction.

In the above procedure we have used a kinematical model of diffraction for finding changes of the surface structure of Ni(100) with respect to the bulk Ni-structure. The experimental curves of this material were measured at Aarhus university [2]. As it was expected, the kinematical model, taking into account only single scattering events, did not provide the perfect agreement between the theoretical and experimental dependencies of intensities. The lowest difference between areas bounded by both curves was 14%. For comparison, calculations carried out on the base of dynamical theory of scattering approached values between 1.5-3% [2]. However, the positions of corresponding intensity peak maxima found from the theory and experiment were in a very good agreement. The structural model giving the best accordance between the curves (i.e. 14%) supposed the distance between the 1st
and 2nd layer 1.78 Å, whereas the distances between lower layers were 1.76 Å (relaxation). The vibration amplitudes of atoms in the 1st, 2nd and lower layers were 0.17, 0.09 and 0.07 Å, respectively.

Regarding the interaction of ions with a surface, a kinetic model of the argon ion beam cleaning of the copper surface from carbon atoms was developed. The model is based on the kinetic equation for a time development of the layer thickness of carbon on the copper surface. The equation describes the competition between the growth of the carbon-based layers (due to the adsorption of carbon containing molecules) and the ion sputtering of these layers. The sticking (adsorption) coefficient of carbon atoms on the Cu-surface was for simplicity taken independent on the thickness of the carbon containing layer and was chosen as $S_C = n$, where $n$ is the average number of carbon atoms in hydrocarbon molecules ($n \approx 2$) [3]. The sputtering yield of carbon (copper) from the carbon layer on the copper substrate for the energy corresponding to the experiment (600 eV) was calculated by means of the static TRIM 92 [4] as a function of the thickness of the carbon layer for the normal and 60° angle of ion beam incidence. Dependence of the sputtering yield on the angle of incidence is discussed in [3] in detail. The equation was solved numerically.

The simulation revealed that to increase the efficiency of the cleaning process, the sputtering should be carried out at higher angles of incidence (60°–70°). Such arrangement increases the sputtering yield and reduces the penetration of carbon into the material to be studied. Further increase of the angle of incidence above this range would lead to a substantial decrease of the sputtering yield and so the growth of carbon on the surface, instead of its etching, could be initiated. Further, the energy of the ion beam should be kept as low as possible to reduce a penetration of recoil carbon atoms into copper (at least during the final phase of sputtering process). On the other hand, the sputtering yield corresponding to too low ion energies may not be high enough to keep going on the etching process. Thus the energy of 500–600 eV seems to be a reasonable compromise between these two opposite requirements.

References:


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ION BEAM MODIFICATION OF CERAMIC SURFACES AND DEPOSITION OF THIN FILMS


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Key words: surfaces and thin films, ion beam technologies, ceramics

Ion beams have become widely used tool for modification of surfaces and deposition of thin films. The apparatus based on this technique was designed in our group [1]. The primary ion beam source with a grid diameter of 150 mm was applied to modification of the ceramic samples and sputtering of the ceramic and metallic targets. The secondary ion source with a grid diameter of 75 mm was used to a simultaneous bombardment of growing thin films in order to modify their properties. The energy of the argon primary ion beam was 600 eV, the secondary ion source was run with the ion energy 100-600 eV.

In this study mainly the role of the energy of ions bombarding simultaneously the growing thin films in changes of their composition, structure, morphology, mechanical, optical and electrical properties was investigated. The ions transfer their energy to the neighbouring atoms of the surface layers creating here a localized thermodynamically unbalanced area. From the general point of view this makes it possible to generate metastable compounds and structures which are not attainable at balanced conditions [2-4]. The techniques used for the analyses and measurements of the above properties were e.g. RBS, XRD, STM, SEM, profilometry, microhardness and ellipsometry.

In our experiments ceramic materials were treated in two steps. The first step of this treatment involved surface modification and sputtering of ceramic samples as Al2O3 and hydroxyapatite Ca10 (PO4)6 (OH)2. An influence of the ion beam parameters (ion energy, angle of ion beam incidence) on modification and sputtering of the ceramic surface was studied. The second step was aimed at the application of the sputtering effect of the ceramics to deposition of thin films. Targets sputtered by the ion beam in order to deposit thin films were Al2O3 and ZrO2 – base ceramics (98% and 99.97%). Thin films were deposited on different substrates such as a mirror polished single crystal Si(100), polycrystalline Mo and stainless steel, ceramics (Al2O3, ZrO2) and hydroxyapatite, glass and quartz.

Modification of ceramic surfaces by ion beam bombardment showed some interesting effects depending on the energy and direction of the ion beam (e.g. compositional changes...
and texture formation). Al₂O₃ and ZrO₂ thin films prepared by ion beam sputtering revealed the chemical composition close to the stoichiometric values and good optical properties, however, the positive role of the ions bombarding films during their growth was not clearly observed [5]. Therefore, additional experiments, e.g. X-ray reflection method for a study of film density changes must still be carried out.

The metallic targets sputtered were Mo (99.6%), Ti (99.95%), and Al (99.995%). Thin films were deposited on different substrates such as a mirror polished single crystal Si(100), polycrystalline Mo, Al₂O₃-base ceramic, glass and quartz. The concentration of Mo (Al) in the thin films was decreasing (increasing) with ion energy as the Ar-content was increasing (decreasing). The RBS spectra of molybdenum thin films possess only molybdenum in the films at lower energies. At higher energies (400 and 600 eV) Mo content was decreased to 90% due to Ar-atoms penetrated into Mo-layers. The content of Ti was below 35% for all ion energies. Depending on the ion energy, the aluminium content in Al-thin film grows from about 85 to 99%.

In contrast to the films mentioned above, titanium in the films prepared by sputtering of a titanium target is not a major element and its concentration is below 35% for all ion energies. This is caused by a high ability of titanium to bind chemically oxygen and other reactive elements. For all ion energies up to 400 eV oxygen was the major element accommodated in the films. The ratio O/Ti was close to the stoichiometric value of 2 for all ion energies up to 400 eV. Higher ion beam energies and doses led to higher values of the index of refraction for Al and Ti-thin films, most probably due to densification of the films. Further, it was found that increasing energy of ions caused a decrease of the deposition rates of all films due to re-sputtering of the thin film atoms and in the case of Al-thin films it intensified amorphisation processes in the Al/Si structure [6].

References:


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ANALYSIS OF RESIDUAL STRESS STATE DUE TO CUTTING

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Key words: X-ray residual stress analysis, laser cutting, abrasive water jet cutting

Macroscopic residual stress state in the surface layers of the ČSN 11373 steel due to different cutting technologies has been investigated. The following cutting processes have been realized: $C_L$ – laser cutting, $C_F$ – cutting with a disk cutter, $C_{AWJ}$ – abrasive water jet cutting. Besides, a comparative measurement has been performed on a reference specimen $S_{AE}$ (ground, annealed – $650^\circ$C/2 hours, electrolytically etched – the layer removed being 0.1 mm).

Shape and dimensions of the specimens:

- $C_L$ – see Fig. 1,
- $C_F$ – prism $5 \times 25 \times 12 \text{mm}^3$,
- $S_{AWJ}$ – prism $5 \times 25 \times 15 \text{mm}^3$,
- $S_{AE}$ – prism $5 \times 25 \times 15 \text{mm}^3$.

Fig. 1: Scheme of the cutting of primary material with a laser and a disk cutter; during the laser cutting the steel prism moved in direction $\varphi = 90^\circ$

Cutting technologies used:

- $C_L$: continuous $\text{CO}_2$ laser with the beam diameter of 0.5 mm at the focus, the output being 2.5 kW. The cutting was realized in an $\text{O}_2$ atmosphere with the cutting rate of 1200 mm/min and 800 mm/min for surfaces $L_1$, $L_2$ and $L_3$, $L_4$ respectively.
- $C_F$: feed 28 mm/min, 90 revolutions per minute, cooling emulsion.
- $C_{AWJ}$: water pressure 250 MPa, jet diameter 0.325 mm, rate of cutting 14 mm/min, abrasive material – beads (0.12-0.35 mm in diameter);
  - cut $C_{AWJ1}$ – garnet sand with flow rate 630 g/min,
  - cut $C_{AWJ2}$ – quartz sand, flow rate 550 g/min,
  - cut $C_{AWJ3}$ – quartz sand, flow rate 240 g/min.
Diffraction techniques used:

- **Phase analysis** of cutting surfaces L₁, L₂, L₃, L₄ and F (Fig. 1); CoKα radiation was used to measure the diffraction patterns within 2θ = 10° ± 135°.
- **Tensometric method** sin²θ was performed on an α-goniometer SIEMENS using CrKα radiation; diffraction line {211} α-Fe was measured for 2θ = 149° - 162° with a step scan 0.2° and time of acquisition t = 30s for L₁, L₂, L₃, L₄, t = 10s and 2θ = 149° - 162° for specimens C₄W₃ and F. The peak position 2θ²₁₁ was determined as a centroid of {211} Kα diffraction line of ferrite crystallites in all azimuths of measurement.

Results of measurements

1) Crystallites of α-Fe are present on the cutting surfaces F, L₁, L₂, L₃, L₄. In addition to austenite, sections L₁, L₂, L₃, L₄ contain wustit FeO (L₁, L₂, L₃), hematite Fe₂O₃ (L₂, L₃), and magnetite Fe₃O₄ (L₁, L₂, L₃).

2) Macroscopic stresses σ (MPa) obtained from surfaces L₁, L₂, L₃, L₄ depend on the direction of measurement (Tab. 1).

<table>
<thead>
<tr>
<th>Cut</th>
<th>φ = 0°</th>
<th>φ = 90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>L₁</td>
<td>-293 ± 7</td>
<td>-203 ± 7</td>
</tr>
<tr>
<td>L₄</td>
<td>-374 ± 12</td>
<td>-159 ± 8</td>
</tr>
<tr>
<td>L₂</td>
<td>-222 ± 11</td>
<td>-263 ± 25</td>
</tr>
<tr>
<td>L₃</td>
<td>-313 ± 14</td>
<td>-255 ± 19</td>
</tr>
</tbody>
</table>

Tab. 6: Stresses σ (MPa) on the L₁-L₄ in azimuths φ = 0° and φ = 90°

3) The surface of the reference specimen SAE is free of stresses, i.e. σ = 0 MPa.

4) The triaxial residual stress state characterized by component σ₁₁(0) = σ₂₂(0) = -532.1 MPa and gradients g₁₁ = g₂₂ = 32.4 MPa/μm⁻¹ and g₃₃ = 11.1 MPa/μm⁻¹ [1] was found in the surface layer of CF.

5) In the surface layer C₄W₃, σ₁₁(0) = σ₂₂(0) = -144.2 MPa, g₁₁ = g₂₂ = -13.5 MPa/μm⁻¹ and g₃₃ = 10.2 MPa/μm⁻¹.

6) The biaxial stress state was indicated on the surfaces of samples C₄W₄, C₄W₅, and σ(C₄W₆) = -275 MPa, σ(C₄W₇) = -335 MPa.

7) The width of diffraction line {211} Kα found for φ = 0° is the same for any direction of measurement φ and it varies with the cutting technologies applied:

| CF(1.46°), L₁(3.80°), L₂(3.70°), L₃(4.00°), L₄(4.09°), C₄W₆(1.83°), C₄W₇(1.77°), C₄W₈(1.74°), and S(0.42°). |

References:

OPTIMIZATION OF HEAT TREATMENT USING A NUMERICAL MODEL

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Key words: heat treatment, Fourier's equation, optimization, numerical model

During heating and cooling of heavy and massive castings there is the danger of creating considerable temperature gradients with consequent development of strong heat stresses that may be a cause of internal crackings. For this reason it is necessary to pay considerable attention to maintaining optimum heating rates, introducing an appropriate number of equalizing pauses and cooling rates, especially if the question is a cooling medium such as oil or even water.

It is therefore appropriate, for castings which are very demanding technologically as well as financially, to complexly analyze the temperature field during heat treatment at the start of their production. At present, in order to determine the temperature fields, experimental measurement is conducted on several castings which frequently leads to their destruction. Furthermore, the measurement is also very time consuming and it is influenced by many external factors (accuracy and service life of thermocouples, contact of thermocouple measuring ends with the furnace atmosphere etc.) and by random influences.

The original three-dimensional mathematical model of unsteady heat transfer in solidifying castings can, after modification, be applied to the calculation of the temperature field during its heat treatment. It is necessary to define different boundary and initial conditions while heating and cooling.

The presented numerical solution to the temperature field of castings during heat treatment is, according to all available information, the only one of its kind. The test piece was a complex low-alloy steel casting with significant differences in wall thickness. The whole casting was continually measured.

Heating of the casting in a furnace and subsequent cooling by quenching in a water bath is, from the viewpoint of the theory of heat transfer, a case of unsteady spatial (i.e. three-dimensional) heat transfer. In the casting itself the unsteady heat conduction takes place in accordance with the partial differential Fourier equation that mathematically represents the description of time variation of temperature $t$ at indifferent points of the object caused by resultant heat transfer and by the effect of heat sources. Here, the internal heat sources are the latent heats during characteristic structure transformations $A_{C1}$ and $A_{C3}$.

An elegant method for the simulation of the release of latent heat (generally latent heat during characteristic structure transformations or during changes of state) was used. The enthalpy function was introduced. Therefore, the explicit differential method was selected for the calculation.

The solution of the Fourier equation must also conform to the initial and boundary conditions of the solution.

While solving, it is necessary to simulate the supply (while heating) or the release (while cooling) of latent heat that accompanies the structural changes. Therefore, an explicit
network method, that was applied also to the analysis of the temperature field of the ingot (casting)-surroundings system, was chosen for the calculation.

On the outside surface of the casting it is necessary to define the boundary condition of the 3rd kind. Here the surrounding temperature must be specified, in this case the furnace temperature, possibly the temperature of the shop or of the cooling bath and the heat transfer coefficient between the body and the surroundings (atmosphere of furnace, shop, and bath). Time dependent behavior of the furnace temperature must be determined by measurement. The shop and bath temperature are considered to be 20°C.

After being removed from the furnace the casting is spontaneously cooled in the shop atmosphere during several minutes of transport to the bath. The heat transfer coefficient for this short time period is, when calculating, considered using common methods. Dependence of the coefficient of heat transfer in the cooling bath on the temperature of the casting surface is illustrated in the figure.

The measured temperatures served for comparison with the calculated ones. Measurement was conducted in the course of the time of heat treatment, i.e. throughout the heating of the casting in the furnace (approximately 28 hours) and the quenching of the casting in the water bath (approximately 90 minutes). The results of the temperature measurements were very important and invaluable while comparing with the calculation.

It can be stated that both used methods were successful and their results are a valuable foundation for determining the optimum technological process. The computer technique used for these problems, and experimentally checked for the first time, has proved successful and it has shown that in the future it will provide enormous possibilities in further applications.

References:


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INFLUENCE OF LASER HEAT TREATMENT ON SURFACE PROPERTIES OF HIGH-SPEED STEEL TYPE 6-5-2

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Key words: rapid steel, powder metallurgy, laser heat treatment, surface

The experimental results obtained during the research of influence of surface laser heat treatment on properties of rapid steel with the following chemical composition (in wt. %) 0.85% C-4.2% Cr-6.0% W-5.0% Mo-2.0% V are published in this paper.

The subject of study were two steels, on the one hand high speed steel conventionally produced, i.e. of cast and wrought steel, on the other hand high steel produced by powder metallurgy of rapidly solidified particles.

The samples with different initial stage of heat treatment were irradiated with continually working 2.5 kW carbon dioxide laser at different speed of mutual movement of laser rays and sample [1, 2].

Comparison of effect of laser heat treatment on rapid steels with different used technology open the possibility to put this conclusion:

1) Steel produced by powder metallurgy of rapidly solidified particles has the lower energy claims for the same influencing of surface material at lower energy resp. higher speed of laser ray (Tab. 1). This fact is the same in both stage of initial heat treatment. The different is the most expressive in initial state because there is a very important part of degree of structural dispersion.

2) Both materials present after melting process a possibility of precipitation hardening. This ability is more significant in material produced by powder metallurgy of rapidly solidified particles with the maximum hardness 1100 HV after melting process and tempering 550°C/h. The conventionally produced high steel reaches hardness only 1050 HV. This different corresponds with [3] and depends on the structure and properties of materials before laser irradiation.

<table>
<thead>
<tr>
<th>steel</th>
<th>state</th>
<th>limit speed [mm/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>classical</td>
<td>initial</td>
<td>1200</td>
</tr>
<tr>
<td></td>
<td>heat treatment</td>
<td>2400</td>
</tr>
<tr>
<td>produced by P/M</td>
<td>initial</td>
<td>1500</td>
</tr>
<tr>
<td></td>
<td>heat treatment</td>
<td>2500</td>
</tr>
</tbody>
</table>

Tab. 7: Limit speed of movement of laser ray needful to surface melt.
Fig. 1: Precipitation curves for different state of heat treatment (1-P/M steel, heat treatment; 2-P/M steel, initial; 3-classical steel, heat treatment)

References:

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MECHANICAL PROPERTIES AND STRUCTURE OF METALS AND ALLOYS SUBMITTED TO HIGH STRAIN-RATE DEFORMATION


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Key words: mechanical properties, structure, strain-rate, deformation, metals, alloys

The understanding of deformation behaviour of metal materials at high strain rates is of immense value for wide range of applications. The values of dynamic mechanical properties are necessary for quantitative description of armour penetration, new technologies that use the energy of the explosives and, for that matter, for most forming technologies. The demand for these values arises in thermal spraying, crashworthiness, safety problems of nuclear facilities, etc. The number of experimental techniques was devised to ascertain material's response to the high strain rate deformation. One of these methods, used especially for the assessment of dynamic strength of ductile materials, is Taylor test. The Taylor test involves the impact of cylindrical projectile on the non-deforming (rigid) target at normal incidence. The impact causes specimen's permanent deformation. Resulting specimen shape is usually "mushroom-like".

The specimens were prepared from different FCC and BCC materials (single crystal and polycrystalline copper, Cu3Al and Cu30Zn alloys, Al, 18/8 austenitic steel, plain carbon steel (0.5 %C) quenched from 950°C and tempered at different temperatures. Cylindrical specimens 25 mm long and 5 mm in diameter were accelerated by compressed air gun to velocities up to 300 ms⁻¹. Few specimens 50 mm long were also used. The measured parameters were: Initial and final length of the specimen. Initial and final profile of the specimen on all specimens. The critical impact velocity (i.e., the highest velocity that does not induce permanent deformation) was determined. Some specimens were cut axially and hardness along the specimen axis was measured and structure assessed by light microscopy and scanning electron microscopy (SEM); Thin foils for transmission electron microscopy (TEM) were prepared from selected specimens. The substructure was studied and when possible the sub-grain size was measured along the specimen axis. In addition, "inverse" experiments were performed. In this case, the specimen is the immovable target and its response on the impact of the projectile was evaluated. The shape, hardness and structure were followed in relation to impact velocity and specimen's thickness.
We have not observed undeformed regions in the specimens. Wherever the comparison between dynamic and quasistatic yield stresses is possible, it shows that critical velocity values of yield stress equal or surpass the quasistatic tensile strength. The fundamental difference between quasistatic and impact loading is that quasistatic loading "deforms" whole affected volume in the same time while impact loading instigates plastic deformation that spread across the specimen. Therefore, there is a question whether the strain rate dependence of quasistatic and "impact" stress characteristics should lie on a smooth curve. Specimen profiles and hardness variation can be generally described as follows: near the impact surface the drop in both characteristics takes place. Its position depends on the length of the specimen. Possible explanation is that this "tooth" arises from the interaction of propagating plastic front (compression) and reflected elastic tensile stress wave. The drop represents local softening (tensile deformation). The variation of diameter near the free end of specimens (often the diameter less than the original is encountered) could be assigned to the mechanism that under different circumstances (higher loading rates, larger specimens) leads to the spalling. In these specimens decrease (softening) on the hardness course can be observed in this region.

The transmission electron microscopy shows expected dependence of the structure on the stacking fault energy. Near impact surface, a region of heavy deformation appears at higher impact velocity. This region is similar to the regions adjacent to the adiabatic shear bands observed in low SFE materials. The easiness of dislocation movement (value of SFE) does not seem to be the decisive parameter of the material's response to the high strain rate deformation. The initial dislocation density (cold worked versus annealed copper), grain size and particles presented (plain carbon steel) appear to be more substantial parameters. The plateau (or low slope) on the dependence of cell size vs. distance from impact surface suggests that the region of almost constant plastic wave front propagation rate (and amplitude) do exist but only in the central part of the specimen. The results are being complemented continuously with the aim to obtain relatively comprehensive set of data that would allow further theoretical evaluation.

The project is designed for two years. First task, was making the experimental equipment fully operative after it was moved from the Institute of Physics of Materials. In due course the test apparatus was improved, so that the velocity measurement is more precise and velocities well above 300 m/s were achieved. New experiments (e.g., flyer plate, soft target, displacement of free surface) are being prepared. The structure evaluation of the already exposed specimens continues. The results obtained were used in following conference contributions [1, 2] (two papers for international journals are being prepared).

References:


This research has been conducted at the Institute of Material Engineering as part of the research project "Structure and Mechanical Properties under High Strain Rates" and has been supported by TU grant No. FP359578.
JOINING OF DISSIMILAR MATERIALS

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Key words: joint, dissimilar materials, electron beam welds, reactive solders, intermetallic compounds, terminal solid solutions

Instruments and apparatuses for unconventional function need very often not only unusual solution of their construction but also uncommon combinations of dissimilar materials connected by undismantling joints. Necessity of development of vacuum tight joints of aluminium or aluminium alloys with titanium, titanium alloys and corrosion resistant steels appear to be very actual. These material combinations are considered to be unweldable by common methods of fusion welding because of the formation of very brittle intermetallic compounds in weld metal [1].

Research work in frames of the grant project F-63-94 was aimed at the possibility of such type of joint, in which undesirable formation of continuous layers or zones of intermetalides does not take place at all or is minimised. Experimental materials were aluminium 42 4002 and corrosion resistant steel 17 246. Two possible ways of their mutual joining have been tested:

1. Melting of aluminium only in very narrow zone adjacent to solid steel. Only the formation of terminal solid solution takes place. This method was previously verified by us with success for the combination of aluminium-titanium [2].

2. Joining by reactive solders of the eutectics type. For the given materials combination a thin layer of silver with or without underlayer of nickel has been verified. Silver reacts with aluminium during the process of contact melting resulting in a formation of an eutectics solder.

Experiments were performed with pipes of the outer diameter 38 mm and the wall thickness 1.6 mm. Joints were tested for vacuum tightness by a helium leak detector. Sound joints were heated to 300 °C, kept at this temperature for 20 minutes, then cooled in free air to the room temperature and then undercooled to very low temperature in liquid nitrogen. Such drastic heat treatment was repeated five times altogether for each specimen. Then the joints were tested again for vacuum tightness. There were tested 6 pipe specimen altogether, all having superb final vacuum tightness.

Structure of joints was evaluated by metallographical analysis. For each structural part the microhardness was determined. Qualitative and quantitative X-Ray microanalysis was applied for the determination of chemical composition of all structural parts. Tensile and bend strengths were verified by simple mechanical testing of strips cut from the pipe specimens.
Conclusion: The results obtained have shown that it is possible to prepare vacuum tight, mechanically strong enough joints between aluminium and titanium, nickel or corrosion resistant steel. Following research programme will be aimed at the optimization of conditions and parameters of joining in order to eliminate possible but undesirable local overheating of materials during their joining.

References:


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Section 10

MATERIALS SCIENCE
IN ELECTRICAL, CHEMICAL
AND CIVIL ENGINEERING
The aim of this paper is to describe the process of the structural relaxation of splat cooled 75Ce-25Al alloy. Intermetallic compound Ce₃Al attracted attention as a heavy fermion with antiferromagnetic ordering at temperatures below 115 K [1]. The Ce₃Al compound exists in three allotropic modifications. The alpha phase having hexagonal structure No. 194 of Ni₃Sn type [2] is stable in the temperature range 115-523 K.

The process of structural relaxation in splat cooled 75Ce-25Al alloy samples was investigated by measurement of the diffraction intensities of the hexagonal intermetallic compound Ce₃Al, which arose from the non-crystalline state during isothermal annealing in a diffraction chamber. Annealing 90°C/5 h/argon did not affect the X-ray diffraction pattern of the metallic glass structure. Structural relaxation started at temperature $T_g = 100 ^\circ C$.

At the beginning of the first stadium of structural relaxation, the diffraction 002 was one order of intensity higher than the 201 diffraction which has the highest intensity of a stable, ordered crystalline compound. Both the computing of diffraction intensities for ordered and disordered Ce₃Al and the measurement of preferred orientation for partly relaxed structure proved that the observed intensity of 002 diffraction is due to the creating of very thin plates having (001) orientation and thickness $d < 100 \text{ nm}$.

Annealing for 39 hrs at 100 °C in a diffraction chamber enabled the determination of the kinetic coefficients $k$ and $n$ in Avrami equation [3]. The transformed volumes of material for the Avrami equation were determined from the relative intensities of diffractions.

The values of kinetic coefficients $n = 0.5, k = 0.57$ for diffraction 002 and $n = 0.5, k = 0.37$ for diffraction 201 were computed from the Avrami equation applied to experimental diffraction intensities. The value of kinetic coefficient $n = 0.5$ has confirmed (see [3]) the role of thin plates in the first stadium of structural relaxation. Extrapolation of kinetic curves for different rate constants $k$ made it possible to assess time necessary for complete ordering. Plates oriented along the basal plane of the stable crystal structure were built up at temperature 100°C in 80 hrs. Transformation from the non-crystalline phase to the crystalline chemically ordered alpha Ce₃Al phase at temperature 100°C would be finished in 400 hrs.

The experiments and their analysis proved that the first stadium of structural relaxation did not started by a topological ordering in local 3D micro-volumes of sample, but by the long range ordering of atoms in the volume of very thin plates having the orientation of the basal plane (001) of hexagonal structure of alpha Ce₃Al phase. During the diffusion controlled thickening, topological and chemical ordering took place simultaneously.
Measurement of the preferred orientation by a texture X-ray diffractometer proved that the plate-like shape of analysed samples did not influence the orientation of new grains which were transformed from the glassy state.

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References:


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CONDUCTANCE CHANGES
AND PREMATURE CAPACITY LOSS
IN POSITIVE LEAD–ACID
BATTERY PLATES

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Key words: lead–acid batteries, collector-active mass interface, contact resistance, active mass resistance, grid alloys, premature capacity loss

Our research work has been devoted to identification of processes that cause premature capacity loss (PCL) in lead–acid batteries. Special attention has been paid to the conductance of the active material $G_m$ and to the conductance of the interphase between the active material and the lead grid $G_k$ in positive electrodes.

Test electrodes were pasted on grids made of pure lead and seven different grid alloys, both antimonial and antimony-free (with calcium), and with different tin contents. The area for pasting was $55 \times 20$ mm, the thickness was 7 mm. The paste had a typical industrial formulation (from Bären Batterie, Austria). The test cells contained a large excess of both electrolyte and negative active material. The negative electrodes were placed at either side of the test electrode at a distance of about 25 mm. No separators were used. The plates were formed in the usual way.

The test electrodes were arranged into two groups (eight electrodes each); one group was cycled under a "bad" regime and the other under a "good" one [2]. In the bad regime, the charging current was adjusted so that the charge passed after 18 h be equal to 150% of that obtained after discharge in the preceding cycle. In the good regime, the electrodes were charged more rapidly with a current corresponding to the discharge time of four hours (in our case 0.5 A) until the cell voltage reached 2.4 V, and then with a current of half the preceding value so that the total charge be 125% of that obtained during the discharge. The electrodes were discharged daily at about one-hour discharge rate to a cut-off voltage of 1.6 V (100% DOD).

The results of the measurements were obtained in the form of the dependences of the interphase conductances $G_k$ and of the active mass conductances $G_m$ together with the discharge capacity $C$ on the number of cycles. The conductance measurements were carried out by means of our original method [1]. The conspicuous decrease of the capacity, that was observed, is obviously a manifestation of the PCL effect.

Under the bad cycling regime, a close resemblance between the curves of the capacity and of the active material conductance can be observed. The capacity increases linearly with the specific conductance of the (charged) active material up to the value of $G_m \approx 200$ S.cm$^{-1}$
and then it remains almost constant. This is particularly true for electrodes with Pb–Ca 0.09, Pb–Ca 0.09–Sn 0.32, Pb–Ca 0.09–Sn 0.70 and Pb–Sb 1.61–Ca 0.37 grids (numbers indicate the component contents per cent).

Similar dependences were obtained for electrodes cycled under the good regime, but their life was appreciably longer, except for the electrode with Pb–Ca grid, which broke down after several cycles. For antimony-free collectors under the bad regime, the cycle life decreases with increasing tin content, while for antimonial lead collectors the cycle life increases with the content of antimony. With respect to 100 % DOD, the electrodes attained a rather high cycle life. Shedding of the active material, but no deterioration of the current collector was observed at the end of the test.

Electrodes with pure lead grids broke down before finishing the six conditioning cycles. Their capacity fell in parallel with the conductances, \( G_k \) and \( G_m \). These results strongly suggest the presence of some form of passivation of the lead grid. Further evidence of passivation was obtained from voltage-time curves which were of usual shape, but shifted to lower voltage values. Such behaviour is typical for passivation due to the formation of high-resistance layers close to the grid [3, 4]. Generally, a fall in the discharge capacity was accompanied by a decrease in the conductance of the active material, whereas no correlation with the interphase conductance (except, perhaps, for electrodes with the pure lead grid) was found. Under the bad regime, the \( G_k \) values usually began to fall when the end of cycle life (i.e. \( \frac{2}{3} \) of \( C_0 \)) was attained; and under the good regime, the changes of \( G_k \) values were relatively small or, with antimonial lead grids, even negligible.

The decrease in capacity under the bad cycling regime is a typical manifestation of the PCL effect, although, as anticipated, the rate of capacity loss was lower for antimonial lead grids. The clear correlation with the active material conductance is in line with active-material-based causes of capacity loss, such as described by the model proposed by Winsel et al. [2]. (Experiments carried out under the good cycling regime led to a similar correlation.) A theory of the effect of active material resistance on the discharge capacity was elaborated by Bouet and Pompon [5], who concluded that the loss of capacity is largely due to an increase in the resistance of intergranular contacts and not to a decrease in the electrochemical activity of lead dioxide.

References:


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ELECTRICAL PROPERTIES OF CARBON FIBER–EPOXY COMPOSITES IN RADIOFREQUENCY RANGE
100 MHz – 1.8 GHz

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Key words: carbon fibres, composites, electromagnetic compatibility

Absorption of electromagnetic waves is the irreversible conversion of electromagnetic energy into heat energy. Material loss is loss that occurs after the wave enters the material. The basic input dates for solution of this problem are complex permittivity and permeability. For nonmagnetic fillers only complex permittivity must be determined. Electromagnetic interference is a specific kind of environmental pollution. Although metals can provide adequate shielding against EMI, conductive polymer composites are being increasingly used too. Structure and distribution of electroconductive fillers or their aggregates are dominant properties that control complex permittivity.

Short carbon fibbers was coated by epoxy resin and so prepared fibbers was embedded in low temperature liquid epoxy. Because carbon fibbers are not in electrical contact and creates only “big” dissipative dipoles, material has interesting properties. It was observed that composite creates resonant peak in radiofrequency range. This phenomena can be suitable for construction of boxes or chip packages or as a lossy medium to reduce device-to-device crosstalk. The results of our measurements will be presented (HP 4291A Impedance/Material Analyzer up to 1.8 GHz).

A simplified calculation of the $SE$ (shielding effectiveness) value is obtained by

$$SE = 20 \log(1 + 188.5/R_{square})$$ (1)

This relation follows from a simplified shielding theory. It is very useful for high conductive materials [2] but behaviour of polymer composites [1] is more complicated. A problem in measuring the square resistance of filled conductive plastics, is that the conductive layer is not available at the surface area of the material. Electrical conductivity for threshold of percolation is frequency dependent and volt-ampere characteristics are non-linear. From this point of view noncontact methods [3, 4] for conductivity measurement are important.

References:
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CHECKING OF QUALITY AND POSSIBILITY OF USE OF RECYCLED BUILDING MATERIALS

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Key words: building, materials, recycling, their, properties, testing, and, use, brick, concrete, recyclates

At the reconstructions and demolitions of buildings a great amount of waste arises that has been used so far only a little. For the possibility of further use of recycled building materials, it is necessary to pay attention to both the quality and properties of the original material and the way of secondary processing and the finding out of special requirements for preparing, treatment of prepared mixtures and finding out physico-mechanical and chemical properties of products created from the recyclates for their further use.

The finding out of physico-mechanical properties was at first done on the brick and concrete recyclates, obtained from the mobile crushing machine equipped by the RCL-1232-EV impact pulverizer of the SBM Wageneder Company in Austria. The machine is operated by the Dufoner s.r.o Company at the spoil heap in Brno-Cernovice and it produces fractions of 0–16 mm, 16–32 mm and 32–80 mm. Individual grains can be described as slightly rounded, with the shape index 1.5–2. The grain size, done by a standardized series of sieves, showed the continuous granulometry, corresponding to the grain size curve with a higher proportion of fine particles to 2 mm, especially in the brick recyclate.

The volume mass of the brick recyclate was up to 1950 kg.m$^{-3}$ and of the concrete recyclate around 2200 kg.m$^{-3}$. The absorption capacity of the brick recyclate was up to 23% and of the concrete recyclate up to 10%.

The compacting capacity of the brick recyclate fraction 0–16 mm, when used as the back filling material, found out by the Proctor test, can be done at the moisture content of 6–7 natural moisture. By the measurement of the mass activity the limit of Ra 120 Bq.m$^{-1}$ was not exceeded.

On the basis of these and other found-out properties we checked experimentally the possibilities of the use of brick recyclate in practice – for the production of unburnt compressed bricks 300 x 150 x 100 mm from the mixture of recyclate and soil 40/60% with the 10% admixture of cement CEM II/B-S 22.5 and without cement. With the cement admixture we achieved the compression strength of 6.7 MPa and without cement 3.3 MPa, after 14 days of free drying in the air. The bricks were used for building a garage in Prerov in the way of monolithic bricklaying.

By crushing arises a large amount of fine fractions. These can be used as the filler for mortars for bricklaying with a higher thermal resistance than that of natural aggregate. The lower volume mass of the brick crushed material improves the thermal-insulating properties.

Our aim is the use of the brick recyclate for the production of construction and construction elements, for example brick-concrete. Basic tests were performed on the mixtures
of various compositions with the cement CEM II/B-S 22.5 and brick crushed material 0-16 mm. The performed experiments showed that the resulting properties are influenced by the properties of the original material. The compression strength was between 13 and 20 MPa. The elasticity modulus is in comparison with the concrete with natural aggregates lower by as much as 50%. The air shrinkage and increase in volume is higher by as much as 20% in comparison with the concrete of natural aggregates of similar strengths. The higher absorption capacity shows that the brick-concretes will not be frostproof. It is necessary to say then that for the use of the brick-concrete in contact with water and temperatures below zero it will be necessary to take certain measures.

On the other hand it seems to be quite natural to use the recycled concrete as the replacement of natural aggregates for the production of construction concrete. However, great attention must be paid to its faultlessness and to the harmful substance content. The comparison tests, done by Doc. J. Filous, CSc. (TU Brno), showed that the recycled concrete influences negatively the concrete mixture consistency, while the strengths are comparable (max. 15% lower than in the case of use of natural aggregate), the elasticity modulus is lower by approx. 15-20%, the creep coefficient higher by as much as 50% and the shrinkage by 20-40%.

If we know these data and take them in account, the use of concrete recycle as the aggregates for concrete can be quite advantageous.

References:


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DEVELOPMENT OF NEW MATERIALS MAITENENCE OF CONCRETE

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Key words: new building materials, concrete, maitenence, durability, fly ash

Increased applicability of existing deteriorated concrete constructions stresses requirements for better maitenence of the concrete. The aim of maitenence has to be first of all to stop corrosion ofthe inside reinforcement, to prevent condensed water from getting into parts below the surface of concrete and to stop or at least maximally slow down the process of carbonization.

Increased numbers of excellent maintenance materials are being used nowdays. Maintenance materials used for constructions can be divided into four or three types:

a) materials aimed at protection of the reinforcement (conservation)
b) adhesive bridge (penetration of concrete)
c) correction (reprofilation) material
d) secondary surface protection (impregnation, paint)

Requirements for correction materials together with paint we can summarize into the following points:

- good coherence with the base (min 1.5MPa in simple tension)
- compression strength or tensile strength in bend equal or slightly better than that of the base concrete.
- modulus of elasticity lower than that of the base concrete
- frostresistance minimum at T 50
- minimal changes of volume resulting from changes in humidity as well as temperature
- low absorption
- shrinkage cracking totally eliminated
- good watertightness
- alternating diffusion resistance to the penetration of water vapour according to the construction (for instance in cooling towers low on the outside but on the inside of the casing.
- high diffusion resistance to the penetration of carbon dioxide, sulpher dioxide and other acid-forming gases in the given enviroment.
The aim of our internal task was within the development of new correction materials was to find the most suitable way of processing fly ash. Because here we discuss a very wide area, the aim was narrowed to the development of fine grained mortars and smoothing materials together with a binding agent based on Portland cement and epoxy resins. Several types of fly ashes, differently treated (for instance Melnik power plant, Chvaletice, Zdas Zdar n. S.) have been used together with only Czech binding agents. In its qualities this material should be comparable with the qualities of reprofilation materials on our market.

For the purpose of use as a fine grained mortar and smoothing material several recepies of mixtures with binding agent based on acrylate were developed in the first stage. The aim was to find the maximal filling weight rate of cement to fly ashes. For the said requirements the most advantageous rate is 1:3. Higher rates of filling are not interesting for this purpose. Generally we can say that adding of dispersions increases bending strength, elasticity of mixtures, improves the forming property of compositions and adhesion to the base. The danger is in the foaming of “Socrat” when stirring which decreases volume weight, increases porosity and causes that total strength is lower. Dry fly ash can be produced only as a single-component composition. In case of agglomerated fly ash it is possible to produce multi-component mixtures. The reason is 30% humidity which acts as a negative factor in premature hydration of cement.

Based on the above stated results and tests with PCC mortars in acordon with methodology we have made tests with different fly ashes as the filling agent for PCC. The physical and chemical parametres of both types of ashes are different. The required parameteres under the same technologic conditions are different. This sort of filling agents is water diluteable, that is it hardens after it is mixed with a hardener in the presence or water. This is a very advantageous fact from the technology point of view, as it is possible to use damp filling agents and there will be no cost for its drying. Consistence of mixtures can be changed by batching water and cement can be added as another part of the filling agent which can hydrate in damp medium. Resins, on the contrary, which harden only in dry medium, reach higher strength are being used for hydroinsulation cannot be used in combination with mortars. For testing of PC mortars we have chosen normally available CHS EPOXY 516, which was filled in suitable rates 1:2 to 1:6 with fly ashes. The best results we have obtained with rate 1:2 and this mixture was suggested for production as a single-component with process flow sheet.

All the factors influencing prices are generally known, that is price of raw materials, transportation costs, machinery costs, productivity and so forth. The suggested prices are dramatically lower than prices of maintenance materials produced under the same principle abroad that are available on the Czech market.

References:


This research has been conducted at the Department of Technology of Building Materials and Components as part of the research project “Development of new materials for maintenance of concrete” and has been supported by TU grant No. FU 250027.
MAGNETIC ANISOTROPY: A NEW BASE FOR ANALYSIS OF STRUCTURAL PROPERTIES OF BUILDING MATERIALS?

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Key words: building materials, structural properties, magnetic anisotropy, measuring practice, ceramics, ferrofluid

We report on new developments in the analysis of structural properties of ceramic building materials using the measurement of magnetic anisotropy.

Functional properties of building materials are mostly predetermined by their structure. That is why searching for new methods and techniques of analysis of structural properties of building materials is all the time very important. Analysis of magnetic anisotropy is efficient technique in the study of the fabrics of rocks in geology and geophysics (e.g. Hrouda, 1982, Tarling and Hrouda, 1992). The possible use of magnetic anisotropy data for identifying building material structure is the fundamental idea of this project.

The magnetic anisotropy was measured in low magnetic field with the KLY-2 Kapabridge (Jelinek, 1973, 1980) and evaluated using ANISO software (Jelinek, 1977). With this instrument we have measured samples of ceramic (brick) material (cubes 2 cm in edge) in two steps.

First, the magnetic anisotropy was measured on three ceramic specimens in natural state to obtain information concerning preferred orientation of magnetite, hematite and/or other carrier of magnetism. Second, the magnetic anisotropy was investigated on these specimens after saturation by the magnetic liquid to find the existence of an oriented system of cracks and pores. These studies of fabric of solid particles and of pore space were completed by the density measurement of ceramic material.

We present comparison of results from the measurement of the magnetic anisotropy of ceramic materials before their saturation by the magnetic liquid and after the saturation. The specimens had shapes of rods with quadrate base. The specimens for measuring magnetic anisotropy were made in an oriented way with respect to the rod axis. The magnetic susceptibility of dry materials is relatively high (0.86 \cdot 10^{-3} to 1.1 \cdot 10^{-3} SI Units) which indicates relatively high content of magnetic materials. The magnetic anisotropy of the investigated materials is characterized by relatively low variability from specimen to specimen.
The degree of magnetic anisotropy is moderate, indicating clear and well measurable (but not extremely strong) preferred orientation of magnetic materials in the specimens investigated. The susceptibility ellipsoids are almost perfectly rotational prolate, indicating linear preferred orientation of the magnetic materials (preferred orientation of rod-like particles and/or zonal orientation of cake-like particles). The axes of maximum susceptibility (the rotational axes of susceptibility ellipsoids) are parallel to the rod axes of the specimens (within the error interval for the specimen cutting and magnetic anisotropy determination).

This magnetic fabric evidently reflects the technique of the specimen preparation (axially symmetric protrusion of the specimen). The magnetic susceptibility of the specimens with pores saturated by ferrofluids is almost three orders of magnitude higher \((7 \cdot 10^{-1} \text{ SI Units})\). Therefore, the anisotropy of susceptibility indicates in this case the preferred orientation of pores filled in the ferrofluid. This susceptibility increase corresponds to the porosity of 33-38\%. The anisotropy degree is again moderate, but slightly higher than that of dry specimens. This indicates that the pores are anisometric and show some degree of preferred orientation. The susceptibility ellipsoid is again near the prolate spheroid, but not as near as that of the dry specimens. The maximum axis is parallel to the rod axis of the specimens. It means that the pores were made in an oriented way during the process of material formation. One can deduce that in the process of material formation the solid particles were oriented preferably and the pores were oriented in the same way as the solid particles, i.e. parallel to the rod axis.

References:


This research has been conducted at the Department of Concrete and Masonry Structures as part of the research project “Verifying the Possibility to Use the Magnetic Anisotropy Data for Determination of the Texture and Pore Structure of Building Materials.” and has been supported by TU grant No. 0026.
USING MICROWAVES FOR BUILDING CERAMICS MOISTURE DETERMINATION IN MANUFACTURE

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Key words: non-destructive measurement, moisture, building ceramics, microwaves

One of the most important problems in the technology of building ceramic manufacturing is to find out the right moment to start drying and burning of ceramic semi-product. This moment strongly depends on moisture of semi-product. The right drying and burning start value of moisture decides on the quality of a final product.

Our research team is interested in the problem of building materials and raw materials moisture determination (especially in the applications of microwave method) for a long time. According to obtained experiences, the microwave method has been proposed for a quick and non-destructive determination of moisture content in ceramics semi-product in manufacturing.

Due to experiences obtained from the number of measurements of the connection between attenuation $L$ of microwave radiation passing through wet material and water concentration in this material we can state that the dependence of attenuation $L$ on water concentration in building materials can be expressed (with accuracy which fulfils a practical using) by piecewise linear dependence

$$L = A_i + B_i D_{eq}$$

where $A_i$ and $B_i$ are the coefficients of the linear approximation of the real course of dependence in the i-th interval of equivalent layer thickness $D_{eq}$ of contained water.

Using empirical values of the coefficients $A_i$ and $B_i$ for the certain material, the known values of water density $\rho_w$ and the density of dry material $\rho_s$, the measured value of attenuation $L$ it is possible to evaluate values of volume and mass moisture $u_V$ and $u_m$ of measured material by relations

$$u_V = (L - A_i)/B_i$$
$$u_m = \rho_w (L - A_i)/(\rho_s B_i)$$

The intervals of attenuation for which the coefficients $A_i$ and $B_i$ are valid have to be determined by the relation (1) from the relevant intervals of equivalent water layer thickness $D_{eq}$.

The relations (1-3) are valid in the case of the constant thickness of measured samples only. In the case of variability of the thickness it is necessary to use the value of specific attenuation $\lambda = L/d$ which relates to the unit thickness of measured sample.

The coefficients $A_i$ and $B_i$ can be determined by statistical evaluation of set of measured pairs – the attenuation of electromagnetic radiation vs. mass of the irradiated layer of wet material.
The measurements and following statistical evaluation of the dependence between the attenuation of microwave electromagnetic radiation and the moisture of irradiated layer of ceramics raw material were carried out on the semi-products of stoneware sewer pipes. This semi-products were taken from the production in the Keramické závody Poštorná, a.s.

The following conclusions have been done:

1. The mass moisture of these semi-products can be determined quickly and non-destructive by the application of the open air microwave method.

2. The mass moisture of measured ceramics raw material can be find out from the value of attenuation of microwave radiation passing through the layer of this material by following ways:
   a) using relation
   \[ u_m = \rho_v (L/d - A)/(\rho_s B) \]  
   where \( u_m \) is the mean value of mass moisture of irradiated layer of material, \( L \) is the measured value of attenuation, \( d \) is the thickness of irradiated layer, the assumed values of the water density and the density of dry material are \( \rho_v = 996\, \text{kg.m}^{-3} \) and \( \rho_s = 1925\, \text{kg.m}^{-3} \), the coefficients \( A, B \) are:
   \[ A = 0,15\, \text{dB}, \quad B = 0,057\, \text{dB/\% pro} \, L/d < 0,95\, \text{dB.mm}^{-1}; \]
   \[ A = 0,44\, \text{dB}, \quad B = 0,036\, \text{dB/\% pro} \, L/d \geq 0,95\, \text{dB.mm}^{-1}; \]
   b) calculating the value of the specific attenuation \( \lambda = L/d \) and then reading the relevant mass moisture from the graph of the dependence \( u_m(\lambda) \) shown on the Fig. 1.
   c) reading the value of mass moisture from the nomographic chart \( L-d-u_m \) shown on the Fig. 2.

Based on this conclusions the development of the microwave equipment for measurement of moisture content in materials used in manufacture of building ceramics has begun in cooperation with HTT Tesla Opočenek and Keramické závody Poštorná.

This research has been conducted at the Department of Building Design, Faculty of Civil Engineering, TU in Brno as part of the research project "Microwave equipment for measurement of moisture content in materials used in manufacture of building ceramics" and has been supported by TU grant No. FU250032.
BOND OF EPOXY-COATED REINFORCEMENT

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Key words: associative plastic flow law, bond of reinforcement, testing, numerical modelling

In a natural way, reinforcing bars in concrete are protected against corrosion by their comparatively high alkalinity. In healthy concrete and on the surface of the insert there is merely a thin layer of ferric oxide that forms, protecting it, together with the alkaline surroundings, against further corrosion. If there is a change in the material property of the concrete surrounding the reinforcements, under the influence of the environment (e.g. aerial carbon dioxide or an aggressive atmosphere), the beginning of corrosion of the reinforcing bars may take place. The layer of the corrosion product on the reinforcing bars is several times higher in volume than the original volume of the iron; this may cause inner stress in the concrete, leading to the deterioration of its surface. Extensive attention is now being given to structures damaged by reinforcement corrosion.

Several methods for protecting reinforcing bars have been applied, the most efficient being to coat them. In the developed countries a coated reinforcement is used in structures exposed to an aggressive environment.

The Nová hut' metallurgical plant in Ostrava, in cooperation with the State Research Institute of Material Protection in Prague, has been engaged on these problems. Reinforcements covered by protective coats, produced by the powder plastification technique, have already been manufactured and tested.

The thickness of the coat is very important; a considerable thickness gives better protection against corrosion, but the bond with the concrete needed for the static function of the reinforcement becomes weaker.

A system for bond testing for reinforcing steel and concrete, the so-called Pull-out Test, was developed at the Klokner Institute in the past, in accordance with the CEB-RILEM Recommendation. This system has now been modernized, using the new efficient MTS loading system combined with the INOVA hydraulic system.

Mathematical modelling of the experiments has been performed on two levels:

- The behavior of a single bar being pulled-out from the concrete. This was calculated as an axisymmetric problem. The contact between steel and concrete was modelled by means of contact elements. The plastic mathematical model of the properties of the contact in terms of shear stress and compressive stress perpendicular to contact plane...
The associative plastic flow rule (isotropic hardening) results in coupling between shear and compressive deformation. Calculations with various hardening functions were performed to provide information about its influence on the failure mechanism.

- The response of a beam with reinforcement taking into account the bond effect. The constitutive law for bond effect is taken in terms of the relations between shear stress and deformation. In order to determine this relation previous results were used. Many numerical difficulties occur because of coupling of cracking of concrete in the tensile zone and bond failure.

The objective of the project is to extend our knowledge of the failure process in the bond between concrete and reinforcement. The load carrying capacity and mechanism of concrete failure are being investigated experimentally and by numerical modeling.

References:

This research has been conducted at the Klokner Institute of CTU as a part of the research project “Bond of Coated Concrete Reinforcement”, and has been supported by GACR grant No. 103/95/0550.
SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF SULPHUR CONCRETE

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Key words: sulphur, sulphur concrete, physical and mechanical properties, corrosion resistance

Sulphur concrete is a material where elementary sulphur is used as a binder of inert particles of the aggregate. Sulphur thus replaces the mixture of cement and water which is used as a binder in classical concrete. Sulphur concrete is formulated by heating sulphur to the liquefying temperature of about 140°C, when it may be mixed with any type of aggregate. After cooling, this mixture turns to a firm matter with good mechanical properties and very high resistance to a variety of aggressive materials.

The 1995 experiments are a follow up on previous results (1). Sulphur concrete formula was further improved to enable its placing in layers 40 to 60 mm thick and to maximally suppress its volume changes and to avoid shrinkage induced cracks. To this end, the dicyclopentadiene (DCPD) dose was increased and polypropylene fibres 6 mm long were added to the formula. All these modifications were supposed to suppress volume changes and to avoid shrinkage induced cracks. The resulting formula consisted of:

- sulphur 225 kg
- 0/4 fraction aggregate 650 kg
- 4/8 fraction aggregate 310 kg
- ash 50 kg
- DCPD 10 kg
- polypropylene fibres 2 kg

Sample prisms of 40 x 40 x 160 mm were made of this optimized mixture. Thermal expansivity coefficient was to be assessed in a temperature interval of +20 to +80°C both in dry and aqueous environment. Repeated measurements showed that this formula of sulphur concrete displays thermal expansivity coefficient in the interval of $9.48 \times 10^{-6} \text{K}^{-1}$ to $12.21 \times 10^{-6} \text{K}^{-1}$. These values come under the average thermal expansivity area of structural concrete, which typically equals to $10^{-6} \text{K}^{-1}$. This implies that sulphur concrete anchored to a concrete base would, if heated from one side, dilate only as a result of the respective temperature drop and not as a result of different thermal expansivity coefficients.

The sample prisms were further used for establishing statistic and dynamic elasticity modules for sulphur concrete. The statistic elasticity module was established in keeping with the ČSN ISO 6784, dynamic elasticity modules were established by means of the ultrasound pulse method after the ČSN 73 1371 and also by means of the resonance method after ČSN 73 1372.
The average static elasticity module established from 6 partial results was 31.84 GPa. The average dynamic elasticity module established by the resonance method was 36.72 GPa and the ultrasound method resulted in 39.37 GPa. Thus, the dynamic elasticity modules show 15 to 20% higher values than the static module values. This is a typical difference established for various types of concrete, stemming from different principles used for establishing the elasticity module by the individual testing methods.

Simultaneously, long-term sulphur concrete corrosion tests were performed, using 65% nitric acid, 85% phosphoric acid and 25% aqueous solution of ammonia. The testing prisms of 40 x 40 x 160 mm were first weighed to 0.01 g accuracy. 12 samples were placed into each medium, 12 samples were kept for comparison, exposed only to lab ambience. The tests were performed after 7, 28 and 90 days of exposure. Three samples were removed from each medium, thoroughly rinsed with water, surface dried and weighed to 0.01 g accuracy. Sample appearance was checked, together with a simple scratch test for surface hardness. Then the exposed samples and the control samples were subjected to tensile bending strength and compression strength tests.

The average sample mass after the 90 days exposure in the individual aggressive media did not merely drop, it grew in average by 0.13%. This corresponds to the average saturation level of the corrosion solution in porous system of sulphur concrete.

Similarly, tensile bending strength compared with compression strength in samples under test and control samples showed insignificant differences between individual groups, possibly arising from usual statistical fluctuations. Average tensile bending strength of control samples after 90 days was 9.81 MPa and compression strength was 43.84 MPa.

The corrosion tests thus imply that sulphur concrete exposed to nitric acid, phosphoric acid and aqueous ammonia will neither be damaged, nor will its basic mechanical properties deteriorate.

Based on these results and in cooperation with Chemisol company practical application of sulphur concrete in situ was performed. A layer of sulphur concrete was put onto a retaining tank walls in Autobaterie in Česka Lípa. Formulation of larger quantities of sulphur concrete is technologically difficult, thorough homogenization of large quantities is needed, including its uniform heating to a required temperature in the range from 130 °C to 140 °C. This is a challenge, but not an unfeasible one.

Performed experiments clearly showed suitability and practicability of sulphur concrete as a special building and insulation material, its physical and mechanical properties comparable with high quality concrete, and on top of that with excellent corrosion resistance especially towards inorganic acids.

This research has been conducted at the Department of Technology of Concrete of the Klokner Institute, CTU Prague as part of the research project “Sulphur concrete” and has been supported by the Fund for Development of Universities, grant No. 8218.
INFLUENCE OF DISPERSION REINFORCEMENT BY POLYPROPYLENE FIBERS ON RESTRRAIN SHRINKAGE OF CONCRETE

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Key words: polypropylene fibers, concrete, free shrinkage, restrain shrinkage, toughness

Shrinkage and cracking (if the shrinkage is restrained) is a major concern for concrete, especially for flat structures as a pavement (highway pavement), slabs (parking garages), walls. One of the methods to reduce the adverse effects of shrinkage cracking is to reinforce concrete with short randomly distributed fibers. The efficiency of polypropylene fibers to arresting cracks in concrete was studied.

Polypropylene fibers are low modulus fibers (modulus of elasticity varies from 4 to 8 GPa). There are two types of fibers (according to a way of manufacturing) which can be used as a dispersion reinforcement:

- monofilament polypropylene fibers,
- fibrillated polypropylene fibers.

Main difference between these types of fibers is cross section an surface of fibers. Monofilament fibers have circle cross section (diameter varies from 15 to 200 μm) and smooth surface. Fibrillated fibers have irregular cross section (thickness varies from 50 to 250 μm), sharp edges and uneven surface.

For purposes of evaluation of fiber reinforced concrete materials (FRC), toughness in the form of energy absorption in bending, so-called “flexural toughness” is most widely used. Flexural toughness can be expressed in energy terms as absolute values. In Czech republic there is no standard for testing and evaluation of flexural toughness. According to the RILEM recommendation [5] energy absorption is defined as the area under the load-deflection curve (deflection measured at load point). The tests were carried out according to that RILEM recommendation. The testing notched beams (100 × 100 × 400 mm, notch 33 mm in the middle of beam) were prepared and were subjected to third-point load. There were tested two types of mixtures. Plain concrete and the same type of mixture with dosage of monofilament polypropylene fibers FIBRREX (dosage of 0.1 % by volume = 0.9 kg/m³, length 12 mm) with special surface treatment (lubrication) to improve water wettability. Dosage of chosen fibers (0.1 % by volume = 0.9 kg/m³) was specified as an optimum during the tests which were carried out during the years 1992-94 [1-4]. The test were done on three specimens for plain and three specimens for FRC after 28 days of hardening of concrete in wet condition (humidity higher than 95%). During the tests the load-deflection curve was obtained. From that curve the “first crack flexural toughness” (first crack strenght = max. load) and “total flexural toughness” (whole load-deflection curve) was calculated. The result is that in comparison the “first crack flexural toughness” is about 25% higher for...
FRC than for plain concrete and "total flexural toughness" is about 50% higher for FRC than for plain concrete.

The compressive tests were carried out too. There was no significant difference between FRC and plain concrete. Compressive strength (test specimens were three cubes 150 x 150 x 150 mm) was for FRC 28.9 MPa and for plain concrete 28.6 MPa.

For restrained shrinkage cracking test, a ring type specimen was developed. The special formwork was made with inner steel ring (diameter 300 mm, wall 30 mm thick) and outer steel mould. Both of these rings were placed centrically on steel plate so that annulus space between them could be filled with a concrete. There were again two mixtures investigated. FRC and plain concrete. Cracking in restrained specimens was investigated between 1 and 60 days (after casting). The first crack appeared in plain concrete specimen after 20 days in FRC specimen after 48 days. After 60 days there were two cracks (in different places) through whole body of plain concrete ring with total width about 0.4-0.5 mm and one crack in body of FRC ring with width about 0.1-0.15 mm. To get more experimental data and validate results from the tests mentioned above is necessary to continue experimental work.

To see effectiveness of reinforcement by polypropylene fibers results of reinforced specimens were compared with the control specimens from the plain concrete of the same mix proportions. From this comparison it is seen that reinforcement by monofilament polypropylene fibers FIBRREX has significant positive influence on energy absorption of concrete and is very effective in controlling restrained shrinkage cracking in hardened concrete.

References:

This research has been conducted at the Department of Engineering Structures as part of the research project "Influence of Dispersion Reinforcement by Polypropylene Fibres on Properties of Concrete" and has been supported by CTU grant No. 10148309.
STRAIN RATE DEPENDENT CONCRETE FRACTURE ENERGY

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Key words: concrete, strain rate, fracture energy

Transient dynamic events in RC structures are considerably affected by concrete fracture energy. The energy absorbed in concrete may increase the limit load in these circumstances (although the static limit load is nearly independent of the fracture energy). Unfortunately, standard fracture mechanics (either linear or nonlinear) is not directly applicable to reinforced concrete members with common reinforcement ratios since the cracks are arrested by reinforcement bars and relatively dense system of cracks develops instead of a singular crack in plain concrete. This has two consequences for computational modeling. First, discrete cracks models are not applicable (too dense cracks), second, the strain softening in smeared cracks models becomes position dependent (crack density decreases with the distance from a reinforcement bar). The latter phenomenon requires a crack pattern to be assumed in the bar vicinity. A smeared cracks model for reinforced concrete based on fracture mechanics concepts was suggested [2]. Smooth transition to the well established crack band concept for plain concrete is guaranteed in this model. The strain rate dependence of several parameters is to be determined experimentally. Published results are scarce and cannot be incorporated in constitutive equations [1]. Original tests were therefore designed and partially carried out for this purpose. The strain rate effects in cracking reinforced concrete can systematically be explored when the above material model is accepted. In the first step, the rate sensitivity of the fracture energy $G_f$ was assessed. The specimen, a concrete cylinder reinforced by an axial reinforcement bar was subjected to fast axial tension. If the relative stiffness of the bar to that of the surrounding concrete is sufficient then a uniform strain can be assumed along the bar and the total elongation of the specimen need be measured. The specimen size and strain distribution allow for average strain rates of the order $10 \text{s}^{-1}$. The actual strain rates depend on the loading device. The arrangement also was used for static tension tests. The same tests were carried out with bare reinforcing bars, too. The difference between the reinforced concrete and bare steel bars curves allows for the concrete fracture (or strain softening) share of the specimen stiffness and energy to be determined. For the fast tension tests the results are shown in Fig. 1. The scatter of tests with concrete cylinders is due to parasitic bending effects introduced by insufficient specimen precision. From the area between bare bars and concrete (average) curves in Fig. 1 the concrete fracture energy $G_f$ can be found by means of a calibration curve. The calibration curve is derived by numerical evaluation of the above material model for each actual case of the specimen and test arrangement. The first series of tests indicates that fracture energy decreases with growing strain rate but the result is not yet sufficiently reliable. Next specimen series will be given special care in order to avoid the parasitic strains and narrow the scatter of results. Two special devices were designed and built for the experimental part of the project. One of
them is the launching apparatus for free fall impact loading with the capacity up to 1000 kg. The other is an optical displacement gauge in the range 1 mm and resolution 10 μm.

Fig. 1: Impact tests on reinforced concrete and bare reinforcement bars in uniaxial tension

References:

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COMPRESSION STRAIN-SOFTENING IN CONCRETE

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Key words: Concrete, uniaxial compression, softening, specimen size, composite material, quasi-brittle material

Softening is a gradual decrease of mechanical resistance due to a continuous increase of deformation forced upon a material specimen or structure. It is a salient feature of quasi-brittle material like concrete, which fails due to a process of internal crack growth. Softening of concrete is important in the assessment of structural safety due to the fact that well-designed structures show considerable crack growth before attaining peak load.

Softening is found in a deformation-controlled test on a specimen of concrete. A characteristic nominal stress-deformation relation found in such a test is shown in Fig. 1. Under increasing deformation, the tangential stiffness of the specimen shows a continuous decrease until it is zero for peak stress. The post-peak decrease of mechanical resistance due to the continuous increase of deformations is called softening. It is characterized by the descending branch of the nominal stress-deformation curve which has a negative tangential stiffness.

Fig. 1: Characteristic nominal stress-deformation relation of a concrete specimen loaded in compression under deformation control
Concrete is a heterogeneous material comprising hardener-cement paste, aggregates and voids. Internal stiffness and strength show significant variation. Initial stress and cracks are already present before loading. This causes a progressive crack growth found in a concrete specimen when it is subjected to a progressive deformation. Especially the weak interface between the large aggregates and the mortar play an important role in this process of crack growth. The material is gradually weakened because a continuously diminishing number of internal bonds is capable of opposing the externally applied deformation. This finally results in softening of the specimen.

References:


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STRUCTURE OF THE Na(H,D)Y ZEOLITES WITH CHEMISORBED MOLECULES BY NEUTRON DIFFRACTION

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Key words: neutron diffraction, zeolites, Rietveld analysis

The continued interest in the structure investigation of zeolites is stimulated by their potential for the practical use in the chemical technology. It is generally expected that catalysts based on zeolites would be able to approximate the properties of very effective biological catalysts-enzymes. Zeolites exhibited regular, but easily modifiable structure, are important pretenders of this type catalysts. The basic condition for successful preparation of well defined structures is to manage suitable and precise methods for characterization of the synthesized structures. Spectroscopic method (mainly IR, NMR) together with neutron diffraction are suitable for this purpose.

Our conclusions on the distribution of protons and cations in NaH,Y zeolites [1] were fully confirmed and found very wide responses[2]. Therefore, we started to continue our investigations on the NaY and NaX type of zeolites with chemisorbed methyl groups (13CD3I, 13CH3I) during 1994 year. Results of our structure investigations of the NaY and NaX zeolites were presented on the EPDIC IV Conference [3].

The period of the 1995 year was concerned with the low temperature diffraction experiments and on the determination of the position of the chemisorbed groups. The powder samples (NaX, NaY, NaY+CH3I and NaY+CD3I) for neutron diffraction experiments were prepared in the J. Heyrovsky Institute of Physical Chemistry CAS. The materials were decomposed in a vacuum of 10^-5 Torr at 400 °C (10-12 hours) and sealed under vacuum in cylindrical glass with an inner diameter of 12mm (glass thickness was 0.4mm). The height of the column of powder was about 50 mm. The sorption of CH3I groups was carried out in vacuum at 80 K and then the sample was mixed up in the course of 60 minutes at 160 °C.

Powder neutron diffraction experiments were performed on the KSN-2 diffractometer installed at the 15 MW research reactor LVR-15 in Rež near Prague. The wavelength of the monochromatic beam was 0.1362 nm. The diffractometer is equipped by the close cycle refrigerator system Mod. CP-62-ST/1.

The diffraction patterns recorded were refined using the Rietveld profile method (code RIET-N : it was modified from the original Petten version by our laboratory). We used the range of the sin(θ)/λ from 0.025 to 0.360, i.e. 2θ = 3°-57°. We note, however, that at higher angles the pattern becomes featureless even at reasonable resolution due to rapid decrease of the diffracted intensities of Y-zeolites with 2θ. A total of 283 diffraction lines was used.
in the refinement process. The scattering lengths used were taken from the "Neutron News, 3 (1992) 28-37". We reached the values from 7.9 to 11.1 % for the discrepancy factor $R_{wp}$ and confirmed cubic symmetry in the space group Fd3m.

Our structural results gave us the possibility to determine the cation distribution ($S_{I}$, $S_{II}$ and $S_{III}$ positions) and the position of the methyl groups with respect to the lattice oxygen atoms inside the cavities of the basic structural framework of the NaY type zeolite. With respect to the determined structural parameters we can conclude:

- the shift of the cation positions with respect to the zeolite state without chemisorption
- the position parameters of methoxyl groups were obtained
- the exchange H by D showed the same change of the occupation numbers of the $S_{I}$, $S_{II}$ and $S_{III}$ seats and the better condition of the refinement process of powder diagrams
- we continue our work on the NaX type zeolites with chemisorbed $CH_{3}I$ and $CD_{3}I$ groups

The structural investigations of chemisorbed zeolites by neutron diffraction together with the $^{13}C$ MAS NMR experiments is a basic tool for the identification and location of the catalytic active sites, knowledge of which is extremely important for the better understanding of catalytic processes.

References:


This research has been conducted at the Department of Solid State Engineering as part of the research project "Neutronographic Structure and Texture Analysis" and has been supported by CTU grant No. 8216.
A METHOD FOR EVALUATING THE WATER-REPELLENT PROPERTIES OF COATING MATERIALS

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Key words: coating, external lining, water-repellent, integral capillarity

The water-proofness quality of coating materials can be evaluated by various methods. A first look into the evaluation process can provide the knowledge of the material parameter which is most characteristic for the moisture transport in porous materials, namely the diffusivity of liquid moisture $K$. However, this parameter may not be known in some cases because $K$ measuring is very difficult for materials containing small pores only, and in addition $K$ itself does not tell anything about the influence of coating thickness and about the properties of the contact surface between the coating and the substrate. Therefore, direct testing of the coating-substrate system is more desirable.

One of the physical quantities characterizing the behavior of capillary-porous materials in contact with water is the height of capillary rise, i.e., the maximum height $h_{\text{max}}$ of the water column in the material above the main water level. However, the measurements of $h_{\text{max}}$ are very lengthy and, in the main, inaccurate [1].

As a more suitable quantity for evaluating the water-proofness quality can be considered the capillarity $C$ defined by the relation

$$C = \frac{1}{S} \frac{\text{d}m}{\text{d}t},$$

where $S$ is the surface of the specimen which is in contact with water, $m$ is the mass of the moistened specimen, $t$ is the time. As a matter of fact, the capillarity defined by (1) is identical with the water flux in the material.

The value of $C$ is an instantaneous quantity which does not provide any information on the history of the moistening process. Therefore, it appears reasonable to define the integral capillarity $C_{\text{int}}$ (see, e.g., [2])

$$C_{\text{int}}(t) = \int_0^t C(\tau) \text{d}\tau = \frac{m(t) - m_d}{S},$$

where $m$ is the mass of the moist specimen, $m_d$ is the mass of the dried specimen.

The integral capillarity is capable to express not only the absolute amount of water in the specimen but also the time history of the moistening process which is particularly useful in comparing the effectiveness of various coatings on a specified substrate. Therefore, we employ the $C_{\text{int}}(\tau)$ function as the main parameter in evaluating the water-proofness quality of coating materials throughout this paper.

In a practical application of the evaluation of water-repellent properties of coating materials, we have chosen the coatings used in building constructions for protecting the
external linings. We studied four lining materials, Dekalux 5, Dekalux 12, Dekalit P6, Dekalit P10, and three types of the surface treatment, Rudicolor, Aquafob and Rudicolor-Aquafob combination (Rudicolor on the face, Aquafob on the back). The experiments were also performed with the lining materials without any surface treatment in order to evaluate the effect of the coatings in a direct comparison with the basic material.

The influence of Rudicolor (a thin-layered plaster material) on the water-proofness of the lining was qualitatively very similar for all the lining materials we studied. The Rudicolor layer was effective only for short-time water influence, typically one hour. The relative integral capillarities

$$C_{rel} = \frac{C_{int}}{C_{max}} \cdot 100 \quad [%]$$

achieved 30-50% after 1.5 hours and after 8.5 hours already 80-90%. The quantitative effect of the Rudicolor coating on the studied lining materials differed significantly. We have observed that this effect increases with the increasing volume mass of the lining, which is more pronounced for longer times.

The possible explanation lies in the fact that the adhesive properties of the plaster to the materials with higher porosity (Dekalit P, for instance) are better since the plaster penetrates easier into the porous structure. Consequently, the moisture transfer coefficient is higher and the moisture content reaches relatively high values already after a short time - 90% of the maximum moisture content, $u_{max}$, in 8-10 hours for Dekalit P6. On the other hand, the heavier materials such as Dekalux 5 reach comparable values after more than 48 hours. It should be noted, however, that after several days both Dekalux and Dekalit P achieved 100% $u_{max}$ despite the presence of Rudicolor coating.

The hydrophobic coating material Aquafob exhibited water-proofness much better than Rudicolor - the moisture maxima after 4.5 days were in the range of 50% to 80% $u_{max}$. However, the effectiveness of Aquafob increased with the decreasing volume mass of the basic material.

The probable reason of this fact was that also here the coating penetrated deeper into the material with lower volume mass but due to its water-repellent properties the larger contact area acted in an opposite way than in the case of the plaster material Rudicolor.

The Aquafob coating on the back side of the specimen in the Rudicolor-Aquafob combination was observed not to have any additional water-proofness effect compared to the specimens with Rudicolor only.

References:

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AN ANALYSIS OF WATER-VAPOR DIFFUSION PROPERTIES OF COATING MATERIALS ON EXTERNAL LININGS

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Key words: water vapor, diffusion, coating, lining

Diffusion of water vapor through coating materials on external linings can be evaluated by several methods. One of them is described in the general Czech standard for coating materials ČSN 673093 [1] where the coating is analyzed separately from the basis. This is certainly a method which is physically correct and objective but its application for coatings on porous building materials can often lead to some misunderstandings as the coating can easily penetrate into the porous structure of the basis and its real thickness may not be known with a sufficient precision. Therefore, from the point of view of practical usefulness it is more appropriate to analyze the diffusion properties of a coating just on the material which will form its basis in the construction.

In modeling the water vapor diffusion in porous materials, two main phenomenological relations for the flux of water vapor \( j \) are used, \( j = -D \text{grad} p_c \), \( j = -\delta \text{grad} p_v \), where \( p_c \) is the mass of water vapor per unit volume of the porous material, \( D \) is the diffusion coefficient of water vapor in the porous material, \( p_v \) is the partial pressure of water vapor, \( \delta \) is the water vapor permeability. Besides \( D \) and \( \delta \), several other coefficients are introduced in building physics for the sake of better clarity for the building practice. Among them, the vapor diffusion resistance number \( \mu \) (e.g., [2]), the water vapor resistance \( Z \) (e.g., [3]) or the diffusion thickness \( S_D \) (e.g., [4]) belong to the most frequently used.

In measuring the diffusion of water vapor in coating-lining systems, as a matter of fact, we do not determine exactly the diffusion material parameters but only their effective values for a two-layer system. However, knowing the diffusion parameters of the basic lining materials and the thickness of the coating, we can calculate the diffusion parameters of the coating materials using the water-vapor resistance \( Z \). In an analogous way as with the electric resistances, the water-vapor resistance of a series of elements can be expressed as

\[
Z = \sum_{i=1}^{n} Z_i.
\]

Therefore, we have

\[
\frac{d}{\delta_s} = \frac{d_b}{\delta_b} + \frac{d_c}{\delta_c} \quad (2)
\]

where \( d \) is the thickness, the indices \( s, b, c \) denote the system, the basis and the coating, resp. From Eq. (2) it follows that

\[
\delta_c = \frac{d_c \delta_b}{d_c \delta_b - d_b \delta_s}. \quad (3)
\]
For measuring the diffusion coefficient of water vapor $D$ we have chosen a steady-state method, commonly used for experimental work on other materials. The measuring apparatus (see [5], for details) consists of two airtight glass chambers separated by the sample of the measured material, which is typically board-type. In the first chamber, a state near to 100% relative humidity is kept (achieved with the help of a cup of water), while in the second one a state close to 0% relative humidity (set up using some absorption material, such as silica gel). After certain time, the measurement is interrupted, and the changes of the mass of water in the cup, $\Delta m_w$, and of the silica gel, $\Delta m_s$, during the chosen time interval $[0, \tau]$ are determined. If $|\Delta m_w| = |\Delta m_s|$, i.e., if the steady state is established within the measuring system, the experiment is terminated. Otherwise, the measurement continues in the same way as before. The experiment is carried out under isothermal conditions.

In a practical application of the proposed method of analysis of the diffusion properties of coating-lining systems, we studied four lining materials, Dekalux 5, Dekalux 12, Dekalit P6, Dekalit P10, and three types of the surface treatment, Rudicolor, Aquafob and Rudicolor-Aquafob combination (Rudicolor on the face, Aquafob on the back). The experiments were also performed with the lining materials without any surface treatment in order to evaluate the effect of the coatings in a direct comparison with the basic material.

The results of measurements have shown that the influence of both Rudicolor and Aquafob on the diffusion properties of the coating-lining systems was relatively small, 20-30% in average.

This is a favorable feature from the point of view of the water balance of the external walls since the main flux of water vapor is usually in the direction from the interior to the exterior.

The approximate values of diffusion parameters of the coatings themselves calculated using Eq. (3) have shown that this positive effect was not due to the low thickness of the coatings but due to the fact that the diffusion coefficients of both Rudicolor and Aquafob were only several times lower than those of the studied lining materials.

References:

[1] ČSN 673093 Stanovení propustnosti volného náděrového filmu pro vodní páru.

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MONITORING OF AGEING PROCESS OF INSULATING VARNISHES

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Key words: dielectric parameters, insulating varnishes, complex permittivity measurements, quality testing

Insulating varnishes are used for impregnating of windings, insulation of wires and for surface insulation of printed circuit boards, too.

Temperature, humidity, radiation and the other environmental influences cause ageing of insulating varnishes and this fact can be observed as a change of some of their electrical properties. The aim of our experiments was:

- monitoring of ageing process of the selected insulation varnishes by the measurements of relative permittivity and dissipation factor at wide frequency range from 50 Hz to 50 MHz,
- to determine of the information ability level of these dielectric parameter measurements and the possibility of their utilisation at quality testing of the insulating varnishes.

Dielectric parameters of insulating varnishes type S 5001 and S 1942 were measured formerly [1] and the informations about the other two varnishes are given in this paper. Relative permittivity and dissipation factor have been measured on:

- electric insulating varnish used for deep impregnation of windings, type S 1901, insulating class B (130 °C), made in CZ, chemical basis of the varnish is fenolic resin and xylene [2]
- electric insulating varnish used for deep impregnation of windings, type Izola-220 T, insulating class F (155 °C), made in Italy (firm Roolizola).

The films for dielectric parameter measurements were prepared from these varnishes on 0.18 mm thick cooper sheets. For evaluation of the influence of ageing, tested films were subject to artificially accelerated ageing in several cycles. Each cycle (A, B, C, D) is represented a 60-hours exposition in oven at the temperature of 155 °C (S 1901) and at 180 °C (Izola). The same measuring equipments and methods have been used as in [1]. The measured frequency dependences of the relative permittivity and dissipation factor of the varnishes S 1901 and Izola-220 T during ageing (curves A, B, C, D) are shown in Fig. 1., Fig. 2. and Fig. 3., Fig. 4.
Fig. 1:

Fig. 2:

Fig. 3:

Fig. 4:

References:


This research has been conducted at the Department of Electrotechnology as part of the research project "Evaluation of Electric Insulating Varnishes" and has been supported by Czech Grant Agency grant No. 102/94/1480.
GROWING OF LEAD IODIDE CRYSTALS


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Key words: lead iodide, X-ray detectors, semiconductors, zone melting, growing crystals

Interest in room temperature semiconductor detector materials has increased [1] significantly in the last two decades. Mercuric iodide (HgI₂) and lead iodide (PbI₂) are two most promising materials [2, 3] besides the well known classical materials (e.g. CdTe, CdSe, GaAs, GaSb, InP) for such applications. Unlike HgI₂ which is a well studied material, PbI₂ is much less mentioned in the literature and the technique of growing high quality bulk crystals from this material has still to be worked out in detail.

PbI₂ is a suitable material for uncooled solid state efficient detectors that can operate over a wide temperature range up to 130 °C. Detectors of this type are ideal for application in medical and environmental engineering to improve diagnostic methods.

Two important physical properties distinguish PbI₂ for detector applications. These are its lower vapour pressure [4] and its higher chemical stability. The polytypism of PbI₂ seems to be one significant property of this material, which can cause the change of characteristic electrical and optical properties.

The main stages of preparation of high quality bulk PbI₂ crystals consist of preparation of stoichiometric lead iodide, its purification by zone melting and growing crystals. Our research focuses on an analysis of all steps in the manufacturing process. The results of the crystal manufacture are characterized by stoichiometry, spectral and X-ray analysis.

The input PbI₂ material for purification by zone melting was prepared by precipitation from Pb(NO₃)₂ with KI, using an excess of KI; the concentration of both solutions was 0.5 M. The temperature was held between 22 and 25 °C, and the solution was constantly stirred. The starting material for purification was found to have a stoichiometric ratio that only varied at the third decimal place.

Zone melting [5] is an excellent purification method. The purity of final product depends on the efficiency of the solid-liquid separation step. The impurity content (Ag, Fe, Ca, Mg, Al, Cu, Si) of the zone-refined PbI₂ material after 20 passes was analyzed to be in the ppm range by atomic absorption. To obtain a constant stoichiometry ratio, zone-refined PbI₂ was iodized with methylene iodide in a quartz glass ampule.
The Bridgman-Stockbarger technique [6, 7] was selected as a method for growing crystals. During the process the temperature profile was carefully controlled. Two temperature profiles were evaluated. A first attempt to grow a crystal without a substrate (secondary nucleus) was unsuccessful. In a second set of experiments, a secondary nucleus of sapphire with the same orientation of the c-axis as PbI₂ and etched by phosphoric acid was used. Control of the substrate preparation was carried out using powder diffractometer. The orientation of the substrates were in good agreement and deviation of the angles of the c-axis were within 1 to 5 degrees. The 'tuned' temperature profile produced the best crystal quality (Fig. 1). It is characterized by a slight increasing the temperature in the upper zone, whereas, in the first unsuccessful case, a slight decrease in temperature was tried.

Our next series of experiments of preparing bulk PbI₂ crystals will be concentrated on determining the optimum number of stages of zone melting and the most suitable temperature profile during crystal growing.

References:


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MODIFICATION OF LiNbO$_3$ OPTICAL PROPERTIES BY He$^+$ IMPLANTATION

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Key words: ion implantation, LiNbO$_3$, refractive index, absorption coefficient

Recently, massive application of optical waveguide elements has taken place to increase the information transmission rate. In the field of integrated optics, namely the LiNbO$_3$ components are commercially employed. To prepare a waveguide based on LiNbO$_3$, it is possible to take advantage of the refractive index change caused by the radiation modification of a material under ion implantation.

By the means of ion implantation it is possible to create either a waveguide channel by increasing the refractive index under a surface or to make an optical barrier in depth of several microns by decreasing the refractive index in the layer where high energy ions stop.

During the ion penetration into a material, two types of energy losses occur. They depend on the ion velocity. When the velocity of an ion is high enough – in the MeV energy region – an essential part of the ion kinetic energy is transmitted to electron excitations, ionizations, and it also results in the breakdown of chemical bonds. Since the electron-hole pairs are created, it can be expected that both color vacancy F centers and interstitial H centers appear. All these effects have strong influence on the absorption. When an ion is slowed down, nuclear collisions are much more pronounced. As it was shown in [1], the refractive index change depends on the density of energy deposited in nuclear collisions which result in material structure defects. These defects accumulate in dependence on the dose of implanted ions and even the amorphisation connected with a volume expansion may occur. This can be one of the reasons of the refractive index decrease generated by the ion implantation. Strong correlation between the changes of refractive index and the material density (volume) changes is expressed by Wei [2] correction of Lorentz-Lorentz equation:

$$\frac{\Delta n}{n} = \frac{1}{6n^2(n^2 - 1)(n^2 + 2)} \left( \frac{\Delta \alpha}{\alpha} - \frac{\Delta V}{V} - \frac{\Delta \kappa}{\kappa} \right)$$

- $n$ – refractive index
- $\alpha$ – polarizibility
- $V$ – volume
- $\kappa$ – influence on the local field

The implantation depth depends besides other features, on the kind and energy of an incoming ion. The development of the radiation damage also depends on the temperature during the implantation process.

Waveguides suitable for technical applications are at least 4 $\mu$m thick. To create such a waveguide, it is necessary to use He$^+$ ion beam with energy at least 2 MeV. In a LiNbO$_3$ crystal the different changes for ordinary and extraordinary refractive indices are induced by the ion implantation. The extraordinary refractive index is slightly increased in the
region just below the surface. However, at the end of the ion path both the ordinary and extraordinary indices are decreased proportionally to the ion dose.

The experiments are performed on ion beam modification of LiNbO$_3$ optical properties. Thin plates of LiNbO$_3$ cut perpendicularly to the crystallographic axis are polished from one side and left ground from the other side. He ions are implanted with energy 100 keV at about room temperature into the polished plane. The ion beam is scanned over the target with the average current $3 \times 10^{-7}$ A/cm$^2$. The surface of the implanted sample is covered by a thin Mo gauze to suppress possible charging. The distribution of implanted ions, simulated by TRIM 90 [4], shows the mean projected range value $R_p = 0.62 \mu$m and standard deviation $R_p = 0.15 \mu$m. So, the surface implanted layer in our experiments can approximate the buried He layer (optical barrier) implanted with MeV energies in a depth of several $\mu$m.

The ellipsometry is applied to measure the refractive index in the barrier. The polarizer-compensator sample-analyser ellipsometer is used and from the measured data the complex refractive index $N$ is evaluated. Its real part gives the ratio of the light velocity in a vacuum and a material, the imaginary part of $N$ defines the absorption coefficient. The real part of the measured refractive index has been in good agreement with the previously published results [3]. Moreover, we have evaluated the absorption coefficient which in $z$ and $y$ planes rises with the dose.

We have also measured the effective thickness of the modified layer and its dependence on the ion dose. The growing thickness of the layer may be due to an expansion of the implanted volume. We intend to investigate changes in optical properties of electrorefractive materials under various parameters of ion implantation with the aim to produce an optical waveguide with special parameters.

The authors would like to thank Dr. Hrdina and Dr. Chvostova from the Institute of Physics of Czech Academy of Science for their help with the ellipsometric measurements and the evaluation of the ellipsometric data.

References:

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DETECTION SENSITIVITY OF ULTRASONIC PULSE VELOCITY METHOD TO INTERNAL VOIDS IN CONCRETE

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Key words: ultrasonic pulse velocity method, detection sensitivity, internal voids

The ultrasonic pulse testing method is recommended for estimation of uniformity and quality of concrete and also for detection of internal voids or cracks in concrete. The real capabilities of this method have been examined in the frame of the special experimental project [1]. Among other the effect of modelled “hidden” faults like internal voids and cracks has been investigated. Prismatic specimens made of cement mortar or concrete had dimensions 100 × 100 × 400 mm. In the central part of some tested specimens modelled faults of different sizes have been created with the aid of the foam polystyrene plates of sizes as follows: 20 × 20, 50 × 50, 80 × 80 mm at a constant thickness of 30 mm.

The effect of the modelled faults has been tested by direct method of measurements of ultrasonic pulse velocity. Transducers have been placed on the both sides of test specimens (in longitudinal or transversal directions). Simultaneously, the influence of the magnitude of the working frequency of the transmitter as well as the influence of the procedure of the reading of time have been examined.

From the experimental results follows that the diagnostic capability of ultrasonic pulse velocity measurements for identification of modelled faults in the test specimens is very low in comparison with results of the other tests. Specimens with the largest modelled fault have shown decrease of maximum pulse velocity 2 to 3% approx. in longitudinal and 6 to 7.5% approx. in transversal direction only. However, at the same time the generally accepted mean value of the coefficient of variation of the ultrasonic pulse velocity has been 1.5% approx. (e.g. [2]). On the contrary, maximum decrease of the values of dynamic moduli of elasticity estimated by resonance method has shown 42 to 53% resp.

The central part of the test specimens has also been examined for compressive strenght, flexural strenght, direct tensile strenght and splitting strenght. In the last case the most pronounced decrease in strenght has been about 85% for both tested materials, i.e. cement mortar and concrete.

The results indicate that the ultrasonic pulse velocity method provides a very low detection sensitivity for assessment of the internal voids in concrete, respectively none (see e.g. [3]). This reveals that in concrete the ultrasonic pulses does not propagate rectilinearly, but reflect multiplicatively on surfaces of aggregates grains. This is probably why, that the interpretation of obtained results is not easy. In order to obtain reliable data, it is necessary to carry out the pulse velocity tests under strict supervision and by experienced operators.
The interpretation of data should be done by competent experts to avoid non-desirable fallacies.

References:


This research has been conducted at the Department of Concrete Technology and has not been supported by any grant.
MATERIAL PROBLEMS
OF CASTOR 440 CASK PACKAGE

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Key words: CASTOR 440, cask body, IAEA, regulations testing

CASTOR 440 is a transport and storage cask for spent fuel assemblies from reactors of the VVER type employed in the Czech Republic. It is manufactured by GNB Essen company; a part of the production is performed by Skoda Plzen company. The cask is designed for 84 spent fuel assemblies. The cask is to meet essential safety criteria summarized as follows:

- shielding
- criticality safety
- leak tightness

The construction conception of the package and materials used guarantee the observance of these general requirements under normal operating conditions as well as after assumed accidents. From the mechanical point of view the cask is a massive thick-wall can with flat bottom and double lid equipped at the side walls with four trunnions for the handling. Radial fins at the outer side wall of the cask body enlarge the heat transfer surface. The thermal power of the cask after loading burn-up fuel elements is up to 20 kW. The maximal thermal power mentioned reduces in the course of time. In lengthwise holes in the cask body, circular moderator rods out of polyethylene are arranged. The spent fuel elements are accommodated in the cask cavity in a honeycombed basket, which ensures the residual heat transfer and critically-safe fuel arrangement within the basket. The cask cavity is filled with helium with underpressure of 20 kPa. The leak tightness of the cask monitoring is performed by means of pressure measuring between the primary and secondary lid. The cask is during the transport equipped with add-on impact limiters installed at the two cask ends. They consist of orthogonally set wooden prisms enclosed partly in steel plate shells. Metal cover protects the impact limiters from outer side.

Main material groups used in the cask design:

- **Cask Body** – massive cask (over 100 t) out of ductile cask iron of the GGG 40 type. Minimal mechanical values guaranteed: $R_p 0,2 = 200$ MPa, $R_m = 250$ MPa, $\Delta 5 = 6\%$. The structure is made out of ferrit (at least 80%); the rest is made of perlit. The anti-defect control of the body is performed completely with ultrasound. The cask interior is nickel-plated in an electroplating method. The design of the cask does not permit the pressure in the side wall of the cask to exceed 21 MPa.

- **Lids, Trunnions, Screws** – made of maraging stainless forge steel X5CrNi 134. Allowable limit values: $R_m = 780$–980 MPa, $R_p 0,2 \Rightarrow 635$ MPa, $\Delta 5 \geq 15\%$. The anti-defect control of the lids and the trunnions is performed by means of capillary and ultrasound tests. Under the strains of normal operating conditions the values are considerably below the allowable limit values testified by high safety coefficients (indexes).
• Basket – serves for inner arrangement of burn-up fuel elements, heat transfer and partial absorption of fast-moving neutrons. It is made out of corrosion-resistant borated steel. The heat transfer is performed by heat conducting plates of Al99,5W7, which are not strained.

• IAEA regulations testing. In addition to normal operating conditions, the cask must also comply with IAEA regulations concerning accident situations.

• Drop from a 9 m height onto a flat impact plate. Impact limiters installed at the two cask ends serve for reducing the impact effecting. The impact deceleration is dependent on the angle of incidence; nevertheless the 100 g value is not exceeded. These results proved a drop test of a cask with similar design. All parts of the cask resist these dynamic powers.

• 1 m drop on the pin with 150 mm diameter, length 200 mm.

• Impact with the lid surface – two steel plates (60 and 30 mm) are installed in the impact limiters. Experiments and calculations prove that these plates absorb all energy.

• Impact with the side wall line – both the test calculation and the experiment were performed in Japan CASTOR. The maximum stress in the inner side wall of the cask is only 86.9 MPa.

• 200 m water immersion test – the outside pressure 2 MPa increases the stress in the cask side wall only by 8.04 MPa.

• Thermal test – the cask has the 30 min. resistance to the outside temp. of 800 °C.

All manufacturing processes concerning the cask are performed in ISO 9001 quality.

Resume. Considering possible application of the CASTOR cask package in the Czech Republic, the Faculty of Mechanical Engineering of CVUT was entrusted with the task of assessing the cask from the point of view of material used and mechanical strain. All tests were based on information from manufacturer. The cask had to be modified, partly also in accordance with our comments. Only the third modification fulfilled prescribed requirements. The modifications concerned strengthening of the inner basket, changes in several screw tightening moments and explaining questions about assumed fragile damage. Several computations had to be defined more precisely and clearly.

Short-term changes of mechanical values of material used in the cask construction are predictable. We propose, however, to put inside the cask several test bodies, so that could be possible to examine assumed time-depending changes of structure, firmness, ductility and persistence. After future deposition of burnt-up fuel into permanent place, this will make easier the decision concerning further possible employment of the cask.

References:


This research has been conducted at the Department of Materials Science Fac. of Mechanical Eng., CTU, Praha for SÚJB Praha.
NONDESTRUCTIVE EVALUATION OF TIMBER STRUCTURES

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Key words: timber, wood-based panels, timber structures, test methods

The contribution deals with the use of modal analysis for the investigation of dynamical properties of timber structures.

Modal analysis involves the determination of modal parameters for components and structures. Modal parameters are essentially dynamic characteristics of an element determined by the mechanical interaction of structural geometry and material. An element will freely vibrate at one or more of its natural frequencies when subjected to some form of external triggering force. At each natural frequency the element forms a certain shape called a "mode shape". The mode shape formed may be predicted by computer models but still requires measurement to determine accurately the modal frequency and amplitudes. Vibration can be caused by any number of external sources. Should the fundamental frequency of the external source coincide with any of the natural frequencies (particularly those with the most significant amplitudes) large amplitudes of vibration can occur. This phenomenon, known as resonance, results in large amplitudes that can have destructive effects on components and structures. In some cases this causes the deterioration of members, in general this contributes to increased fatigue of the specimen. Study in this area falls into the category of structural dynamics.

This examination is directed towards the modal analysis of thin-flanged beams. This work can be generally divided into sections.

1) Experimental analysis: A large part of this work involves taking field measurements of thin-flanged beams and an analysis of the obtained results.

2) Finite element analysis: The derivation of modal parameters and hence mode shapes using analytical models utilising a special finite element package capable of performing dynamic analysis on a model. In addition to this static load cases can be examined on models already validated with dynamic correlation between experimental and analytical results.

Through the use of relatively inexpensive equipment it is possible to correlate analytical models and experimental data. Using this technique more accurate models can be constructed, which in turn imitates dynamic behaviour. These models can be used to analyse possible alterations to the structure. These modifications involve increasing the structure mass or stiffness to affect directly the frequency at which resonance occurs. This means that it is possible to:

1) evaluate a component and a structure,
2) adjust the mathematical model to represent the component and the structure in situ, and
3) perform modifications on the component and the structure without physically altering the existing component and the structure.

By using this method problem frequencies and mode shapes can be identified and considered in any modifications. The most efficient practical solution can be implemented following trial runs of possible feasible solutions using finite element analysis.

The spectrum analyser used for measurements was a four channel Tektronix. Four channels enable the dynamicist to have one accelerometer measuring the force input and three measuring the structural response, which is a common technique for checking the recorder data simply using measurement comparisons. Measurement checking should be practiced where possible to help to eliminate the possible recording and processing of extraneous data. The spectrum analyser performs Fast Fourier Transforms (FFT) on the measured data creating a continuous curve by joining the discrete measured points with the use of a mathematical series.

The impact hammer used for all these investigations has been specially developed during the recent few years. Essentially the impact hammer has the character of a hammer of a mass about 3 kg. The drop height of the hammer is about 15-20 cm.

Test elements of thin-flanged beams were made of spruce wood and water resistant spruce plywood. The ribs and the reinforcement of thin-flanged beams were connected by nails.

During the measuring the responses were simultaneously recorded with the help of a computer which at the same time decided if the magnitude of the imparted impulses was kept within tolerable limits. The panels were tested on both sides.

It is obvious from the results of experimental testing of thin-flanged beams and their subsequent modelling by means of the Finite Element Method that modal analysis is a convenient method for the verification of computation models. Models verified by modal analysis can further be solved in detail by means of the Finite Element Method. In this way a very good reliability of the obtained results can be expected.

References:


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NONDESTRUCTIVE TESTING OF STRUCTURAL TIMBER


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Key words: timber, timber grading, timber structures, nondestructive testing, vibration technique, ultrasound technique

Wood is generally known as a structural material with strongly orthotropic elastic properties. Furthermore, it is a material susceptible to creep under long-term loading, and it is characterized as having significantly variable strength and stiffness properties. The consequent need for nondestructive testing-grading of structural timber has been recognized for many years. The fundamental hypothesis for nondestructive testing of wood materials was initiated by Jayne in 1959. He proposed that the energy storage and dissipation properties of wood materials, which can be measured nondestructively by using a number of techniques, are controlled by the same mechanisms that determine the static behavior of such material. As a consequence, useful mathematical relationships between these properties and static elastic and strength behavior should be attainable through statistical regression analysis.

Two main methods for such grading are widely used today; visual grading and machine stress grading. Both methods have certain limitations as well as disadvantages. Improvements or alternatives should be welcomed.

For grading it is possible to use vibration techniques. A part of energy, added to a body by a touch (stroke, hammer blow) is transformed into vibrations. First of all these vibrations are very complicated and are dependent on the way and the violence of the blow and also on the physical and geometrical properties of the body. If the body is supported, natural vibrations will be produced after a short time. Depending on the kind of supports and the direction of the excitation bending vibrations of different modes can be produced as well as longitudinal or torsional vibrations. The GOULD-oscilloscope records the vibrations transduced by means of an accelerometer with amplifier. Good results are obtained by supporting of the vibrating body under the desired vibration nodes. The excitation by a stroke has to be effected in direction of the vibration. The approximate solution of the differential motion equation of bending (longitudinal, torsional loading) is given by Euler or Timoshenko theory. The modulus of elasticity can be calculated using the observed frequency.

The ultrasound technique was developed on the basis of the correlation between the physical properties - such as the stiffness properties and the density - and the velocity of the ultrasonic waves; the ultrasound propagation can be used to determine the mechanical properties of wood (stiffness and strength) to grade the sawn timber. The testing apparatus was the PROCEQ CONCRETE TESTER CCT 4, a device conceived for testing concrete; this apparatus measures the time employed by the ultrasonic wave - generated by a piezo-electric...
transducer up to recording transducer, end-to-end through the specimen. The distance between the transducers (which is the length of the specimen) allowed to calculate the velocity of the wave. Thanks to the simplified equation the dynamic modulus of elasticity can be computed.

Works on determining of mechanical properties (modulus of elasticity, strength) of structural timber (spruce) by means of nondestructive methods have been started. Visual grading was also performed. Every beam (nominal size 100 x 120 x 2900 mm) was determined a knot ratio, slope of grain, annual ring width and wane, decay and reaction wood presence according to DIN 4074. The sample of 43 beams has been graded into 4 classes. Transverse vibration, longitudinal stress wave and ultrasound techniques have been carried on to determine elastic moduli. The first natural frequency from “free-free” bending vibration was evaluated both flatwise and edgewise position. The bending stiffness will not be underestimated with more than 5% when the nodal points distance is not below 10 times the beam depth by using Euler theory.

For the vibration technique in longitudinal direction soft supports were used to simulate “free-free” conditions.

The ultrasound measurements were performed along two edges of each specimen.

Results of all these methods will be compared. After nondestructive tests will be carried out destructive tests. Relationships between nondestructive parameters (modulus of elasticity predicted by means of every up-mentioned technique, annual ring width, knot ratio, slope of grain etc.) and strength values will be derived.

References:

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Section 11

POWER SYSTEMS AND ELECTRICAL ENGINEERING
GENETIC ALGORITHM USED FOR ELECTROMECHANICAL SYSTEM IDENTIFICATION

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Key words: genetic algorithm, optimization, mechatronics, electromechanical systems

Introduction. Some technical problems can be solved via computational techniques which are essentially inspired by living nature. One of these is the class of genetic algorithm. It is based on random search and optimisation with selection of the best members from a wide set of stochastically generated and updated vectors. Genetic algorithms are inspired by the theory of evolution based on Darwinian evolution theory. The mathematical model works with terms that are similar to the terms in nature. The set of generated solutions is called the population. The solutions that best fit the optimization criteria are known as the best members of the population. New members of the population are derived from these best members by the procedure called recombination. Method of recombination cannot reach the global optimum, stochastic changes, called mutations, are made in the population to get probably better solutions. The worst members are destroyed during the computation to make space for better solutions. Each member of the population is formed from a set of elements similar to natural genes. These genes forms a genetic string which works as a member of the population. These genes can be elements of the input vectors that produce an input to the optimization function. The initial population is created as a random set of genes in the members of the population. The genetic algorithm is then divided into four steps that are repeated until an optimal solution to the optimization problem is found.

1. Evaluation, – the computation of the optimization criteria (cost function) for all members of population.
2. Selection – the finding and ordering of the best numbers in the processed population.
3. Recombination, a subset on the best members are combined to get new members of the population.
4. Mutation – the method of producing slightly different members in the population.

Parameters optimisation. Parameters of equivalent circuit diagram of an induction motor with single cage is in [5]. The parameters R1, R2, R3, X1, X2, X3 represent the genes. In the process of optimisation it is necessary first of all to set an actual range of parameters R and X. The advantage of genetic algorithm is that the actual range of parameters could be extremely large and therefore no detailed information about parameters is required.
Static characteristics $M = f(s)$, $I = f(s)$ and $\cos\varphi = f(s)$ can be calculated from circuit diagrams. The calculated characteristics are compared with the measured (or obtained from design procedure) and genetic algorithm procedure is repeated until a certain cost function is satisfied. The parameters obtained for the best solution are the optimized parameters required. The parameter optimisation was performed on motors of the power range from 3.6 kW up to 1 MW, nominal voltage 380 V and 6 kV, single-cage or double-cage.

Conclusions. Parameters optimisation of induction motors in the power-range 3.6 kW up to 1 MW by means of genetic algorithm was performed. The results proved the usefulness of that algorithm used. The advantages of genetic algorithm are computer stability, high probability to find the global optimum and reduction of programmers time. The disadvantage is relatively large computer-time.

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CONTROLLED REACTOR FOR A SYMETRIZATION OF LOAD

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Key words: electrical network, unsymmetrical load, thyristor controlled reactor

Electrical network comprises many different types of electric generators, transmission lines and different types of electric load. Generally a three phase system is used. A good efficiency of electrical energy transport from generators to the load requires the symmetrical load in all three phases and the power factor near the one. The first requirement can be fulfilled by use of three phase devices and by a symmetrical apportionment of many small one phase electrical devices to each phase. But these methods cannot be used for large one phase devices. A typical example of large one phase device is the electrical traction with AC one phase system 25 kV, 50 Hz. The load changes with the position and with the number of trains on track. The second requirement can be fulfilled by use of reactive load compensation. This paper informs on a possibility to use the controlled reactors for the symetrization of active load.

We assume, that three phase network is loaded by three different impedances $Z_1$, $Z_2$, $Z_3$. These impedances are connected between three line to line voltages $U_{XY}$, $U_{YZ}$, $U_{ZX}$ (see Fig. 1). In parallel to these impedances there are also connected three condensers with constant reactance $X_{C1}$, $X_{C2}$, $X_{C3}$ and three thyristor controlled reactors $X_{L1}$, $X_{L2}$, $X_{L3}$. Each reactance $X_{C2}$ with its controlled reactor $X_{L2}$ can be replaced by a common impedance $X_2$.

Currents in the impedances $Z_1$, $Z_2$ and $Z_3$ can be determined from the equations

\[
I_{L1X} = \frac{U_{XY}}{Z_1} \quad I_{L1Y} = -I_{L1X} \\
I_{L2Y} = \frac{U_{YZ}}{Z_2} \quad I_{L2Z} = -I_{L2Y}
\]
We assume, that voltages $V_{XY}$, $U_{YZ}$, $U_{ZX}$ form symmetrical system with the phase shift 120°. We will use phasors for a description of relations between different voltages and currents and we will use a complex notation for mathematical analysis of these relations. We define the position of the voltage $U_Y$ phasor in real axis and we write the equations for all currents in the impedances $Z_1$, $Z_2$, $Z_3$, $X_1$, $X_2$, $X_3$. In Fig. 2 the phasors of all phase voltages and line ones and currents in all impedances and reactances are depicted. It is known, that each unbalanced three phase system may be decomposed into three "symmetrical components" with the positive-, the negative- and the zero-phasor sequence. We assume that our system is without the return line. The zero component is equal to zero in this case. We can write four equations from a conditions for sums of real resp. imaginary parts of positive resp. negative components of all currents. The target of symetrisation is to reduce the negative component to zero. This condition defines the right sides of two equations. The ratio of the imaginary and of the real part of positive component determines the power factor. We obtain the third equation for the required value of power factor. If we known currents in the impedances $Z_1$, $Z_2$, $Z_3$, we can calculate three unknown currents in reactances using these three equations.

![Diagram of voltage and current phasors](image)

The detail mathematical solution of the described problem was done and three equations for the calculation of three currents in the reactances $X_1$, $X_2$, $X_3$ were obtained.

The described method of symetrisation of active loads was tested experimentally in laboratory. Results of these experiments support the theoretical conclusions.

References:


This research has been conducted at the Department of Electrical Drives & Traction as contribution to the research out of any project.
3-PHASE VOLTAGE STIFF INVERTER WITH PWM

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Key words: voltage stiff inverter, DC/AC conversion, PWM

The inverter is a device which performs the DC/AC conversion, synchronized with voltage of the main supply and which is able to control the electrical power. The inverter can be used e.g. for energy conversion of alternative sources (energy of sun, water, wind, etc.).

The paper deals with the experimental equipment developed for proving of fundamental characteristics of 3-phase voltage stiff inverter with PWM. A control strategy employing feedback modulation of inverter output current is presented. It permits to form output current wave (amplitude, phase shift, power factor) easily and efficiently by means of PWM. The proposed inverter control scheme allows improvements of the AC drive performances while using relatively simple hardware. Fig. 1 shows the principal diagram of the equipment. The prototype inverter uses the IGBTs. These voltage controlled devices allow the use of low power drive circuit and can operate at higher frequency than bipolar transistors. The main component of power circuit is a EUPEC 3-phase bridge with six IGBTs (type F6-50R06KF). Parameters of these transistors are: $U_{CE} = 600$ V, $I_c = 50$ A. The transistors are controlled by SEMIKRON IGBT drivers (type SKHI22). Each of them permits to control two transistors (one leg of inverter). The driver can be controlled by CMOS compatible control signals.

Electrical characteristics of SKHI22:
- supply voltage: $+15$ V non isolated
- input signal level: CMOS
- output voltage: $\pm 15$ V
- peak output current: 3.3 A
- isolation between control/IGBT up to 4 kV
- interlock top/bottom avoids two IGBTs of the same leg being switched-on at the same time

The drivers are controlled by a modulator. The modulator is implemented by analogue components. It uses feedback current modulation with sampling [1]. By this method the real phase current is compared with the reference sinusoidal wave of demanded phase current using the comparator with sampling (without hysteresis). Real phase current is measured by ABB current sensor EH050.

Electrical characteristics of EH050:
- nominal current: 50 A
- turns ratio: 1/1000
- supply voltage: max. $\pm 18$ V
The output signal of the comparator is converted to TTL level and controls the switching of corresponding IGBT (with antiparallel diode). Inverter is controlled by SIEMENS microcontroller SAB 80537 and synchronized to a main supply by hardware circuits and software. Fig. 2 shows results of measured phase currents of voltage stiff inverter.

Fig. 1: Principal diagram of inverter

The SAB 80537 is the 8-bit single chip microcontroller based on Intel 8051 family with enhanced on-chip peripheral devices, such as COMPARE/CAPTURE unit, INTERRUPT controller and auxiliary datapointers. The software is designed as Real-Time system managed by interrupts. It is divided into several tasks:

- initialization (selfcheck, detection of phase sequence)
- synchronization to the main supply voltage (PLL)
- generation of one 3-phase sample of reference sinusoidals
- HW errors management (activated only if HW error occurs)
- communication (background process).

The maximum achieved sampling frequency is 10 kHz.

References:


This research has been conducted at the Department of Electrotechnology as part of the research project “Analysis and Synthesis of High Performance AC-to-DC PWM Converters” and has been supported by GACR grant No. 102/94/1360.
PWM RECTIFIERS

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Key words: rectifier, AC/DC converter, modulation, PWM

The transistorized rectifier with pulse width modulation is a new type of semiconductor converter. It is based on the well known principle of pulse control, but its practical applications started to be used only a few years ago, thanks to the modern power semiconductor devices and control circuits. PWM rectifier successfully solves the traditional problem of classic rectifiers – the noncompatibility with the feeding network caused by the consumption of the nonsinusoidal current, by unfavourable crest factor and by the variable and often very poor power factor.

Two basic types of the PWM rectifiers can be distinguished – current stiff and voltage stiff rectifier. These both types differ each other not only in output filter, but also in the circuit arrangement and fundamental operational principles. The paper deals with the PWM voltage rectifier. It summarizes the control problems of this converter corresponding to the Fig. 1, that means the control range of output direct voltage $U_d$, modulation modes in the block MOD and control modes in CONTR.

From the operational principles [1] it is obvious, that the converter realizes the boost function, i.e. its output direct voltage is higher than the output voltage of a diode rectifier. Taking account of the voltage dimensioning of power semiconductor devices, the range of output voltage is limited from above as well. The rectifier is consequently suitable for the control of output voltage in the narrow range only, i.e. for voltage stabilization. The analysis of minimum admissible output voltage for single phase and three phase bridge rectifier is performed. The results are verified by computer simulation, the consequences of inappropriate output voltage are demonstrated.

![Fig. 1: PWM rectifier – complete arrangement and power circuit](image-url)
The fundamental characteristics of the rectifier are substantially influenced by the modulation mode, i.e. by the switching algorithm of the converter branches. The goal of it is the sinusoidal shape of input phase currents with demanded (zero) phase shift according to the phase voltages. The analysis of the principal modulation modes of ac current or voltage is performed. The limit of switching dynamics of power semiconductor devices is taken into account. The harmonic analysis of simulated phase currents is realized. The computer model is used for the comparing of the rectifier dynamic behavior with different modulation modes. The fundamental principles and characteristics of space vector control are mentioned. The obtained results serve for comparing of the performed modulation modes.

The controller of the rectifier ensures the demanded constant value of the output direct voltage, i.e. it eliminates the effect of disturbances (input voltage, output current). The transient functions of the controlled system, used for the design of controller parameters, are stated from the power balance equations of the converter for both directions of power transport. The filter of direct voltage feedback signal is discussed. The analyzed variants of the control algorithm are proved by computer simulation of control or disturbance effects. Sensing of the main disturbance – output current – seems to be very effective.

The above mentioned analyses are verified by computer simulation of the converter system considering the real transformer parameters and modulating algorithm; the power semiconductor devices are modelled as ideal switches. Two programs processing the block diagram of the simulated system have been applied – PSI/c (Delft Univ. of Technology – BOZA) and MATLAB & SIMULINK (Mathworks). The second one was used also for harmonic analysis of the results.

The conclusions of the submitted paper suggest, that PWM voltage rectifier represents a progressive AC/DC converter with high compatibility. It can be used as an input converter in AC/AC indirect converters, in on-line uninterruptible power sources, etc. The performed analysis is used for following experimental works.

References:

This research has been conducted at the Department of Electrotechnology as part of the research project “Analysis and Synthesis of High Performance AC-to-DC PWM Converters” and has been supported by GAČR grant No. 102/94/1360.
A NEURAL CURRENT CONTROL OF THYRISTOR RECTIFIERS

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Key words: neural network, inverse model, thyristor rectifier, current control

A control structure of a D.C. motor with a separate excitation, supplied in the armature by a thyristor controlled rectifier consists of a velocity feedback loop with a subordinate current control loop. A PI-controller with a fixed gain is usually used to control the system in the continuous current mode. This type of regulator has a bad performance in the discontinuous current mode because of the system-gain variability.

To solve this problem we need an adaptive controller. The classic solution is a variable structure I/PI controller. A nonlinear inverse model of the system as a feedforward, which is more suitable for nonlinear systems, was designed (see Fig. 1). For the direct input-output path of the control signal it applies

\[ F_{IM}(p)F_S(p) = 1 \]

in which \( F_S(p) \) is a transfer function of the system and \( F_{IM}(p) \) is a transfer function of an inverse model, which is a nonlinear function of two variables: current command \( I^* \) and back e.m.f. \( E \)

\[ F_{IM}(p) = f(I^*, E) \]

Fig. 1: Indirect inverse model control and a nonlinear transfer function of the model
The inverse model was performed as an artificial neural network with two inputs \((I^*, E)\), eight neurons in a hidden layer and one output neuron. The hidden neurons were of the type "tansig", with a sigmoidal transfer function, whereas the output neuron was a "purelin", with a linear transfer characteristic. The backpropagation as a learning method was used.

The control structure with a neural network feedforward and PI current controller is shown in Fig. 2.

Fig. 2: Simulation of the neural feedforward current control of a D.C. drive

References:


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EMI AND ELECTRICAL APPARATUSES

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Key words: electrical apparatus, electromagnetic interference, electronic components, overvoltage protection

Electronic components are important parts of many electrical apparatuses in low voltage mains distributors. Electrical apparatuses with electronic elements provide wider operational possibilities in comparison with traditional arrangements. However, such apparatuses must be very good protected against overvoltages and voltage peaks superimposed on mains voltage to respect their sensitivity on voltage peaks and other types of electromagnetic interferences (EMI).

There are used three typical ways to reduce mains AC voltage for feeding electronic parts of apparatuses:

1. transformer with insulated secondary winding (12-24 V)
2. serial capacitor
3. serial resistor

Feeding transformer is very good not only from the point of view of efficiency, but also with the respect to the influence of EMI. Insulation and low capacitance between primary and secondary windings are very effective protection against EMI penetration. Negative property of this solution are high costs for transformer mass production.

AC digital time delay relays, time switches and similar apparatuses use serial capacitor to reduce the mains voltage to 12 or 24 V. The voltage is rectified and stabilized on this level. This supply operates without problems when EMI does not occur in mains voltage. But for high frequency and voltage impulses is the used serial capacitance to low. High amplitudes of current impulses penetrate into recifier and destroy them. This is given by high-pass frequency characteristics of this arrangement. Therefore additional overvoltage arrestor must be applied. However, the use of serial capacitor with respect to EMI effects cannot be in principle recommended.

Serial nonlinear resistor for voltage reduction is the best arrangement for low-consumption apparatuses. Such solution is acceptable in time delay relays, time switches etc. based on CMOS integrated circuits. For feeding of this circuits it is possible to use low-pass R-C filter with high damping effects for EMI. Switch “power relay” is then feeded by integrated circuit controlled chopper having input rectified voltage (310 V DC).

This solution has advantages given by low costs and EMI resistance. It also enables wide range of supply voltages, typically from 24 to 240 V AC or DC. This conclusions were made on the basis of defect-analyses of many apparatuses, used in mains industrial distributors.
References:


This research has not been supported by any grant.
CONVERTERS FOR GENERATORS IN WIND STATIONS

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Key words: wind power stations, electric generators, power converters

Wind power stations with the power over 50 kW are mostly connected to the public electrical network. The standard squirrel cage induction motor in the generator regime or synchronous generator for larger power, are used for the production of electric energy. For better exploiting of the wind motor power, it is necessary to change the operational r.p.m. of the motor, when the wind speed changes (Fig. 1.). Maximal power of the wind motor is limited by the generator control. The speed of the synchronous generator is given by the number of its poles. The speed of the induction generator increases for about 1–2% in dependence on the load. It is necessary to insert a semi-conductor converter into the system when the wind motor is full exploited at different r.p.m.. With the respect of the converter price attempts are made to exploit it also instead of mechanical gear box used to the increase of the speed to 1500 r.p.m. for four-pole generators. Low-speed generator with low stator frequency (10–15 Hz), working at the variable speed, connected to the network through the convenient frequency-converter is the consequence of this approach.

![Fig. 1: Operational speeds of the wind motor](image)

Therefore we elaborated mathematical models and programs for the design of low-speed generators and semi-conductor frequency converters for wind power stations 50–1000 kW. Programs for the design of generators, for given power and speed of the wind motor, voltage and frequency of the generator enable to calculate dimensions, weights and electrical quantities of the generator. These programs were made for synchronous generators with the excitation winding or with permanent magnets, for induction generators and for the switching reluctance generators.

Mathematical models and programs for the design of frequency converters were also elaborated. With the help of these programs, it is possible to fix the type of semi-conductor elements for special types of converters, and also their numbers and data for their current and...
voltage dimensioning. It is possible to use these programs for the design of these converters with the rectifier connected to the generator and with the inverter connected to the network:

- Diode bridge rectifier, DC inductance and thyristor inverter. The scheme is useful for the synchronous generator, with good magnetical and electrical performance load. Inverter consumes reactive power from the network, and therefore a compensation device must be added to the system.

- Thyristor bridge rectifier, the other elements of the converter are the same. This scheme of the converter enables the synchronous machine to work as a motor for the run up of the wind motor rotor.

- Diode bridge rectifier, capacitor is added into the DC-circuit, switched semi-conductor elements, controlled by the PWM are used in the inverter, to pass the active power from the DC-circuit to the network. The generator possesses full electrical load, but full magnetical load occurs only for the low speed control zone. It is possible to use this converter also for the induction generator.

- The DC voltage converter is added to the rectifier and inverter from the previous scheme. DC voltage converter lowers the rectifier voltage to a value proper for the inverter. The independence of the generator voltage on its speed is an advantage. The converter can be used also for the induction generator.

- Cycloconverter is used for low speed generators with frequencies of \( \approx 10 \) Hz. A large number of thyristors and consumption of the reactive power from the network are obvious disadvantages. Power factor is very low when an induction generator is used.

- Converter for the switched reluctance generator. This generator cannot work without converter.

Created programs enable complex design of low speed generator and converter for big power wind power station working on the network. We can also get the price comparison of useful combinations of generators and converters when the information about the actual prices of semi-conductor elements are given.

Voltages, currents, efficiency, power-factor, torque and electric power curves can be determined in dependence on the frequency control by other related programs. In this way we get the comprehensive program complex, which enables to verify the correctness of each solution of combinations of the electric generator and of the converter including detailed information on the influence of the converter on the generator and on the network. This enables the proper choice of the drive type and therefore the reliable base for the consultation activity and for the propagation of wind power stations.

References:


This research has been conducted at the Department of Electric Drives and Traction as part of the research project "Generators and Inverters of Wind Power Stations for Conditions in Czech Republic" and has been supported by CTU grant No. 38186.
IDENTIFICATION OF INDUCTION MOTOR PARAMETERS

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Key words: AC drives, microprocessor control, parameter identification, system self-commissioning

The control method used for high performance applications with induction drives usually utilize the field oriented approach techniques. Core of these methods is in the mathematical model of induction motor. As model inputs could be taken the terminal quantities (like currents and shaft revolutions), the produced output is the information of magnetic field inside the machine. Based on this knowledge the control method could work as classical dc machine control - the independent managing of torque and magnetic field.

Besides the benefits of using the maintenance-free machine there are also disadvantages. One of the main drawback of that commonly applied indirect vector control schemes is the requirement of correct adjusting the parameters used in internal computation model. The analysis in [?] shown that inaccurate machine model parameters deteriorate both the transient and steady state performance. Unfortunately, the machine parameters aren't constant, but vary with temperature and magnetic flux level and are affected by skin-effect.

To help to find the correct equivalent model parameters the new method, suitable for microprocessor controlled drives, has been developed. Equivalent scheme of the induction motor drive takes various types of descriptions ('T'-form, 'T'-form, 'T'-form, etc.). Identification method is based on the fact that the equivalent scheme of induction motor could be taken as frequency dependent impedance circuit. By controlling the voltage inverter switches in a special mode the induction motor could be fed by one phase voltage with constant (but changeable) frequency. The phase current and the line voltage vector act as input signals for computing procedure. Output of this is the first estimation of system parameters.

Induction motor behaviour under these conditions is the same as in lock-rotor test (like the transformer with shorted secondary winding). If the supplied frequency is low (below 1 Hz), the imaginary part of equivalent impedance is close the value of magnetizing inductance. If the supplied frequency is higher (approx. 20 Hz), the imaginary part come close to the leakage inductance (see Fig. 1). The real part of impedance has also similar behaviour - for low frequency the real part is near the value of rotor resistance. Equivalent inductance \( L_{eq} \) in Fig. 1) alter from value of magnetizing inductance to value of the leakage inductance according the changes of frequency. Varying the input frequency from low to high value the phase and amplitude frequency characteristics is recorded. Final procedure approximate the measured data and calculate the parameters of equivalent scheme of induction motor.

Proposed method has been proved on the testing drive with voltage fed GTO inverter (switch frequency 300 Hz), controlled by two microprocessor boards with Intel '196 KC controller. One of them perform the pulse width modulation task, the second realize the identification procedure. Communication between the boards is done by dual-port RAM. All algorithms are written in low-level programming language because of requirements of
high computation speed. The method doesn't require any additional hardware; all necessary algorithms are executed inside the microprocessor control board and work with help of the conventional GTO drive inverter.

![Frequency characteristic of IM equivalent circuit](image_url)

**Fig. 1:** Frequency characteristic of IM equivalent circuit

**References:**


This research has been conducted at the Department of Electrical Drives & Traction FEE CTU as part of the research project “Microprocessor and Adaptive Control of Electrical Drives” and has been supported by GA ČR grant No. 102/94/1544.
MODERN TRACTION DRIVE?
HERE COMES OUR SOLUTION

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Key words: traction AC drives, digital signal processor, field oriented control

The aim of our work was the complex solution of control system of AC traction drive according to ČKD Trakce development programme. The traction drive is developed for use in electrical city transportation systems for tramway vehicles, trolley-buses and subway vehicles, usually supplied from power net of nominal voltage of 600, resp. 750 V.

The analysis of global features leads to the following conclusions:

• traction drive is fed by trolley wire net with rapid disturbances of source parameters (eg. voltage, impedance);
• traction drive should fulfill the correct and safety response to the operational stages - like overtravel of the trolley section, temporary disconnection of the overhead collector;
• dynamic regenerative brake is the operating braking system, stand-by rheostatic brake;
• operation of EDB (electrodynamic brake) independent on supply voltage;
• drive should operate also on reduced voltage (passage through a washing machine);

Power circuits were developed in ČKD Trakce as the voltage inverter based on IGBT devices. The inverter supplies two parallel induction motors (nominal values 470 V/75 Hz, 85 kW (114 HP)) in one boogie. Top frequency of output voltage is 145 Hz - which corresponds to velocity of 80 km.h⁻¹ (50 mph). The modulation frequency has been set to 2 kHz (we suppose step up to 4 kHz).

Because of the requirement mentioned above we use full digital control of the drive based on field oriented control technique. The control board is equiped by digital signal processor and completed with additional devices (glue logic, generation of firing impulses, protection circuits). Connection to the power part provide fibre optic cables, the terminal values of currents and voltage are measured by sensors based on Hall-effect. The revolution of motors are scanned by incremental speed sensors.

Field oriented control algorithm uses current-based reference model of induction machine, magnetic flux linkage of rotor is calculated in 62.5 μs repetition period. This way of determination of magnetic flux and its space angle seems to be robust in various states of operation of the drive. The computation of reference model runs continously and independetly on other tasks.

Control algorithm uses the results of reference model. The repetition period of computation of control tasks is the same as period of modulation. The control structure of controlled flux operation region is given in Fig. 1, the one of flux weakening region in Fig. 2. Both structures are developped in order to provide as fast response to supply net disturbances as possible.
Special algorithm to provide dynamic brake on supply voltage was developed. Whenever the vehicle is in motion and supply power lost occurs, the drive will maintain its filter voltage on minimum value using regenerative braking energy. Certainly, the trolley line is disconnected. Although the input filter capacitance of an inverter can be fully discharged in 6 ms, the drive is able to provide suitable response from each operation state.

The control system is installed on a special test vehicle, which was built using the reconstruction of a conventional tram (type T7 ČKD Tatra, No. 0024). The vehicle has dual driving system - the front boogie has series-produced DC drive (based on SCR DC converter), the back boogie is equipped by prototype of AC power unit. Since this laboratory vehicle does not carry any passengers, there can be installed measuring technique to make detail tests and optimisation of control algorithms. The vehicle is, successfully, tested in Prague city rail lines.

Our control system is supposed to completion and installation on new types of vehicles for urban transportation.

Fig. 1: Control structure in full-flux region Fig. 2: Control structure in field-weakening region

References:


This research has been conducted at the Department of Electrical Drives & Traction and has not been supported by any grant.
TRANSIENT STUDY
OF A LINEAR ELECTRICAL MOTOR

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Key words: linear partial differential equations, equations of parabolic type, numerical solution, two-dimensional case, quasistationary electromagnetic field, transient eddy currents, linear electrical motor, rail vehicles, vehicles supported by magnetic cushion

The paper presented constitutes a continuation of author's contribution presented at the Computational Physics '90 meeting in Amsterdam in 1990 (written jointly with Nguyen Van Nhac) as well as at CTU Workshops '92, '93 and '95. The simplification of a linear motor to a two-dimensional case has been described in author's contribution at CTU Workshop '95. The method used to calculate the electromagnetic field in the linear motor can be called as "half-way between the finite element method and the finite difference method". We underline that the time is discrete and the winding of the linear motor can be fed by currents of arbitrary waveform. In this way we can follow the effects of feeding the winding of the linear motor by the output of arbitrarily complicated thyristor control circuits. We are not bound by the usual three-phase system. The number of coils of the winding can be arbitrary and the successive coils can be fed by a "current wave", propagating along the body of the linear motor.

References:

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RELIABILITY OF POWER EQUIPMENT
INSULATING SYSTEMS

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Key words: reliability, diagnostics, measurement, testing, detection, monitoring, data processing, partial discharges, distortion, transformer, winding, computer supporting

In this research, Department of Physics, Department of Electrotechnology, Department of Electrical Drives and Traction and Department of Power Engineering – mainly High Voltage Laboratory (HVL) of this Department – have taken part.

We have continued in fulfilling the team project aim which have dealt with research and development of the headlined topic. This paper presents only the summary of activities and results achieved in 1995. The internal research reports complete the information and several other papers [1–6] have also been presented in 1995.

The HVL – Dept. of Physics group proved the possibility of PD-detection and measuring in oil-insulated transformers by ultrasound using new acoustoelectric converters with a built-in preamplifiers. These transducers are both broad-band and highly sensitive and allow multisensor detection and the comparison of time delays between transducers. The initial measurements were performed on the model arrangement (a small spark gap connected in RC-circuit and placed in the oil tank). Most problems caused by inadequate shielding of electrical field must have been solved.

The analysis of PD-activity measurements with respect to the possibility of on-line measurement and expert-deciding technique, respectively, was conducted by HVL in cooperation with other institutes. As a result, processing and saving data from both (on-line and off-line diagnostical measurements was solved by a new expert system which has been developed in other cooperation and support.

The growing extent of testing activities in the EMC branch induced the HVL team to make first experiments with short-time overcurrent testing of low voltage power- and telecommunication-equipments. A proper technique and conditions for takeover of specimens to testing have been proved. The tests are provided with respect to the IEE 801-5 Standard. Overvoltage arresters can be tested as well.

A new approach to the mathematical evaluation of overvoltages caused by ferromagnetic resonance has been studied by the Dept. of Power Engineering, and applied to real conditions of this overvoltage type.

Authors of the frequency characteristic method (for detection of winding distortions or other changes) provided in situ transformer winding state measurements with respect to the repeatability of results. They found that long cables between measuring equipment and a large transformer represent a limitation for the repeatability because of their capacity which can not be neglected. Thus, an optical fibre waveguide system was used for measuring signals translation. A new program for verifying the repeatability of measurements on transformers in power plants and switchgears has been prepared in the HVL.
The Dept. of Electrotechnology group has continued in verifying the pulse-frequency technique for detection of turn short-circuits and insulation system changes, the correlation between changes of the frequency characteristic, and changes of other parameters measured by other methods. Further, the time rates of both absorption- and resorption-currents have been measured on two hydroaltermators and the results have been related to the changes of the loss factor characteristic.

The Dept. of Electrical Drives and Traction research group has designed and realized (in a model) a new system for complex measuring time rates of currents, voltages, vibrations and noise on transformers. The system is supported by a computer which enables recording and off-line processing of above mentioned quantities. The goal of the new method lies in a diagnosis of the actual mechanical state of a transformer from measuring the four mentioned quantities during transformer switching on.

References:


This research has been conducted at the Department of Power Engineering (and other departments mentioned over) as part of the research project “Reliability of Power Equipment Insulating Systems” and has been supported by CACR grant No. 102/94/1358.
DIELECTRIC ABSORPTION 
OF HYDROGENERATORS

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Key words: diagnostic, ageing of materials, insulating system

Dielectric absorption is caused by complicated unstable processes, which pass in insulating system past connection to a direct voltage source. The main reason of this absorption are low polarisations, namely the volume polarisations. Time dependence measurements of the current characteristics (absorption current) are one type of nondestructive measuring method used for investigation of insulating stage of electric equipment. Due to operation conditions comes debasing of insulation and this fact can be observed as change of mentioned absorption current characteristics.

A substitute circuit of the real insulating system is shown in Fig. 1., where $C_g$ represents geometric capacity, $R_g$ insulating resistance at DC, $C_{p1}...C_{pn}$ and $R_{p1}...R_{pn}$ represent individual polarisations in insulating system.

![Fig. 1:](image)

Total volume of the current $i(t)$ past connection of voltage $U$ is possible to express by equations

$$i(t) = i_o + i_p(t) \quad \text{or}$$
$$i(t) = U/R_g + U/R_{p1} \exp(-t/T_{p1}) + \cdots + U/R_{pn} \exp(-t/T_{pn})$$

where $T_{p1}...T_{pn}$ are time constants of the polarisating processes ($T_{pn} = R_{pn} C_{pn}$).
Current \( i_p(t) \) may be approximately expressed as \( i_p(t) = k \cdot t^{-n} \), where \( k, n \) are material constants of given insulating system.

For mentioned simplifications is function \( i_p(t) \) in logarithmic coordinates expressed as straight line. From function \( i_p(t) \) is possible to determine one minute \((p1)\) or ten minute \((p10)\) polarising index expressed as \( p1 = i_p(0.25)/i_p(1) \) and \( p10 = i_p(1)/i_p(10) \).

The dielectric absorption was measured and evaluated for different voltage at hydrogenerator 112.5 MW, 13.8 kV, 136.6 min\(^{-1}\), insulating class F and hydrogenerator 11.25 MW, 10.5 kV, 166.6 min\(^{-1}\), insulating class B, during their 13 years working period. The measurements of voltage dependences of the dissipation factor were evaluated simultaneously in mentioned period, too. The values of index \( p10 \) for hydrogenerator 112.5 MW are shown in Fig. 2. The other results will be performed on workshop.

![Fig 2:](image-url)

References:


This research has been conducted at the Department of Electrotechnology as part of the research project “Reliability of Power Equipment Insulating Systems” and has been supported by GACR grant No. 102/94/1358.
THE INTELLIGENT ELECTRIC DRIVES WITH SWITCHED RELUCTANCE MOTORS

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Key words: switched reluctance motor, SR-technology, tranzistor convertor, genetic optimization, hybrid and distributed algorithms

The reluctance motors and stepping motors are used in many cases of control by electric drives. The reluctance motor, also called a switched reluctance (SR) motor, is used for mechanisms with variable speed and is very similar to a variable reluctance step motor. The reluctance motor is shown in Fig. 1. The toothed stator and toothed rotor are constructed from a soft steel that retains very little residual magnetism. Coils wound around the stator teeth provide the magnetic attraction that establish the rotor position. The reluctance of the magnetic circuit formed by the rotor and stator teeth vary with the angular position of the rotor. Energizing one or more stator coils causes the rotor step forward (or backward) to position that forms a path of least reluctance with magnetized stator teeth. The six stator coils are connected in 2-coil groups to form three separate circuit called phases. Each phase has its own independent switch. The mechanic torque is produced solely by reluctance variation and is therefore independent of current direction.

![Fig. 1:](image-url)
The common grant (first stage) was solved by workers and student of doctoral degree of both departments at VUT Brno. Every of participated group is doing its research, where parts of this problem are dealing with all structures of the co-set: intelligent drives (in the power and control fields). The functional prototype of motor was designed and used. This motor was tested to gain the parameters of mathematical model using nonlinear theory. Our goal is to explain the basic principal of motor torque. The measurements alone were concentrated to get torque dependancy on the speed of circulation of the rotor. By experiment the characteristics of magnetic flux were received. This are very important values for selection of strategy switching of power tranzistor of convertor. In the second part the connection of power part of convertor were created to supply every phase of motor. The system was design as three separated two-quadrant convertor. The device has six tranzistors together with operated voltage about 300 V and current 40 A. There are 6 tranzitors and their cooling, three sensors of current, pulse source to excite 6 circuits in the unit. There is of course very fast current electric protection. Switches can operate up to 10 kHz/20 A. For lower values of current, it is possible to work with frequency of 20 kHz.

The flexibility of the SR motor drive is noteworthy and so is its high efficiency at partial loads. It is both easy and inexpensive to modify the switching angles to give a variety of different torque-speed characteristics. The parameters of electronic control system is prepared to be optimized by genetic algorithms (GA). We use the GA for optimization the signal in electric drive. The trend to digital computer control is evident in application with the reluctance mototors.

A genetic algorithm is an optimization algorithm based on the mechanics of natural selection. The GA contains three basic operators – reproduction, crossover, and mutation. To increase the efficiency of a genetic algorithms the influence of migration in hybrid and distributed GA is tested. The second stage of grant will continue next year.

References:

This research has been conducted at the Department of Electric drives and power electronics as part of the research project "Inteligentní elektrický pohon se špinaným reluktačním motorem" and has been supported by TU grant No. FU 450052.
RADIATION TRANSFER
IN ELECTRIC ARC PLASMAS

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Key words: plasma radiation, radiation transfer, electric arc

One of the most intractable problems of plasma physics has been the calculation of energy transfer due to radiation. It is generally accepted that radiative transport of energy plays an important role in the design of many engineering applications. Radiation transfer is a significant energy exchange process in high pressure arc plasmas having temperatures of greater than 15 000 K and pressures of 0.1 MPa or more.

Typical radiation quantities of interest: radiation intensity, radiation flux and divergence of radiation flux are calculated from integrals over the radiation frequency and angles. Values of radiation flux at a given point depend on the temperature distribution of the entire volume of plasma. Description of the radiation field in the arc plasmas is a very difficult problem since integration over frequency and angles must be carried out simultaneously. Radiation wavelengths span the far infrared to the short ultraviolet spectrum regions. Both continuum and line radiation with hundreds of spectral lines have to be taken under consideration. Furthermore in some regions of the plasma there is radiation emission, but in other regions there is usually a net absorption of radiation due to ultra violet radiation from hot regions of plasma being absorbed in cold regions. Exact calculations, though possible in principle, are usually impossible in practice, even with modern computers, due to the large computation times required. Several approximation methods for prediction of radiation transfer in plasmas have been investigated.

We have used the approximate method of partial characteristics as formulated by Sevast'yanenko [1, 2] for prediction of radiation intensities, radiation fluxes and the divergence of radiation fluxes for specified temperature profiles of SF₆ arc plasmas.

In the method of partial characteristics, integrations over frequencies and angles are separate operations. The most time consuming frequency integration is carried out in advance to create tables of the two functions Som and ΔSim.

Solution of the radiation transfer equation for the radiation intensity in any direction involves the quantity $\exp(-\tau)$, where $\tau = \int K_\nu dx$, $K_\nu$ is the absorption coefficient and $x$ is distance along a particular line segment. The essence of the approximation is that in performing the integral in the exponential, it is assumed that the temperature variation is linear between the two end temperatures. Although $\tau$ varies by over 5 orders of magnitude with different radiation frequencies, the exponential is fairly insensitive to $\tau$. For all values of $\tau$ less than 0.2, the exponential is between 0.8 and 1, and for all values of $\tau$ greater than 1.6, the exponential is less than 0.2.

For arc plasmas, we characterize each component line segment of the calculation by its length $x = |X - Y|$ and two end temperatures $T_X$, and $T_Y$. The two functions, partial
sink $\Delta \text{Sim}$ and source $\text{Som}$, as formulated in [1], are functions of the macroparameters $T_X$, $T_Y$ and $x$:

$$\text{Som}(T_X, T_Y, Y - X) = \int_0^\infty B_\nu(X) K_\nu(X) \exp \left(-\int_X^Y K_\nu(x) \, dx\right) \, d\nu,$$  

(1)

$$\Delta \text{Sim}(T_X, T_Y, Y - X) = \int_0^\infty [B_\nu(X) - B_\nu(Y)] K_\nu(X) K_\nu(Y) \exp \left(-\int_X^Y K_\nu(\eta) \, d\eta\right) \, d\nu,$$  

(2)

where $\nu$, $B_\nu$ and $K_\nu$ are radiation frequency, Planck function and absorption coefficient respectively.

Calculations of radiation flux density or of its divergence are possible by the summation of components from representative line segments and directions to integrate over all solid angles. Absorption coefficients of SF$_6$ plasmas were calculated as a function of temperature and radiation frequency [3].

We have calculated [4] tables of $\text{Som}$ and $\Delta \text{Sim}$ functions for SF$_6$ plasmas. The temperatures $T_Y$ are specified with a step of $\Delta T_Y = 1000$ K from 2000 K to 35000 K. The temperatures $T_X$ are given for 300 K, 500 K and from 1000 K to 35000 K with a step of $\Delta T_X = 1000$ K. Geometric dimensions $x$ (in cm) are given in logarithmic scale from $-2.0$ to $2.0$, which corresponds to dimensions from 0.01 cm to 100 cm. Tables for 0.1, 0.5 and 1 MPa have been calculated. Complete tables of SF$_6$ partial characteristics stored on floppy discs can be obtained from the authors of the paper.

Furthermore the method of partial characteristics has been used to evaluate net emission of radiation, as a function of position, in an algorithm to predict temperature profiles of wall stabilized arcs at any given current. A comparison with experimental results is made of predicted electric field strengths and central arc temperatures as a function of current for SF$_6$ arcs of radius 0.25 cm at a pressure of 1 bar. The method gives agreement with exact calculations of flux density to within 20% with a reduction in computation time of about four orders of magnitude.

References:


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PROCESSING OF THE RESULTS
OF HOLOGRAPHIC INTERFEROMETRY

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Key words: optical diagnostics, holographic interferometry, electric arc, temperature, numerical processing of images

Introduction. The measurements were carried out on an arc burning between vertical carbon electrodes. This configuration guarantees an optical symmetry of the plasma which is necessary for the application of the employed holographic method. Since the arc was fed by AC current, it was necessary to select sufficiently short time intervals with regard to the duration of one period of the feed current in order to be able to presume that in the selected interval the measured temperature field is constant in time.

Theory. The implementation of a sufficiently short time interval was made possible by a stroboscopic device formed by a slot in a disk rotating at synchronous speed, whereby one revolution corresponded to the duration of one period of the feed current. The exposure period of the recording material was defined by the width of the slot, the position of the slot was indicated by a pulse transmitted at a time when it allowed exposure. The pulse was recorded oscillographically together with the time waveform of the current feeding the arc. The time instant of the exposure with regard to the time waveform of the current, determined by the position of the slot, could be varied by skewing the small synchronous motor driving the stroboscopic device.

The measuring apparatus was the Mach-Zehnder interferometer described in [1].

The measured hologram is created in two steps. In the first one is created on the recording material a hologram without the arc discharge and after developing it is accurately adjusted into the location where it was formed. The measured thermal field of the arc manifests itself in the form of interference fringes formed by the interference of the arc radiation and the hologram obtained without the arc. The interfering radiation of the arc is suppressed by optical filtration and the overall structure is exposed onto the photographic emulsion.

The structure of the interference fringes is determined by changes of the refractive index of light for the air heated by the arc plasma, the recording of which can be evaluated by classical photometrical and equidensitometrical methods. These allow the obtainment of accurate results, but with great demands onto time; in our case they have been employed as a control of the results.

The results which we are publishing have been obtained by a method which allows greater comfort during the work, a large shortening of the time required for processing and the obtainment of almost the same accuracy. We have utilized the possibility of digitizing the image by scanning in with a CCD camera.
Since the arc plasma in cylindrically symmetrical, for its description in the selected
time is sufficient only a single interferogram obtained by computer processing using the
DIPS program.

During the evaluation is determined from the system of interference fringes the mag-
nitude of the refractive index in relation to the distance from the arc plasma axis, and by
comparison with the known dependence of the refractive index on temperature in determined
the sought temperature.

Employing the Gladstone-Dale dependence of the refractive index on temperature is
obtained after rearrangement for the calculation of temperature

\[ T = \frac{T_R}{1 - \frac{T_R \lambda}{C_p \pi} \int_0^R \frac{d[S_{11}(y)]}{dy} \sqrt{y^2 - r^2} \, dy} \] (1)

For a known atmospheric pressure and a known ambient temperature this equation
is solved by a numerical approximation while taking into account the course of the phase
changes in the transversal section by the least squares method.

Conclusion. In the paper is presented the application of holographic methods upon
the determination of temperature and its time waveforms in the vicinity of the electric
arc fed by an AC current and the evaluation of the interference recordings of the studied
environment, their digitization and processing by numerical methods [2, 3]. The described
procedure is applicable also outside the laboratory. The errors of measurement are smaller
than for spectroscopic methods where the error is 10%.

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This research has been conducted at the Department of Electrical Machines & Apparatus
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MODELLING OF THE ARC
IN THE CURRENT ZERO REGION

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Key words: electric arc, terminal model of the arc, modelling of the arc

Introduction. The behaviour of the arc in the current zero region determines the course of the rupturing process, its successful mastering allows the determination of the rupturing limit without mechanical damage to the circuit breaker. The parameters influencing the rupturing process can be obtained upon rupturing relatively small powers by an analysis of the oscilographic recording of the rupturing process.

Theory. The arc is considered according to Gritz [1] as an electric dipole, with the instantaneous electrical conductivity (dynamic) $g$ varying with time and the static conductivity $G$ which depends on the current and as a consequence of fluctuations in the arc on time. The electrical conductivity approaches at the time $t$ at a rate of $dg/dt$ the steady-state value which is proportional to the difference of the static and dynamic conductivity. The proportionality constant is the reciprocal value of time, for which would have to be supplied into the arc the power required for its maintenance, so that the electrical conductivity changes in the ratio $1 : e$. This time is identical with the time constant $\tau$ introduced by Mayr. The static conductivity corresponds to the electrical conductivity which is set up in the plasma of an arc which is burning for a sufficiently long time and its magnitude is determined by replacing the static characteristics of the arc with the positive branch of a hyperbola which is almost equiaxial.

Taking into account these assumptions the starting differential equation can be derived in the form

$$\frac{dg}{dt} = \frac{1}{\tau} \left( \frac{t^2}{N_0} - g \right) \tag{1}$$

which represents one of the forms of the Mayr equation.

The numerical integration of equation (1) allows the determination of the parameters which influence the quenching of the arc. One of the three quantities: time constant, ruptured current, voltage feeding the ruptured circuit can be arbitrarily selected as a parameter.

From the plot of the solution of the equation can be unambiguously determined, at what value of the parameters the rupturing arc will be quenched.

It is thus possible for a known $\tau$ and $N_0$ to determine in a defined circuit the rupturing limit of the circuit breaker. The calculation starts out from equation (1), in which is appearing apart from the sought quantities the electrical conductivity and its time derivation.

The procedure is relatively simple, the greatest difficulty presents the numerical determination of the time waveform of the electrical conductivity of the plasma, since a small random change of conductivity leads to large changes in the course of the derivation, but nevertheless it provides in the majority of cases applicable results. We have been using this.
procedure with very good results in the analysis of experimentaly determined VA characteristics of fuses [2, 3].

Conclusions. The paper describes the possibility of utilizing a mathematical arc model for determining the rupturing limits of a circuit breaker by a non-destructive method. The switch is tested while rupturing a much smaller power than is its nominal rupturing performance. From the oscillographic recording of the ruptured current and the relevant voltage are determined the parameters for the determination of the rupturing limit of the switch under test.

References:


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HOLOGRAPHIC DIAGNOSTICS
OF AN ARC FED BY DC CURRENT

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Key words: optical diagnostics, holographic interferometry, electric arc, temperature

Introduction. In the paper is described the application of holographic diagnostics for the determination of radial temperature waveform in the immediate vicinity of the electric arc plasma fed by DC current.

Under the assumption that the discharge path is short, the formed thermal field in rotationally symmetrical and for its accurate description one interferogram is sufficient. For the recording of the latter a modified Mach-Zehnder interferometer was used [1].

Theory. The interference fringes, the position and density of which corresponds to changes of the magnitude of the refractive index of the environment, are obtained by double exposure. During the first one is created on the photographic material a hologram of the environment without the burning arc and after placing it into the location where it was taken, is created on the second negative is system of interference fringes which allows the determination of the sought quantity.

The position of the interference fringes is measured photometrically in the selected sections. Since we proceed point after point, this procedure requires a lot of time. For speeding up, enhancing the accuracy but mainly for automating the procedure has been used the equidensitometer designed and assembled at the Institute of Electric Machines and Apparatus FEI VUT in Brno which allows the accurate and effective evaluation of photographs, their digitization, processing by numerical methods and storage in the form of files in the memory medium of the computer. The digitization accuracy of this instrument is large, its resolution is limited only by the grain of the employed photographic material.

The theoretical foundation for the determination of the sought temperature are based on a change of the optical path of the ray in the studied cross-section. For a change of the interference order holds true

\[ \Delta S(y) = \frac{2}{\lambda} \int_r^R \Delta n(r) \frac{r}{\sqrt{r^2 - y^2}} \, dr, \]  

where \( \Delta S(y) \) is the change of the interference order by 1 and \( \lambda \) is the wavelength.

Taking into consideration the rotational symmetry of the measured environment, then after rearrangement is obtained

\[ n(r) - n(R) = -\frac{\lambda}{\pi} \int_r^R \frac{d(\Delta S(y))}{dy} \frac{1}{\sqrt{y^2 - r^2}} \, dy. \]
After taking into account the dependence of the magnitude of the refractive index on temperature, at a known pressure, gas composition of the measured environment and ambient temperature, it is possible after the evaluation of the integral on the right-hand side to determine the sought temperature [2, 3].

The actual evaluation was carried out by a computer program. The optical recording was after digitization by the equidensitometer inserted into the program and after balancing it by numerical methods the latter computed the sought temperature.

Conclusions. Holographic interferometry allows a determination of a change of the magnitude of the refractive index of a transparent environment set up by a physical influencing of the environment with a substantial reduction of the demands onto the quality of the optical elements employed in classical interferometry.

References:


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TEMPERATURE DISTRIBUTION IN NON-STATIONARY PLASMA

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Key words: optical diagnostics, electric arc, non-homogeneous plasma, non-stationary plasma

Introduction. The spectral lines irradiated by the arc plasma pass as a consequence of its non-homogeneity through locations with a different temperature. The ray emerging from the vicinity of the arc axis is partly absorbed in locations with a lower temperature, the relevant spectral line has a characteristic profile which is called self-reversal. From the profile of the line can be determined the temperature. The latter is calculated from the marginal intensities, i.e. the intensities emitted in the immediate vicinity of the self-reversal minimum. Bartels limits this procedure by the elimination of the resonance lines. For these the described procedure can be utilized only when widening of the line is caused by collisions with electrons.

The procedure is relatively simple and requires the measurement of the marginal intensity only on one observation ray. The knowledge of further determining quantities is not required and thus the results are given with a minimum of assumptions.

Theory. It is assumed for the measured plasma that in it a thermic equilibrium exists and that the states sum can be replaced by the statistic weight of the basic state. By a calculation taking into account ionization and the higher terms of the states sum can be proved that a 10% concentration of the ions does not influence the results; thus the higher terms of the states sum can be neglected.

The described method is theoretically derived on the basis of papers of Bartels [1, 2]. The temperature is determined by the measurement of intensity on lines which indicate an observable self-reversal. The maxima surrounding the self-reversal minimum are denoted as reversal peaks, the intensity emitted in them is called peak intensity, from which the sought temperature can be determined.

For the determination of the temperature is used the relationship

\[ T(r) = T_w(v) \frac{1}{1 - \Theta_{Ww}(v) \pi(\beta)}, \]

where \( T_w \) is the Wien temperature given by the relationship

\[ I_v = \frac{2h\nu^3}{c^2} \exp \left( -\frac{h\nu}{T_w} \right), \]

where \( h \) is the Planck constant, \( k \) the Boltzmann constant, \( I_v \) the peak intensity, \( \nu \) the frequency of the line under consideration, \( \Theta_{Ww}(v) \) is an auxilary quantity.
\( \pi(\beta) \) is a relatively complicated function of the excitation voltage of the upper term of the considered line and of the ionization voltage of the element with emits the employed spectral line.

The equation (1) is the first approximation in a complicated iterative procedure. For temperatures up to 7000 K this first step is sufficiently accurate.

At higher temperatures several iterations are used, upon computer processing this causes no great difficulties.

The described method has hitherto been employed for temperature measurements of a stationary non-homogenous plasma and in this work we have extended it into the measurement of the temperature of a non-stationary arc plasma fed by AC current.

During the measurements stroboscopic equipment was used which allowed the photographing of the arc spectrum in short time intervals. The relevant line of the spectrum was photometered in selected locations of the transversal section of the measured arc.

The cylindrical symmetry of the measured arc plasma was guaranteed by the vertical arc burning between the copper and carbon electrode. With the aid of two mirrors and an optical system the arc was displayed onto the slot of the spectrograph, so that the axis of the arc image was perpendicular to it.

Conclusion. In the paper is applied the Bartels method of measurement of the radial temperature distribution in the electric arc plasma. The method utilizes spectral lines with a self-reversal and is suitable for temperature measurements of a non-homogenous plasma. The subject of the paper is the measurement of the radial temperature distribution of a non-homogenous plasma in a non-stationary state.

References:


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ON USING FRESNEL MIRRORS
IN SOLAR SYSTEMS
TO CONCENTRATE ENERGY

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Key words: solar energy, concentrator, Fresnel-mirror

For achieving higher temperature of heat-transporting medium, optical (usually mirror-type) concentrators are used. They concentrate direct sun rays onto heat-exchange surface. Unlike flat-type collectors (that make use of both direct and indirect sun rays) the concentrators have to be quite precisely oriented to the sun – this is provided by a sun-tracking mechanism. The sturdiness and therefore the price of the sun-tracking mechanism depends principally on the size and the weight of the concentrator. The following text points out to some advantageous properties of Fresnel-type mirrors. A construction of the Fresnel mirror is based on replacing curved optical surface by a set of partial cone surfaces (cone rings). These surfaces are then placed all into one plane. The diameter D and the focusing distance f remain the same as they would be with the original curved surface. The number of partial cone surfaces replacing given curved surface depends on the required precision of focusing.

In solar system applications the precision is given with the size of the heat-exchanging surface placed in the focus of the concentrator because every cone ring should reflect all incident direct sun rays onto the heat-exchanging surface. While with the only inner ring (the smallest one) the coefficient of area utilization is 1, with more rings the coefficient is less then 1 due to the shadow caused by the next inner ring (see Fig. 1a – circular heat exchanging surface and Fig. 1b – spherical heat exchanging surface). Concentration ratio (CR) and coefficient of area utilization (CE) plotted against value f/d₀ are shown in Figs. 2, 3 for various number of rings. These figures have been made with the aid of the table processor that has enumerated the respective formulae. The formulae have been deduced from the geometry shown in figures 1a and 1b. It can be easily seen in Figs. 2 and 3: the more rings the less coefficient of area utilization. An interesting concentration ratio is obtained with as few as 2 or 3 rings. As an example, the basic parameters of Fresnel mirror system are computed (with f = 240 mm and d₀ = 80 mm) and filled in to an enclosed table. The four can be considered as a sufficient number of rings. From the practical point of view, another advantage of the Fresnel mirror is the less mechanical stress of the concentrator by wind.

<table>
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<th>number of ring</th>
<th>α [°]</th>
<th>d [mm]</th>
<th>D [mm]</th>
<th>CR [-]</th>
<th>CE [%]</th>
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<td>45.4</td>
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<td>700.7</td>
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</table>
Fig. 1:

Fig. 2:

Fig. 3:

References:


This research has been conducted at the Department of Special Electrical Engineering and Quality, FEECS TU Brno as a part of the research project “Laboratory of renewable sources of energy” supported by FEECS.
SYSTEM FOR CHECKING OF AUTOMATIC INSTRUMENT TRANSFORMER TEST SET TETTEX 2767

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Key words: Instrument current transformer (CT), instrument voltage transformer (VT), ratio error, phase angle, measuring system

The automatic instrument transformer test set Tettex 2767 is perspective and the most used device for the instrument transformers (IT) testing. It operates on voltage phasor measurement prinicp. The measured voltage is proportional to the deviation between errors of tested and standard transformers [2]. As it is a complicated electronic system, so is regular check necessary [3, 4]. The block diagram on Fig. 1 shows typical configuration for testing of current transformers (CT). The secondary of tested transformer is connected to $k_x - I_x$ terminals and the secondary of standard is connected to $k_N - l_N$. The instrument evaluates the current deviation as ratio error $\varepsilon_I$ and the phase angle $\delta_I$. The device is testing by serially connected and fed by common current $I_S$.

Fig. 1:
The ratio error, given by the formula
\[ \varepsilon_{IS} = -\frac{\Delta I_S}{I_S} = -\frac{U_1 \cdot R_{N_1}}{U_2 \cdot R_{N_2}}, \quad \delta_{IS} = 0 \] (1)
can be simulated by means of resistors \( R_P \) and \( R_{N_1} \) connected in parallel. The phase angle, given by the formula
\[ \delta_{IS} = \arctan \frac{\Delta I_C}{I_S} = -\arctan \frac{U_C \cdot R_{S2} \cdot U \cdot C_P}{U_2}, \quad \varepsilon_{IS} = 0 \] (2)
can be simulated analogically by means of capacitance \( C_P \) (in Fig. 1 dashed).

The voltages \( U_1, U_2 \) and \( U_C \) are measured by voltmeters \( V_1 \) and \( V_2 \) using the PC controlled system according to Fig. 1. The data transfer to the PC is realized by means of IEEE 488 bus. The informations about the ratio error \( \varepsilon_{Im} \) and the phase angle \( \delta_{Im} \) measured by means of system Tettex 2767 are transfered by IEEE 488 or RS 232 bus. The true value of ratio error \( \varepsilon \) and phase angle \( \delta \) is calculated according to relations (1) and (2). The described method allows the simulation of errors of one polarity and of limited range. The whole error range can be simulated by means of additional current source \( \Delta I \), connected to \( k_X - l_X \) terminals. The source should allow adjustment of amplitude in range 0–20% \( I_S \) and phase in range 0–360°. The value of phase angle \( \delta = 0 \) will be set on the test set by phase adjustment and the value of ratio error \( \varepsilon \) will be checked and the other way round. The currents \( I_S \) and \( \Delta I_S \) will be determined from the voltage drops on the serial resistors. The true values of ratio error \( \varepsilon \) and phase angle \( \delta \) will be calculated according to relations (1) and (2). The testing method for the VT checking is similar. The errors are simulated by serial resistor or capacitance, respectively by additional voltage source.

References:


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THE NEW INTEGRAL CHARACTERISTICS

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Key words: illumination system, integral characteristics, mean spherical illumination, mean cylindrical illumination, mean cubic illumination, working plane, contrast rendering factor, glare discomfort

The illumination of the horizontal working plane surface is still usually used for the quality evaluation of a lighting system. This characteristic only describes illumination of planes and not three dimensional things. Watched details are usually three dimensional in most of illuminated areas, so it is necessary to use characteristics that objectively describe space quality lighting. The integral characteristic is in general equal to the mean value of the basic model of the illumination receiver so far mostly used are the ball (the average spherical illumination $E^s$) or cylinder (the average cylindrical illumination $Ec$).

During resolving the project we have taken attention to the possibility of using the cube as the model receiver and the practical application of newly proposed values.

It is mostly illumination of all six surfaces of the cube (the cubic illumination $E_{06}$), eventually illumination of four, usually vertical, walls of elementary cube ($E_{04}$).

We calculated some values in the model room with diameters 6 x 7.2m. Five various types of luminaries (with its various distribution curves) were step by step installed in this room. Illuminating system was created according to the valid Czech norm CSN 36 04 50 which demands 500 lx on the working place. Than we took away 20 to 30 percent luminaries. Than we compared all various situation.

We analysed the average spherical illumination ($E^s$), the illumination of the plane surface ($E_\phi$), the average cylindrical illumination ($Ec$), the direction of the flow of light ($c$), the cubic illumination ($E_{06}$) illumination of four vertical walls of the cube ($E_{04}$), luminance of ceiling, walls and working plane, contrast rendering factor, system efficiency and glare discomfort was checked there.

The analysis showed that according to watched parameters the illumination system with semi-direct luminaries was the best used variant. On the opposite the luminaries with diffuse cover showed a lighting environment as the worse. This illumination system had double energy consumption in comparison to the others.

Subjective evaluation of the lighting system was done at the Warsaw university and in general the results were the same as the computed.

Evaluation of illuminated systems with various luminaries optical systems shows the analogous distribution of both values $E^s$ and $E_{06}$ as well as $Ec$ and $E_{04}$.

The calculus of direct and indirect part of the mean cylindrical illumination $E_{06}$ is not complicated, because it deals with the illumination of planes.

Simultaneously the calculation and the measurement of the average cubic illumination offers both the value of the illumination of the horizontal plane and one of four vertical planes.
and also the projective of the direction of the light flow vector into a given co-ordinate axis, signifying the difference of illumination of the cubic's opposite walls. Difficulties of design calculation decrease significantly.

It is not necessary to use a special cells extension (as it is needed for $E_{4x}$ and $E_c$) for measuring, but it is used cosine-corrected photometer from the common luxmeter.

Our team constructed a prototype of device that sets the photocell into all six wanted positions, collects and computes the data.

As we tried to suggest the recommended values $E_{06}$, which should be recommended for certain lighting systems, we found out that it is possible to proceed from the values $E_{4x}$ in the Czech norm (part for residential rooms) that could be taken as a starting point. It will be necessary to make data more exact especially from the time point of view. Target values of the average cylindrical illumination $E_c$ is not at disposal in the Czech norm yet.

Obtained evaluation (in spite of fact that the number of lighting system was limited) confirms the hypotheses that instead of value $\epsilon/E_{4x}$ can be practically used $\epsilon/E_{06}$ and also $\epsilon/E_{04}$ instead of $\epsilon/E_c$.

Further research about this problems should be done.

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This research has been conducted at the Department of Power Engineering as a part of the research project "The New Integral Characteristics" and has been supported by grant No. 10038271 of the Czech Technical University.
THE CONNECTION OF POWER ENERGY SYSTEMS

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Key words: reliability of power energy system, ecological impact to environment, diagnostic expert systems, fuzzy logic, control of power energy system

The state of the power energy system is defined by means of operation parameters of the power energy system and its devices. The character of the operation parameters determines various states of power energy systems (PES):

- normal state,
- alert state,
- state of disturbances,
- state after disturbances.

The research activities were carried out for emergency states, i.e. states occurring during major disturbances with great interruption of electric energy supply to industrial sector and to inhabitans, often with a long time duration. These studies are very important for the interconnection of the Czech PES with UCPTE and for the control of lower levels of power transmission and distribution systems.

The application of artificial intelligence to the control of PES (expert systems, neural network, fuzzy logic) is given by effort to use also the human operational experience and operational opinions. The aim is to:

- decrease the demand of the dispatchers, the reduction of activities in preparing the operation of the PES,
- standardise the fast action,
- decrease time for restoration of energy supply,
- prevent the failure of the dispatcher,
- use the experience of experts for training of dispatchers.

The results of research activities were presented in following fields - the mathematical model of PES reliability, the expert system for diagnostic task of electrical devices (engines and transformers), the basis of fuzzy regulation, the use of fuzzy logic for control of flicker in supply of electric energy and for control of the power system in emergency states.

The control of PES in emergency states is realised by means of modules:

- control module provides the control of the whole system. The control is performed by help of other computer programs, simulation programs etc,
- failure module gives the advice during failures in the PES. It is not active in the normal state.
• operational module provides all normal manipulations in the PES, control of production, demand, regulation $U/Q$, regulation of $P$, control of energy exchange etc,

• information module provides the connection with the dispatcher and the fulfillment of the information base. An important part of that module is a filter of the data. This module is very important, because the operation of the PES depends on the quality of informations.

We studied at first the fuzzy control in the application of the failure module. We have used the Linguistic Model Processing System (LMPS). For this empty expert system it was necessary to define:

• the model of the PES,
• fuzzy variables and their word values,
• fuzzy sets of variables,
• description of relationships between variables.

The control system was proved in the energy region in South Bohemia. Emergency states can arise also from smog situations. Therefore we want to use the fuzzy logic for solving of these situation in the PES.

The results of scientific activities were presented during 1995 five times at conferences and seminars, and six papers in international conferences were called for.

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This research has been conducted at the Department of Electroenergetics as part of the research project "The Connection of Power Energy Systems" and has been supported by CTU grant No. 10038198.
USING RULE-BASED EXPERT SYSTEM FOR EVALUATION OF DIAGNOSTIC MEASUREMENT OF POWER-ENGINEERING SYSTEMS

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Key words: expert system, rule-based expert system, dielectric diagnosis, diagnostics, predictive maintenance, insulation, reliability, evaluation, electrical machine, alternator, transformer, insulating oil

The insulation of high-voltage (HV) machines and equipment in operation is regularly tested with special diagnostic methods and its real state is evaluated. Based on the results of these diagnostic tests, it is possible to determine the reliability of machines and equipment in subsequent service, to prolong the inspection periods or to reduce the number of inspections.

Diagnostic measurement data was formerly gathered in database systems, which were oriented for recording results and for storing operational equipment data. However, a comprehensive view of a specific subject from the point of view of its future reliability in service may be ensured only by an expert system which evaluates the individual diagnostic methods, provides expert propositions, makes correlations between different methods. Expert systems are based on the principle of passing the knowledge of an human expert onto the system and using it with the same results as consulting the expert. Expert systems can be a very efficient tool for fast, high-quality decision-making but cannot fully replace humans and cannot solve non-standard situations. The statement of an expert system corresponds with conclusions and recommendations of a colloquy of top experts in the field whose advice can either be taken or ignored.

There are several different types of expert systems which are based singularly on production rules, neural networks, genetic algorithms, etc. as well as expert systems of a mixed type. Most experts in the field of dielectric diagnosis decide according to directives, limit values and rules of the IF-THEN type. For processing information of the type assumption, hypothesis, production rule-based expert systems provide the best solutions. That is why the rule-based expert system was chosen in this case.

The staff of the High Voltage Laboratory (HVL) of the Czech Technical University (CTU) in Prague collaborated with several top workplaces in this field on the construction of a rule-based expert system for dielectric diagnosis. This group consists of universities (CTU Prague, VSB Ostrava, VUT Brno, WBU Pilsen), research institutes and laboratories (R&D Bechovice, Skoda Pilsen, ZCE), individual companies (Czech Power Company, ORGREZ, private companies, etc.) and other experts interested in this area. The empty rule-based expert system SPEL-EXPERT (a modification of the FEL-EXPERT expert system [1], created at the Department of Control Technology of the CTU) was chosen. In this rule-based expert system any uncertainty in the knowledge is represented with the help of Bayesian
conditional probability. A weight factor is associated with each rule, representing the degree of certainty of an expert about the given statement. The consultation results in a grading of final hypotheses, which is carried out by means of weighing the influence of supporting and rejecting rules. Upon first consultation with the expert system, each rule is associated with an a priori probability which expresses the rate of validity of the rule without taking into account any additional knowledge supplied during the consultation.

The created rule-based expert system for dielectric diagnostics was named IZOLEX [2] and the sources used for its creation were chiefly Czech (ČSN) and international (ISO) standards, operational regulations (Czech Power Company, ORGREZ), consultations with experts, and domestic and international scientific literature. The IZOLEX expert system evaluates diagnostic measurements from 37 commonly used diagnostic methods for evaluating the state of HV insulation of rotating machines (16 methods), non-rotating machines (10 methods) and insulating oils (11 methods). The current knowledge base of the expert system consists of 628 nodes, 783 rules, 65 context connection rules, 262 priority connections, 107 goals and 3 taxonomies. The biggest advantage of the IZOLEX expert system is the fact that this expert system enables even a non-expert user to determine the risks of further operation of a HV device without having to consult top experts. Wide use of this expert system is expected in practice, for example, at the workplaces of servicemen.

Results of the work of and information about the IZOLEX expert system were published by the staff of HVL at the IEEE SPT Conference in Stockholm [3], at the ISH'95 Conference in Graz [4] and at 8 other conferences in 1995. Three articles were also published in scientific journals in 1995.

References:


This research has been conducted at the Department of Power Engineering as a part of the research project “The Expert System for Diagnostics of HV Electrical Machines” and has been supported by GACR grant No. 102/94/1481.
CLASSIFICATION OF DISCHARGES IN HV INSULATING SYSTEMS USING A NEURAL EXPERT SYSTEM

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Key words: insulation, high-voltage, monitoring, discharge activity, reliability, measurement, recognition, partial discharges, expert system, neural network

Detection of discharge activity is an important means of testing the reliability of insulating systems of high-voltage (HV) equipment. Therefore many successful methods for detection, location and evaluation of partial discharge (PD) have been developed for this purpose. Several discharge quantities used for standard diagnostics do not predict the lifetime of the insulation systems, they give us information about its quality. The aim of our research is to determine the actual stage of the HV insulation and to estimate the safety in operation and the reliability of HV equipment. The results of this project will help to increase the reliability of diagnostics of power equipment (alternators, transformers etc.) used in the power system of the Czech Republic.

Measurement of PD is a modern non-destructive method for HV insulation diagnostics [1]. Measurement of PD in electrical insulation is provided by the global method of PD-measurements [2], which was developed for this purpose in the high-voltage laboratory (HVL) of the Dept. of Power Engineering, CTU Prague. This method is advantageous for its completeness, high sensitivity and relatively short measuring and evaluating times. This method can be used not only for off-line diagnostics, but also in on-line monitoring of stage insulating systems.

Each defect in electrical insulation has its own particular degradation mechanism. It is important to know the correlation between discharge patterns and the kind of defect. Recognition of internal discharges and their correlation with the kind of defect is becoming increasingly important in the quality control of insulating systems. For purposes of describing the characteristics of PD, discharge quantities have been divided into three groups [3]:

- Basic quantities, which are observed by the classic PD measuring unit
- Deduced quantities, which are integrated characteristics of basic quantities
- Statistical operators on basic and deduced quantities

For measuring PD characteristics and evaluating PD quantities a measuring system for analyzing PD pattern was developed [4]. The measuring system consists of a classic PD-measuring unit, which can output non-processed data (real-time PD characteristics), and of a computer, where data is processed and PD quantities and statistical parameters are evaluated. Data from PD-measuring unit is transferred to the computer via an I/O PC card with a 16-bit A/D converter. In this unit, detected analog signals are digitized
and prepared for processing in the computer. Evaluated parameters are input vectors for a neural network classifier.

Neural networks (NN) have promising capabilities as automatic discriminators and intelligent alarm processors [5, 6]. They have the ability to learn from examples without knowledge of explicit rules, to recognize input patterns which are different from learned patterns, and to adapt to differing pieces of equipment and they require only minimal customization. The expert system used in this project is based on an empty neural expert system called NEUREX which was developed at the Dept. of Computers, TU Ostrava [8]. The knowledge base of this expert system (the training set for neural network) consists of characteristics and parameters measured on models or on insulating systems with well-known defects which are used as input parameters and of output results of stage HV insulation and kinds of detected defects [9].

The next steps of research activity in this project are to build a real knowledge base for the expert system and to test this system on real HV equipment in the power system of the Czech Republic.

References:


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Hierarchical Fuzzy Control for Power Energy Systems

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Key words: Fuzzy control, fuzzy inputs, neural networks, hierarchical control

Presented work aims at development of a hierarchically distributed nonlinear controllers for the use in Networked Electric Power Systems. The controller is internally implemented as interconnected fuzzy systems described by Horáček and Binder (1995). Fuzzy Logic Controllers (FLC) with hierarchically structured rule base are static, generally nonlinear functions, mapping numerical inputs to numerical outputs. Static mapping or rather its parameters, basically reference fuzzy set Membership Functions (MF) and rules, can be designed (i) purely manually, (ii) by automatic learning scheme processing input/output pairs of data representing the reference behavior of the FLC or (iii) combined scheme where manual design is used for presetting rules and MFs with fine tuning of selected MFs and rule weights using reference training data.

Single Stage Decision Making. Minimal realization of a fuzzy system can be achieved by implementing layered rule base (Horáček and Binder, 1995). This structure is based on the idea of exception handling. The nonlinear control map which works satisfactorily almost in all situations, process states, is generated using large granularity. Note that the background strategy is linear in number of practical cases. The union of support of fuzzy sets representing the rules of the background strategy is equal to the input space. Exceptions from the background strategy are realized by additional, rather locally invoked rules. The global strategy should be gradually disabled when the more specific rules are activated. No chaining of rules is done. The resulting layered structure of decision rules is shown in Fig. 1a.

Multi Stage Decision Making. Chaining the rules might be required when rules play different role in the control system. A typical example is a FLC with a rule based, measured signal preprocessor and a controller shown in Fig. 1b. It is well known that the human operator is not able to cope with the amount of detail information available in the computer control of a complex system like the power distribution network. The information describing the state of the process has to be preprocessed and as an aggregate presented to the operator who reacts to it more efficiently. The output of the preprocessor is a fuzzy set or sets. The controller processes fuzzy values provided by the preprocessor and not the crisp values given by all the particular sensors. A FLNN is extended to the multi-stage decision case where rules are grouped and groups are chained in order to get a hierarchy of decisions as proposed by Horáček and Binder (1995).

The two hierarchically structured fuzzy logic controllers lead to simplification in the FLC design and tuning as the dimensionality of the design problem is reduced and transparency of the input/output reasoning is improved. A reference data driven fine tuning of part of a nonlinear function of a FLC, implemented as a hierarchically structured Fuzzy Logic Neural Network, has been developed. However, manual design of FLNN topology
and its parameters in the form of a rule base and membership functions dominates in the engineering practice at present. The main reason is that bad reference data may lead to incorrect FLC tuning as is often the case in training of conventional neural networks. To prevent this a designer prefers using rather his experience for primary setting of parameters of preprocessor and leaving few parameters of the final decision part of a hierarchically organized FLC for automatic tuning by reference data driven algorithms.

References:


This research has been conducted at the Department of Control Engineering as part of the research project "The Connection of Power Energy Systems" and has been supported by IGS CTU grant No. 10038198.
This paper deals with sources of flicker in power distribution systems. The limits of flicker regulation are developed and presented graphically. It is shown that in the frequency band from 1–15 Hz, classical methods are capable of suppressing flicker in power systems, but that the classical methods are not sufficient for suppressing higher flicker frequencies. In this paper, the improvement of flicker regulation for all frequencies by fuzzy technology is described.

Electrical equipment with non-linear characteristics is a source of disturbance by harmonics, interharmonics, voltage fluctuations, voltage dips, supply interruptions, and voltage imbalances. This paper concerns voltage fluctuations in supply systems. Generally, since voltage fluctuations have an amplitude not exceeding 10%, most equipment is not disturbed by them. The main disadvantage which can be attributed to them is flicker, the fluctuation of luminosity of incandescent lamps. This phenomenon is only important as a source of discomfort to individuals. The physiological discomfort associated with this phenomenon depends on the amplitude of the fluctuations of the component frequencies, the rate of repetition for voltage changes, and the duration of the disturbance.

From the physical point of view, flicker can be compared to the amplitude modulation process when the supply voltage at angular frequency 50 Hz is modulated by a voltage fluctuation in the band from 0.5 to 30 Hz.

Electrical arc furnaces are the most complicated sources of voltage fluctuations with chaotic character. Fluctuations of current in electric arc furnaces cause voltage fluctuations in the supply network. To reduce these fluctuations, we use a Static Var Compensator that operates on the principle of indirect compensation of reactive power. This SVC is composed of a thyristor-controlled reactor and a fixed capacitor bank.

The aim of the regulation of flicker is to limit the fluctuation of voltage and reactive power in the frequency spectrum from 2 Hz to 30 Hz. One of the dynamic parameters that decreases the possibility of elimination of flicker is time delay in the measurement and calculation of reactive power. This time delay can take as long as 25 milliseconds.

When we analyze the envelope of reactive power and voltage, we can see a good correlation between them. For this reason we can study the influence of SVC in limiting voltage fluctuations in the sub-harmonic band. We know from the theory of the calculation of electrical networks that drops in voltage in the distribution network are approximately equal to the change in reactive power. For this reason, the target for regulating flicker is determined by the value of reactive power. In order to determine the quality of regulation, we express the Flicker Suppression Factor.

When we consider the accuracy of the amplitude, the time of delay corresponds to the time it takes for the phasor to shift 60 electrical degrees. It follows that to reduce flicker to 25 Hz, the time delay must be less than 6 milliseconds. It is impossible to reduce time delay
because it occurs in the process of measurement of voltage and current and the calculation of reactive power. Because flicker cannot be regulated efficiently by a standard regulator, we have used a regulating procedure with a predictor to limit flicker in all bands of the spectrum.

For this procedure, we use our knowledge of typical frequency spectra from electrical arc furnaces. The model can be derived from ANFIS or GENFIS, which are fuzzy logic tools in the MATLAB computer program. The procedure uses the learning ability of neural networks and uses fuzzy logic to compose rules. In order to confirm the fuzzy prediction we erase from the rules the assumption that the system is based on the history of the measurement of the real process in the real environment. Prediction will be a response to the average value of the system and will be less accurate when the system deviates from the average.

The prediction limits the time of delay. The regulator can be modified so that the output from the predictor can be used to respond as if the time delay did not exist. The filter output is connected to the predictor, which uses a neural network and fuzzy logic to calculate the future value of the controlled variable for compensation of the time of delay.

The simulation proposes that the time delay is a multiple of the data collection period. The history of data can be divided into blocks. One represented value can be determined from each block by local filtration. In our case, we use two blocks, input 1 and input 2. When teaching the predictor, we form a prediction surface for our sample with the help of ANFIS and GENFIS. In the control process the same value passes through the prediction surface and we receive a prediction of output.

Conclusion. From an analysis of flicker it follows that its regulation has a limit due to time delay in the regulation loop. Flicker of the electric arc furnace cannot be limited in all bands by classical regulators. For limiting high frequencies of flicker, we try to use fuzzy technology. Our experience shows that teaching a fuzzy predictor enables the prediction of future values with a high degree of accuracy and allows better control of flicker than from classical regulators, particularly for high frequencies. Because the spectrum of flicker is unstable all the time, we propose using an adaptation of the prediction surface to change the character of input.

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Section 12

ELECTRONICS, MEASURING AND COMMUNICATION ENGINEERING
NEW RESULTS IN THE NONLINEAR DYNAMICAL SYSTEM MODELLING

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Key words: dynamical systems, modelling, piecewise-linear approach, chaos

New canonical state models of Chua's circuit family. The third-order piecewise-linear (PWL) dynamical systems are intensively studied as the simplest autonomous systems which can exhibit chaotic behaviour. Such systems belong to the Class $C$ of vector field in $R^3$ [4] and can be described by the general matrix form

$$\frac{dx}{dt} = Ax + bh(w), \quad w = \alpha^T x, \quad A \in R^{3x3}, \quad b \in R^3, \quad \alpha \in R^3.$$

The simple memoryless PWL function $h(w) = (|w+1| - |w-1|)$ is continuous, odd-symmetric, partitioning $R^3$ by two parallel planes into one inner ($D_0$) and two outer regions ($D_{+1}, D_{-1}$). The dynamical behaviour of such systems is given by two sets of three eigenvalues determining two characteristic polynomials associated with the corresponding regions

$$D_0: \det(sI - A_0) = s^3 - p_1s^2 + p_2s - p_3 \quad D_{+1}, D_{-1}: \det(sI - A) = s^3 - q_1s^2 + q_2s - q_3$$

where $A_0 = A + ba^T$ and $1$ is the unity matrix. State matrix $A$ determines equivalent eigenvalue parameters $q_1, q_2, q_3$ while matrix $A_0$ determines coefficients $p_1, p_2, p_3$. Some of the known systems topologically conjugate to Class $C$ (e.g. Chua's universal circuit or Chua's oscillator) are canonical with respect to all possible behaviour of the associated vector field, and with respect to the number of necessary parameters. They are not canonical, however, with respect to the relation between these parameters and the equivalent eigenvalue parameters. Such a property is useful especially for the study of chaos. New elementary canonical state equations have the following forms:

1st form:

$$\begin{align*}
\frac{dx_1}{dt} &= q_1x_1 - x_2 + (p_1 - q_1)h(x_1) \\
\frac{dx_2}{dt} &= q_2x_1 - x_3 + (p_2 - q_2)h(x_1) \\
\frac{dx_3}{dt} &= q_3x_1 + (p_3 - q_3)h(x_1)
\end{align*}$$

2nd form:

$$\begin{align*}
\frac{dx_1}{dt} &= q_1x_1 + q_2x_2 + q_3x_3 + h(w) \\
\frac{dx_2}{dt} &= -x_1 \\
\frac{dx_3}{dt} &= -x_2 \\
w &= (p_1 - q_1)x_1 + (p_2 - q_2)x_2 + (p_3 - q_3)x_3
\end{align*}$$

The corresponding circuit models consist of three ideal integrators, three summators, and one PWL element. Both structures contain the known canonical forms of the third-order nonautonomous linear system (AC and FLF networks) and a nonlinear feedback block described by a simple memoryless PWL function $h(w)$. In the modified structures (one additional summator) the equivalent eigenvalue parameters $q_1, q_2, q_3$ and $p_1, p_2, p_3$ directly determine the summator gains. References - [1, 2].
Piecewise-linear modelling and circuit design. Piecewise-linear models are suitable especially for strongly nonlinear systems. The decomposed implicit state model has the form

\[ y = Au + Bj + f, \quad x = Cu + Dj + g, \quad 0 = Mu + Nj + q \]

where \( x \in \mathbb{R}^n \), \( y \in \mathbb{R}^m \) are input and output model variables and \( u, j \in \mathbb{R}^k \) are state variables satisfying the linear complementary condition \( u \geq 0, j \geq 0, u^T j = 0 \). The design of such a model is a very difficult mathematical problem the general solution of which is not known so far. New two different algorithms for the 1-D case have been developed, the exact and the numerical one. The exact algorithm covers continuous PWL relations in general case. The numerical algorithm based on optimization procedure allows to design the state model with less state variables than that designed by the exact algorithm.

The implicit models are also suitable for PWL circuit realizations. The circuit then consists of a linear multiport corresponding to the linear model equations and a loading block of ideal diodes corresponding to the orthogonal state variables. Method of the resistive multiport design that has been developed is based on multiple D/A converters integrated on one chip in CMOS technology. Besides higher accuracy and time invariability the system can be controlled via a standard digital interface. A grounded four-port operating in the voltage-mode has been implemented having each port driven by a summing voltage amplifier with digitally adjustable gains using octal D/A converter DAC-8840. The gain values are derived from parameters of an arbitrary four-port network matrix. It has been built especially for the realization of the elementary canonical state models of Chua circuit family mentioned above. This 3-region symmetric PWL system contains three capacitors and two antiparallel diodes connected to the individual ports of the resistive four-port. Special software package including a driver for converter programming and an optimization module (stability and optimum parasitic poles) has been written. References – [3-5].

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THE RECONSTRUCTION
OF A GAP BANDPASS SIGNAL

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Key words: bandpass signal, gapped time series, modulated signal

The SVD reconstruction of a gap signal can be very successful, if the original signal is strictly band limited and if the known samples are exact. As opposed to it, when original signal's frequency restriction is not perfect or when the known samples are inaccurate, it can be difficult to achieve satisfactory reconstruction. There are some possibilities to improve reconstruction in such cases. The Miller regularization can bring very effective suppression of the quantization noise influence if the combination of reconstruction task parameters, namely the number of lost samples, the number of neighboring known samples, the upper bound angular frequency, sampling interval and quantization step are reasonable. The performance of a new proposed simplified method is similar to that of Miller. Computational complexity of the simplified method is small with respect to the Miller's one [1].

A method of the two-band signal consisting of lowpass component and bandpass component has been proposed in [2] and [3]. The calculation complexity of the reconstruction is low.

Theory of the bandpass signal sampling has been studied too [4]. There were calculated spectra of the interpolation functions. Than the interpolation functions has been calculated using inverse Fourier transform. Some simplifications have been found for particular cases of sampling. Examples of signal reconstruction have been given.

New MATLAB m-files have been created for simulation of BPSK and QPSK signals. The program simull allows to simulate the transmission of data through the communication channel.

The SVD reconstruction quality of a bandpass signal depends on the type of signal, the number of samples, the precision of samples, the sample instants distribution and the choice of boundary angular frequencies. The reconstruction formula is relatively simple and the calculation complexity is low, if values of the set of sampling instants and the boundary angular frequencies are fixed [5]. The reconstruction of the odd and even harmonic signals was simulated. Reconstruction of the 12 lost samples from the using the 20 known exact samples were successful for harmonic signals in the band. The central frequency 1.8 Hz, bandwidth 1.2 Hz and sampling interval 0.104 s were used. The reconstruction errors of the aliasing signals were very big, therefore, reconstruction method is not robust. It is expected the Miller regularisation can bring some improvement in this matter. The reconstruction errors of the aliasing signal are meaningfully dependent on the sampling frequency.

It was tried to reconstruct gap in the simulated bandpass BPSK signal. Signal was corrupted by a bandpass noise, the signal-to-noise ratio was 15 dB. The band limited noise
was, as it was expected, reconstructed by the same way as a useful signal. It represents serious problem. An example of the reconstruction is shown in Fig. 1. The plus '+' marks the known sample, the circle 'o' marks the lost sample and the cross '×' marks the calculated sample.

![Diagram of BPSK signal reconstruction](image)

Fig. 1: The reconstruction of the BPSK signal.

Done work have brought several published or prepared to publishing results. On the other hand it is probably, that a part of the original grant aim consistent in shifting the demodulation threshold, can not be simply achieved. Authors therefore propose to continue in more general research of the bandpass signal reconstruction.

References:


This research has been conducted at the Department of Radioelectrics as part of the research project "The Reconstruction of the Gap of a Narrow-Band Signal" and has been supported by TU Brno grant No. FU 45 0050.
GENERALIZED CANONIC STRUCTURES
OF THE LTI-DISCRETE SYSTEM
FOR DIGITAL SIGNAL PROCESSORS

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Key words: Digital signal processor, digital filter structure, zero input response

The digital signal processor (DSP) architecture has been designed to maximize throughput in data-intensive DSP applications. The architecture of the DSP is mostly the Harvard architecture. The linear time invariant (LTI) discrete system is implemented with finite accuracy using typically fixed- or floating-point arithmetic. The most popular representation of negative numbers is two's complement convention. The recursive frequency digital filter can be realized as a cascade of partial sections. It is well-known, that a parallel or cascade connection of the partial sections of the first and the second order is less sensitive to finite wordlength effects than the direct canonic forms of the sth order. If it is supposed, that the discrete system is stable and has the real coefficients of the system transfer function, then the modulus of the system poles will be less than one and will exist at real axis in complex plane or in complex conjugate pairs. In this case the maximum value of coefficients can be less than two, but it may be permitted only the maximum one. This is the reason why both generalized canonic models are modified with basic condition not to change the system transfer function. Modified generalized models for the canonic form 1, resp. 2 (CF1 resp. CF2) of the i-th second partial section are described by these difference equations

$$
\begin{align*}
v_{2i}(n) &= \frac{1}{b_{2i}} v_{2i}(0) \delta(n) + 2 \left[ \frac{a_{oi}}{2b_{2i}} x_i(n-1) - \frac{b_{oi}}{2b_{2i}} y_i(n-1) \right], \\
v_{1i}(n) &= \frac{1}{b_{2i}} v_{i}(0) \delta(n) + 2 \left[ \frac{a_{ii}}{2b_{2i}} x_i(n-1) - \frac{b_{ii}}{2b_{2i}} y_i(n-1) + \frac{1}{2} v_{2i}(n-1) \right], \\
y_i(n) &= 2 \left[ \frac{a_{2i}}{2b_{2i}} x_i(n) + \frac{1}{2} v_{1i}(n) \right].
\end{align*}
$$

\text{CF1}

$$
\begin{align*}
v_{1i}(n) &= v_{ii}(0) \delta(n) + v_{2i}(n-1), \\
v_{2i}(n) &= v_{2i}(0) \delta(n) + 2 \left[ \frac{1}{2b_{2i}} x_i(n-1) - \frac{b_{ii}}{2b_{2i}} v_{2i}(n-1) + \frac{b_{oi}}{2b_{2i}} v_{ii}(n-1) \right], \\
y_i(n) &= 2 \left[ \frac{a_{2i}}{2} v_{2i}(n+1) + \frac{a_{ii}}{2} v_{2i}(n) + \frac{a_{oi}}{2} v_{i}(n) \right].
\end{align*}
$$

\text{CF2}

The symbols $y_i(n)$ and $x_i(n)$ are the output and input signals, respectively, and $v_i(n)$ is the state variable of the $i$-th section. In speech processing the partial section involves, as usual, lattice structures with two or four multipliers. Fig. 1 shows the block diagram of the lattice structure.
The i-th section, above mentioned as a digital two-pair one, is completely characterized by parameters $k_i$, for $i = 1, 2, \ldots, N$. These parameters are known as reflection coefficients. The difference equations of the i-th section are

**lattice form 1**

\[
y_i(n) = z_i(n) - k_i v_i(n),
\]

(2 multipliers per section)

\[
v_i(n + 1) = (1 - k_i^2) v_{i-1}(n) + k_{i-1} y_i(n).
\]

The symbols $y_i(n)$ and $z_i(n)$ are again the output and input signals, respectively, and $v_i(n)$ is the state variable of the i-th section.

**lattice form 1**

\[
y_i(n) = g_i z_i(n) - k_i v_i(n),
\]

(4 multipliers per section)

\[
v_i(n + 1) = g_{i-1} v_{i-1}(n) + k_{i-1} y_i(n), \text{ where } g_i = \sqrt{1 - k_i^2}.
\]

All of the models were implemented on the Motorola's digital signal processor DSP56002. The multiplication by 2 is automatically realized by setting bits $S_1$ and $S_0$ in the Status Register without adding any other instructions.

**References:**


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SPEECH SPECTRUM CODING USING MULTIGRAM SEGMENTATION

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Key words: speech coding, speech segmentation, speech spectrum

The multigram method allows us to split a sequence of symbols into a set of variable length sub-sequences. In this research, we studied the segmentation of vector quantized speech spectra. The results are reported for two small codebooks of 32 and 256 code-vectors. The applications to low-rate speech coding and to image processing are discussed.

Segmental Coding of Speech. In the majority of speech processing systems, the signal is divided into fixed-length frames which are processed independently, without taking into account the inter-frame dependencies. However, these dependencies exist and the description of three techniques (Matrix Quantization, Multiframe Coding and Phonetic Segmentation) can be found in recent speech-coding literature [1]. The crucial problem of these systems is the choice of segments. We used a new technique of segmentation developed by Bimbot et al. [2, 3], which chooses the segments in order to maximize the likelihood of the segmented sequence.

Speech Spectrum and its VQ. The speech sampled at 16kHz was divided into 20 ms frames and the spectral envelope was represented using vectors of 10 LPC-cepstrum coefficients. Then we performed a vector quantization with two codebooks of 32, resp. 256 code-vectors (calculated from the training set using a simple LBG algorithm). We obtained two sequences of code-vector indices of length 100 000.

Multigram Segmentation. The optimum segmentation of the sequence maximizes the likelihood

\[ L(W) = \max_{\text{all segmentations}} \prod_k p(S_k) \]

where \( S_k \) are the sub-sequences of length \( l(S_k) < n \) (\( n \) is the maximum length of multigrams) and \( p(S_k) \) their probabilities. These are not known a-priori and have to be estimated in an iterative process "segmentation" \( \Rightarrow \) "reestimation of probabilities".

Evaluation and Results. For a direct lossless coding of spectral information, the possible bit savings are given by the difference of two entropies: \( H(V) = - \sum p(V_i) \log_2 p(V_i) \) of VQ codebook and the modified entropy of multigram dictionary:

\[ H'(M) = - \sum_{i=1}^{n} \sum_{j=1}^{n} p(M_{ij}) \frac{\log_2 p(M_{ij})}{i} \]

where \( i \) denotes the length of multigrams, \( M_{ij} \) the \( j \)-th multigram of length \( i \) and \( p(M_{ij}) \) its probability. Another criterion is the size of resulting multigram dictionary.

Having performed numerous tests with several lengths of multigrams and with different pruning factors \( a \) (in the reestimation of probabilities [2]), we obtained following optimum results:
Discussion and Application to Low Rate Speech Coding. The direct coding of multigrams is offering a possibility of bit reduction. However, for a precise spectrum representation, the codebook must be larger. We worked with these codebooks but the results were not satisfactory (symbol-by-symbol division of the sequence). We see the reason in the variability of typical spectral sequences, which is much greater than that of typical sequences in written texts (original field of application of multigrams in [2, 3]). To overcome the “rigidity” of the method, we have proposed following solutions:

- **Modification of the method.** Instead of demanding the equivalence between a sequence and a multigram in the dictionary, we may introduce a distance. This will allow two sequences with the distance below a threshold to be represented by the same multigram, as a result we will obtain more compact multigram dictionary. The sequences can be of equal or unequal (with time alignment) lengths.

- **Multigrams only for the segmentation.** Using multigram segmentation together with another technique of spectrum representation will allow us for example to create two-stage VQ with the symbols of length greater than one (Matrix Quantization with unequal length of matrices).

Application to Image Processing. It is possible to develop an extension of the method to 2-dimensional sequences, where the symbols are replaced by pixels. The image is segmented into figures of variable dimensions. On the contrary to 1D-case, where a multigram is entirely defined by its length, in 2D it is necessary to specify the possible forms - rectangular, convex, concave, and the connexity (4- or 8-).

References:


This research has been conducted at the Institute of Radioelectronics of FEI VUT Brno and at the Department Signal of ESIEE Paris as part of the research project “Speech Coding for the Transmission on HF and VIIF Channels” and has been supported by TU Brno grant No. FU45 0001 and by French Government scholarship No. 94/4516.
TRACKING OF A MOVING BODY
BY CCD CAMERA

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Key words: robot control, stereofotogrammetrie, CCD camera, position detection, Kalman filtering, camera calibration

According to development of robot control algorithms for fast detection and tracking of objects with CCD cameras has been analyzed.

We have solved two common tasks:

• 2D task: if object is moving in working plane, it is enough to find only two coordinates, the third one is defined by working plane. The orientation of working plane according to camera is fixed. The parameters of rules to transform object coordinates in the scene to coordinate system coupled with working plane of robot could be done by finding defined fixed points of working plane.

An accuracy of location computation based on resolution of camera and fixed points on working plane. With TV camera with standard CCD chips by SONY ICX 039 (resolution 752(H)x287x2(V)) and pixel oriented digitizer for optically well defined object could be find place with accuracy up to 3 mm vertically and up to 1.5 mm horizontally (if camera runs in non interlaced mode).

The values are valid if object is scaned with angle higher than 60 degrees and robot’s working plane is 1000 x 750 mm. The accuracy of coordination definition could be improved by smaller working area or by using subpixel values. The knowledge of inner coordinates of camera, for coordinates corection, is assumed.

• 3D task: the object could be situated anywhere in the working area. In this case it is necessary to find all object coordinates by some of stereofotogrammetrics methods. Due relatively easiert of mathematic apparat (requirements of high speed processing) we have choosen system with couple of cameras with fixed base. In this case both cameras are scanning objects with aproximatively the same angle. It makes easier to find stereocouples in sequence of stereo images. Analyses of accuracy of stereofotogrammetrically finded coordinates is relativelly difficult task.

Roughly we can start with information that coordinates in object plane could be find with accuracy equal to step of base ratio. For example if the width of object plane is 1 m and base is 0.3 m and with CCD camera with ICX 039 chip could be reached resolution approximately 1.5 mm without using subpixel methods. Accuracy of computation of object distance from camera is in this case 3 mm.

The accuracy of object coordinates calculation depends on accuracy of outer and inner cameras orientations. The most important items of inner camera orientation includes principal point, camera constant and distortion of lenses. We have develope method to find nonlinear objectiv distortion and principal point.
To describe the objective distortions we can use formula $r_n = r_o(1+c\cdot r_o)$. The values $r_o$, $r_n$ are real and measured distances of testing point from the principal point. The value $c$ is the only calculated parameter. Described method allows correction of objective distortions at corners of image under one pixel. The same results as with classical methods could be reached by this solution.

To calculate of outer cameras orientation were used classical stereofotogrammetrical methods, which were modified to converge even for relatively roughly digitized image.

To detect and calculate the object coordinates in the image were used corelation methods. As corelation pattern was used idealized image of object or its edges. After object detection was used Kalman's filter with prediction to follow the trajectory. The predicted values allows to find an object area which has to be searched in next step and then cut down computation time.

We have assembled the stereofotogrammetrical pair CCD cameras with fix base equal to 300 mm with pixel oriented digitizer and with software. Algorithms for object trajectory tracking were implementea in 32 bits DSP TMS320C30. Measured coordinates were used to move arm of robot to object.

Robot control with CCD camera has some restrictions due to properties of CCD camera. The resolution of common CCD cameras, in case when the whole working area is taken, allows rough position detection. For accurate positioning of robot we must use next camera coupled with robot for detail image. Computational expensive algorithms could be calculated by using simple board with DSP. The object trajectory in the picture is possible to find with step under 0.1 s.

This research has been conducted at the Department of Automatic Control and Instrumentation as part of the research project "Advanced Schemes of Robot Control" and has been supported by GACR grant No. 101/93/2435.
ACTIVE RC FILTERS
IN CURRENT MODE

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Key words: analogue filters, active RC biquads, voltage current and hybrid modes, current conveyors, transimpedance and current amplifiers

Active RC filters are well-known and popular. There is a voltage signal processing in classical voltage mode, using a conventional opamps. Unfortunately parasitic inherent features of the real opamp play there more characteristic role, specially in high frequency region [1]. For this reason an adjoint current mode has been developed, where the current signal processing is used.

From principle of methodology we would recommend to distinguish more hybrid mode too, next to basic mentioned voltage and current one, namely voltage-current or current-voltage respectively, if certain subcircuit (usually an active element) operates in the opposite mode. Note that the conventional opamp operates in voltage mode, while the current conveyor and the transimpedance amplifier in current one respectively.

At first, several modes in simple ARC single amplifier, second order filters have been analyzed, compared and experimentally tested in detail. Specially the Huelsman highpass ARC filter was studied [1] in voltage, current and hybrid current-voltage mode respectively. Computer experimental results ware given to numerically compare performances of the modes, assuming a limited frequency response of the real opamp, modelling conventional LM 741 in program Microcap.

Furthermore migration of poles and zeros of this circuit was studied, using programs COCO and LINO. In all, the hybrid current-voltage and specially full current modes are closer to the ideal case. There are much wider bandwidth, high gain, lower noise, large linearity and high slew rate, than in the corresponding classical voltage mode.

The current mode version can be simply obtained from the known voltage filter, as a prototype, using the concept of adjoint networks, namely interchanging the input and output of active elements (nullator and norator of the opamp) and reversing the input output ports of the overall filter.

New high performance ARC biquadratic filters, using commercially available transimpedance opamps have been given in [2] in all mentioned modes. These circuits are there designed from already known double-ladder multiple-loop feedback conventional opamp structure, operating in voltage mode, using adjoint transformation and special modification for the transimpedance opamp respectively. The papers [2] and [6] demonstrate that transimpedance opamp, including a compensation pin, are much more versatile and better than other opamps, specially in high frequency range, what was supported by computer modelling and experiments. There is given an equivalent circuit of the real transimpedance opamp, modelling its parasitic properties, using voltage and current controlled sources. Parameters are named for commercially available AD 844 (Analog Devices). Furthermore, in [2] are given some comments on the Fabre's paper from IEE Proc. G 1993, No. 5, too.
Simple implementations of functional blocks (voltage and current followers, derivators, integrators, immitance convertors and invertors) and synthetic elements-inductors and frequency dependent negative resistors, using transimpedance opamps are given in [7].

A true current operational amplifier in monolithic integrated form was proposed by Mucha [8], in two versions, namely a differential input-single output one and a complementary single input-differential output, respectively. Specially second one is more suitable for the full current mode filter applications, adjacent to the voltage prototypes, what was shown in [4]. Biquadratic elliptic low-pass ARC filter using single input-differential output current operational amplifier was proposed in [3]. This full current mode filter was ingeniously transformed from the known voltage mode prototype as an adjacent counterpart. Both circuits were compared in detail by computer modelling.

The other current and hybrid mode filters using current operational amplifiers, second-generation current conveyors (CC II) and transimpedance opamps are given in [5-7], too.

References:


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NEW CURRENT-MODE FILTER STRUCTURES

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Key words: current-mode filters, SC filters

In Ref.[1] we have introduced new lossless non-reciprocal structures suitable for high-quality filter implementation. An efficient synthesis algorithm was developed and tested and a behaviour of designed filters was investigated. To improve dynamic properties and to decrease influence of Op-Amp imperfections, the transformation to the current-mode was studied. Two ways were tested to obtain desired structures:

• Direct synthesis procedure arising from the re-arrangement of fundamental building block. This way leads to the modified form of synthesis algorithm under “current-mode” starting conditions.
• Adjoint transformation of a voltage-mode counterpart.

Both the ways have been found to be efficient and together with the new improved form of synthesis algorithm lead to the flexible design of current-mode all-pole LP, BP and HP filters. The design flexibility allows to choose the type of loading immitances and working immitances, which, in the end, make possible to adapt final structure to the technological constraints flowing from the implementation technique.

Because the design procedure is based on an application of two-port transmission (chain) parameters, a problem of the derivation of starting parameters arises. The solution is trivial, when single-terminated circuit is considered. In the case of both-port terminated circuit was necessary to find a new solution because of non-reciprocal character of the synthetised circuit. For this purpose a generalized form of Feldtkeller’s equation was derived and used in the evaluation procedure of transmissiom two-port parameters. This work was presented in Proceedings of the conference ECCTD’95 [2].

To get a global information about a behaviour of different filter realizations, following topics were observed:

• An influence of synthesis procedure (particularly the order of transfer zeroes realization) to the spread of values of circuit elements,
• an influence of Op-Amp non-idealities, especially influence of the ratio of Op-Amp GBW-product to filter cut-off frequency,
• dynamic properties of structures designed.

As reference LP-filters were used Cauer’s 4th and 6th-order filters of the type C 04a 35 25 and C 06b 68 25 designed in the all possible modifications. In global, 16 different circuit structures were compared. The results showed very low sensitivity of current-mode structures to OP-Amp gain-bandwidth product and excellent dynamic properties. On the other hand, the dynamic properties strongly depended on an arrangement of loading immitances, which was found as a critical point of the optimal design.
A detail comparison of current-mode LP designs to their voltage-mode counterparts was made in [3].

Another part of our work was oriented to the development of filter structures, based on generalized divider configuration. A synthesis of these filters arises from the direct realization of the coefficients of given transfer function, and, from this point of view, such circuits are able to serve as equalizers or basic structures of analog adaptive filters. An original structure using generalized immitance converters (GIC) was developed and tested in its voltage-mode and current-mode form. A behaviour of the mentioned structures was studied. A comparative study performed in the frame of diploma-thesis [4] was devoted to the evaluation of a set of the 2nd and 4th-order filters and a detail investigation of their properties. Especially the influence of Op-Amp inaccuracies to the transfer poles and zeroes location was analysed. In this case current-mode structures were found as insensitive in the wide extent of Op-Amp's GBW and trajectories of pole- and zero-shifts caused by GBW-changes were oriented along the direction of minimal sensitivity of the circuit frequency response. These results were presented at the conference RADIOELEKTRONIKA 95 [5].

Simultaneously discrete-time SC structures, derived from the above mentioned basic continuous-time prototype have been investigated. To minimize a number of Op-Amps used, a simplified type of SC-GIC was developed by using “negative SC-resistor effect”. In connection with the detail description of SC-GIC, the influence of SC-resistor implementation to the circuit behaviour was studied. On this occasion new properties of studied circuits were found. The obtained results led to the optimum switch-phasing design and, in general, made possible to decrease the total capacitance of the final circuit.

The presented structures seem to be prospective in a wide area of applications. For example, the second-order blocks based on generalized-divider structure could serve as an universal building blocks of tunable filter or equalizer structures. An application of the mentioned structures will be a topic of the future investigations.

References:


This research has been conducted at the Department of Circuit Theory as part of the research project “Current-Mode Analog Circuits” and has been supported by CTU grant No. 10098274.
FILTERS WITH TRANSIMPEDANCE OPERATIONAL AMPLIFIERS

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Key words: transimpedance opamp, active filters, high order synthetic element

The paper shows one possible solution how to design high order synthetic elements with the type D admittance [1] which is described by formula

\[ Y_D(s) = D_1s + D_2s^2 + \ldots + D_n s^n. \]  

The second part deals with the possible usage of these elements in the high order filter design.

By means of suitable circuit with transimpedance opamp (TIA) we can obtain a two terminal network with input admitance

\[ Y_{in} = \frac{Y_1Y_2}{Y_3H} + Y_1 + Y_2. \]  

\( H \) is the voltage transfer function of the TA filter. The circuit is shown in Fig. 1.

![Fig. 1: Ordinary transfer element for the type D synthetic element design](image1)

![Fig. 2: Frequency dependent voltage divider](image2)

If we choose \( Y_1 = sC_1, Y_2 = sC_2, Y_3 = 1/R_3 \) and \( H \) as noninvert lowpass transfer function of the n-th order \( H(s) = 1/Q_n(s) \), we will obtain high order two terminal network of type D with input admittance

\[ Y_{in} = Y_D(s) = s^2C_1C_2R_3Q_n(s) + s(C_1 + C_2). \]

The order of the synthetic two terminal network is two units higher than lowpass TA filter used.

The usage of the higher order two terminal network in the frequency filter synthesis can be demonstrated in the example of lowpass filter (LPF) design. This LPF can be obtained by using of the frequency dependent voltage divider (see Fig. 2). The synthetic element with the type D admittance is utilized in this divider. The voltage transfer function of this two port network is given by

\[ H(s) = \frac{1}{1 + R_0 Y_D(s)}. \]
If we apply eq. (1) in eq. (4) we will obtain

\[
H(s) = \frac{1}{1 + R_0 D_1 s + R_0 D_2 s^2 + \ldots + R_0 D_n s^n}.
\]  

(5)

Now we can work up this circuit more in detail. We will use the synthetic two terminal network from Fig. 1 for admittance \( Y_D \), where we will put the fourth order LPF in place of TA. Fig. 3. shows the final circuit, which is the fifth order low-pass filter.

![Fig. 3: Fifth order low-pass filter](image)

The magnitude of frequency characteristic was obtained from the computer simulation \([2]\) and from the measurement of real circuit (see Fig. 4). The cut-off frequency of LPF was chosen \( f_c = 1 \text{ kHz} \) and the Butterworth approximation was used.

![Fig. 4: Comparison of computed and measured gain response of presented LPF](image)

References:


This research has been conducted at the Department of Telecommunications as part of the research project “Filters with Decreased Tolerance Sensitivity Using Transimpedance OpAmp” and has been supported by TU grant No. 1-991/05.
CONTRIBUTION TO THE DIRECT SYNTHESIS OF SC CIRCUITS

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Key words: circuit theory, SC filters, synthesis of discrete-time filters

The internal CTU grant No. 10038274 backed the investigation of the SC structures, which were based on a new analog nonreciprocal lossless prototype, published in [1]. The procedure of an effective Z-domain design, analogical to the chain parameters partial removal procedure for the continuous-time prototype, described in [2], was searched for these structures.

The formulation of such design procedure consists of two steps:

1. Formulation of multiphase Z-domain chain parameters.
2. Adapting the individual analog procedure steps in the Z-domain,

which is briefly mentioned in the following paper with a couple of more detailed references.

The multiphase SC chain parameters based on the [3] were formulated for the particular kind of two-phase circuits in the form of:

\[
\begin{pmatrix}
V_1 \\
Q_1
\end{pmatrix} = \begin{pmatrix}
A_{11} & A_{12} \\
A_{21} & A_{22}
\end{pmatrix} \begin{pmatrix}
V_2 \\
Q_2
\end{pmatrix}, \quad \text{where} \quad V_1 = \begin{pmatrix}
v_1 \\
v_i
\end{pmatrix}, \quad A_{11} = \begin{pmatrix}
a_{11} & a_{1i} \\
a_{i1} & a_{ii}
\end{pmatrix} \quad \text{etc.} \quad (1)
\]

The solution using algebraic cofactor was formulated for these parameters. This approach was successfully tested by means of mathematical software MAPLE. Relations to remaining SC transfer functions, namely to four basic voltage and charge transfers \( K \) and \( H \), came out as

\[
A_{11} = K^{-1}, \quad A_{22} = H^{-1}, \quad \text{where} \quad K = \begin{pmatrix}
K_{ee} & K_{eo} \\
K_{oe} & K_{oo}
\end{pmatrix} \quad \text{etc.} \quad (2)
\]

which are the generalized analogies of the well-known continuous-time relations, see [4].

The above mentioned chain parameters were then applied to carry out the Z-domain design procedure analogically to the continuous-time prototype. To complete this objective successfully, three main topic had to be performed, what is briefly described as follows:

- Analysis of Z-domain loads.
- Decomposition of \( K(z) \) to \( a_{11}(z) \) and \( a_{12}(z) \).
- The removal step.
As it was established in [5], the multiphase structure of $A_{11}$ and $A_{12}$ is simplified by strays insensitive resistor simulation under the condition that an appropriate switches phasing is used. In that case the design procedure can be performed separately for $K_{ze}$ (even to even) transfer function; in the odd phase the load has no influence on the circuit function.

The analogy of the even-odd part separation (in order to establish $a_{11}$ and $a_{12}$ necessary for the removal procedure) was developed in the second step. The reciprocal and antireciprocal polynomials were established as counterparts of even and odd part of the function in $s$-domain respectively. This separation is not unambiguous in the $\mathcal{Z}$-domain and depends on used $s \leftrightarrow z$ transformation. For the strays-insensitive structures the following relations are valid (where $n_0^e$ and $n_k^e$ are the reciprocal and antireciprocal parts of the transfer function numerator, respectively):

$$n_0^e = n_0 \quad n_k^e = n_k + n_{N-(k-1)} - n_{k-1}^r$$

The rules for removement of one second order building block were formulated in the last step of the design procedure. Taking into account that the chain matrix of the building block is the $4 \times 4$ matrix, the removal formula can be written in the form:

$$A' = \left( \begin{array}{cc}
    a_{11} & 0 \\
    - & -
\end{array} \right) A_{BL}^{-1}$$

where $a_{11}$ and $a_{12}$ are the above mentioned chain parameters and $A_{BL}^{-1}$ is the inverse chain matrix of the removed block. The conditions of $a_{11} = 0$ and $a_{12} = a_{12}z^{-\frac{1}{2}}$ necessary for the successful removement are valid for specific switches phasing again which can be formulated for an individual structure unambiguously.

The entire procedure was successfully tested on the fourth-order elliptic filter of type A, the strays-insensitive resistor simulation was used. The results are summarized in [5], a contribution for a foreign journal is now being prepared. Since the structures discussed in [2] have their current-mode counterparts we are going to apply the above mentioned design approach for this class of circuits as well.

References:


This research has been conducted at the Department of Circuits Theory as part of the research project "Current Mode Analog Circuits" and has been supported by CTU grant No. 10038274.
PALplus transmits video pictures in 16:9 format and is compatible with conventional PAL. Creating PALplus signals involves conversion of the input TV pictures, with standard 4:3 format to the letterbox format of the PALplus picture. The conversion of image is performed by means of the interpolation-decimation vertical filtering. Considering the length of the filter and the fact that processing of the image signal is time consuming, use has been made of parallelization of the algorithm for processing. The parallel structure of the interpolation-decimation vertical filter proposed in this solution has been verified using computer for the case of zone-plates test image – Fig. 1.

**Fig. 1: Test image zone-plate**

| a) Original image | b) Image after LP filtering | c) Image after HP filtering |
Parallel processing achieved using 9 partial processors, which have 78% utilization. Each of them contains an elementary processor for multiplication and addition as well as video line memory. In comparison with serial processing which has an efficiency comparable with that of a single partial processors in the parallel structure, the parallel processor is approximately 50 time faster.

The coding scheme discussed above requires vertical filtering of two types. The whole filter has two outputs. Using the first filter is possible to take out the low frequency component of the function spectra associated with the original image (as a signal) with the second filter generating the remaining high frequency part of the spectra. This arrangement forms the basis of the modern coding method used in PALplus system. The results obtained during the research for the computer simulation of this arrangement are illustrated on the Fig. 1. In this diagram Fig. 1b and Fig. 1c correspond to the input image show the effect of the filter on the reproduced image.

The first version of the filter is modelled in terms an electronic parallel processor. This study also takes heed of the optical realization of this operation. This supposes the use of spatial light modulators, optical Fourier transform systems and image sensors in performing the required functions. The concept of the specified image sensor has been worked out and the timing diagram of its operational regime for said two pass vertical filter calculated.

References:


This research has been conducted at the Department of Radioelectronics as part of the research project “Tools for systems of the fast processing of image information” and has been supported by CTU Prague grant No. 10038285.
EMPLOYMENT OF 2\times 2 SWITCHING ELEMENTS IN ATM SWITCHING NETWORKS

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Key words: multistage interconnection network, self-routing, throughput

ATM (Asynchronous Transfer Mode) was chosen by the CCITT to serve as a base for the future Broadband Integrated Services Digital Network. The main challenge in ATM switching is to build fast packet switches which can handle data rates ranging from 150 to 600 Mb/s per input line.

A switching network \( N \times N \) combines two functional components: buffer memory to store the cells and an interconnection mechanism to transfer them from the inputs to selected outputs. A number of switching network architectures has been proposed. According to the interconnection principle used, three basic types of ATM switching networks are identified: the shared-memory type, the shared-medium type, and the space-division type (switching networks combining these principles can be met as well). Generally, in switching networks based on shared-memory and shared-medium, traffic from all input lines is multiplexed into a single stream of bandwidth equal to \( N \) times the bandwidth of a single line. This represents a great difficulty for large \( N \) since such switching networks become very complex and expensive.

Although space-division switching networks present problems of their own, interconnection networks based on identical small switching elements seem to be very attractive. In this article we will concentrate on switching networks built with \( 2 \times 2 \) switching elements. Switching networks \( N \times N \) where \( N = 2^n \) \( (n = 2, 3, \ldots) \) can be built with \( nN/2 \) switching elements arranged in \( n \) stages. A class of such networks is usually referred to as banyan networks although it encompasses networks of various topologies (e.g. flip network, omega network, delta network, shuffle-exchange network). Regardless of the particular form they take, all of the above \( N \times N \) multistage interconnection networks possess the following properties. There exists a single path which connects an input line to an output line. The establishment of such a path may be accomplished in a distributed fashion, using a self-routing procedure. If the outputs of such an interconnection network are numbered from 0 to \( N \) and expressed by a binary word (of the length of \( n \)) then switching elements are able to configure themselves by considering one bit of the destination address of routed cells.

The networks possess a regular structure which is particularly suitable for VLSI implementation; furthermore their structure is modular allowing the construction of large networks from smaller ones without the need for modification in the physical layout or in the algorithms needed for their operation. All these features have made these interconnection networks among the most desirable building blocks for fast packet switches. But a serious shortcoming of these architectures is internal blocking, i.e. even if all cells at inputs are destined to different outputs (there are no output conflicts) several cells may contend...
for an internal link. This induces throughput limitations, and so additional techniques are used to relieve the internal blocking.

The first solution to mention is placing buffers at the points of conflicts. It is known as the buffered-banyan switching network. For uniform input traffic pattern a buffer of about 4 cells at each switching element can improve the capacity (throughput when offered load equals to 1) of the switching network above 0.6. Nevertheless in case of bursty traffic severe congestions can occur. One solution may be to operate internal links at a higher rate than external lines. From a hardware implementation point of view this is not very convenient. Another possibility is to randomize the traffic at the input so as to distribute it across the entire network and break the unpleasant effects of long bursts. For this purpose additional stages may be included to switching networks which provide for each input/output pair several paths (e.g. Bonek networks).

Another approach to internal conflicts is implementation of a sorting network which passes to a banyan network only cells free of both output and internal conflicts. Of course such a solution implies a more sophisticated architecture dealing with recycling of unsuccessful cells and resequencing them at the outputs. Combining this idea with the one mentioned above (increasing the number of possible paths for input/output pairs, for example by using several parallel banyan networks) very satisfactory results can be obtained.

Yet another solution using multiple banyan networks consists of placing the banyan networks in tandem. Upon a conflict between two cells at some switching element, one of the two cells is routed according to its destination, while the other is derouted and marked as such. At the output of the first banyan, successful cells are extracted to output port buffers, while those which appear at the wrong outputs are unmarked and start a new round with lesser chances for conflicts this time. It can be shown that for uniform traffic six banyan networks in tandem result in the network capacity very close to 1.0.

A high switch capacity can be obtained also with pure banyan networks where buffers are placed at outputs as well as at inputs. Cells which would cause output conflicts are stored in the input buffers waiting to be switched at a later time. This means that the same number of output lines remains idle (so called head-of-the-line blocking) while behind these HOL cells, cells destined to the idle outputs might be placed. To avoid this, bypass queues are implemented, i.e. during one time slot, $w$ cells from each input buffers are given chance to contend for idle outputs. This requires a slightly higher internal rate. In [4] it is shown that with the window depth $w = 4$ and four parallel banyan networks, capacity around 0.9 can be obtained.

References:


NOISE CANCELLATION SYSTEMS

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Key words: noise suppression, microphone array, voice activity detector, time delay estimation

Continuing our work on noise cancellation systems, we have investigated algorithms for time delay estimation, voice activity detection and noise suppression. These algorithms are important parts of noise cancellation systems.

The objectives of the research were:

• To analyze and compare methods for time delay estimation and compensation. Special attention was paid to use of higher order spectra.
• To analyze and compare methods of voice activity detection. Emphasis was put on the development of reliable speech activity detectors suitable for real-time implementation.
• To implement a chosen noise suppression method on a signal processor.
• To test the implemented noise canceller under real noisy conditions in a running car.

Noise suppression systems are widely used in various speech processing systems, e.g. speech recognition, hands-free mobile telephony, aids for hearing-impaired, etc. We focused on the mobile telephony application. Our final goal was to implement a low-cost simple and reliable algorithm for the real time suppression of additive car noises. That is why we used the spectral subtraction algorithm. We tested this algorithm for one microphone and multimicrophone noise cancellation systems. We have found that the one microphone system performance is heavy dependent on the proper detection of speech activity segments, while the performance of the multimicrophone system is influenced by the time delay estimation algorithm. Owing to our hardware configuration we focused on the implementation of the spectral subtraction system using one and two microphones.

Delay estimation and compensation. Multimicrophone noise cancellation systems are based on the assumption that an additive noise is a diffusive signal while speech is a coherent signal. These assumptions are valid if the distances between microphones are greater than 30 cm. Inspite of the microphone configuration the speech signals picking up by microphones have different time delays. Prior to the spectral subtraction is applied these delays had to be compensated. Second order spectra (SOS) and higher order spectra (HOS) can be used. HOS require the gaussianity of car noises. We have found this assumption is not valid for many types of car noises. Inspite this fact HOS outperform SOS when the crosscorrelation of noises is large and signal to noise ratio (SNR) is low. On the other hand HOS are more sensitive to the parameters selection than SOS. Further details and results can be found in [1].

Spectral subtraction. Spectral subtraction subtracts an estimation of the background noise spectrum from the input signal spectrum. The difference between one microphone spectral subtraction and multimicrophone spectral subtraction lies in the way of
getting the estimation of the background noise spectrum. For one input signal this estimation has to be done in nonspeech segments. This approach requires a reliable voice activity detector (VAD). For more input signals the background noise estimation is got from the subtraction of input signals. Before the subtraction the delays between signals have to be compensated. This compensation also requires a VAD. If the ideal voice detection is used the average figure in the noise suppression varies from 6 to 12 dB depending on the rate of signal parameters changes.

One microphone spectral subtraction was implemented on the floating point signal processor TMS320C30. Details and results are in [2].

Voice activity detector. As described in the preceding text the VAD is the common part of noise suppression methods. We suggested several VADs based on spectrum, cepstrum and coherence, which are suitable for the real-time processing. These detectors exhibit high reliability even for low SNR (about -6 dB). The description, implementation requirements and achieved results are described in [3-8].

References:


This research has been conducted at the Department of Circuit Theory, Faculty of Electrical Engineering, CTU in Prague, as part of the research project “Speech Enhancement Systems” and has been supported by CTU grant No. 10098275.
NEW MULTIMEDIA TECHNOLOGIES
AT THE DEPARTMENT
OF TELECOMMUNICATIONS
AT FEE–CTU IN PRAGUE

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Key words: multimedia technology, telecommunication, video compression, MPEG, JPEG

At present time, the term “multimedia” is used very frequently, although its definition is ambiguous and various branches of industry understand it in different ways of technical and technological solutions.

The initial approach to multimedia technology at our department was stimulated by demand for better effectiveness of the teaching process.

In the first period (between the years 1989–1990), the technological equipment was quite meagre (computers based on 80286 processor, software like Basic, Pascal etc.). Usage of graphical subsystems was limited, while that of sound or moving picture was simply impossible.

Later on (1992–1993), within the TEMPUS project, the department obtained an authoring system – Authorware Professional for Windows, which made the development of new teachware much easier. This enabled the authors to concentrate on educational aims, with the advantage of using graphics, animations, and especially sounds. The mentioned system is used for teachware development up to the present day; and more than ten multimedia educational programmes have been prepared; their topics concern especially data communications (signal converters, packet communications), electromagnetic compatibility (measuring, EMC of a personal computer), telematics (document telegraphy), and often the common problems of communications (the OSI model).

Since 1994 we have been exploring another approaches to more effective preparation of teachware. Thanks to the grant of MŠMT (Czech Ministry of Education, Youth and Physical Culture) we were able to equip a new workplace for designing videoprogrammes and to update the workplace for multimedia programmes preparation. We learned about the possibilities of recording our own CD-ROMs and, in context, of modern compression technologies application. In 1995, building of a new multimedia presentation laboratory has started, and a multimedia presentation workstation is being equipped. The full operation should start in the next year (1996).

Nowadays, the main struggle is focused on creating an original authoring system, which forms a part of an extensive project called “The Telecommunications Engineering Encyclopaedia”. The mentioned system will enable to compile a large amount of information concerning telecommunications to the form of encyclopaedia, while the information carrier should be CD-ROM.
The basis of our multimedia workplace is a PC with Pentium processor (running at 90 MHz), equipped with 16 MB RAM, PCI and ISA internal bus, SCSI-2 interface adapter. Besides the common peripherals, the colour scanner HP3c, a 1 MB hard disk, removable media hard disk drive SyQuest 270 MB and a quad-speed CD-ROM drive are the additional devices.

The functions of input, sampling, recording, playback and output of sound are supplied by a sound card Monterey that have a wavetable sound synthesis and a MIDI interface integrated on it. Thus, it is possible for any audio device to act as a peripheral of the sound subsystem, which is supplemented with an electronic musical instrument with MIDI interface and with an amplifier with a pair of loudspeakers.

The video subsystem constitutes the set FPS60, that is capable of digitising S-VHS video, compression to M-JPEG format and storing to hard disk, and playback of the video (from M-JPEG or MPEG-1 format) on the SVGA monitor. The input peripherals are S-VHS devices (professional videorecorder Panasonic AG-5700 and camcorder Panasonic NV-MS4E).

In future, we want to focus on solving various problems concerning:

- Real-time compression and decompression of video;
- Connecting the "terminal" multimedia systems with multimedia/multifunction/ISDN/computer networks;
- Finishing the preparation of the new authoring system;
- "The Telecommunications Engineering Encyclopaedia" project;
- The building of the teaching laboratory.

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This research has been conducted at the Department of Telecommunications Engineering as a part of the research project "Multimedia" and it has not been supported by CTU.
**FUZZY SIGNAL PROCESSING**

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Key words: fuzzy logic, fuzzy signal processing, fuzzy clustering, fuzzy control, fuzzy sets, neural networks, fuzzy-neural networks, fuzzy associative memories, fuzzy filters, signal filtering and prediction, nonlinear filters, biomedical diagnostics

The new technique of digital signal processing known as “Fuzzy Signal Processing”, is developing at a rather slower rate than other Fuzzy logic applications. In the area of signal processing, fuzzy logic finds its applications in nonlinear filtering (e.g. for nonstationary signals) with the possibility of utilizing adaptive algorithms, in the estimation of parameters of nonstationary signals, in speech and image encoding and in signal identification/recognition.

Our work involves two areas of applications: medical diagnostics and radiolocation. Although these areas are completely distinct, they share a similar methodology of digital signal processing. Our work is focused on nonstandard cases of signal processing, where we substitute nonlinear filters (often based on neural networks or the radial function) by fuzzy filters and in the case of parameter estimation, or tracking, by “Fuzzy Kalman filters”. Our work can be roughly divided into the following three areas. The first area is focused on the sole utilization of fuzzy cluster analysis of input data, which allows the achievement of a better characterization of the actual signal than using analogous statistical methods. This method was used e.g. for better detection of a signal in noise. The second area attempts to implement IF–THEN rules into the design process, which allows a substantial increase in the accuracy of conditions for signal processing. Such a type of filter is capable of substituting existing nonlinear filters, and with suitably set conditions, achieving better results. An equalizer in a nonlinear channel may serve as an example. The third area of our work combines the advantages of fuzzy processing of data and neural networks. This combination allows us to make use of the advantages of both techniques. The methodology such as learning and adaptation, already developed in the field of artificial neural networks, may be utilized. Within the framework of the project, properties of selected nonlinear filters were verified by computer simulation, and it was ascertained that with “fuzzy filtering”, qualitatively better results may be achieved than using standard filtering techniques.

References:


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USE OF GPS TECHNIQUE 
IN EDUCATION AND PRACTICE 
AT TU BRNO

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Key words: GPS, geodesy, navigation, education

The Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) under development by the US Department of Defense will soon provide new opportunities for surveyors and their profession.

Department of Geodesy, FCE TU Brno purchased in last two years two GPS receivers WILD System 200 of the swiss firm LEICA, belonging to the class of highest precision. Together with the receivers the SKI (Static Kinematic software) GPS processing software was also purchased. In October 1995 the third GPS receiver WILD System 300 was obtained by courtesy of Swiss government (Agreement between Swiss and Czech governments according to the project of Czech Office for Surveying and Cadastre from June 1995).

In the beginning of 1995 the building of research and training GPS laboratory at Department of Geodesy, TU Brno started. The laboratory will be used also by other departments of FCE, other faculties, and other universities in Brno. The main part of the laboratory is the GPS reference station, which will be employed in international, national and regional GPS measuring campaigns. The station is placed on the roof of building “B” of FCE and it was named “TUBO” (TU Brno). It is monumented by a steel pillar in centre of previous astronomical observatory. The station “TUBO” was included in the national control network of reference points (densification of zero-order network over the whole Czech territory - DOPNUL campaign).

One of the experiments had to test the possibility of continuous GPS data collection with help of special software WILD BASE. Another task was to solve the problem of permanent monitoring and storing of meteorological parameters (in cooperation with meteor-station of FCE). In present time the reference station “TUBO” is able to serve as a permanent 24 hours station for campaigns lasting several days. For the purpose the connection to INTERNET network was accomplished. The station was equipped with necessary computer technique enabling the data collection and data processing at laboratory and also in field conditions. Main activities at this research station in 1995:

• data collection at “TUBO” in May-June 1995 for international geodynamic project CERGOP (Central European Regional Geodynamics Project) which is being realized by joint effort of ten European countries within the frame of the section C-Geodesy of the Earth Science Committee, Working Group on Science and Technology of the CEI.
• preparation and measurements in the national geodynamical control network (GEODYN 95-2 campaign in October 1995). In preparation phase the laboratory cooperated with Research Institute of Geodesy, Topography and Cartography in Zdiby on testing the possibility of simultaneous measurements with various types of GPS receivers (PEBRMIX campaign in February 1995) together with test epoch measurements (GEODYN 95-1 campaign in April 1995).

• GPS measurements for the research grant “Monitoring of Displacements of Supra-Crustal Blocks on Border of Czech Massif and Alpine-Carpathian System With Help of GPS” (MORAVA campaign in October 1995) covering the inclusion of “TUBO” station into this project, including preliminary, exploratory and test measurements.

• continuous GPS measurements in local geodynamic network “Sněžník” (1995 epoch). This experimental geodynamic network was established in 1992 by TU Brno and UA Wroclaw in “Sněžník” mountain region. The network covers an area on both sides of the Czech-Polish border.

• experiments with combinations of various types of GPS receivers and with various GPS post-processing software products (TRIMBLE – VUGTK Zdiby, ASHTECH – Geovap Pardubice, TOPCON – Geodis Brno).

In pedagogic sphere the GPS was included in several subjects in geodesy and cartography studies at TU Brno, FCE (subjects “Geodetic Astronomy and Space Geodesy”, “Theoretical Geodesy”, “Positioning Systems” and special GPS Seminar). At FECS the GPS problematics were included mainly in subject “Navigation”. The Department of Radioelectronics, FECS intends to purchase one GPS receiver in near future. Department of Geodesy, TU Brno is making efforts to obtain the BERNESE GPS software for precise GPS post-processing.

GPS is also included in post-graduate studies at both faculties, and in themes of diploma works. In 1995 a text-book on GPS problematics was released at FCE. Students of the 5th course of geodesy and cartography studies visited in October 1995 the Leica factory in Switzerland where GPS equipment is manufactured. The GPS laboratory served as a consulting and lecturing centre for external GPS users and for students of other universities in Brno. Laboratory specialists participated in many international and national conferences, workshops and seminars on GPS problematics.

GPS practical applications were studied in detail in 1995, for example in field of creation and densification of local geodetic networks (problems connected with transformations between WGS 84 and S-JTSK coordinate systems in neighbourhood of “TUBO” station, employment of GPS for control points establishment in photogrammetry, use of GPS for objectivisation of geodetic measuremets in undermined areas of the Ostrava region, establishment of local networks for engineering projects – e.g. highway tunnel in Brno etc.)

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PRACTICAL TRAINING IN EMC

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Key words: EMC education, EMC practical training, EMI and EMS measurements

This pedagogical research is continuation to the 1994 educational project entitled “Practical Forms of EMC Education” in which the educational problems set were examined at the Institute of Radioelectronics TU Brno in co-operation with the Military Technical Institute in Vyškov. In the year 1994 the graduate curriculum in EMC for electronic engineering specialisation of the study was developed [1, 2]. The aim set for 1995 was the practical realisation of a special course “Electromagnetic Compatibility” and the elaboration of its experimental and laboratory parts.

The dedicated EMC course was introduced at the Institute during the summer term of the academic year 1994/95 for students in the last year of their graduate-study as a review of the main technical aspects of EMC. The theoretical lectures [3] are accompanied by the IEE Distance Learning Video Course named “Electromagnetic Compatibility (with particular emphasis on EC Directive 89/336/EEC)” which have been purchased from the grant project support. This IEE course, produced by the York Electronics Centre, University of York, consists of 9 videos in four modules and it is intended to be a “stand-alone” training aid to be used in the regular lectures. The following modules with total running time about 7 hours are used at the time: EMC-An Introduction; The European Directive on EMC; EMC Measurement and Tests; EMC Design Techniques.

The lectures of the course “Electromagnetic Compatibility” are complemented by a serie of four-days laboratory and computer experiments in form of practical industrial training held in EMC test laboratories of the Military Technical Institute in Vyškov. The student’s experiments are running in two EMC areas:

a) Measurements of electromagnetic interference (EMI) was realised in a screening room 17 x 7 x 7 m with the E field attenuation level of 55 dB in the frequency range from 30 MHz to 1 GHz. The automatic HP measuring system with a 20 Hz–2 GHz pre-selector was used. The whole measuring process was controled with the help of HP 236 computer with specialized EMC test software. Both peak- and quasi-peak detector results were obtained and on a plotter documented. Following practical experiments were realised:  

• Measurement of conducted emissions:
  - Voltage measurement by using the 50 Ω or 150 Ω line impedance stabilizing network (LISN) in the frequency range 9 kHz to 100 MHz for AC up to 30 A.
  - Current measurement by using the HP current probes from 150 kHz to 1 GHz.
  - RF power measurement with the absorbing clamp Rohde & Schwarz MDS-21 in the frequency range of 30–1000 MHz.

• Measurement of radiated emissions:
  - Electric near-field measurement (vertical and/or horizontal polarisation) in the frequency range 150 kHz–1 GHz.
  - Magnetic near-field measurement from 0.15 to 30 MHz.
Electromagnetic field measurement with various types of antennas in the range of 27 MHz to 500 MHz (1000 MHz).

An example of a radiated emission measurement on a personal computer with the i386 processor is shown in Fig. 1.

![Fig. 1: Radiated emission of a PC 386 in the frequency range 30-1000 MHz](image)

b) Measurements of electromagnetic susceptibility (EMS) were realised according to the IEC-801 requirements mainly in following areas:

- **Electrostatic discharge susceptibility (ESD)** was tested by indirect contact discharge. The 5/30 ns voltage pulse with the amplitude of maximum 15 kV was discharged over an air gap on the case of the electronic equipment under test (EUT).
- **RF harmonic field susceptibility** was tested for electric field strengths $E = 1 \text{ V/m}$, $3 \text{ V/m}$ and $10 \text{ V/m}$. The test unit was a parallel plate transmission line providing a uniform electromagnetic field in the frequency range of 27 to 500 MHz.
- **Conducted fast transient immunity** was tested by using the burst generator simulating an usual industrial EM environment. The 5/50 ns burst pulses with the amplitude of maximum 4 kV are capacitively injected into the AC power line and data line of EUT.

References:


This pedagogical research has been conducted at the Institute of Radioelectronics as part of the project “Practical Forms of EMC Education” and has been supported by TU grant No. FU 45007.
OPTIMIZATION OF THE SYSTEM FOR EXTRACTION OF CERAMIC BINDERS

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Key words: ceramics mixture, extraction, experimental system sensors, measurements, experiment regulation, process optimization

Extraction processes enable substantial quality improvement of production processes. However, multiparameter systems are concerned where it is rather difficult to maintain precisely defined and reproducible working conditions. Within the framework of VUT B4 Project it has been proved that such a system can be regulated. The final stage of the project was based on theoretical and practical experience gained in the previous years. The aim was the modification and optimization of the entire process, including the software, and expansion of the system to enable study and complete regulation of the process of thermal extraction of organic polymere ceramic binders, and further to make it adaptable to similar technological processes carried out at the Department of the Faculty of Mechanical Engineering. In practice, the construction of the upper part of extraction furnace had to be changed to achieve a better distribution of temperature, and to exchange the utilized balance module. The previous module from the laboratory balance Mettler, model College 244 DR didn't suit our purposes and had to be substituted with module B303 from the same manufacturer. A simple exchange was impossible because of differences in connection and dimensions. Moreover, it was necessary to devise another system of sample lock and thermal protection (shielding) of the upper part of extraction furnace. In addition the temperature measurement using the thermocell PtRh-Pt was improved - all measuring channels were equipped with converters located in close vicinity of the place of measurement. The regulation algorithm was adapted to suit the changed parameters of extraction furnace, and to achieve a better regulation dynamics and to minimize the deviations from the required value. At the time when this abstract was written, verifying experimental measurements were carried out at the Department of Mechanical Engineering. The results and conclusions will be presented at WORKSHOP 96. Nevertheless, it can be stated now that all the required properties will be achieved, and that all tasks will be fulfilled.

References:

This research has been conducted at the Department of Automation and Measurement Engineering as part of the research project "Optimization of the System for Extraction of Ceramic Binders" and has been supported by TU of Brno, Grant No. FU450061.
AN AUTOMATED OPTICAL MEASURING SYSTEM

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Key words: source of optical radiation, monochromator, radiation bandwidth, synchronous detector, fibre optics, optical power, wavelength, index of optical refraction, optical attenuation

Optoelectronics, as a rapidly developing field, has various technical and scientific applications, and therefore technical university students should be well acquainted with this branch of science. Being aware of the fact that the equipment necessary for work in this field requires substantial financial support, we have launched a project within the framework of which an integrated workplace would be established in cooperation between the Faculty of Mechanical Engineering and the Faculty of Electrical Engineering. There is no such equipment available either at Technical University or at Masaryk University in Brno. It is an optical computer-controlled system for measurement of the basic parameters (properties) of optical fibres (multimode stepindex PCS, both gradient and single-mode), fibre optics components, and namely light-conducting sensors. The basic version of the system should enable measurement of optical power in dependence on time and wavelength (in the range from 250 to 2000 nm), colorimetric measurement, measurement of numerical aperture (index of refraction), and polarization measurement.

The PC-controlled optical system is modular, with great variability, which is an advantage considering the different character of measurements carried out at both workplaces involved (an adjustable source of incoherent radiation, a coherent source of radiation, spectral analyzer, and other configurations). The research was aimed at realization and installation (for pedagogical and research purposes) of a unique, fully automated,

PC-IBM-controlled measuring optical system for measurement, evaluation, and further processing of the characteristic properties of optical fibres, both with the step change of refractive index, and gradient, eventually single-mode properties (optical attenuation, wavelength, numerical aperture, refractive index, etc.). During the first year of the project up to the date of writing this abstract, the Department of Automation and Measurement Engineering in cooperation with the company MIKROKOM Prague have developed a PC-IBM-controlled optical measuring system for automated measurement, data processing (evaluation) and storage.

The system features:

- automation of spectral and time measurements of radiation intensity
- optical input for a loose beam of optical radiation or optical connector
- dynamic range 10–115 dBm for Si detector (10 mm)
• wavelength range 250–2000 nm with Si and Ge detectors for bandwidth of approx. 20 nm
• measurement precision of 3%
• automatic equalization of the dc component of optical signal
• optical detector transimpedance 1–10³ V/A
• frequency range 1–5.10⁴ Hz
• basic sensitivity of synchronous amplifier of 50 mV at adjustable attenuation 1–10⁶, resolution of 19 bits at signal/noise ratio of over – 20 dB and time constant in the range 25 ms to 25 s
• programmable generation of phase lock samples in the range 5–5 000 Hz
• step drives control (measuring sensor with TTL inputs)
• optical modulator stability of 4% (lamp source of optical radiation or an external source according to requirements.

Currently under way are verifying measurements of all the system parameters, testing and completing the control software and of hardware according to the requirements of both teams.

References:


This research has been conducted at the Department of Automation and Measurement Engineering and Department of Physics as part of the research project “An Automated Optical Measuring System” and has been supported by TU of Brno, Grant No. FU450062.
When measuring frequency spectra of periodical waveforms using FFT it is necessary to take into account errors caused by signal quantization. Errors caused by imperfections of the ADC used, by possible jitter of sampling period, possible aliasing and spectral leakage have to be also analysed [1].

In case of noncoherent sampling (sampling not synchronised with measured periodical signal) the most important source of errors is usually the spectral leakage. It causes spectrum deformation in cases when periodical extension of the measured part of signal has discontinuities at the ends of repeated intervals. One possible way of leakage reduction is using tapered windows applied on signal. Disadvantage of this method is that applying a window on signal (in time domain or frequency domain) causes deformation of both signal and its spectrum. This is due to the convolution of signal spectrum with spectrum of the window used. For error reduction some interpolation in frequency domain is usually needed, since the frequencies for which spectral lines are found do not correspond in case of noncoherent sampling with the maximum of the main lobe and with the minima of the side lobes of the spectrum of the used window [2].

An alternative method of spectral error reduction for the case of noncoherent sampling was suggested and experimentally verified. More than one period of periodical measured signal is sampled and stored in computer memory. Afterwards its period time is found and one period (or some integer number of periods) is interpolated. (Linear, polynomial and spline interpolation were used for this purpose.) The interpolated waveform is resampled so that there be exactly \( N = 2^m \) (\( m \) – positive integer, \( N \) – number of FFT points) samples per period or per integer number of periods. Applying FFT on the resampled signal results in large error reduction.

Experiments were carried out both on sinusoidal waveforms and more complicated periodical waveforms. For example, a harmonic signal with 10 V amplitude was sampled so that FFT yields the basic component of error spectrum of about 4 V. This component was reduced to about 0.02 V when polynomial interpolation and the above described resampling were used.

Complete information concerning error of measurement of frequency spectrum is provided by the error spectrum, defined as the difference between ideal spectrum and measured spectrum of a signal. Expressing an over-all error of measurement of amplitude spectrum by a simple numerical error is easy in case of a harmonic signal – SNR or THD can be used for the purpose. In case of a general periodical signal a similar approach can be used. The ratio of the RMS value of the error signal to the RMS value of the signal expressed in percent and called total relative error (TRE) was used by us. Both RMS values were computed in the frequency domain. The above described method of error reduction has lead to pronounced
error falling: e.g. the TRE was changed from 43% to 0.3% or from 94% to 0.6% if the National Instruments PC plug-in board was used for signal sampling and quantization.

Finding the signal period time is of basic importance for this method. In case of complicated periodical signals with several zero crossings during period this is not a simple task. An overview of methods which can be used for that purpose is presented together with numerical results in [3]. The work [3] was performed within the same project as was the reduction in error spectra described in this contribution.

References:


This research has been conducted at the Department of Measurement as part of the research project “Investigation of Algorithms for Dynamic Measurement and the Specification of Methods for Estimation of Errors of these Measurements by the Use of PC Plug-in Board Systems” and has been supported by GACR grant No. 102/93/0907.
PROPAGATION EXPERIMENT
TRANSMITTER DESIGN

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Key words: propagation, microwave

Equipment for the experiment dealing with propagation in millimeter frequency band was designed. The previous similar projects on this topics are described in [1-3]. The frequency 37 GHz and the transmission line of the length 60 m were chosen. Due to the short distance for the measurement the attenuation about 0.2 dB was estimated. To measure such a small fluctuations usually caused by hydrometeors and interferences, the extremely stable equipment is necessary to use. The whole experimental system is shown in Fig. 1.

![Diagram of the experimental system](image)

Fig. 1: The experimental system

The transmitter-receiver setup consist of the microwave generator (transmitter), horn antennas, reflector, microwave receiver, signal processing and control unit, and PC. The signal processing unit contains signal processor TMS 320 C 25 working on clock frequency of 40 MHz, 64 kB cache RAM, two 12 bits AD convertors with sampling rate 250 ksamp/seg. Using described equipment and the self calibrating method the estimated total stability of the system is 0.05 dB. The block diagram of the transmitter is in the Fig. 2.
Fig. 2: The transmitter block diagram

References:


This research has been conducted at the Department of Electromagnetic Field as part of the research project “The Experimental Equipment for the Verifying Conditions of the Electromagnetic Waves Propagation” and has been supported by CTU grant No. 10038273.
AUTOMATIC MEASUREMENT OF INELASTIC ELECTRON TUNNELLING SPECTRA

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Key words: tunnelling spectrometry, tunnelling spectrometer, automation

Inelastic electron tunnelling spectroscopy (IETS) is a modern analytical technique. Due to its high sensitivity, many applications are considered, such as studies of biomaterials or the study of ageing or adsorption mechanisms. We have used this technique for measurement of vibrational spectra of electric insulating varnishes for an analysis of adhesion mechanism and ageing. The main goal of our work is an automation of IETS measurement.

IET spectra were recorded by the lock-in amplifier using detection of the second harmonic response to the 2.6 kHz modulating voltage which has been applied across the junction together with a continuously varying DC voltage. The DC voltage has been obtained from DAC (digital to analog converter) and controlled by the notebook IPC Porta P5 (486DX2/66 MHz, 8 MB RAM).

DAC is a part of the expansion computer card PCA-1226 which is given by D/A and A/D converters (12 bits resolution) with a possibility of setting smoothly growing voltage (in 4096 steps) from zero to five volts. A junction was powered by the low-level pure sinus current (the AC voltage across the junction was 1.5 mV). For the measurement of the 2nd harmonic voltage across the junction the Lock-In amplifier SR 830 (Stanford Research) has been used. Lock-In has been connected via General Purpose Interface Bus (GPIB - industry standard IEEE-488) and has been controlled by the notebook IPC Porta.

Both expansion cards PCA-1226 and GPIB have been placed inside expansion docking station IPC DSP2. It contains two full size 16-bit bus slots for installation of AT-compatible expansion cards (PCA-1226 and GPIB), one port for a standard PC/AT desktop keyboard, one VGA port for connecting external monitor and internal power supply for IPC notebook. Advantages of the DSP2 are its dimensions and weight so it can be easily transferred.

Measured data have been stored by the notebook and processed by the software developed at the Department of Electrotechnology. The program has been written in programming language C (Borland International) using GPIB libraries (National Instruments Corp.).

The basic steps of program are:

1. Initialization of the GPIB expansion card and the Lock-In amplifier with checking of error occurrence.
2. Initialization of the PCA-1226 expansion card and setting the DAC output voltage to null.
3. Increasing the DAC output voltage about 1.2 mV.
4. The 2nd harmonic voltage is measured by the Lock-In amplifier and stored by personal computer.
5. Graphic processing of measured data.
6. Repeating from the step 3 until the maximum voltage is reached.
7. Storing data to a hard disc.

Main functions of the program are to control the DAC and the Lock-In amplifier, to store and process measured data, to load and display previously measured data, to display course of measurement in real time on computer monitor, and to export measured data into another applications such as Microsoft Excel and MathLab for further analysis.

Diagram of measuring system is presented in the Fig. 1.

![Diagram of measuring system](image)

**Fig. 1:**

References:


This research has been conducted at the Department of Electrotechnology as part of the research project "Evaluation of Electric Insulating Varnishes" and has been supported by GAČR grant No. 102/94/1480.
CONTACTLESS CURRENT MEASUREMENT

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Key words: current sensors, contactless measurements, current measurement

DC current sensors are usually based on Hall sensors in the airgap of the magnetic joke surrounding the conductor. The mentioned principle works well for the current clamps with 20 to 2000 A full-scale range and 1-2% precision. However, it is difficult to built current sensor small in size, having high resolution or high precision and/or having high full-scale range. Sensors based on Rogowski loops have problems with integrator DC stability. The present paper discusses non-standard methods and instruments for contactless measurement of DC and low-frequency AC currents.

Fluxgate current clamps. The sensor consists of two L-shaped ferrite parts with symmetrical winding and permalloy shielding. It is based on fluxgate principle: the magnetic flux created by the measured current causes asymmetry in the magnetic characteristic of the sensor core, which creates second harmonic component in the sensor excitation current. 0.1% linearity + hysteresis error, 0.01 mA p-p noise and long-term offset stability of 0.1 mA was achieved [1]. The shielding suppresses the external fields and close currents, but slightly degrades the sensor linearity and increases the sensitivity to the position of the measured conductor.

Magnetometric methods. This method is the only possible one when there is no direct access to the conductor, as in the case of underground cables. Parasitic currents flowing through the pipelines or building constructions as an effect of magnetic field variations may be also detected. In the case when not only the amplitude of the current, but also the position of the conductor is not known and eventually should be determined (full reverse problem), magnetometric method requires vector measurement of the magnetic field created by the current in at least two locations. Best method is to use fluxgate magnetometer. The sensors developed in our department have 100 pT p-p noise and 1 nT offset stability [2].

Large current detection by NMR. Magnetic field in the hole in cylindrical transducer of specific geometry is homogeneous and can be measured by a nutation method using NMR in flowing water. Small transducer developed at our department has 200 ppm uncertainty and can be used up to 5 kA. Using precise instrumentation, compensation for the back-conductor field and larger transducer size, 25 kA/100 ppm meter development is realistic.

DC/AC current comparator. Amorphous core DC current comparator with increased frequency range is in the development phase. The basic principle is similar to the mentioned fluxgate current clamp, but the more complex magnetic circuit results in larger precision: units of ppm error is typical. Detection core consists of two equal halves excited in opposite direction to reduce the first harmonic voltage induced in detection winding. Magnetic shielding reduces the penetration of the Earth field and suppresses the effect of core nonhomogeneity on the sensor linearity.
Magnetoresistor sensor array. A sensor array of 8 permalloy anisotropic magnetoresistors was used in the rose-like current transducer. The current has a resolution of 0.1 mA and large geometrical selectivity: 5 A false current located 10 cm apart of the sensor array axis causes 20 mA equivalent current response. Fig. 1 shows the transducer response on a 2 mA current step. Further improvement of the sensor resolution and stability and reduction of hysteresis and offset may be obtained using the flippling mechanism [3].

Fig. 1: Response of the current meter on 2 mA step

References:

This research was partially supported by the Grant Agency of the Czech Republic under No. 1197. The project will be proposed for CTU grant.
DYNAMIC TESTING OF A/D PLUG-IN BOARDS

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Key words: dynamic testing of A/D modules, effective bits measurement, sinewave curve fit test, virtual instruments

Knowledge of dynamic performance of A/D modules is necessary for application of these modules in complicated tasks. The dynamic quality of the used A/D converter is usually (in case of a sampling ADC) declared by a producer, but the dynamic characteristic of PC A/D plug-in boards or other A/D modules are not described in user manuals.

Number of effective bits is the most useful parameter for verifying dynamic performance of plug-in A/D boards. This parameter quantifies globally most forms of sampling errors, distortion and system noise in A/D board.

The effective bits test is performed using spectrally pure sine wave generator. A full scale sine wave from this generator is digitized by an A/D plug-in board. The measured data samples are recorded and used for calculation of the idealized best fit sinewave. The difference between the ideal and the measured waveform is assumed to be error.

The number of effective bits $n_{ef}$ is usually defined as follows:

$$
n_{ef} = n - \log_2 \frac{\text{rmse}_{actual}}{\text{rmse}_{ideal}}
$$

where $n$ - resolution of A/D converter, $\text{rmse}_{actual}$ - rms error of the digitized signal, $\text{rmse}_{ideal}$ - rms error of the ideal n-bit converter. The $\text{rmse}_{ideal}$ (assuming that quantization noise is uniformly distributed and quantization errors are statistically independent) is given by

$$
\text{rmse}_{ideal} = \frac{2^{-n}U_m}{\sqrt{12}}
$$

where $U_m$ - range of A/D converter and $\text{rmse}_{actual}$ is given by

$$
\text{rmse}_{actual} = \sqrt{E}
$$

where $E$ is calculated over the period of digitized data using the formula

$$
E = \frac{1}{N} \sum_{k=1}^{N} [X_k - A \sin(\omega t_k + P) - C]^2
$$

Parameters $A$, $C$, $\omega$, $P$ correspond to amplitude, offset, frequency and phase of the fitted sine wave. Formula (4) is used to find the best sine wave by minimizing error $E$ (see [1, 2]).
Two original algorithms were proposed for the parameter estimation of the idealized sine wave. The first algorithm operates iteratively in two steps:

1. Calculation of $A$, $P$, $C$ from recorded waveform using an estimate of frequency $\omega_0$
2. Calculation of more precise frequency value with parameters $A$, $P$, $C$ (Regula-Falsi method)

Iterative process is repeated until difference of two successive results is roughly zero.

The second algorithm is based on exact determination of frequency $\omega$ and application of the fixed frequency algorithm (see [3]). Both algorithms were tested by simulated waveform and comparable results were obtained. The iterative method gives a more accurate results but the time of calculation is much longer (detailed description in [4]).

The measurements performed proved that a dynamic performance of stand-alone sampling A/D converter (ADC) and that of a PC A/D plug-in board, which contains not only a ADC but also a multiplexer and an amplifier, is not identical.

In our case the dynamic quality of A/D modules is characterised by the dependence of effective bits on frequency. The partial results were presented in [4].

Software tools for data acquisition and processing were developed in LabWindows/CVI environment.

Testing is performed on boards from Meihaus, Axiom, Advantech and mainly on boards from National Instruments. The PC plug-in boards were tested in one channel mode, and in multichannel mode. Now we execute tests on Lab PC+ board from National Instruments.

The dependence of $n_{ef}$ on frequency of input signal of the ADC used on this board is known (it is described in factory manual for the converter ADS 774), so that we can compare the measured dependence with the dependence published by the producer.

Results of dynamic testing are very important in the development of high precision virtual instruments based on A/D plug-in modules.

References:

This research has been conducted at the Department of Measurement as part of the research project "The Investigation of Algorithms for Dynamic Measurements and the Specification of Methods for Estimation of Errors of These Measurement by the Use of PC Plug-in Board Systems" and has been supported by Grant Agency of the Czech Republic grant No. 102/93/0907.
PRESSURE INDICATOR WITH RESONANT SENSOR

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Key words: Pressure, Resonant Sensor, Measurement

A system for high-accurate measurement of absolute pressure of dry non-aggressive gases was developed. The system is based on resonant pressure sensor kept at constant temperature, which guarantees high accuracy, negligible hysteresis and excellent stability of the whole system. In this article, main features, design and performance of the system are discussed. Design of the sensor has been done in Mikrotechna Praha Ltd. Design of the electronic circuitry, software and performance measurement have been performed at CTU, Faculty of Electrical Engineering, Department of Measurement.

The simplified diagram of the system is shown in Fig.1. The measured pressure is led into the Pressure-to-Frequency Transducer unit, where are the sensor and auxiliary circuits. The output signal from the unit, which frequency is a function of the measured pressure, is connected to universal laboratory counter. Measured frequency is then transmitted via GP-IB bus to the PC computer, where the corresponding pressure is calculated and displayed. The software was written using C language in LabWindows environment.

As the sensing element of the system, the resonant pressure sensor DPT-A [1],[2] developed in Mikrotechna Praha Ltd. is used. The resonant element of the DPT-A sensor is a thin-wall cylinder made from ferromagnetic material, the resonant frequency of which is a known function of the pressure in the inner cavity of the cylinder.

The diagram of the transducer is shown on Fig.2. The cylinder of the resonant sensor is made to oscillate at its resonance point using two pairs of electromagnetic coils, which are connected to the amplifier. The amplifier has minimum phase shift to reduce its influence on the resonant frequency and automatic gain control to keep amplitude of the oscillations on constant level. Since the resonant pressure sensor has considerable temperature drift, it is kept on constant temperature 40degC by a simple two-state temperature regulator.

Performance of the system has been measured using pressure calibrators Druck DPI510 and DPI530. Results are shown in the following table:

<table>
<thead>
<tr>
<th>Pressure range:</th>
<th>0..600 kPa abs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure media:</td>
<td>dry non-aggressive gas</td>
</tr>
<tr>
<td>Accuracy:</td>
<td>better than 0.05% F.S.</td>
</tr>
<tr>
<td></td>
<td>the figure includes: non-linearity, hysteresis, ambient temperature changes</td>
</tr>
<tr>
<td></td>
<td>0.40°C and 7 days stability</td>
</tr>
<tr>
<td>Resolution:</td>
<td>0.002%</td>
</tr>
</tbody>
</table>
Fig. 1: System for pressure measurement

Fig. 2: Pressure to frequency transducer

References:


This research has been conducted at the Department of Measurement and has not been supported.
SYSTEM FOR ULTRASONIC RAILS TESTING AND ONE YEAR'S UTILISATION CONCLUSION

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Key words: rail, ultrasound, detectoscopy

There are many defects in rails especially in a transition zone bellow a rail head and in the upper part of the web. The surveys of these defects see [1, 2].

One of the serious defect is a doubling of the web. The thickness of this crack is very small. So we cannot obtain any reflected signal from that defect. We only find, that the reflected signal from the end of the rail's foot called "end" echo, is attenuated.

In addition transverse cracks (the so called kidney cracks) can occur in the head. They are especially dangerous because they can occur in groups over short distance and can therefore cause a short piece of rail to break out. These can be detected with angle probes. We used 70° angle probes facing in opposite direction from the rolling surface. This arrangement is the most suitable for detection of defects with different orientation.

To be able to detect the described defects we designed a combined probe. This probe assembly contains one direct probe and angle twins having already been mentioned.

The coupling face is made from plastic and has to be changed after several thousand kilometres. One liter of coupling water required for the testing of 1 km is contained in a plastic bottle.

The control system cyclically drives transducers of the probe and evaluates received echoes. The founded defect is indicated acoustically and also optically on a display of the device. The repetition rate of the transmitters is 1 kHz. It was chosen according to velocity of the probe movement relative to the rail.

The 8 bite's processor Z80 is the heart of this system. This unit contains time measuring circuits, interface, display, push buttons, input and output ports.

A menu offers so called "complex" mode when all transducers are cyclically excited. In "handy" mode the finding is done by a mean of one transducer. This mode serves for careful afterfinding or supervision of the defect that was already found.

The gain of amplifiers, the timing of transmitters' circuits and the blocking of unwanted echoes is processor controlled. The time window, called monitor, is independently set for each channel.

The distance of the defect from the rolling surface is determined by time delay of the received echo. This delay is compared to one, obtained a cycle before. The shorter delay means a defect.
What concerns of angle probes – received echo means a defect. Its distance is not measured.

The device is handled by four push buttons. The settled parameters are displayed. The defects are announced acoustically and by a mean of characters or signs on the display.

The described device together with proposed methodology offers exact evaluation of the position, character and orientation almost all defects of rails. This system is much quicker and simpler than system with screen. In one year’s application of this system a lot of new defects were discovered e.g. cracks lying in the head of the rail and transverse cracks of the Shalling type. The method of evaluation a flake was created and verified. Both mentioned methods are going to be homologated.

This system was designed and manufactured as diploma project. Two years of experimental and research work of student and his tutors were spent.

References:


This research has been conducted at the Department of Nondestructive Testing as part of the research project “Innovation of Devices and Technology for Nondestructive Testing of Rails” and has been supported by Czech Railways grant No. R-012-610446.
THE SATELLITE LASER RANGEFINDER FOR REMOTE SENSING OF THE EARTH


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Key words: satellite laser ranging, NASA, ESA, EUROLAS, geodesy, remote sensing, geophysics

The use of laser ranging to measure the distance of an Earth satellite is an attractive technique applied in geodesy, geophysics, remote sensing of the Earth and other applications. The laser ranging precision has been improved from one metre in the seventies to a subcentimetre value in 1991. This increase in precision has been obtained mainly by shortening the transmitted laser pulse, employing the higher resolution time interval meters and applying faster optical detectors.

In 1974 a cooperative program was undertaken by the Helwan Institute of Astronomy and Geophysics, the Czech Technical University, the Soviet Academy of Sciences and the Smithsonian Astrophysical Observatory, USA to set up a satellite laser ranging station in Helwan, Egypt. Since 1974 the quality and quantity of acquired data has continually improved, to the point where Helwan is now one of the fundamental stations in the global network and the only one permanently located on African continent [1]. The station was included in the EUROLAS network in 1992 [2]. The technical description is available at http://www.dgfi.badw-muenchen.de/edc/helwan.html. The existing SLR system [3], was unable to cope with future demands for accuracy of ranging and range of the high orbit satellites and will be replaced by a new system. The RMS of the normal point will be less than 10 mm with a range up to 20 000 km.

Recently the number of satellites and scientific projects and applications related to satellite laser ranging has increased dramatically. The new satellites ERS-1, ERS-2, Meteor 3, Lageos 2, Topex/Poseidon, Stella, GPS 35, 36, Glonass will serve, among others, global ecology studies, new positioning and navigation techniques and general relativity studies. In 1996 the Japanese space agency will launch the RIS experiment for atmospheric monitoring, using satellite laser ranging techniques.

To meet the growing demand on general station performance, ranging productivity, data quality and data interchange speed the station in Helwan has been upgraded during 1994-1995 under the joint auspices of NRIAG and CTU FNSPE.

According to the upgrade projects [4-6] presented at the 9th International Workshop in Canberra, Australia, November 1994, the objectives of the Phase A were to increase the maximal ranging distance up to 20 000 km by the introduction of visual guiding capability.
(full blind tracking until September 1995), to increase operation productivity by upgrading the control system, tracking mount system (step motors, no encoders until the end of June 1995) and improve the communication facilities (full SLIP Internet connectivity, two independent Internet channels from the end of June 1995). Phase A has been completed this year. Phase B objectives planned for 1996-1997 are to increase the ranging precision from 2-3 centimeter levels to the subcentimeter value and to participate in the upcoming scientific project.

The operation of the SLR station in Helwan was not interrupted during Phase A. Acquired data was daily delivered to EDC (EUROLAS Data Center) to support the requirements of the scientific projects. The SLR Helwan is operated by scientist from CTU FNSPE for four months each year.

More detail information concerning the SLR global network, satellites with laser retroreflectors, scientific projects and SLR data are available at URL:

http://www.dgfi.badw-muenchen.de/edc/edc.html (home page - EDC),
http://gds.esrin.esa.it/7c8651bb (ESA Earth Observation Guide & Directory Service)
and on WWW pages of the SGAPO GSFC NASA (The Space Geodesy & Altimetry Project Office, Goddard Space Flight Center NASA) at URL:


References:


This research has been conducted at the Department of Physical Electronics and at the SLR station Helwan. The joint research is supported by these grants:

1. Grant Agency of the Czech Republic 205/94/0440
2. National Research Institute of Astronomy and Geophysics, Helwan
3. European Space Agency
THE EXPERIMENTAL INTEGRATED GPS/GLONASS RECEIVER


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Key words: GPS/GLONASS

Satellite navigation is a very perspective and powerful means for position determination. User is able to determine his position by the receiving of signals from at least four navigation satellites. There are two usable satellite navigation systems at present. It is the American system GPS/NAVSTAR and Russian system GLONASS.

Both systems give precision of position determination within the order of tens of the meters, but this precision is unusable for some applications.

One method of improving results of satellite navigation is integration of both used systems GPS and GLONASS into one system. This integration can improve reliability and accuracy because of greater number of visible satellites.

Integrated GPS-GLONASS receiver, which is able to receive and process signals of both systems, is developed at our department. The receiver is based on LSI integrated circuits GP1010 and GP1020 made by GEC-PLESSEY Semiconductors. GP1010 is radiofrequency part of GPS receiver. It includes a low noise preamplifier, two mixers, IF amplifiers and two oscillators with PLL.

The integrated circuit GP1020 contains six parallel digital correlators which are able to proceed GPS and/or GLONASS signals. PC is used as a navigation computer, which controls receiver and process measured pseudodistances and pseudoranges to count the position of the user.

The input preamplifier and first mixer of the IC GP1010 is used for both GPS and GLONASS. The rest high frequency part of the GLONASS receiver is designed outside of the IC GP1010 (Fig. 1). The method of one bit quantization is user in the GLONASS receiver design. A full digital signal processing follows.

The frequency conversion of received signals to the GP1020 optimum frequency is provided by digital means. The signals of each satellite are not transformed to the same frequency because of complicated digital mixer circuit. The correction, which has to be done in this case, will be done by the software means. The GP1020 allows to use one mixer for up to three GLONASS satellites.

Two layer printed circuit board was designed. This BCP was made in DICOM, Uherské Hradiště by surface mounted technology.

The signals of GPS satellites was received for the first time in the beginning of November 1995. The development of navigation software will follow. The problem of union of the system time bases and different geodetic systems of coordinates have to be solved in a future.
Fig. 1: GPS/GLONASS receiver - architecture of the GLONASS part

This research has been conducted at the Department of Radioelectronics... as part of the research project “Integrated navigation receiver” and has been supported by CTU grant No. 10038286.
INFLUENCE OF THE CONSTRUCTION OF THE RADIOFREQUENCY PART OF THE NAVIGATION RECEIVER ON THE INTERFERENCE IMMUNITY

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Key words: GPS, GLONASS, interference

Navigation receivers with one bit quantization and sampling of the radiofrequency signals are often used in Eastern Europe. The following data processing is fully digital. This technically very smart and very simple solution has some drawbacks. We will discuss some drawbacks of this type of navigation receiver in our contribution.

There are a lot of ways how to study properties of mentioned receivers. The comparison of probability of correctly received code bit for different situations and configurations of the navigation receiver and different input signals is one of possible ways.

The probability of correctly received code bit can be expressed for a receiver with one bit quantization and with sampling at Shannon rate or below it by following expression:

\[ P_1 = \sum_{i=1}^{N-1} \binom{N}{i} p_v^i (1 - p_v)^{N-i} \]

N - number of samples during one code bit, \( p_v \) - probability of correct receiving of one sample.

The probability of correct receiving of one sample can be calculated from noise distribution function and level of input signal.

If the receiver with one bit quantization and the ideal receiver are compared for the same probability of receiving one code bit, a well known result will be obtained, that the first receiver is two decibel worse then the second one. The additive white Gaussian noise is assumed.

We developed method, which allows us to determine influence of interference of an additive noise with non-Gaussian distribution on one bit quantization receiver. Navigation receivers interferences are often common because the other satellites' signals, not received by considered channel of the receiver at the moment, appears to be source of non Gaussian noise. Let us notice that deliberation interference has non-Gaussian distribution function too.

The interference influences of input signal with the uniform distribution and deviation \( \sigma \) and input signal with the same deviation and with Gaussian distribution are compared on Fig. 1 (the noise background with Gaussian noise with deviation \( \sigma_W = 30 \) is considered on the input of the receiver).

The same situation as on Fig. 1, but with the alternating distribution is shown on Fig. 2.
Our method of calculation of navigation receiver parameters was used in design of conception of the radiofrequency part of the GPS/GLONASS navigation receiver. A chip set GP 1010 and GP 1020 by PLESSEY is used in our receiver. Because the GLONASS needs wider band for every satellite signal than the GPS, and IC GP 1020 does not support sampling by the needed rate, we discussed possibility of sampling of the input signal by lower rate than the Shannon rate too.

GLONASS receiver is more sensitive to interferences because of its wider bandwidth. RF part of such receiver is to be designed and optimized very carefully.

![Graph](image1)

**Fig. 1:**

![Graph](image2)

**Fig. 2:**

*This research has been conducted at the Department of Radioelectronics as part of the research project “Rozvoj a zkvalitnění výuky v oblasti letectví” and has been supported by CTU grant No. 35032011.*
THE PROPAGATION
OF ELECTROMAGNETIC WAVES
FOR CMR AND PCS

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Key words: propagation, CMR, PCS

The results of the first period of the work on the propagation prediction for the cellular
telephone and personal communication systems are presented. This work can be divided
into the theoretical studies with the software modelling and the experimental evaluation of
the models. We focused on the signal propagation in so-called microcells in urban areas.

The ray tracing approach was chosen to model signal propagation in the specific urban
area. Buildings are described by its ground plan and the height, the data available from
the common urban database. The building is considered to be consisted of square vertical
facets with a flat roof. Every facet includes information on its dimensions and position,
an electrical properties of a building material and a surface roughness. The ground is
considered flat. The vegetation and other terrain obstacles are not included in the model.
The ray tracing engine uses 2D/3D hybrid algorithm [1]. The ray with the reflection from
the ground is added to each ray found in 2D horizontal plane. There are three types of
the rays taken into account: the direct, reflected and diffracted rays. All combinations of
such rays between the transmitter and receiver are found. Number of possible reflections
and diffractions along the ray path is limited by the user. The transmitter antenna is
positioned below the rooftops level, so the rooftop diffraction is not dealt with. Reflected
and transmitted rays are evaluated using geometrical optics. Diffracted rays are calculated
using the geometrical theory of diffraction [2].

A helpful software tool, the CAD program for the design of point-to-point links, which
are also needed in signal distribution for modern communication systems, was developed.
It is described in [3, 4].

To obtain the exact geometrical and electrical description of the scene and to avoid
unpredictable outdoor interference and fades, laboratory experiments were chosen for the
first evaluation of the ray tracing software under development. The simple model of the
urban area was built in the laboratory using the scaling factor of about 25, considering the
frequency 900 MHz for the personal communications. The building walls were represented
by the panels with a smooth perfect reflective surface. Various ‘wall’ arrangements were
used. Two types of experiments were done [5]:

A. The scanning of the single incoming ray contributions with a directional receiver
antenna. Several measurements with the rotating horn on a turntable in different positions
and different site arrangements were done. The Fig. 1 shows one of the arrangements. All
reflected rays up to five reflections and first level diffracted rays are taken into account.
There was a good agreement between the theoretical ray incoming direction expectations
and the measured patterns.
The measurement with an omnidirectional receiver antenna moving along the line path in scaled street model. This experiment represents a signal coverage measurement. The fast fading effect caused by the complex field vector superposition on the omnidirectional receiver antenna could be observed.

Scaled laboratory experiment can be successfully used for the modelling of the signal propagation for the personal communication systems. The next step is the full implementation of the model into a user-friendly program. More experiments with a consideration of the whole system of orthogonal polarisation and the non perfect reflectors should be done. Special equipment for both indoor and outdoor experiments on 900 MHz is being prepared.

References:


This research has been conducted at the Department of Electromagnetic Field as part of the research project “The Propagation of Electromagnetic Waves in CMR and PCS” and has been supported by CTU grant No. 10038272.
ANALYSIS OF SLOTLINE DISCONTINUITIES AND RESONATORS

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Key words: uniplanar circuits, slotline discontinuities, slotline resonator, modelling

Short- and open-circuited slotline stubs and resonators are widely used in uniplanar MICs. Results of their analysis we have achieved in 1995 are presented in this paper.

Investigated slotline discontinuities and resonator are shown in Fig. 1. They are analysed by the well known spectral domain method (SDM). The area of slots and slot patches in each structure is divided into cells by rectangular mesh. The tangential electric field is then described by a sum of proper basis functions defined on each particular cell. One of the field elements is imposed by known amplitude while the other ones are determined in dependence on this excitation. Using the Galerkin's method a set of linear algebraic equations for unknown amplitudes of the basis functions is obtained. Least squares method (LSM) applied to the resulting standing wave pattern along the slotline provides the reflection coefficient of the termination. For the slotline resonator the procedure has to be modified. In the sourceless case the final set of equations is homogeneous and has non-trivial solution when the determinant of the system matrix equals zero. Accomplishment of this constraint provides the complex resonant frequency. Once this is known impedances terminating the slotline resonator at both ends can be determined by means of the transmission line theory.

Numbers of different short- and open-circuited slotline terminations shaped according to Fig. 1a-c and made on substrate 1.27/0.635 mm thick with permittivity 11 were investigated both theoretically and experimentally [2, 3, 5, 6]. Calculated normalized impedance of the short-circuited slotline is drawn in Fig. 2, where \( h \) is substrate thickness, \( W \) is slot width. An exact model of this structure using SDM is not suitable for setting into CAD packages. For that a set of calculated normalized terminal impedances has been fitted by the LSM and resulted in their closed-form formulae [5, 6]. Short-circuited slotline resonators, Fig. 1d, were manufactured on the same substrate as above and their resonant frequencies and quality factors were calculated and measured [4, 7]. A few results referring to short-circuited slotline resonator are in Tab. 1.

New achieved results were presented at seven international conferences (4 abroad, 3 inland) and published in their proceedings [1-7]. Suitability of the SDM for modelling of terminal impedances has been demonstrated. New facilitated calculation of the reflection coefficient of one port discontinuity has been presented. Closed-form formulae for CAD of short-circuited slotline have been provided. Conception of complex resonant frequency has been applied first to unshielded short-circuited slotline resonator. Agreement of calculated and measured characteristics of investigated circuits have been found out. It is assumed that the next stage of the project will be devoted to investigation of further slotline discontinuities frequently used in uniplanar circuits.
Fig. 1: Slotline terminations and short-circuited slotline resonator

Fig. 2: Normalized resistance and reactance of the short-circuited slotline

<table>
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<tr>
<th>L (mm)</th>
<th>f = f₁ + jf₁ (GHz)</th>
<th>Q₁</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>fₘ = fₘ₁ + jfₘ₁ (GHz)</th>
<th>Qₘ</th>
<th>Δf₁ (%)</th>
<th>Δfₘ (%)</th>
<th>ΔQ (%)</th>
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<td>14.95</td>
<td>4.308+j0.0352</td>
<td>42.11</td>
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<td>1.04</td>
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<td>6.46</td>
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<tr>
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<td>15.35</td>
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<td>14.340+j0.4813</td>
<td>13.81</td>
<td>1.37</td>
<td>9.14</td>
<td>10.03</td>
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Tab. 8: Calculated f₁, Q₁ and measured fₘ, Qₘ complex resonant frequencies and quality factors of the short-circuited slotline resonators.

References:


This research has been conducted at the Department of Electromagnetic Field as part of the research project "Analysis of Uniplanar Waveguiding Structures" and has been supported by CTU grant No. 10038202.
THE 37 GHz SHORT DISTANCE EXPERIMENT

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Key words: propagation, microwave

The Short Distance Experiment for measurement of the attenuation electromagnetic waves at 37 GHz frequency range and the results are described below.

Raindrops cause the absorption and scattering of the electromagnetic waves what is appeared as increasing of attenuation. The attenuation $A$ as a function of a rainrate $R$ is expressed satisfactorily by the functional form

$$A = a R^b$$

where $a$ and $b$ are tabulated coefficients for given frequency range and polarisation [1].

The measuring system consists of the transmitter (vertical polarization) and the receiver (vertical polarization); distance between them is 52 m. The raingauge, the control unit and the PC for storing the data are also components of this system. The measure devices are situated 35 m above the terrain at roofs of building CTU. The detail description of the system is in [2, 3].

The system was built up and the experiment started during spring 1994. The measurement started work in noncontinuous operation (when a rain started the system was switched on and when a rain stopped, the system was switched off). Disadvantage of this operation was that the data on beginning of measurement (several minutes) were devalued by changing of parameters of receiver and transmitter until were achieved working temperature. It was reason to change operation of measurement on continuous operation, that removed this disadvantage.

Measuring of the attenuation in the experimental line in non rainy days showed fluctuations of the attenuation [4]. These fluctuations are probably caused by the temperature dependence of receiver and transmitter and represent limit of measurement of the attenuation due to mild rains.

Measured data including the attenuation and intensity of the rain are stored and statistical processed. Distribution of the attenuation is affected by the fluctuation of system, but is evident increasing of the mean value of everyday attenuation versus the mean value of the attenuation of the days without rain. Distribution of the intensity of rain shows very fast decreasing of probability high intensity rains. Example of the distribution of the intensity of rain is shown in Fig. 1.

Accuracy of attenuation caused by rain in 37 GHz frequency range is influenced by fluctuation of measuring system, but statistic processing of measured data shows increasing of mean value of attenuation.
Fig. 1: Time distribution of rain intensity for 4 months (June–September 1995)

References:


This research has been conducted at the Department of Electromagnetic Field as part of the research project "The experimental equipment for the verifying conditions of the electromagnetic waves propagation" and has been supported by grant CTU No. 10038273.
THE COMPUTATION OF THE SCATTERED FUNCTION FOR THE COMPLEX PERMITIVITY OF RAIN WATER AT 37 GHz

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Key words: propagation, attenuation, rain

By using of higher frequency ranges (the millimeter wavelengths domain) for the signal transmission the fade effects occurs. They cause the attenuation and the crosspolarization in the receiver side. The rain is one of the worst factor participating in that. The rain particles have comparable size with the wavelength in this millimeter wavelengths region and the diffraction appears.

That should be possible to determine the total rain attenuation, there is a necessity to compute the partial attenuation of the raindrops of the single size and the form [1] from the reason of the rain inhomogenity. Then these partial attenuations are summarized according to the pattern of the single size density at volume unit according to the raindrops size for the definite rain rate.

The determination of the scattered function, which is giving the certain scattered field to the certain direction for certain size of the raindrop, is the base for the attenuation computation. This function depending generally on the shape and the material properties of the given obstacle is determined by means of the used numerical method. Since the scattered function was computed, there had been a necessity to give the material properties (the complex permittivity) of the rain water because of the nonuniform references of this field. That is why the microwave measurement of the rain water complex permittivity was taken. This measurement at principle similar to the waveguide measurement of the solid material complex permittivity [2] was performed by using R220 waveguide and 37 GHz frequency band under 20 °C temperature. The complex permittivity values were computed from the measure data and the average value was find as 2.7154 + i 0.03294 under conditions given above. The scattered functions were computed by means of The 3D Electrodynamic Wave Simulator [3], which is based on the Multiple MultiPole method. These functions were computed for raindrops with the effective radius 0.25, 0.50, ..., 3.50 mm for both the vertical polarization $E$ (the electric field) and the horizontal polarization $E$ of the incident wave.

The main goal of this research is to evaluate the rain attenuation in dependence on the different patterns of the raindrops density at the volume unit (according to the raindrops size and the rain rate) and to propose the prediction of the rain attenuation at 37 GHz range. The prediction will be verified by results of the short terrestrial link measurement at 37 GHz running currently at the department.
Fig. 1: The pictures show the patterns of the average time values of the electric field (left), the average time values of the Poynting vector (right) for vertical polarization of electric field for raindrop with radius 3.5 mm, after plane wave incidenting at 37 GHz.

References:


This research has been conducted at the Department of Electromagnetic field as part of the research project “The Electromagnetic Compatibility at Microwave Transmission Link and at the Nonlinear Microwave Elements Research” and has been supported by GACR grant No. 102-93-0937.
THE MATERIAL DIELECTRIC CHARACTERISTIC MEASUREMENT

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Key words: microwave measurement, permittivity

Different methods of the measurement of the dielectric characteristic of materials available at the Department of Electromagnetic Field (DEF) of CTU are listed. Special attention is devoted to the broadband microwave measurement using the correction method for the waveguide measurement of reflection and transmission coefficient and discussion of the determining of the complex permittivity components.

The dielectric characteristic of materials can be measured by different methods which differ by an accuracy, frequency band, system of measurement (waveguide, resonator, coaxial, free space) etc. The methods are: the direct complex permittivity components measurement or their calculation from the material reflectivity and transmissivity measurement.

A. The waveguide method of the complex permittivity measurement available at the DEF:

1. Waveguide single frequency method of measurement by [1] including the appropriate software for numerical processing of the measurement results is available on single frequency in the frequency bands 4-6 GHz, 6-8 GHz, 8-12 GHz, 12.4-18 GHz, (35-37 GHz, 90-110 GHz).

2. Waveguide broadband method of measurement using the HP 8410 system was developed at the DEF. This method is based on the automatic PC controlled vector network analyser with HP8410 [2] including the correction methods [3]. Waveguide test sets for this measurement are in frequency bands 4-6 GHz, 6-8 GHz, 8-12.4 GHz, 12.4-18 GHz available. This measurement produce the measurement of reflection and transmission coefficients (S matrix). After the processing (using the correction methods based on the precision calibration) the accuracy of these parameters measurement is better then 1%. The next step is the calculation of complex permittivity components. It is necessary to include the correction of the frequency dependent of waveguide characteristic impedance. Especially it is necessary to include the change of the waveguide diameters between individual bands. The synthesis of the layered (low-reflection) media can due to the software [4] be done.

B. Free space reflectivity level measurement. This can be used for the total reflectivity level of the layered media measurement as well as for the reflectivity level of anechoic chambers testing. Generally speaking, the reflectivity level varies with position, polarisation and frequency and also depends on transmitting and receiving antenna radiation patterns.
If the receiving level $a$ [dB] will due to the reflections vary between levels $b$, $c$ [dB], the total reflectivity is then given by

$$R = \frac{E_r}{E_i} = A \frac{B - 1}{B + 1}$$

where $A = 10^\frac{a}{10}$ and $B = 10^\frac{b+c}{10}$.

Free voltage standing wave ratio (VSWR) is one of the methods which can be used [5]. The source antenna is pointed to the measured surface. The probe antenna is moved linearly along the surface and the interference pattern due to the direct and reflected field is recorded. In the anechoic chambers the movement is usually transverse to the line between the antennas but it could be as well as longitudinal. From the maximum ripple, $b - c$, of the received power reflectivity level can be calculated using equation above.

The total accuracy of the wave guide methods depends on the calibration set up and on the precision of the dimension of the materials under the test. The vector measurement allow to calculate the complex permittivity components. The free space methods need good attenuator, and/or linearity of the receiver. The negative influence of the antenna pattern can be solved by choosing a source antenna having higher gain and lower sidelobes with a good polarisation purity e.g. corrugated horn antenna.

The method described above are available at the Department of Electromagnetic Field of the CTU in Prague [6, 7]. The comparison of the single frequency measurement with broadband correction method measurement and calculation with proper software processing is a good way to study the material properties and to support the synthesis and practical design of layered structures.

References:


This research has been conducted at the Department of Electromagnetic Field as part of the research project “Non Reflective Layered Media in 1–100 GHz Band” and has been supported by CTU grant No. 8191.

The development of the correction method applied on the HP8410 has been supported by Grant Agency of the Czech Republic, grant No. 102-93-937 (“Electromagnetic Compatibility in Microwave Transmission Systems...”)
FIRST EXPERIENCE WITH USING A VME SYSTEM FOR MEASUREMENT

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Key words: VME, OS/9, dynamical measurement

Systems with VME-bus are developing, measuring and control systems for industrial use, which are usable in a number of different applications. General advantages of VME-bus are: high rate of data transfer (40 Mbyte/s), high noise and vibration immunity, and a structure, corresponding to real time operating system (multiuser, multitasking). From these characteristics it follows that these systems are advantageous for real time measurement and data processing in industrial processes, especially in the case, when IBM PC/AT compatible computers do not match speed and noise requirements.

The system at our disposal at Department of Measurement contains two types of measuring boards: VMEbus board VAN8 and VMEbus carrier board for MODULbus boards. To this carrier it is possible to attach simple MODULbus boards, which can also be attached to IBM PC/AT compatible computers via PC/AT carrier board. The general advantages of MODULbus boards (low price and wide offer of modules with different functions) are outweighed by their excessive simplicity (no internal timer, no FIFO buffer, an external trigger signal cannot be used etc.). We use them to compare the quality of using these simple MODULbus boards at the VME system with that of the IBM PC/AT compatible computer. The boards are compared from following points of view: internal noise, jitter, sampling rate, number of effective bits etc. The first experiences have shown, how many problems can arise.

MODUL bus boards used for the first tests are following:

8E8: 8 SE analog inputs, 8-bit resolution, conversion time 1 μs, end-of-conversion interrupt, 8-channel multiplexer
12E8: 8 differential analog inputs, 12-bit resolution, conversion time 12.5 μs, end-of-conversion interrupt, 8-channel multiplexer.

Following problems were observed:

1. Measurement of maximal sampling rate with software triggering. The maximum sampling rate is given by the speed of A/D converter or by the speed of the measurement system, if this system is slower than the A/D converter. There are no timer or trigger input to use a hardware trigger, but the software trigger command has to be used. For evaluation of the sampling rate a short program loop was used (as short as possible). There is a trigger command in this loop for initializing the conversion. The sampling rate was determined from the number of samples per signal period.
2. Measurement of a jitter. The next consequence of software triggering is the time uncertainty between two samples. This jitter can arise owing to memory refresh or interrupt routines delay during sampling loop (some of RTOS minimize this influence). The ramp waveform signal was used for estimation of this kind of jitter. In ideal case \( u_n - u_{n-1} = \cdots = u_2 - u_1 = \Delta u \), where \( u_1, \ldots, u_n \) are \( n \) samples per period of the ramp waveform. There is a long term nonlinearity, in the fact, but it can be determined using the sampling of a great number of periods. Because the influence of jitter and internal noise have a random or pseudorandom character, the difference between two successive samples without noise and jitter influence can be defined as

\[
\overline{\Delta u_i} = \sum_{j=1}^{m} \Delta u_{ij} = \sum_{j=1}^{m} (u_{i,j} - u_{i+1,j}) \quad i = 1, \ldots, n - 1
\]

The internal noise can be determined for low rise speed of ramp. Then the of standard deviation of delta \( u_{ij} \) for measurement using the ramp with maximal useable rise speed and low rise speed can be considered as the influence of jitter.

3. Measurement of internal noise. Internal noise arises owing to emission of electrical components and circuits placed in the measurement system (VME, PC/AT, etc.). The value of internal noise depends on the arrangement of input circuit and on the resistance of signal source or on the resistance, which is connected between low and ground terminals (for differential input only). From this reason the measurement of internal noise were realised for different values of resistors, which were connected between input and ground terminals (SE input) or high and low terminals and low and ground terminals (differential input) (see [1]).

4. Measurement of the number of effective bits. This method of determination of dynamic quality of A/D conversion implicates influences of both jitter and noise (see [2]).

All the above mentioned measurements were performed for identical MODULbus boards placed on both VME and PC systems. All results of testing will be presented at Workshop'96.

References:

[3] JANZ COMPUTER AG: VAN8, 12E8, 8E8: Hardware references

This research has been conducted at the Department of Measurement as part of the research project “The Investigation of Algorithms for Dynamic Measurements and the Specification of Methods for Estimation of Errors of These Measurement by the Use of PC Plug-in Board Systems” and has been supported by Grant Agency of the Czech Republic grant No. 102/93/0907.
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