PART II.

PART II.

These are the Proceedings of the Fourth Annual university-wide seminar WORKSHOP 95 which will take place at the Czech Technical University in Prague from 23-26 January, 1995.

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 more than 420 contributions divided into 21 different areas of interest.

The program for WORKSHOP 95 consists of an introductory plenary session followed by four concurrent sessions: A, B, C and D.

Part II has contributions in the areas of:

- mechanics in engineering
- theory of construction
- materials engineering
- power systems, electrical engineering & power supply
- communication engineering

Organizing committee:
Chairman: V. Weiss
Co-chairman: J. Jan

Prague, December 1994

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CONTENTS

7. MECHANICS IN ENGINEERING

STRAIN GAGE TRANSDUCERS FOR MODEL INVESTIGATION AND MEASURING IN SITU IN GEOMECHANICS .......................... 327
S. Holý, J. Skořepová

ON AN ANALYSIS OF STRAINS IN MICROSTRUCTURES ............... 329
L. Berka, M. Růžek, M. Sova

THE ELASTOPLASTIC PROBLEM IN UNIDIRECTIONAL COMPOSITE ........ 331
P. Šlapák

A CONTINUUM DAMAGE MODEL FOR COMPOSITES .................... 333
M. Černý

LOW-CYCLE FATIGUE DUCTILITY ........................................ 335
P. Brož

YIELD LINE ANALYSIS OF STEEL PLATES BY FINITE ELEMENTS II .... 337
M. Tocháček

PLASTIC EFFECTIVE WIDTH ................................................ 339
M. Eliášová

FEM ANALYSIS OF THE JOINTED CONCRETE PAVEMENT ............... 341
B. Novotný

EXPERIMENTAL ANALYSIS OF COMpressive STRAIN – SOFTENING IN CONCRETE ................................................. 343
P. Konvalinka, Z. Bittnar, K. Kolář

STRAIN SOFTENING OF CONCRETE IN COMPRESSION .................. 345
Z. Bittnar, P. Bouška, O. Löwitová

POSITION DEPENDENT TENSION STIFFENING IN CONCRETE ......... 347
P. Řeřicha

OPTIMIZATION OF STRUCTURES BY METHOD OF EVOLUTION STRATEGIES ......................................................... 349
D. Novák, Z. Keršner

STATISTICAL AND SENSITIVITY ANALYSES OF STEEL FRAME ........ 351
E. Hebedová, M. Karmazínová, Z. Keršner, M. Šmak

BRIDGE'S SERVICE LIFE ..................................................... 353
J. Culík

FAILURE MECHANICS OF JOINTED ROCK MASS ......................... 355
J. Vacek, P. Procházkova
ANALYSIS OF SOME EXPERIMENTS CARRIED ON CAM CLAY MODELLING .................................................. 357
P. Kuklik, J. Záleský

USE OF FREE SOFTWARE IN RESEARCH AND EDUCATION OF POST-GRADUATE STUDENTS .................. 359
P. Kryšl, Z. Bittnar

OBJECT-ORIENTED EXPLICIT FINITE ELEMENT COMPUTATIONS .......... 361
R. Chudoba, P. Kryšl

ANALYSIS OF STRUCTURES USING OBJECT-ORIENTED APPROACH .... 363
J. Kruis, B. Patzák

DAMPING OF ROLLING GUIDEWAYS OF MACHINE TOOLS ............... 365
M. Kral, J. Houša, P. Bach, J. Dvorak

STATIC STUDY OF THE DERAILMENT PROCESS IN CURVED TRACK .... 367
J. Šiba, T. Heptner, J. Koldář

DYNAMICS OF FLEXIBLE MULTIBODY SYSTEMS .......................... 369
M. Valašek, J. Znamenáček, T. Vampola

TESTING OF MULTIBODY SYSTEM VIBRATION .......................... 371
J. Svoboda

COMPUTER AIDED FLEXIBLE MODELLING OF MULTIBODY SYSTEMS ... 373
M. Valašek, V. Stejskal, T. Vampola, J. Znamenáček, O. Vaculín, Z. Šík, V. Bauma

ANALYSIS OF STATIC COMPLIANCE AND MODAL PROPERTIES OF A SU16 LATHE ........................................... 375
S. Stejskal, V. Bauma, P. Bach, M. Kral, D. Houdek, J. Houša, V. Stejskal

BEHAVIOUR OF LINEAR GUIDE SYSTEMS BY USING ADDITIVES FOR OILS ......................................................... 377
L. Preisler, S. Urbánek, J. Houša

MULTIPLE MODEL METHOD IN EXPERIMENTAL MODAL ANALYSIS .... 379
J. Dvorak

PROBLEMS OF THE DYNAMICS OF MACHINE AGGREGATES .......... 381
J. Vondřich, J. Kůš, S. Jirká

STRENGTH MODELS OF LINEAR HYDROMOTORS .......................... 383
K. Vitek

8. THEORY OF CONSTRUCTION

SERVICE LIFE PROLONGATION OF HARMONIC DRIVE UNITS .......... 387
L. Jančík, Z. Bauer, V. Dynghyl, J. Kanaval, R. Němec
WORKSHOP 95

CONTENTS

STRUCTURAL PERFORMANCE OF COMPOSITE REINFORCED CONCRETE SLABS WITH RESPECT TO CREEP AND SHRINKAGE OF CONCRETE .......................................................... 389
J. Navrátil, M. Lavický

NEW METHODS OF NONDESTRUCTIVE INSPECTION OF REINFORCEMENT IN FERROCONCRETE STRUCTURES ....................... 391
O. Anton

PUNCHING SHEAR FAILURE OF CONCRETE SLABS ....................... 393
P. Bouška, M. Novák, O. Sutner

ATMOSPHERIC BOUNDARY LAYER WIND TUNNEL FOR TESTING BUILDING STRUCTURE ........................................... 395
J. Kříž

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF STEEL SLENDER WEBS UNDER REPEATED SHEAR LOADING .................. 397
M. Novák, O. Lőwittová

HYPOTHESIS OF STRUCTURAL FAILURE OF MASONRY UNDER IMPACT LOAD .................................................................. 399
D. Makovička

ENVIRONMENTAL EFFECTS ON SHRINKAGE OF BRIDGE SEGMENTS ...... 401
J. L. Vítek, B. Barr

STUDS IN COMPOSITE BEAMS - SIMPLIFIED MODELLING .............. 403
J. L. Vítek

INFLUENCING FACTORS ON DEFORMATIONS OF PRESTRESSED CONCRETE BRIDGES .................................................. 405
P. Vítek, J. L. Vítek

IDENTIFICATION OF ENGINEERING STRUCTURE MODEL ............ 407
M. Polák

DYNAMIC BEHAVIOUR OF SYSTEM RAILWAY BRIDGE-VEHICLE ........ 409
V. Bílý

CONCRETE REINFORCED WITH DIFFERENT KINDS OF FIBRES .......... 411
J. Kratky, K. Trlik, J. Vodička

A PROBABILISTIC APPROACH TO THE STEEL FRAME, FOUNDATION AND SOIL INTERACTION ......................................... 413
F. Wald, M. Pultar, J. Kos, Z. Sokol, D. Jarůšková, J. Vítek

THE INFLUENCE OF AXIAL FORCE ON THE COLUMN-BASE STIFFNESS .... 415
F. Wald, I. Šimek, Z. Sokol, J. Pertold

TRIANGULATION OF 3D CAD SURFACES .................................. 417
P. Krystl, D. Rýpl

317
9. MATERIALS ENGINEERING

COUPLED MODELING SOLUTION OF STRESS IN ROCK MEDIUM ........... 421
V. Doležel, P. Procházka

MONTE-CARLO SIMULATION IN ELECTRON PROBE X-RAY MICROANALYSIS (EPMA) .................................................. 425
V. Starý

RELIABLE SURFACE RECONSTRUCTION BASED ON STEREO PAIRS OF SEM IMAGES .................................................. 427
D. Janová, J. Jan

MATHEMATICAL MORPHOLOGY IN COMPUTER AIDED FRACTOGRAPHY ................................................................. 429
P. Kodl, M. Blahout

SCANNING TUNNELING MICROSCOPY ....................................... 431
L. Beneš, J. Švejcar

MEASUREMENT OF THIN VARNISH LAYERS BY THE USE OF TUNNELLING SPECTROSCOPY .............................................. 433
P. Mach, M. Kuška, M. Kubečka

THE CRYSTAL STRUCTURE OF THE SYNTHETIC NaX & ZK5 ZEOLITES DETERMINED FROM NEUTRON POWDER DIFFRACTION DATA ............. 435
M. Dlouhá, S. Vratislav, D. Janeba, V. Bosáček

STRESS GRADIENT DUE TO POLISHING AND SHOT-PEENING ........... 437
N. Ganev, I. Kraus, G. Gosmanová

EFFECT OF REMELTING ON MECHANICAL PROPERTIES OF WELDS IN Cr-Ni-Mo MARAGING STEELS ................................. 439
J. Janovec, K. Macek, R. Husak

MECHANICAL BEHAVIOUR OF A STAINLESS MARAGING STEEL AT ELEVATED TEMPERATURES ........................................ 441
K. Macek, J. Sasko, P. Špíka

INFLUENCE OF THE DEFORMATION CONDITIONS ON THE DYNAMIC AND POSTDYNAMIC DEHARDENING PROCESSES .................... 443
P. Zuna, F. Hušilka, P. Stará, V. Stary

MECHANICAL PROPERTIES OF UHSLA 300M STEEL .................... 445
L. Bartík, J. Pokluda

CYCLIC CREEP OF HIGH TEMPERED LDHA POLO D STEEL ............. 447
L. Bartík, J. Pokluda
STUDY OF MATERIALS FOR MULTIPHASE ELECTRO-CHEMICAL SYSTEMS ................................................................. 449
J. Kazelle, M. Cenek, J. Cihlář, J. Havel, R. Aušrata

NEW MAGNETIC MATERIALS FOR MEASUREMENT TECHNOLOGY .......... 451
P. Ripka, K. Dražler, P. Kaspar, J. Roztopil, R. Kasal

THE INFLUENCE OF THE PALLADIUM DIFFUSION ON CARRIER LIFETIME IN POWER DIODE STRUCTURES ........................................... 453
D. Štěpáková, V. Benda, J. Fušková

INFLUENCE OF ENVIRONMENT AND STRUCTURE ORIENTATION ON FATIGUE CRACK GROWTH IN AlZnMg ALLOY (PART I) .................. 455
J. Stehlík, P. Kopriva, I. Nedbal, J. Kunz

INFLUENCE OF ENVIRONMENT AND STRUCTURE ORIENTATION ON FATIGUE CRACK GROWTH IN AlZnMg ALLOY (Part II) .................... 457
J. Stehlík, P. Kopriva, I. Nedbal, J. Kunz

FATIGUE CRACK GROWTH UNDER HIGH STRESS RATIO .......................... 459
V. Oliva, L. Cséplő, A. Materna, I. Kuneš

COMPUTATIONAL ANALYSIS OF THE FATIGUE FRACTURE SURFACE (COMPUTER AIDED FRACTOGRAPHY) ................................................. 461
M. Blahout, M. Kusmirek

INJECTION MOULDING OF ALUMINA CERAMICS FOR MEDICAL APPLICATIONS .......................................................... 463
J. Cihlář, M. Trunec

THERMOPLASTIC BINDERS FOR INJECTION MOULDED CERAMIC SUSPENSIONS .......................................................... 465
M. Trunec, J. Rozsa

INTERACTIONS OF NICKEL AND TITANIUM ALLOYS WITH SINGLE-CRYSTAL ALUMINA .................................................. 467
K. Maca, J. Cihlář

STRENGTH OF CERAMICS .............................................................. 469
B. Vlach, M. Trunec, M. Reinisch, R. Hudc, L. Váčka, I. Dloubý

MICROWAVE QUALITY TESTING OF CERAMIC MATERIALS ...................... 471
V. Papež, V. Benda

GERM-GRAIN MODEL OF SHORT FIBRE COMPOSITES ............................... 473
K. Pelikán, J. Sazí, P. Poníšek

MODELLING OF PERCOLATION PROCESSES IN SHORT-FIBRE COMPOSITES .......................................................... 475
P. Poníšek, K. Pelikán

FIBRE LENGTH REDUCTION IN THE POLYMER MATRIX DURING EXTRUSION .......................................................... 477
D. Dospíšil, P. Sáha, J. Šváblík

319
THE EFFECT OF WATER ABSORPTION ON THE DYNAMIC PROPERTIES OF KEVLAR-EPOXY COMPOSITE ........................................... 479
Z. Korinek, Z. Jeníkova, V. Zilvar

THERMAL FATIQUE SPALLING OF YPSZ PLASMA SPRAY COATINGS ........... 481
J. Švejcar, J. Zeman

ION BEAM TECHNOLOGIES ..................................................... 483
L. Dittrichová, T. Šikola, D. Janová, F. Matějka

INFLUENCE OF THE SURFACE LAYER AND OF THE NON-LOCAL EFFECT ON THE STRENGTH OF BODIES ........................................... 485
V. Kvet, V. Kajka, J. Cejv, V. Stary, F. Hnilica, J. Jeník

EQUIPMENT FOR DIAGNOSTICS OF THE CONTACTS QUALITY .................. 487
P. Mach

METHODOLOGY OF ELECTRIC INSULATING VARNISHES TESTING ............... 489
P. Mach

SULPHUR CONCRETE .................................................................. 491
J. Dohnálek

REASONS FOR THE IMPROVEMENT OF CONCRETE STRUCTURES ............... 493
I. Šímařek

EFFECT OF CLOSELY-SPACED REINFORCEMENT ON CRACK RESISTANCE OF CONCRETE ..................................................... 495
V. Weiss

THE DEVELOPMENT OF EXPANSION MATERIAL ................................... 497
J. Bydzovsky, R. Drochytka, B. Bártova

EVALUATION OF IMPERIABILITY OF CONCRETE WITH SURFACE TREATMENT BY IMPREGNATION COATING ................................. 499
T. Klecka, J. Kolisko

APPLICABILITY OF THE SURFACE HARDNESS METHOD FOR STRENGTH DETERMINATION OF CONCRETE EXPOSED TO ENVIRONMENT ............................................................. 501
P. Fidranský

GENERALIZED RELATIONSHIP BETWEEN TENSILE SPLITTING STRENGTH OF CONCRETE AND FRACTURE AREA SIZE ......................... 503
S. Modrý, V. Kadleček

STRAINS OF STEEL FIBRE REINFORCED CONCRETE UNDER LONG-TERM LOAD ................................................................. 505
J. Vodička, K. Trtík, J. Kratky, H. Dudrova

CONTRIBUTION TO THE RESEARCH OF AGEING OF NPP'S CONTAINMENTS ................................................................. 507
V. Tydlitlil, V. Vydra
MEASURING THE WATER VAPOR DIFFUSION IN DEKALUX ................. 509
Š. Hošková, J. Toman, R. Černý

10. POWER SYSTEMS, ELECTRICAL ENGINEERING & POWER SUPPLY

THE OPERATION OF INTERCONNECTED SYSTEMS ......................... 513
J. Tůma, J. Doležal, F. Fend, J. Thustý

RELIABILITY OF POWER EQUIPMENT INSULATING SYSTEMS .............. 515
F. Wohlmuth

ECONOMICS AND MANAGEMENT OF ELECTROENERGETICS ................. 517
J. Dudarkin, M. Jeeger, F. Jirsa, J. Šáva, J. Vastl, J. Vašiček, M. Vítek, B. Wilmann

NEW TECHNOLOGIES OF ENERGY PRODUCTION AND CONSUMPTION WITH MINIMUM IMPACT ON ENVIRONMENT ..................... 519
J. Kadonožka, L. Ochrana, J. Vaverka, J. Plch

THE USE OF ALTERNATIVE ENERGY SOURCES AND WATER SAVINGS IN SCHOOL BUILDINGS ..................... 521
K. Brož

OPTIMUM ENERGY UTILIZATION OF THE BROWN COAL ..................... 523
F. Jírůš, T. Dlouhý

HARDWARE FOR ENERGY CONVERSION FROM ALTERNATIVE SOURCES ... 525
T. Cetl, M. Klečka, K. Kunzel, S. Seborský, J. Žáček

ELECTRIC GENERATORS FOR WIND POWER STATIONS ..................... 527
J. Janoušek, P. Voženílek

FIRST EXPERIENCE WITH MAGNETIC BEARING ............................. 529
J. Focelka, J. Jara

DYNAMICAL CHARACTERISTICS OF A FLEXIBLE ROTOR SUPPORTED BY MAGNETIC BEARING ............................. 531
S. Stejskal, J. Znamenáček, J. Březina

THEORY AND DESIGN OF MAGNETIC POWDER SHAFT SEAL ................ 533
J. Fiedler

RECENT PROGRESS IN ENGINEERING THERMODYNAMICS RESEARCH .... 535
V. Vacek, M. Lisal

START OF A RAIL VEHICLE RIDING ON A MAGNETIC CUSHION AND DRIVEN BY A LINEAR INDUCTION MOTOR ..................... 537
J. Kafka
EVALUATION OF SPACE QUALITY LIGHTING THROUGH A NEW INTEGRAL CHARACTERISTIC ........................................... 539
J. Habel, T. Straka

FREQUENCY PROPERTIES OF POWER TRANSFORMERS ............... 541
P. Mindl, P. Mařík

MODELLING OF AN ARC BEHAVIOUR ..................................... 543
V. Aubrecht, P. Jadrný, J. Bartl, L. Peška

SWITCHING ARC DIAGNOSTICS ........................................... 545
P. Jadrný, V. Aubrecht, B. Bušov, B. Gross

APPLICATION OF ALKALINE ACCUMULATORS FOR PROTECTION OF ENVIRONMENT ........................................ 547
M. Cenck, J. Kazelle, R. Bařinka

STUDIES OF THE COLLECTOR/ACTIVE MASS INTERFACE IN THE LEAD–ACID BATTERIES .................................. 549
M. Calabek, P. Bača, V. Šmarda

USING OF NOREG CONVERTORS FOR TEACHING OF ELECTRICAL DRIVES AND MECHATRONICS .................. 551
J. Novák, J. Vlček

NEW CONTROL METHODS UNDER DEVELOPMENT AT DEPT. K-314 .... 553
J. Javůrek, J. Gerlich

THE ELECTRICAL DRIVE WITH A RELUCTANCE MOTOR ............. 555
J. Skalický

EXPERT SYSTEM FOR DIAGNOSTICS OF HV ELECTRICAL MACHINES ... 557
K. Zdiš

EXPERT SYSTEM FOR AN INCREASE IN THE RELIABILITY OF POWER-ENGINEERING SYSTEMS .............................. 559
K. Zdiš

A STUDY OF THE DYNAMIC BEHAVIOUR OF VOLTAGE CONTROLLED POWER DEVICES EXTREME CONDITIONS ........... 561
J. Mayer, V. Benda, V. Papež

MONITORING OF TRANSFORMERS AGEING BY PULSE FREQUENCY TECHNIQUE ........................................... 563
J. Petr, J. Kuba

UNIFIED SPECIFIC UNIT OF VIBRATING WIRE GAUGE FOR EXTREME DEMANDS FOR LONG-TERM STABILITY AND RESISTANCE IN AGGRESSIVE ENVIRONMENT .............................. 565
J. Galas, J. Kratochvíl
11. COMMUNICATION ENGINEERING

SPEECH RECOGNITION SYSTEMS ....................................................... 569
J. Uhlíř, et al.

SUB-BAND SPEECH CODER 16 KBIT/S ........................................... 571
J. Černocký

FREQUENCY SHIFT OF 2-D REAL COEFFICIENT ZERO PHASE FIR
DIGITAL FILTERS ........................................................................... 573
P. Zahradník

LOW-SENSITIVITY NON-RECIPROCAL LOSSLESS FILTERS ............... 575
P. Martinek

SC FILTERS OPTIMALIZATION ....................................................... 577
L. Diviš, J. Bičák

DESIGN OF FIR NOTCH FILTERS .................................................... 579
M. Vlček

FILTERS WITH SYNTHETIC ELEMENTS OF HIGHER ORDER USING
TRANSIMPEDEANCE OPAMP .......................................................... 581
V. Zeman, K. Vrba

ARTIFICIAL HEAD FOR MEASUREMENT OF HEARING PROTECTORS
BASED ON THE ANC ..................................................................... 583
I. Bašta, R. Milek, P. Novák

THE ANTENNA CHARACTERISTICS MEASUREMENT SYSTEM .... 585
P. Pechač, P. Hudec, P. Zlámal, M. Mazánek

THE USE OF ACOUSTOOPTICAL EFFECTS IN THE TESTING OF
PIEZOELECTRIC TRANSDUCERS .................................................... 587
J. Uher

MODEL OF ELECTROSTATIC TRANSDUCER BASED ON COUPLED
SYSTEM DESCRIPTION ................................................................ 589
Z. Škvor, L. Husník, Š. Nezbeda

VECTOR MEASUREMENT USING SCALAR SENSOR ONLY ............. 591
Z. Škvor, K. Hoffmann

PROPERTIES OF SLOT LINE AT HIGH FREQUENCIES ..................... 593
J. Machač, J. Zehentner

IONOSPHERIC DELAY PREDICTION FOR WIDE AREA DGPS USERS ...... 595
F. Vejražka, M. Brown, Z. Hrdina, L. Seidl, V. Obuskevič, J. Zápotočný

MM WAWE PROPAGATION EXPERIMENT ...................................... 597
M. Mazánek, P. Zlámal, H. Bártík, J. Janík, P. Pechač
WORKSHOP 95

CONTENTS

ATM SWITCHING NETWORKS ......................................................... 599
Líša Valášková

PIECEWISE-LINEAR MODELLING AND CIRCUIT DESIGN .................... 601
Z. Kolka

HIGH-FREQUENCY LINEAR TRANSCONDUCTOR .................................. 603
M. Švajda

DESIGN AND CHARACTERISATION OF FUNDAMENTAL ANALOG
FUNCTIONAL BLOCKS FOR CMOS DIGITAL-ANALOG ASIC .................. 605
M. Kejhar, M. Kirschner, C. Navrátil, R. Kráček, L. Nikolić, P. Tesař, R.
Víť, V. Libal, K. Žáček, J. Nedvěd, I. Adaměk, P. Neumann

DESIGN AUTOMATION OF PASSIVE COMPONENTS FOR ANALOG
INTEGRATED CIRCUITS ............................................................ 607
M. Kejhar, C. Navrátil

VLSI DESIGN OF ANALOG NEURAL NETWORKS ................................ 609
K. Zacek, L. Nikolić

324
Section 7

MECHANICS
IN ENGINEERING
In geomechanics, in spite of the great success of computational methods, it is necessary to use either parallel or consequent experimental solution which is giving unknown boundary conditions for the above mentioned computational solution or better picture, because technical problem shows high complexity as inhomogeneous and/or anisotropic medium, geometric parameters, nonlinearities and hysteresis of material qualities. The physical experiment can support the assumptions, verify and precise the conditions for failure origin of geomechanic structure [1],[2],[3].

Fig. 1:
One of the basic tasks in geomechanics is pressure measuring in soil and rocks. For this purpose proved pressure transducers [3] in the shape of flat cylinders were modified. Practical design can be done according to the optimization program for transducers with elastic body in the form of thin circular plate [4]. In many applications the transducer size caused nonomitting inhomogeneity in the observed continuum and due to it also signal distortion. Minimization of the transducer size is limiting by the length of strain gages and by the manufacture possibilities. Minimal outer dimensions is 8 mm and height 3 mm. For the measuring membrane must be used special technology. That is why other principles have been sought.

Good experience with tactile sensors with conductive rubber [5], [6] of the layer thickness 0.5 mm makes possible to design pressure transducer with minimal sizes (active area of the conductive rubber can be 0.4 x 0.4 mm). Relation between resistance change and the loading pressure acting on the area of the electrode having 3 mm diameter is given in the fig.1. This diameter is relevant the relation of the designed transducer appointed for measuring of pressure distribution in sand models [2].

In the last period there were solve problems of transducer sensitivity, linearity of output signal, parasite influence as temperature and humidity and transducer protection against them.

Activities of fellow-workers of both institutions have been supported by the Prague representative of the German company Hottinger-Baldwin-Messtechnik Darmstadt.

References:
[4] VÍTEK, K.: Optimization of dimensions of Circular Thin Plate Loaded by Pressure or Perpendicularly Acting Load in print
[6] Technical documentation of the conductive rubber CS57-7RSC Yokohama Rubber Co. Ltd. Japan

This research has been conducted at the Department of Elasticity and Strength of Materials as a part of research project “Application of Experimental Stress Analysis in Geotechnics for Minimization of Structure Failure” and has been supported by the Grant Agency of the Czech Republic No. 205/94/1788.
ON AN ANALYSIS OF STRAINS IN MICROSTRUCTURES

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Key words: residual stress, microstructure, analysis

Improvements in the technological processes for making microparts and devices and for developing them would be more likely, if expertise on the magnitude of strains and stresses and on their distribution throughout the microvolume existed. The problem of measurement of these quantities must be solved. Many micromethods of strain measurement have been developed during the last fifteen years. There are interferential, stereoimaging and computational (identificational) ones.

Unlike similar macro techniques where a TV screen is the usual means for imaging on the studied object, microtechniques need a device for a micro imaging, i.e. some kind of a microscope. Our laboratory is dealing with microphotogrammetry, which is one of a group of similar stereoimaging techniques. In essence, the imaging technique consists of comparison between a pair of pictures of an object which are taken from exactly defined positions or from one position, but at different time points, where between them the object went through a deformation process. This modification of the method is named time base photogrammetry. An evaluation of the strains between a pair of stereoscopic pictures is carried out by stereocomparator. It is a device in which the identical points from both pictures are stereoscopically coincided and a difference in the distance between a couple of points is then measured. The measured quantities are named paralaxes and the resulting strains are then calculated from them using special software. The pair of stereoscopic pictures of an object are provided in our laboratory by a Scanning Electron Microscope (SEM).

The method described above was applied to the study of deformation processes in polycrystals. The picture (Fig. 1) shows the results of a strain analysis of the contact between three grains in a polycrystalline aluminium, where a one-dimensional macrostrain reached 3%.

We have now embarked upon application of the method to determination of residual stresses. The hole drilling method currently used has some disadvantages, which arise from the nonhomogeneous distribution of strains on the proximity of the hole. The application of a micromeasurement method permits the measurement of strain in a much smaller area, where the state of strain is sufficiently homogeneous. It is therefore convenient to replace the procedure of hole drilling with a ring cutting one. It is then possible to measure the released strain at the top of the central column.

In our on-going research two examples of residual stresses are now being investigated. The first example stresses being studied are the residual stresses in the neighbourhood of a weld and the second stresses are the ones in a polymer composite floor surface. Results will be presented at the meeting of Workshop 95.
This research has been conducted at the Department of Central Laboratories of Faculty of Civil Engineering as part of the research project "Analysis of residual stresses in surface layers" and has been supported by Faculty of Civil Engineering CTU grant No. 2019.
THE ELASTOPLASTIC PROBLEM
IN UNIDIRECTIONAL COMPOSITE

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Key words: cell, subcell, microvariables, average stress and strain, initial yield condition

This paper deals with the unidirectional fibrous composites with the periodic structure. The representative element is defined as a cell such that the continuum is constructed by repeated this element. We consider an elastoplastic material subjected to common loading.

Using average small strain tensor $\bar{\varepsilon}_{ij}$, the micromechanical method [1] leads to relations between the average stresses $\bar{\sigma}_{ij}^{(mn)}$ in the subcell $mn$ ($m, n = 1, 2$) and the average composite stresses $\bar{\sigma}_{ij}$ ($i, j = 1, 2, 3$).

The components $\bar{\sigma}_{ij}^{(mn)}$ are functions of six microvariables which are solved from the conditions for continuity of the inner forces and displacement in the cells. After some manipulation we obtain

$$\left\{ \bar{\sigma}_{11}^{(i)}, \bar{\sigma}_{22}^{(i)}, \bar{\sigma}_{33}^{(i)}, \bar{\sigma}_{12}^{(i)}, \bar{\sigma}_{13}^{(i)}, \bar{\sigma}_{23}^{(i)} \right\}^T = A^{(i)} \left\{ \bar{\varepsilon}_{11}, \bar{\varepsilon}_{22}, \ldots, 2\bar{\varepsilon}_{23} \right\}^T .$$

It follows from the definition of the average composite stresses

$$\left\{ \bar{\sigma}_{11}, \bar{\sigma}_{22}, \ldots, \bar{\sigma}_{23} \right\}^T = A \left\{ \bar{\varepsilon}_{11}, \bar{\varepsilon}_{22}, \ldots, 2\bar{\varepsilon}_{23} \right\}^T .$$

These are the useful constitutive relations with six independent values $a_{ij}$ forming the elastic stiffness matrix in the case of an orthotropic material with a square symmetry. The matrix elements $a_{ij}$ or $a_{ij}$ resp., are functions of the material constants $\varepsilon_{ij}$ (fiber), $c_{ij}$ (matrix) and the geometrical characteristics $h_1, h_2$ concerning the cells.

The components $\bar{\sigma}_{ij}, \bar{\varepsilon}_{ij}, u_i$ must fulfil the basic equations, especially the static equations

$$\bar{\sigma}_{ij} + f_i = 0$$

with the nonhomogenous boundary conditions

$$\sigma_{ij}n_j = p_i^0 \text{ (on } S_1) \quad \text{or} \quad u_i = u_i^0 \text{ (on } S_2) \quad \text{resp.}$$

(see construction in research report [2]).

Supposing elastic fibres and an elastoplastic matrix, the initial yielding is governed by the yielding of the matrix phase.

The most used Mises micro-yielding criterion is given by means of the stress deviator tensor or the stress tensor resp.,

$$\frac{1}{2} \sigma_{ij}^{(i)} \varepsilon_{ij}^{(i)} - \left( \tau_{ij}^{(i)} \right)^2 = 0 .$$
\[
\frac{1}{6} \left[ \left( \sigma_{11}^2 - \sigma_{22}^2 \right) + \left( \sigma_{22}^2 - \sigma_{33}^2 \right) + \left( \sigma_{33}^2 - \sigma_{11}^2 \right) \right] + \left( \sigma_{12}^2 \right) + \left( \sigma_{13}^2 \right) + \left( \sigma_{23}^2 \right) - \left( \tau_{ij}^{(m)} \right)^2 = 0
\]

where \( \tau_{ij}^{(m)} \) denote the yield stresses in simple shear. The above micro-yield criteria provide different results related to various subcells of the matrix. Thus, we consider with advantage the yield condition

\[
\frac{1}{6} \left[ \left( \sigma_{11} - \sigma_{22} \right)^2 + \left( \sigma_{22} - \sigma_{33} \right)^2 + \left( \sigma_{33} - \sigma_{11} \right)^2 \right] + \sigma_{12}^2 + \sigma_{13}^2 + \sigma_{23}^2 - \left( \tau_{ij}^{(m)} \right)^2 = 0,
\]

written in terms of the average matrix stresses \( \bar{\sigma}_{ij} \) which are defined in similar manner as \( \bar{\sigma}_{ij} \). Denoting

\[
\bar{\sigma}_{11} - \bar{\sigma}_{22} = r_{11} \bar{u}_{1,1}, \quad \bar{\sigma}_{22} - \bar{\sigma}_{33} = r_{22} \bar{u}_{2,2}, \quad \bar{\sigma}_{33} - \bar{\sigma}_{11} = r_{33} \bar{u}_{3,3},
\]

\[
\bar{\sigma}_{12} = r_{44} (u_{1,2} + u_{2,1}), \quad \bar{\sigma}_{13} = r_{55} (u_{1,3} + u_{3,1}), \quad \bar{\sigma}_{23} = r_{66} (u_{2,3} + u_{3,2}),
\]

we obtain the yield condition

\[
\frac{1}{6} \left[ \left( r_{11} \bar{u}_{1,1} \right)^2 + \left( r_{22} \bar{u}_{2,2} \right)^2 + \left( r_{33} \bar{u}_{3,3} \right)^2 \right] + \]

\[
+ r_{44}^2 (u_{1,2} + u_{2,1})^2 + r_{55}^2 (u_{1,3} + u_{3,1})^2 + r_{66}^2 (u_{2,3} + u_{3,2})^2 - \left( \tau_{ij}^{(m)} \right)^2 = 0.
\]

Taking into account that \( A \) is a regular square matrix, the inverse \( A^{-1} = [\alpha_{ij}] \) is known. Now, the Mises micro-criterion can be expressed in the form

\[
\frac{1}{6} \left[ \left( \alpha_{ij} \bar{\sigma}_{ij} \right)^2 + \left( \alpha_{ij} \bar{\sigma}_{ij} \right)^2 + \left( \alpha_{ij} \bar{\sigma}_{ij} \right)^2 \right] + \]

\[
+ (r_{11} r_{44} \bar{u}_{1,1})^2 + (r_{22} r_{44} \bar{u}_{2,2})^2 + (r_{33} r_{44} \bar{u}_{3,3})^2 - \left( \tau_{ij}^{(m)} \right)^2 = 0,
\]

with the coefficients constructed in our research report [2]. Plastic behaviour is initiated when the load parameter reaches the magnitude above which plastic deformation takes place. Thus, the corresponding composite stresses \( \bar{\sigma}_{ij} \) fulfil the latter condition.

The analysis of the constitutive relations in the yield phase are presented in [2].

References:


This research has been conducted at the Department of Composite Materials and Structures and has been supported by Universities Development Fund No. 0180 88.
Fibre reinforced composites subjected to loading develop matrix cracks and fibre failure in layers which affect the resulting stiffness.

Damage development consists of three stages: initiation, growth and localization leading to failure of composite. Failure in composites can be described effectively using continuum damage mechanics (CDM) on thermodynamical basis. During the loading process the crack density increases up to a limit, called the characteristic damage state (CDS). The constitutive equations of CDM can be used in finite element method for predicting of progressive failure in composite structures.

The following relations are necessary for the analysis by FEM:
(a) the stress-strain relation of the damaged composite
(b) damage growth law and criterion for damage growth.

**Stress-strain relation** is influenced by matrix cracks and fibre failure. Compliances $[S]$ in constitutive equations for unidirectional layer can be evaluated by self-consistent method. In this method only compliances $S_{22}, S_{44}$ and $S_{66}$ depend on damage parameter $d_1$ (density of matrix cracks)

\[
S_{22} = S_{022} + d_1 (S_{22}S_{33} - S_{23}^2)(\sqrt{\alpha_1} + \sqrt{\alpha_2})/S_{33} \quad (1)
\]
\[
S_{55} = S_{055} + d_1 \sqrt{S_{44}S_{55}} \quad (2)
\]
\[
S_{66} = S_{066} + d_1 \sqrt{(S_{22}S_{33} - S_{23}^2)(S_{11}S_{33} - S_{13}^2)(\sqrt{\alpha_1} + \sqrt{\alpha_2})/S_{33}} \quad (3)
\]

where $\alpha_1, \alpha_2$ are the roots of equation

\[
(S_{22}S_{33} - S_{23}^2)\alpha^2 - (S_{23}S_{66} + 2(S_{12}S_{33} - S_{13}S_{23}))\alpha + S_{11}S_{33} - S_{13}^2 = 0 \quad (4)
\]

Compliances $S_{22}, S_{55}, S_{66}$ have been solved for varying matrix crack densities. Compliances $S_{11}, S_{33}$ and $S_{66}$ have been assumed inversely proportional to the damage parameter $d_2$ (density of broken fibres).

In the resulting matrix $[S]$ compliances $S_{22}, S_{55}$ and $S_{66}$ were fitted by exponential functions
Damage growth occurs when the associated thermodynamic force exceeds a critical value. The thermodynamic force can be written in the form

\[ Y = \frac{1}{2} \sigma : \frac{\partial S}{\partial d} : \sigma \]  

where the semi-colon denotes the contracted tensorial product and S the compliance tensor. Using (5) and (6) the thermodynamical force associated with fibre failure has been found

\[ Y_2 = \frac{1}{(1 - d_2)^2} \sigma_1^2 / 2E_1 + \exp(a_{33}d_1) \sigma_3 \sigma_2^2 / (1 - d_2)^3 G_{23} + \exp(a_{66}d_1) \sigma_1^2 / (1 - d_2)^3 G_{12} \]  

and the thermodynamical force associated with matrix cracking

\[ Y_1 = \exp(a_{22}d_1) a_{22} \sigma_2^2 / 2E_2 + \exp(a_{33}d_1) a_{33} \sigma_3 \sigma_2^2 / 2G_{23} + \exp(a_{66}d_2) a_{66} \sigma_1^2 / 2G_{12} \]  

The thermodynamic forces can be used in evolution laws for damage [2]. Development and experimental verification of the damage evolution laws is of particular interest for our future research.

References:


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.
LOW-CYCLE FATIGUE DUCTILITY

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Key words: cyclic loading, damage evolution, deflection concept, fatigue life, macroscale crack

The continuum damage mechanics now being applied in engineering gives an understanding of the fatigue process by means of a damage variable that expresses the degradation of a material before the initiation of macrocracks.

Let us introduce $A$ as the sectional area of a volume element on the macroscale and $\hat{A}$ be the resisting area, (i.e. $A$ is subtracted from the surface intersections of microcracks and cavities). In so doing, the damage variable reads

$$D = 1 - \frac{\hat{A}}{A}. \quad (1)$$

Or else, the variable mentioned can be defined with the help of the variation of the elastic modulus, in the isotropic contingence

$$D = 1 - \frac{\hat{E}}{E}, \quad (2)$$

where we have denoted the modulus of undamaged material by $E$ and the damaged material one by $\hat{E}$.

Likewise, the damage may be measured in terms of the variation of cyclic plastic effect. Regarding a test in constant plastic strain amplitude condition, if $\Delta \sigma^*$ is the stress amplitude at the close of the cyclic softening or hardening period before the damage initiation, then $\Delta \sigma$ is the stress amplitude pertaining to another cycle. At that point:

$$D = 1 - \frac{\Delta \sigma}{\Delta \sigma^*}. \quad (3)$$

Fig. 1: Strain amplitude × life curves
At fatigue failure, the identification $2N_f$ is used to express the number of reversal cycles. In Fig. 1, the strain amplitude curve × life is demonstrated.

Seeing that $\Delta \epsilon = \Delta \epsilon_1 + \Delta \epsilon_p$, we may draw, according to (2), curves $\log(\Delta \epsilon_1/2) - \log 2N_f$ and $\log(\Delta \epsilon_p/2) - \log 2N_f$. The straight lines on the logarithmic charts may be simulated by normal forms of power functions. We will obtain:

$$\frac{\Delta \epsilon_1}{2} = \frac{\sigma_f}{E} (2N_f)^b$$  \hspace{1cm} (4)

$$\frac{\Delta \epsilon_p}{2} = \epsilon'_f (2N_f)^c$$  \hspace{1cm} (5)

Equation (5) is termed the Manson-Coffin relation, where $\sigma'_f$ and $\epsilon'_f$ represent the fatigue strength and fatigue ductility coefficients, while $b$, $c$ fatigue strength and ductility exponents, respectively. It is possible to indicate from (5) that $\epsilon'_f$ is related to the fatigue life. Experimental results have verified that the cyclic ductility $\epsilon'_f$ stands in relation to the static fracture ductility $\epsilon_f$, such that;

$$\epsilon'_f = \beta \epsilon_f \quad \text{or} \quad \epsilon'_f = \beta \ln \left( \frac{1}{1 - \psi_f} \right)$$  \hspace{1cm} (6)

where the material constant $\psi_f$ is determined from the static uniaxial tension; $\beta = 0.35-1.0$ but for the bulk of metals $\beta = 1$. Under cyclic loading the concept of ductility deflection may be dealt with through Fig. 2.

![Fig. 2: Ductility deflection model](image)

Experiments have been performed on specimens of 16 Mn R pressure vessel steel analogous with steel up to the standard CSN 41 5223, of the following characteristics:

<table>
<thead>
<tr>
<th>Elements (%)</th>
<th>Mechanical properties</th>
<th>Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Mn</td>
<td>Si</td>
</tr>
<tr>
<td>0.17-0.234</td>
<td>1.2-1.6</td>
<td>0.15-0.4</td>
</tr>
</tbody>
</table>

The effectual fatigue life is reached when the material ductility is fully deflected. It is possible to relate the given variable closely to the material properties and to measure it without any difficulties.

References:

This research has been conducted at the Department of 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.
YIELD LINE ANALYSIS
OF STEEL PLATES
BY FINITE ELEMENTS II

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Key words: yield line analysis, steel plates, finite elements, linear programming

In Ref.[1], the yield line analysis of steel plates with a step-wise changing plastic resistance was explained, based on the use of triangular finite elements. The present method employs rectangular elements with crossed diagonals, Ref.[2]. The mesh represents a geometrical place of kinematically possible patterns of yield lines.

Kinematic relations

\[
\begin{align*}
\mathbf{w}' - \mathbf{w}'' &= \mathbf{A} \mathbf{m}' - \mathbf{A} \mathbf{m}'' \\
\mathbf{F}^{T} \mathbf{w}' - \mathbf{F}^{T} \mathbf{w}'' &= 1
\end{align*}
\]

Static relations

\[
\begin{align*}
-\mathbf{s} &= \min \\
\mathbf{m}' - \mathbf{m}'' &\leq \mathbf{m}'_{pl} \\
-\mathbf{E} \mathbf{m}' + \mathbf{E} \mathbf{m}'' &\leq \mathbf{m}'_{pl} \\
\mathbf{s} \mathbf{F} - \mathbf{A} \mathbf{m}' + \mathbf{A} \mathbf{m}'' &= \mathbf{0}
\end{align*}
\]

The unknowns are: In the kinematic formulation, \( \Theta_{k} = \mathbf{\theta}_{k} L_{k} \) = line rotation along the mesh side \( k \), \( w_{j} \) = transverse displacement of a node \( j \). In the static formulation, \( m_{k} \) = normal bending moment per unit length along a mesh side \( k \). The plastic parameter \( s \) (a ratio \( \frac{P_{pl}f_{j}}{P_{j}} \) of plastic limit loads to the considered ones) is to be minimized; maximized in the kinematic; static version of analysis, respectively.

With the variables split into non-negative quantities, \( z = z' - z'' \); \( z', z'' \geq 0 \), problems can be solved by linear programming. For steel, \( m_{pl,k} = m_{pl,k} = m_{pl,k} = R_{pl}f_{j}^{2}/4 \). First rows express the objective functions \( \max s = \min (-s) \). Left, second row introduces the scale of deformations, third row is the compatibility condition (\( \mathbf{E} = \) diagonal unit matrix; \( \mathbf{A}^{T} = \) kinematic transformation matrix). Right, second and third row are the yield conditions, last row - the equilibrium equation.

The elements \( a_{sh}; a_{kj} \) of the matrices \( \mathbf{A}^{T} \); \( \mathbf{A} \) can be easily calculated with the aid of graphical operators, Figs 1 and 2. Results of an illustrative problem are presented in Fig. 3.

Fig. 1: Graphic operators for kinematic method
Fig. 2: Graphic operators for static method

Fig. 3: (a) Plate with stepped thickness; (b) relative deflections and rotations; (c) relative bending moments

References:


This research has been conducted at the Department of Structures as part of the research project “Limit States of Steel Plate Elements” and has been supported by GAČR grant No. 105/94/086.
PLASTIC EFFECTIVE WIDTH

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Key words: steel plates, ribs, effective width

The rigid-plastic analysis of steel plates with constructional orthotrophy is entangled with several problems. One of them is the unknown effective width of the plate along the ribs, Fig. 1.

The elastic effective width $b_e$ depends on the character of the cross section, thickness of the plate, support conditions and kind of load. The relations for the elastic effective width are known and can be found in professional books and standards. On the other hand, the problem of the plastic effective width $b_p$ has not been solved yet.

We can derive the unknown plastic effective width $b_p$ from the ratio of bending capacities $M_p/M_e$ in plastic and elastic ranges. This ratio is between 1,25 - 1,35 for an unsymmetrical I-section and between 1,12 - 1,15 for a symmetrical I-section.

Fig. 2 demonstrates the dependences of the ratios $M_p/M_e$ vs. $b_p/b_e$ or $b_p/A$; $A$ is the distance of ribs. It follows that for an unsymmetrical section the ratio of effective widths $b_p/b_e$ is between 0,43 - 0,7. An examples of effective widths of a typical steel plate with ribs is shown in Fig. 3.

Having now the estimate of the magnitude of the plastic effective width, we plan to verify the results experimentally.

Fig. 1: Steel plate with constructional orthotrophy
Fig. 2: The dependences of the ratios $M_{pl}/M_{el}$ vs. $b_{pl}/b_{el}$ or $b_{pl}/A$

Fig. 3: An examples of effective widths of typical steel plate with ribs

References:

This research has been conducted at the Department of Structures as part of the research project “Limit States of Steel Plate Elements” and has been supported by GACR grant No. 103/94/086.
FEM ANALYSIS OF THE JOINTED CONCRETE PAVEMENT

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Key words: contact problem, jointed concrete pavement, slab system, elastic subgrade

Current design procedures for concrete pavements are based on simplified analyses of a pavement response: often the Westergaard theory of a plate on a Winkler foundation is used. In the present paper, the concrete pavement is regarded as a system of slabs that act together when transferring wheel loads into the pavement support.

The analysed system consists of M rectangular plates \( l_x \times l_y \) which are modelled as elastic bodies with material parameters \( E_p \) and \( v_p \). The subgrade is also assumed to be elastic with material parameters \( E_s, v_s \). The plate thicknesses \( h_p \) are small enough for the Kirchhoff thin plate theory to provide valid plate stress and deformation values. The external load \( Q(x,y) \) and the temperature effects (due to the difference \( \Delta T \) between the upper and lower plate surface temperatures) are considered.

The plate stresses and deformations are computed by the finite element method using triangular elements with six unknown parameters in each node. The free edge conditions are considered and, therefore, plate fixation conditions should be imposed.

A non-negative "contact loading" \( q(x,y) \) (that is related to the contact stress \( p(x,y) \) by \( q(x,y) = -p(x,y) \)) can be sought using the form

\[
q(x,y) = \sum_{i=1}^{r} X_i q_i(x,y),
\]

where \( X_i \) are the unknown nodal intensities, \( r \) is the total number of nodes and \( q_i(x,y) \) is a unit pyramidal loading having unit intensity in the node \( i \) and vanishing outside of the region composed of all elements having node \( i \) as a common vertex.

The collocation method can then be used requiring that in the nodes of the FEM division: either a) the plate and subgrade are in contact, or b) the contact stress vanishes. To account for system interactions we have had to apply a two-level iteration process \( (L,l) \): firstly on the local level \( l \) the complete contact problem for the individual plate is solved, while secondly at the global level \( L \) the system interactions are duly accounted for. The problem unknowns to be iterated are the contact loading intensities \( X_m^{(I,L,l)} (m \in [1,r_I], r_I \) being the total number of nodes of the plate \( I \)) and the plate rigid-body motion parameters \( W_k^{(I,L,l)} \) (three for each plate to compensate for plate fixation in the FEM analysis).

By denoting \( K_a^{(I,L,l)} \) and \( K_b^{(I,L,l)} \) as the set of "contact" and "no-contact" nodes, respectively, the contact equations to be iterated are (\( I \in [1,M], m \in [1,r_I], k \in [1,3] \))

\[
a) \quad \Delta \omega_i^{(I,L,l)}(X_m^{(I,L,l)},W_k^{(I,L,l)}) = 0, \quad i \in K_a^{(I,L,l)},
\]

\[
b) \quad X_j^{(I,L,l)} = 0, \quad j \in K_b^{(I,L,l)}. \quad (2)
\]

The three equations of plate equilibrium should also be fulfilled for each plate of the system.
The gap function $\Delta w_{ij}^{(Lm)}$ measures the distance between the plate and the subgrade in node $i$

$$\Delta w_{ij}^{(Lm)} = \sum_{k=1}^{r_i} \chi_{m_k}^{(Lm)} \left[ v_{p,k,i}^{(L)} + v_{s,k,i}^{(L)} \right] - \sum_{k=1}^{2} W_{(p,q),i}^{(Lm)} \left[ \psi_{p,q,i}^{(L)} + \psi_{s,q,i}^{(L)} - \psi_{s,exf,i}^{(L)} \right].$$  \hfill (3)

Here the values $v_{p,k,i}^{(L)}$, and $w_{s,k,i}^{(L)}$ are the plate deflections caused by the loadings $q_i^{(L)}$ and $Q(x,y)$, respectively, $v_{s,q,i}^{(L)}$ is the deflection due to the temperature difference $\Delta T$ and $r_{i}^{(L)}$ are the coefficients of the rigid-body motion of the plate. The subgrade deflection $v_{s,exf,i}^{(L)}$ is caused by the unit loading $v_{m}^{(L)}$ acting in node $m$ of the plate $J$ and the term

$$v_{s,exf,i}^{(L)} = \sum_{j=1}^{r_j} \sum_{m=1}^{r_i} \chi_{m_j}^{(L)} \psi_{s,m,i}^{(L)} + \sum_{j=1}^{2} \sum_{m=1}^{r_i} \chi_{m_j}^{(Lm)} \psi_{s,m,i}^{(L)}$$  \hfill (4)

takes care of the plate system interactions: it represents the deflection in node $i$ of plate $I$ caused by the contact loadings acting on the adjacent plates $J \neq I$ with intensities $\chi_{j}^{(L)}$ that result from the local iterative processes. The global iterative process terminates, if the accuracy

$$\max_{i,j} \left[ \sum_{j=1}^{M} \sum_{m=1}^{k_j} \left| \chi_{m}^{(L+i)} - \chi_{m}^{(L+i)} \right| \psi_{s,m,i}^{(L)} \right] \leq \varepsilon.$$  \hfill (5)

Numerical verification has been carried out for the input data: $E_p = 37.5$ GPa, $v_p = 0.2$, $h_p = 0.24$ m, $L_p = 5.5$ m, $L_q = 3.5$ m, $E_s = 60.0$ MPa, $v_s = 0.35$.

The current design procedure considers a single plate loaded with a dual wheel load of 50 kN in the edge position (11). The presented method considers a two-plate system $M = 2$ (total length of 11 m), loaded with a heavy vehicle T 815 S3 (12), its 270 kN load being simulated by 10 circular imprints placed on plate 2 at its joint with plate 1. The extreme values of the bending moments $m_x$ (in kPa) presented below indicate the urgent need for analysing concrete pavements with more powerful means than those methods used currently.

<table>
<thead>
<tr>
<th>Method/Configuration/Loading</th>
<th>$\Delta T$ @ $-10^\circ C$</th>
<th>$0^\circ C$</th>
<th>$+10^\circ C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Design Single Plate</td>
<td>own weight</td>
<td>-1.792</td>
<td>6.015</td>
</tr>
<tr>
<td></td>
<td>loading (11)</td>
<td>9.511</td>
<td>13.957</td>
</tr>
<tr>
<td>Presented Method Two-Plate</td>
<td>plate 1</td>
<td>2.057</td>
<td>8.417</td>
</tr>
<tr>
<td>System Loading (12)</td>
<td>plate 2</td>
<td>25.910</td>
<td>32.904</td>
</tr>
</tbody>
</table>

This research has been conducted at the Department of Composite Materials and Structures as part of the research project "Enhancement of Roads Reliability and Safety" and has been supported by CTU grant No. 78152.
EXPERIMENTAL ANALYSIS OF COMPRESSION STRAIN – SOFTENING IN CONCRETE

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Key words: strain-softening, size effect, cube compressive strength, shear stress, specimen size, composite material, quasi-brittle material

Softening behaviour is affected by structural aspects such as specimen size [1], shear stresses between specimen and loading platens, feed back signal [2] and testing-machine characteristics. A systematic survey of these effects is not available. The new RILEM committee aims at establishing a vast data-base for strain-softening of concrete loaded in uniaxial compression.

Parameters of our interest are especially friction between loading platen and specimen and the shape and size of the test specimen. Default values have been decided for these parameters and are as follows:

- default is rigid steel platens, the size of the loading platens should match the size of the specimen,
- default gauge length is the specimen length, i.e. measurements should be taken from loading platen to loading platen,
- default, the loading platens are fixed during the test,
- default have been decided for the specimen shape. The default size for cylinders is diameter 100 mm and length 200 mm,
- no default can be given for the stiffness of the compression machine. The stiffness of the loading system must be supplied,
- default for the feed-back signal is the platen to platen deformation,
- default for the concrete quality is a mix with a maximum aggregate size of 8 mm and a cube compressive strength of approx. 40 MPa.

Special care has to be taken in the manufacturing of the specimens. It is proposed to cast larger blocks of size 450 x 150 x 150 mm from which a 50 mm, a 100 mm and a 200 mm prism can be sawn, or alternatively cylinders of each length can be cored. The specimen ends in contact with the loading platen should be ground flat and parallel with a diamond grinding disk. All specimens must be sawn such that they can be loaded perpendicular to the direction of casting. The casting procedure is as follows. The concrete should be poured in the moulds and compacted on a vibration table for 30 seconds. Next the specimens should be kept in the moulds for two days, kept under wet cloths to prevent drying out. After demoulding the specimens are placed in a fresh water basin. Preferably the specimens should be tested after 8 weeks and before an age of 10 weeks.

Concrete qualities was as follows. Normal strength concrete: Portland Cement, 375 kg/m³, maximum aggregate size 8 mm (rounded river gravel), size distribution 8-4 mm.
540 kg/m³, 4-2 mm 363 kg/m³, 2-1 mm 272 kg/m³, 1-0.5 mm 272 kg/m³, 0.5-0.25 mm 234 kg/m³, 0.25-0.125 mm 127 kg/m³, no admixtures, w/c ratio is 0.5. This mixture will lead to a compressive strength of 45–50 MPa.

The specimens are loaded under moderate loading rate of $10^{-6} \text{ m/s}$. This concerns the axial deformations as feedback signal. It is possible that the gauge length is too large for testing the higher strength concrete. In that case the control parameter has to be adjusted and probably the lateral deformation will work. It is proposed to keep the same loading rate independent of the type of control parameter. Care should be taken that the loading platen and specimen ends are clean to warrant a good contact between specimen and loading platen. This is very important because neglecting this would lead to strong contact effects in the axial deformation measurements. The axial deformation should be measured with at least three LVDTs. Lateral deformations should be measured at three different positions: 10 mm below the top end of the specimen, in the middle of the specimen and 10 mm above the bottom of the specimen.

References:

This research has been conducted at the Department of Structural Mechanics as part of the research project “Experimental Analysis of Compressive Strain – Softening in Concrete” and has been supported by CTU grant No. 18151.
STRAIN SOFTENING OF CONCRETE IN COMPRESSION

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Key words: compression, stress-strain relationship, testing, strain softening

The difficulties of constitutive expression for numerical modelling of concrete follow from properties of the actual concrete structure like a composite, nonhomogenous and quasi brittle material. Characteristics of concrete experimentally derived are strongly affected by the following conditions: stiffness of testing machine, size and shape of specimen, length of gauge measurement, rate and type of loading, and stiffness relationship of specimen and testing machine, friction between loading platen and specimen and way of curing of specimen. A systematic survey of all these effects is still missing [1].

Typical examples of experimentally obtained data from uniaxial tests of cylindrical specimen 150/300 mm are shown in figures, stress-strain and secant modulus of elasticity in Fig. 1, Poisson’s diagram in Fig. 2 [2].

Necessary conditions for obtaining a complete stress-strain diagram including the descending branche are: - testing frame with the sufficient axial stiffness, - loading system with the feed back control.

In the case that the loading system does not possess sufficient stiffness, the elastic energy accumulated in the frame is released immediately after reaching the peak of the diagram and causes failure of the specimen.

A system for the testing of concrete material properties was developed at the Klokner Institute. The system is composed of the hydraulic testing machine with programable loading in the range of 5 MN, the computer controlled data acquisition system and the operating software. A special strain gauge cage is fixed on a specimen and longitudinal and transversal deformations are registered by linear variable displacement transducers. The loading of the specimen is controlled by longitudinal strains. Numerical results are presented in forms of a stress-strain diagram, a volumetric diagram, Poisson’s diagram and a diagram of secant or tangent modulus of elasticity and other numerical characteristics. The capability of the system was proved in a lot of the practical applications. The experimental stress-strain diagrams are approximated by the variety of analytical form; it has been shown that the most convenient expressions are by Model Code 90 [3] formulas or by Karpenko’s proposition [4].

On the other hand, another way for the control of the loading system is realized by the transversal strains. The chain transducers embracing the specimen are commonly used. This type of transducer was developed at the KU; the loading system was controlled by the average of transverse strains in two directions.

The research program consists of an experimental investigation of three different degrees of slenderness cylinders of the and prisms with a diameter of 100 mm. They were properly
cast in larger blocks and after standard curing they were cut into prisms by the diamond saw and cored into cylinders.

The main aim of the investigation focuses on the detailed description of compression failure of the specimen. The experimental data will be compared with results from other foreign laboratories [5]. The final results will lead to the procedure proposition of standard the compression test, determining the real properties of concrete.

![Fig. 1: Stress-strain diagram, secant modulus of elasticity](image1)

![Fig. 2: Poisson's ratio diagram](image2)

References:
[1] VONK, R. A.: Micromechanical Investigation of Softening of Concrete Loaded in Compression, Heron, Delft, 1993
[5] RILEM Committee 118 Strain softening of Concrete, proposal for Round robin test, Delft University of Technology, 1993

This research has been conducted at the Klokner Institute CTU as as part of the research project "Experimental analysis of compressive strain-softening in concrete" and has been supported by CTU grant No. 8151.
POSITION DEPENDENT TENSION STIFFENING IN CONCRETE

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Key words: tension stiffening, cracks, fracture energy

In reinforced concrete, strain-softening and tension stiffening obviously refer to the same physical process - gradual cracking restrained by reinforcement bars. It is clear that the composite carries greater stress at an average extension beyond the concrete tensile strength than the sum of stresses in concrete and steel would be if they underwent the same average extension separately (concrete would carry no stress at all in the latter case). There is a long record of the quantitative assessment of the 'differential' stress since it is the core of the prospective integral material law for reinforced concrete. The smeared crack models will not work unless different strain softening characteristics are used in regions with different reinforcement arrangements. The last clause suggests a partial remedy: to assume the strain-softening characteristics at a point in concrete dependent on the arrangement of the surrounding reinforcement. This improved model will not do in plain concrete. However, a combination of the crack band concept with the position dependent strain-softening appears possible since both can be reduced to the descending branch of the stress-strain diagram.

To expose the basic idea, take into consideration a concrete body with a single reinforcement bar in the state of average uniaxial tension \( \varepsilon \) in the direction of the bar. The crack spacing \( q(r) \) is an increasing function of the distance \( r \) of a material point from the bar surface. Let variable \( b \) be defined as \( b = q(r) \) for \( q(r) < b_c \) and \( b = b_c \) for \( q(r) > b_c \), where \( b_c \) denotes the crack band introduced in [1]. We assume that a variable fracture energy \( G = G(b) \) is spent at each crack since the process zone cannot fully develop around the bar where \( b < b_c \) and the actual fracture energy \( G \) will be less than \( G_f \) in this region. The deformation energy per unit volume spent in the tension failure then is \( G/b \). It equals the area under the stress-strain diagram. For linear descending branch of the diagram, we obtain:

\[
\frac{G}{b} = \frac{1}{2} \varepsilon_m f_t
\]

\[
f_t = f_t'(1 - \frac{\varepsilon - \varepsilon_c}{\varepsilon_m - \varepsilon_c}) = f_t' \left(1 - \frac{\varepsilon - \varepsilon_c}{2G - \varepsilon_c b f_t} \right)
\]

The function \( G(b) \) must meet two obvious conditions. The fracture energy in a finite volume including the points \( b = 0 \) must remain finite which entails \( G(0) = 0 \). Smooth transition from smeared to discrete cracks approaches requires \( G(b_c) = G_f \).

We enhance the smooth transition by the condition (not necessary) \( dG/db = 0 \). Finally, it is assumed that the deformation energy per unit volume spent in the process converges to a certain value \( W \) as the cracks become denser for \( b \to 0 \) that is \( dG/db = W \). When a simple polynomial function is adopted for \( G \): \( G(b) = G_f (1 - (\varepsilon/\varepsilon_c)^n) \) we obtain

\[
W = n \frac{G_f}{\varepsilon_c^n}
\]

The asymptotic energy density \( W \) apparently is a true material constant and the last expression indicates its relation to the fracture energy and crack band. However, it
cannot be measured directly due to strain localization. The parameter $n$ is to be determined experimentally.

A uniaxial tension member is the most straightforward device to determine the tension stiffening parameters. The sensitivity of the present model to changes in $a$ and $S$ is shown in Fig. 1 where the predictions also are compared to test results.

Numerous tests in bending are also available. Particularly interesting are the tests with laminate layer reinforcement [2]. The assumed crack pattern does not depend on the bar radius as long as it is larger than some lower limit and it does not depend on the elastic modulus of the bar. The laminate layer represents, in this context, an infinite bar radius and the laminate elastic modulus is about ten times less than the usual steel modulus. The test thus is a severe check on the above assumptions. The test results in Fig. 1 are an average of five specimens. The analytic solution was obtained by a layer model of the beam using the Bernoulli-Euler hypothesis.

References:


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OPTIMIZATION OF STRUCTURES BY METHOD OF EVOLUTION STRATEGIES

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Key words: stochastic optimization, evolution strategies, simulated annealing, reliability-based optimization, failure probability

In conventional optimum design of structural systems an optimization problem can be represented as

\[
\min f(X) \quad X \in \mathbb{R}^n, \quad \text{subject to:} \quad g_i(X) \geq 0, \quad i = 1, 2, \ldots, m. \quad (1)
\]

The objective function \( f(X) \) is usually the weight or the initial cost of the structure, the constraints \( g_i(X) \) require e.g. that the stresses and/or strains at some critical points have to be less than some given values. All design variables \( X \) and parameters are considered to be deterministic quantities in this deterministic formulation.

In reliability-based structural optimization some of the quantities describing the load and/or the strength are modelled as random variables. A reliability model is formulated into limit state function enabling the estimation of the probability that the structure will fail - theoretical failure probability \( p_f \). A basic probabilistic formulation is to minimize \( (1) \) under the reliability constraint

\[
\mathbb{P}_f(X) < p_f, \quad (2)
\]

where \( p_{fa} \) is the design failure probability.

The aim of this work is to develop an efficient multipurpose optimizer for both deterministic and probabilistic formulation of optimization problem. The stochastic method of optimization was chosen which imitates the biological evolution in nature - evolution strategies (ES) [1]. This promising method uses randomized operators instead of the usual deterministic ones.

ES are recently applied for continuous optimization problems. The simplest form of ES is the two-membered ES which works in two steps: Mutation and selection.

- Step 1 (mutation): In the \( g \)-th generation a new design vector is calculated from

\[
X_{o}^{(g)} = X_{p}^{(g)} + Z^{(g)} \sigma_i \quad (3)
\]

where \( X_{o}^{(g)} \) and \( X_{p}^{(g)} \) are the "offspring" vector and the "parent" vector, respectively; \( Z^{(g)} \) is a random vector whose components have normal probability distribution. By analogy with natural evolution the expectation of these components should have a zero value and the standard deviation \( \sigma_i \) should be small, selected reasonably according to the problem solved. The standard deviation can be considered as a step length. Generation must be performed randomly using a numerical generator of random numbers with normal distribution. \( Z^{(g)} \) has the role of mutation.
Step 2 (selection): The selection chooses the best individual between the "parent" and "offspring" to survive. For the new generation, the best individual has to give a value of the objective function smaller than before and to satisfy all constraints.

This natural simple procedure can easily be applied for both deterministic and stochastic optimization problems. It has one very important advantage: there is no need to calculate partial derivatives of the objective function. The step "Selection" can be improved by simulated annealing approach [2], a technique which is very robust concerning the starting vector. There is a higher probability that the global minimum is found in comparison to deterministic methods (even to simple ES), the method enables us to escape from local minimum. This fact makes the method especially suitable for reliability optimization where a numerical calculation of failure probability is incorporated and local minima are often expected.

For the calculation of failure probability multipurpose package ISPUD was used [3]. This software is based on advanced simulation techniques as importance sampling. The interface between the optimizer and ISPUD program has been developed. The authors believe that the most efficient numerical techniques for optimization and for calculation failure probability are combined into a rather robust optimizer.

The optimizer was applied and tested on several civil engineering problems, mainly those concerning computational structural mechanics, e.g., the optimization of truss and frame structures, the minimization of the cost of reinforced concrete cross-section and the estimation of optimum concrete mixture. Here we provide only an illustrative example: The ten-bar truss, shown in Fig. 1, subjected to a single loading condition. The minimization of weight (volume V) under stress constraints is required, design variables are the cross-sections of bars $A_i$. Simple ES provided the solution $V = 17050 \text{in}^3$, $A = (6.97; 1.56; 10.0; 2.98; 0.10; 1.37; 7.11; 4.20; 4.22; 1.69) \text{in}^2$ (after 5000 generations). This solution appeared to be a local minimum because ES with simulated annealing found better minimum (global) $V = 15938 \text{in}^3$, $A = (7.95; 0.10; 8.06; 3.94; 0.10; 0.10; 5.75; 5.57; 5.57; 0.11) \text{in}^2$.

Fig. 1: The ten-bar truss

References:

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STATISTICAL AND SENSITIVITY ANALYSES OF STEEL FRAME

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Key words: random behaviour, Latin Hypercube Sampling, sensitivity analysis, steel frame

A realistic prediction of random behaviour of steel frame (see Fig. 1) based on a probabilistic approach is the objective of this study. FEM deterministic model IDA is used for the calculation of the frame response: normal forces, shearing forces, bending moments, deflections. Input random parameters considered in this study are summarized in Table 1.

In statistical analysis we are interested in estimating statistical parameters of the frame response, which means: mean value, standard deviation, coefficient of variation and skewness. This analysis is performed based on the numerical simulation Latin Hypercube Sampling [1, 2]. A number of simulations selected is 25 here. See Table 2 for the results of the statistical analysis.

The importance of input random variables in computational model is studied in sensitivity analysis based here on nonparametric Spearman coefficient of correlation [3]. Some results of this analysis are in Table 3.

Fig. 1 Steel frame.
Random Variable | Unit | Mean Value | Standard Deviation | Type of Distribution
--- | --- | --- | --- | ---
\(x, \) | m | 0.0 | 0.02 | normal
\(X_0\) | m | 7.85 | 0.0 | normal
\(A_1\) | m\(^2\) | 2.14E-2 | 1.07E-4 | normal
\(l_{ab}\) | m\(^4\) | 7.7932E-4 | 7.7932E-6 | normal
\(A_e\) | m\(^2\) | 2.436E-2 | 1.218E-4 | normal
\(l_{ae}\) | m\(^4\) | 1.46675E-3 | 1.46675E-5 | normal
\(E\) | GPa | 210.0 | 6.3 | normal
\(F_1\) | kN | 218.14 | 21.814 | log-normal
\(F_2\) | kN | 130.0 | 13.0 | log-normal
\(F_3\) | kN | 180.6 | 18.06 | log-normal
\(F_4\) | kN | 77.7 | 7.8 | log-normal
\(F_5\) | kN | 180.6 | 18.1 | log-normal
\(F_6\) | kN | 151.6 | 15.16 | log-normal
\(F_7\) | kN | 218.14 | 21.8 | log-normal

Tab. 1: Input random parameters.

<table>
<thead>
<tr>
<th>Statistical Parameters</th>
<th>(-N_{10}) [kN]</th>
<th>(-Q_z) [kN]</th>
<th>(Q_z) [kN]</th>
<th>(-M_z) [kN]</th>
<th>(-M_3) [kN]</th>
<th>(-z_2) [mm]</th>
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</thead>
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<tr>
<td>Mean Value</td>
<td>824.6</td>
<td>352.9</td>
<td>464.5</td>
<td>693.2</td>
<td>712.4</td>
<td>320.3</td>
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<tr>
<td>Standard Deviation</td>
<td>29.4</td>
<td>19.2</td>
<td>17.5</td>
<td>50.0</td>
<td>33.2</td>
<td>18.6</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>3.6%</td>
<td>5.4%</td>
<td>3.8%</td>
<td>7.2%</td>
<td>4.7%</td>
<td>5.8%</td>
</tr>
<tr>
<td>Skewness</td>
<td>-0.216</td>
<td>-0.545</td>
<td>-0.355</td>
<td>0.003</td>
<td>0.043</td>
<td>-0.125</td>
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</table>

Tab. 2: Results of statistical analysis.

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<tr>
<td>(-N_{10})</td>
<td>F_1</td>
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<td>F_1</td>
<td>0.785</td>
<td>F_1</td>
<td>0.557</td>
<td>F_1</td>
<td>0.946</td>
<td>F_1</td>
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<td>F_1</td>
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<td>(-Q_z)</td>
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<td>0.583</td>
<td>F_1</td>
<td>0.268</td>
<td>F_1</td>
<td>0.511</td>
<td>F_1</td>
<td>0.283</td>
<td>E</td>
<td>-0.292</td>
<td>(x_1)</td>
</tr>
<tr>
<td>(Q_z)</td>
<td>E</td>
<td>-0.299</td>
<td>E</td>
<td>-0.258</td>
<td>F_1</td>
<td>0.403</td>
<td>l_{ab}</td>
<td>0.271</td>
<td>F_1</td>
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<td>F_1</td>
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<tr>
<td>(-M_z)</td>
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<td>F_1</td>
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<td>F_1</td>
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<td>F_1</td>
<td>0.085</td>
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<tr>
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<td>F_1</td>
<td>0.098</td>
<td>F_1</td>
<td>0.091</td>
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<td>0.093</td>
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<td>F_1</td>
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<td>F_1</td>
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</table>

Tab. 3: Results of sensitivity analysis.

References:


This research has been conducted at Departments of Structural Mechanics and Metal and Timber Structures as part of the research project "Behaviour of Steel Structures: Reliability Approach" and has been supported by TU of Brno grant No. B16/94.
BRIDGE’S SERVICE LIFE

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Key words: simulation, service life, linear fracture mechanics

A bridge service life can be simulated using the EVA system. 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 of Prague. The EVA system consists of a set of programs for the static design of a structure. The program operates using a data base of the structure to be simulated as the in-and output medium. The EVA system is composed of these six programs:

- KONSTR – for data input and database composition.
- ANAL – for stiffness and mass matrix composition analysis using the finite element method.
- EIGANA – for eigenvalue and eigenvector analysis.
- STATIC – for the assessment of the statics of unmoving and moving loads and for steady state oscillation.
- SIMUL – for simulation of unsteady state oscillation (initial displacement, machine changing turns, vehicles, seismicity).
- LIFE – for determining the structure service life of the structure.

The structure may be simulated in two or three dimensions and it can be made up of beams or isoparametric planes, plates and shells elements.

The program SIMUL calculates the unsteady states of vibration. A simulation model of a vehicle is built on a computer, while bridge vibration and the vibrations of vehicles are simulated. This means that the differential equations for the structural vibration and the differential equations for the vibration of vehicle parts are numerically solved simultaneously. The bridge vibration is influenced by the vehicle’s vibration while the vehicle vibrations also influence the bridge’s vibration. The road and railway vehicle models are compiled as planes or spaces. Both the vertical and rotational motions of the chassis are taken into account. The axis and tyres are considered as springs with dampers and friction. A library of vehicle parameters can be used. Such heavy lorries as the TATRA (T148, T815S3, T815S1), and the trailer LIAZ, engine and carriage are included.

The evolution of stress in any part of the structure while a vehicle, a group of vehicles or a train pass over the bridge form the output of an EVA simulation experiment. This output is calculated for some arrangement of vehicles, some distance between the vehicles, some vehicle velocities and some roadway surface unevenness etc. A statistical description of the traffic flow (numbers of vehicles per time unit sorted according to vehicles categories) for each road at the Czech Republic is stored. From this information structure’s service life can be then determined according to the Wöhler curves by using linear fracture mechanics.

The history of stress development is decomposed into the basic harmonic modes by using the rain-flow method. Wöhler curves can be used for the amplitude of the stress
and the number of periods can be approximated on the logarithmic scale by two straight lines. According to the Czech standard ČSN 731401 and its associated comment, the right segment's slope can be set to zero. The formula for harmonic oscillation and the constants of the formula for various detailed type are published in ČSN 731401. If the oscillation is not harmonic, then the Miner hypothesis can be used:

\[ \sum_{i=1}^{m} \frac{T_{ri}}{N_i} = 1 \]  

where \( m \) is the number of vehicle groups, with \( r_i \) vehicles in each group per time unit, where \( T \) is the number of time units before instatiation of a crack and \( N_i \) is the number of harmonic periods before instatiation of a crack for a given stress amplitude. Formula (1) can be used for determining the service life given as time \( T \).

If the service life is to be determined by linear fracture mechanics then the following algorithm can be used. If the basic mode was found by computer simulation, then the amplitude must be added to a corresponding group to finally arrive at the arithmetic or geometric average.

Let the initial width of a crack be given and let each propagation be simulated by linear fracture mechanics. A stress-intensity coefficient, \( K \) is used to decide on the crack growth velocity (the computer algorithm was developed for various crack types).

Let us suppose that a crack does not grow for \( K < K_0 \) and that the Paris law is valid for \( K > K_0 \)

\[ \frac{da}{dN} = C K^n \]  

where \( C \) and \( n \) are constants found from experiments. The simulation algorithm is applicable while the crack width is less than a critical width.

Finding solution using Wöhler curves is advisable for thin profiles as long as no crack is present. Solution based on linear fracture mechanics are advisable for thick walled bridge profiles. The solution method is simple, but the influence of a stress amplitude change in not included.

References:


This research has been conducted at the Department of Structural mechanics as part of the research project "Simulation of material fatigue life of construction on computer" and has been supported by CTU grant No. 2020.
FAIUIE MECHANICS
OF JOINTED ROCK MASS

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Key words: cube, friction, layer

This grant project studies the mechanism (development, kind) of the failure of rock mass. A rock mass is considered as a structure consisting of two periodically repeating layers.

The authors have studied the problem experimentally. Fig. 1 shows the rest of the cube without layers after the test. The samples consisted of two periodically repeating layers. The layers were variously declined. The first kind of layer had a thickness of 50 mm and the second type of layer had a thickness of 3 mm. If the declination of the layers \( \alpha \) was less than 30°, the tension cracks were initialized in the neighbourhood of the sample fringe (see Fig. 3). This is because the soft crack filling is pushed out and brings a tension into the layers. If the layers are vertically or nearly vertically oriented, \( \alpha > 70° \), the failure commences by parting of layers (see Fig. 2). If the angle \( \alpha \) is of about 45°, the failure is combined (see Fig. 4). The measured quantities were the elasticity modulus \( M \), the Poisson number \( \nu_p \) in the direction of the layers and \( \nu_K \) perpendicular to this direction. From the figures can be seen that while the modulus \( M \) does not vary dependent on the declination of layers, the Poisson number \( \nu_p \) shoots up until the declination of the layers attains the angle of internal friction of the rock and \( \nu_K \) descends toward zero for the angle of layers of about 70°.

The experimental results were compared with a mathematical model which involved the physically nonlinear law described in [1]. The 2D problem was solved and plain stress was considered. These assumptions affect the results from the mathematical treatment, but generally, the possibility of making mathematical models of problems like that was principally verified. From Fig. 5 it follows that \( \nu_K \) is higher than that of the experiment while \( \nu_p \) has virtually the same values. Also, a tension crack did not occur in the mathematical study, since in the experiment some friction influence along the surface where the sample is supported and loaded cannot be annihilated while the mathematical model describes virtually an infinite pier.
References:


This research has been conducted at the Department of Structures of Klokner Institute as a part of the research project "Mechanismus porusování horninového masivu" and has been supported by the Fond rozvoje vysokých škol No. 0498.
ANALYSIS OF SOME EXPERIMENTS CARRIED ON CAM CLAY MODELING

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Key words: CAM clay, triaxial test, Biot's equation

One of the aims of the research was to describe the behaviour of clays. Using CAM clay modelling the following parameters $M$, $\lambda$, $\kappa$ and $e_0$ must be measured. There are many impacts which affect the material properties. A standard triaxial apparatus was chosen in our case. By applying constant chamber pressure during triaxial test NCL (isotropic normal consolidation line) and $\kappa$-line (the line of unloading) can be computed. Thus the parameters $\lambda$, $\kappa$, $e_0$ are known. Governing equations of our problem (see e.g. [1], [2]) are:

- Darcy law and fluid continuity equation

$$\text{div}(\lambda_u \text{grad } p) = \frac{1}{M} p_t + b \varepsilon_{st}$$

where $\lambda_u$ is the hydraulic conductivity, $p$ denotes pore fluid pressure, $M$ is Biot's modulus, $b$ represents Biot's coefficient, $\varepsilon_{st}$ is the trace of strain tensor.

- equilibrium equation, in this special case

$$\sigma_{mt} = p_t$$

where $\sigma_{mt}$ is the mean effective stress.

- and CAM clay constitutive equations

$$(1 + e)_t = -\lambda' m_{st}/(\sigma_m' + \sigma_0)$$ for loading

$$(1 + e)_t = -\kappa m_{st}/(\sigma_m' + \sigma_0)$$ for unloading

where $e$ is the void ratio, $t$ is time, $\sigma_0$ is atmospheric pressure.

In this article some results of laboratory tests of clay material are presented. The material was taken from Libouš waste dump (DNT Tušimice - brown coal mine in North Bohemia) in the form of core from depth of 8m below the temporary surface of the waste dump.

In the laboratory soil samples for triaxial testing with actual moisture content about 36% were prepared. The samples were consolidated under isotropic loading. They were loaded up to 300 kPa and unloaded to 0 kPa three times. In the next similar procedure the sample was loaded up to 600 kPa, Fig. 1. We can explain a "soft" increase of pore-water at the beginning of the test by partial unsaturation of the soil sample. Some inaccuracies in the pore-pressure - time development (Fig. 1a, 1c) are caused by temperature changes, see Fig. 1b, 1d. (One increment of vertical scale represents 1 °C, referring to an initial temperature 20 °C). Volume changes of the soil sample measured in capped byrette to
decrease evaporation. This way of measuring was unacceptable because of in accurasy and the impossibility of direct measurement of volume of air escaping from the sample. Based on our experiments we can estimate magnitude of $\kappa = 0.04$.

A new set of tests will be carried out with the use of different ways of the separate measurement of volume of water and air escaping from the sample to improve the possibility and accuracy of interpretation of results. A brief description of the new designed system for measurement of air and water volume changes will be presented in the Workshop session.

![Fig. 1: Isotropic consolidation](image)

References:


This research has been conducted at the Department of Structural mechanics as a part of the research project "Fuzzy-probability concept of time dependent of structures reliability" and has been supported by GA 103/94/0137.
USE OF FREE SOFTWARE
IN RESEARCH AND EDUCATION
OF POST-GRADUATE STUDENTS

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Key words: computational mechanics, free software

The academic programs of research and education for post-graduate students of the computational mechanics often include the use and application of computers in the workstation class. One of the main reasons for this is the computational power of these computers. There is, however, a major disadvantage in using workstations – the software is generally very expensive. The workstations run mainly some derivative of UNIX operating system and the costs of compilers, tools, databases, spreadsheets and visualization software needed are in most cases well beyond reasonable financial limits of the academic budgets. One solution to this problem was investigated by the grant of the CTU No. 18161, the results of which are summarized here.

The solution proposed consists in the use of free or public domain software. Its use in the academic institutions of the Czech Republic is currently rather limited. The reasons for this can be followed to (i) the communication barriers under the communist regime, which prevented the software from being known and the users from obtaining it; (ii) the lack of courage on the side of the academicians to actively participate in the adjustment of the free software to their needs (it is of course much easier to buy something, if someone is willing to pay for it); (iii) the lack of knowledge needed to carry out the necessary adjustments (partly caused by the unwillingness to constitute multi-disciplinary research teams including computer scientists).

The current situation seems to be much more propicious to the use of free or public domain software. Some problems remain, however, for instance most academicians do not know that software that could accommodate their needs exists, and if they do know about it, they do not know where and how to find it.

The main results of the work done by the authors are directed at the discussed issues:

• The sources of software available in the field of computational mechanics and related fields were localized [1].

• Selected software packages were tested and their usefulness was assessed.

• A number of contacts to members of foreign academic institutions with similar interests were developed and strengthened.

• The members of the research team to which the authors belong contributed several free software packages.
The results can be further detailed as follows. Over two hundred software packages were localized and evaluated (computer languages – compilers, interpreters, tools for parallelization, numerical analysis – linear algebra, statistical analysis, multigrid solvers, visualization – user interface builders, graphic libraries, graphing and data analysis tools, document preparation, spreadsheets, databases, finite element packages, comprehensive software environments etc.). The outcome of this process was documented in a report [1] (available from the authors, for free, of course, in concordance with the goals of the grant) and it will be published in reduced forms in journals [2,3].

A number of selected software packages were thoroughly tested (they are actually being successfully used by the members of the research team in their everyday work). The costs saved by these free tools can be estimated to amount to as much as $8900 per seat (price of comparable commercial offerings).

A number of contacts was established with individuals at foreign institutions – Ruhr University in Bochum (Germany), TU Delft (The Netherlands), INASMET San Sebastian (Spain), TU Bangalore (India), TU Göteborg (Sweden), EFP Lausanne (Switzerland). The contacts will hopefully contribute in the future to the sharing of ideas, knowledge etc. in the world-wide network of scientists on the Internet.

References:


This research has been conducted at the Department of Structural Mechanics of the Faculty of Civil Engineering as part of the research project “Use of free software in the research and education of post-graduate students” and has been supported by CTU grant No. 18161.
OBJECT-ORIENTED EXPLICIT
FINITE ELEMENT COMPUTATIONS

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Key words: object-oriented analysis, finite element methods, computational dynamics

The finite element method has been utilized in thousands of programs since its conception in the sixties. A number of problems involved in the finite element systems programming, that can be denoted probably as being of "technological" nature (data management and transfer, interactivity, extensibility, maintainability, ...), had appeared and had also been solved, albeit in many cases only temporarily. One of the most painful exercises has always been the effort to reconcile the need for flexibility (extensibility) and efficiency. Due to the insufficient hardware power, the efficiency was often given primacy in the past. The situation seems to have taken the opposite turn recently.

The use of the object-oriented technique in the finite element applications exhibits some specific features compared to the modeling of the "real-world" problems. The difference is explained by the fact that the primary purpose of objects from this problem domain is to serve to the underlying "well-defined" algorithm. This is not the case for objects which appear in areas like product modeling where the problem specification says what responsibilities the system must have and the output of the object-oriented analysis is then the optimum organization of involved objects for realizing these responsibilities. Under the optimum organization we understand such schema, which minimize the communication bandwidth between objects.

The problem statement in finite element application domain is more specific, because a considerable part of the analysis of the problem has already been done through the formal tools (e.g. variation and matrix calculus). The goal that remains for the object-oriented analysis is similar to the modeling activities - to arrive at such data and execution decomposition, that (a) allows efficient execution of the algorithm and at the same time (b) minimizes the dependencies between objects involved in the algorithm.

The present effort focuses on the programming of finite element systems for explicit integration in time (non-linear finite rotations dynamics of structures). Object-oriented techniques have been applied (Coad-Yourdon analysis methodology, implementation in plain C language). The explicit algorithms tend to be rather straightforward. Therefore, the analysis diagrams of subjects and services translate into the logical steps of the algorithms and vice versa relatively cleanly. Interestingly, it appears that if the analysis is consistently carried over to design and implementation, the results differ in several rather important points from the traditionally accepted "ways of doing these things" (note: this includes all "object-oriented" finite element systems reported in recent publications on the subject).

First, the problem domain coordinates the actions of its constituent subjects and intermediates in the information flow. A high level of functional abstraction is thus achieved as can be demonstrated on the issue of the integration in time: the selected algorithm of time stepping can be very cleanly concentrated into an integrator object, whose main task is to advance the solution one step in time (half a dozen lines of code). The algorithm is in this
way "parameterized" by the methods that the problem domain provides to the integrator (the domain drives the solution by requesting the integrator to step forward).

Secondly, a very natural separation of responsibilities between the finite element and the nodes of the mesh can be achieved. The traditional programming considerations lead to the following situation: an element maintains the equation numbers of unknown parameters at its nodes in order to be able to assemble either directly or indirectly (through an intermediary) the elemental quantities (nodal forces, masses, tensors of inertia etc.). Now, consider that the explicit codes require the system matrix (the effective mass matrix) to be diagonal for efficiency reasons. This means, that (a) the mass matrices of the elements must be diagonalized and (b) that the nodes must use private coordinate systems in the directions of the principal axes of the nodal tensor of inertia. This in turn means that each element type must convert its matrices into appropriate coordinate systems. This is a very cumbersome situation, as it involves not only considerable flow of information but also difficult maintenance.

An example of the application of the Coad-Yourdon model in analysis of the problem is shown in the figure. The simplified version of the schema represented by the Subject layer, Class-&-Object layer and Structure layer is used to show the message connection and their dependencies arising during the realization of the service Integrate provided by the Domain.

References:


This research has been conducted at the Department of Structural Mechanics of the Faculty of Civil Engineering as part of the research project “Safety and serviceability analysis of concrete structures” and has been supported by CTU grant No. 18164.
ANALYSIS OF STRUCTURES USING OBJECT-ORIENTED APPROACH

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Key words: finite elements, object oriented programming

The design of structures is a very complex procedure that involves a series of steps, for example: analysis, evaluation, various experiments and so on, in order to fulfill certain specifications given by codes. One of the most important stages involved in design procedure is finite element analysis. In this paper we are describing an Object-Oriented (O-O) analysis of finite element methods with regard to efficiency, robustness and easy state of the art extensibility. Due to facts to be mentioned in this paper, new O-O finite element program has been developed.

Development of new FEM code may be viewed as useless, as a wide variety of existing programs exists. Despite this fact, however, general purpose programs are often suffering from hard extensibility to state of the art functionality. This means that these codes are unstructured. Today's general well-known finite element codes such as NASTRAN, ADINA and other codes from various authors have limited extensibility and in some cases if you try it, you may encounter severe problems. Such programs consist of large amounts of code, often with unclear specifications and functions. In order for the program become more usable and reliable, it must be programmed as modular one. To summarize, finite element analysis programs are generally very complicated and thus prone to error. Due to the complexity of data-structures and control-flow the maintenance and development of such codes become costly.

There is a requirement for FEM codes to be easily modifiable and extensible for the future demand of engineers. Modification of programs is essential in order to incorporate new design methods, new analysis procedures, newly arising element types and advanced procedures in modelling of material behaviour. Re-usability and reliability of engineering software is very important. Due to these facts, new FEM code has been developed, based on object-oriented approach. C++ programming language has been used, because of it's widespread availability and implementation efficiency.

In O-O programming, data and operations on this data are encapsulated in so called objects. Every object can be an abstraction of a specific real object, then we can imagine any program as a collection of objects, where the program flow is performed by sending various messages to objects, through invoking operations belonging to objects. In O-O languages we can define classes of objects, some may inherit behaviour or data (or both) from some parent class. This is so called inheritance hierarchy of classes. Inheritance helps us to write structured code and as a consequence, it avoids duplication of code by programming general methods and data on the highest possible level. Other features like virtual functions, overloading and data-hiding are not discussed here, they can be found elsewhere.

In program which we are presenting, the most base class for almost all classes is FEM-Component (see Fig. 1). It defines basic behaviour for every derived classes like storing and
returning it's number, printing itself, making connection with domain class (see below) and so on. Only a small number of other classes is not involved in this hierarchy, for example matrix and vector classes and domain class. The last one, the domain class, is intended to be an integrating part of the program. It contains lists of every component, for example element list, node list and load list. It contains also key methods such as `InstantiateYourself()` for setting up the problem, and `SolveYourself()` for interfacing with the Engineering model class which performs solutions of the given problem. Instances of the `Engineering Model` class should be a real engineering model used for analysis of the structure such as the linear static model or the limit load perfectly-plastic analysis. Currently, the program is able to solve linear static and linear dynamic problems including eigen value analysis of free vibration. It contains a number of elements including plane, plate and space elements.

![Inheritance hierarchy starting from FEM Component class](image)

**Fig. 1:** Inheritance hierarchy starting from FEM Component class

**References:**


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DAMPING OF ROLLING GUIDEWAYS OF MACHINE TOOLS

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Key words: machine tools, linear rolling guideways, damping, damper

The negative effect of vibrations on machine tools is twofold. Roughness of a machined surface and resistance against self-excited vibration that limits the working capacity. The criterion of the first aspect is the maximum magnitude of the relative displacement between the tool and the workpiece, and the criterion of the second aspect is the minimum of the real part of the operational receptance. Both parameters can be improved by the increase of static stiffness and damping. It can be shown on the simple mathematic model that increasing damping is more effective. Hereafter it is generally known that moving and fixed joints are the main sources of the damping in machine tools. The structural damping is 10x-100x lower than that in joints and connections. For above mentioned reasons, it is important to study the damping of moving joints, especially rolling guideways, which have very low damping.

At the Department of Machines and Equipment for Engineering Production, CTU, Prague, a piston damping element has been developed for the damping of the linear rolling guideways. The construction diagram is shown in Fig. 1. The mobile part of the rolling guideway vibrating normally and tangentially is separated from the standing piston by squeeze-oil film, which dissipates the vibrational energy. The piston is forced by the small pressure (0.5-1.2 MPa) to the mobile part of guideway. The piston face is covered by the sliding material in order that the addition friction would not cause the stick-slip effect. The INA company produces a different type of dampers for the linear rolling guideways. The vibration energy is dissipated in squeeze-oil film, too. The basic differences are that the oil does not escape from our damper and our damper is efficient also in the feed direction. The piston damping elements were attached to the vertical lathe SKS 16-25 produced by TOS Hulin, where they are used for the damping vibration of the slide ram.

The measurement was performed on the vertical lathe SKS 20, which should detect the influence of the damper on the total dynamic behaviour. This influence was investigated by three types of exciting (exciter, cutting process, rotating spindle inside the slide ram). The experimental results for exciting by the cutting process are shown in Fig. 2. The depth of chip h is plotted at the x-axis and the ratios of the root-mean-square (RMS) acceleration of the machine without the damper and with the damper for direction X-PX and for direction Y-PY are plotted at the vertical axis. If values PX or PY are larger than one, the damper is efficient. The displacement frequency spectra for the direction Y of the machine tool without the damper and with the damper are shown in Fig. 3. The machine was excited by rotating spindle inside the slide ram. The displacement amplitude decreased about 15%. It was determined by the three methods of the measurement that damper decreases the displacement amplitude for the direction X by about 14% on average and for the direction Y by about 21% on average.
This research has been conducted at the Department of Machine and Equipment for Engineering Production as a part of the research Enhancement of Rolling Guides Stiffness, and has been supported by the grant of Czech Republic Grant Agency No. 101/99/2412.
STATIC STUDY OF THE DERRAILMENT PROCESS IN CURVED TRACK

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Key words: rail vehicle, mathematical model, quasi static study, derailment process

A more detailed knowledge of the derailment process is necessary both in connection with push-pull train operation and in connection with unconventional running gears (e.g. bogies with low diameter wheels). Chartet gave the theoretical fundamentals of the quasi static considered derailment process in [1]. The extending of Y/Q criterion for cases of the impulse acting guiding forces (Y) followed from the theoretical and experimental activities of JNR. These criteria express the limit condition of the Y/Q ratio value for the beginning of the guiding wheel flange climbing on the top of the rail and the beginning of the wheelset moving in a lateral direction respectively. However these criteria do not take into account real variations both of guiding forces and wheel loads within derailment.

Fig. 1: Model of the bogie
The aim of this contribution is to suggest preliminary ideas on motion conditions of two-axle vehicle (bogie) in the period, in that the contact of the guiding wheel with the rail occurs only on its flange as a result of the creep forces and/or the external forces (e.g. centrifugal).

The beginning of the derailment process is considered to be the moment when contact on the running surface is lost. It is possible to describe the situation on the guiding wheel and the bogie as a whole in this way:

- after exceeding the limit value $Y/Q$ ratio, the guiding wheel begins to climb by its flange to the rail top.
- the ground plan trajectory of the guiding wheel ceases to follow the circular trajectory determined by the guiding rail. The continuous climbing causes the wheel trajectory to straighten and the longitudinal creep on the steep flange increases rapidly.
- these are two reasons why the guiding force value decreases. According to the intensity of the decrease, the climbing process continues more slowly or [in the case of $(Y/Q) \; \lim(Y/Q)$] the back motion of the wheel in a downward direction occurs.
- the derailment process might continue, on the one hand, or contact on the running surface may be restored.
- the second case is interesting for further study. The guiding wheel follows the rail curvature again and the guiding forces of the bogie increases. If the external conditions do not change the described climbing process may repeat itself.

The model of the bogie (vehicle) in Fig. 1 is described by a system of equations. The behaviour of the mechanical system depends essentially on its eigenvalues as roots of its characteristic equation. The complete equations are determining for estimation of the certain trajectory of the climbing guiding wheel. By using the solution it is possible to estimate limit values of influences which are able to cause the finished derailment or estimate the probability of the finished derailment.

The eigenvalues of the system give the first information on the bogie behaviour from the viewpoints of its predisposition to climb by the guiding flange and of the real danger of derailment. The intensive return effects are to be expected in the interval of flange inclination angles 60-70 degrees. The limited influence of wheel-load variations and the apparent influence of wheelbase are indicated. The complete solution of the equation system will be necessary to create a preliminary idea on the derailment process and on the choice of adequate wheel tread profile.

References:


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DYNAMICS OF FLEXIBLE MULTIBODY SYSTEMS

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Key words: flexible multibody dynamics, FEM

In recent years, greater emphasis has been placed on the design of high-speed, lightweight, precision mechanical systems. In many of these industrial and technological applications, systems cannot be treated as collections of rigid bodies and the rigid body assumption is no longer valid. Hence the systems consist of bulky compact solids that can be modeled as rigid bodies, and of relatively elastic bodies that may deform, such as rods, beams, plates, and shells. The design and performance analysis of these systems, which can be modeled as multibody systems consisting of interconnected rigid and deformable bodies, can be greatly enhanced through dynamic simulation, provided the deformation effect is incorporated in the mathematical model.

The motion of a particle of a flexible body can be divided into a large motion of the body as a whole and a small motion due to deformation. The large motion is described by the motion of the local coordinate frame embedded to the body. Applying Gauss principle the equation of motion of a flexible body was derived. The six coordinates describing the motion of the body as a whole can be separated from the rest of the coordinates describing the deformation of the body. This makes it possible to combine the methods developed for rigid body dynamics with methods used for solution of body deformation particularly FEM.

The number of coordinates describing the deformation can be reduced applying Hurty's "Component Mode Synthesis". The deformed state of the body is approximated by a linear combination of deformation modes, like in Ritz method, but the deformation modes are obtained from FEM analysis, hence they are defined explicitly through displacements of the nodes. However an appropriate choice of the set of deformation modes is necessary and this requires some experience.

Derivation of the equation of motion for a body modeled as an elastic continuum and consistent discretization applying FEM is presented in [2]. The main methods for construction and solution of rigid multibody systems are the Direct Method, the Composite Rigid Body Method and the Articulated Body Inertia, see [3]. As the flexible multibody systems lead to a large number of DOF, the Direct Method is not suitable due to its computational complexity $O(DOF^3)$, so we concentrated our attention on the next two methods.

The modification of the Articulated Body Inertia for simple opened kinematic chain of flexible bodies was presented by Kim and Haug [4]. Their algorithm do not eliminate the modal coordinates one by one, but eliminates them at once for the whole body. This results in computational complexity $O((N_i + \sigma_i)^3)$, where $N_i$ is the number of modal coordinates of body $i$ and $\sigma_i$ is the number of joint coordinates between body $i$ and the preceding body $p(i)$. The recently derived modification of this algorithm, see [2], has computational complexity $O(N_i^2 + \sigma_i)$, which results in considerably shorter CPU time for numerical simulation of a real system. The efficiency of the algorithm was achieved by two modifications of the set of deformation modes. The problem is the kinematic relation between two connected flexible
bodies. The acceleration of body \(i\) depends not only on the acceleration of the body \(p(i)\) and the second derivatives of the joint coordinates, but also on the second derivatives of the modal coordinates describing the deformation of bodies \(i\) and \(p(i)\). It is solved by the first modification. It simplifies the kinematic relationship so that there do not appear all but only six modal coordinates of body \(i\) and six of body \(p(i)\). The second modification is the orthonormalization of the set of deformation modes \([5]\), so that an inversion of a square matrix of order \(N_i\) is skipped.

The Composite Rigid Body Method uses the traditional system of equations of motion written in a matrix form

\[
M(q)\ddot{q} = F(q, \dot{q})
\]

but with the recursive computation of the elements of the matrices \(M\) and \(F\) and consequently lower computational complexity. Using the equation of motion of a flexible body and the recursive kinematic relation this method has been extended to flexible multibody systems. The main advantage of this algorithm compared with the Articulated Body Inertia formalism is the possibility to use for integration the residual algorithm, which has in the present the best computational complexity.

Two algorithms for simulation of dynamics of flexible multibody systems that substantially decrease the computational complexity were derived. This is crucial, because despite the recent increase the computer speed is still far not satisfactory for numerical simulation.

References:


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TESTING OF MULTIBODY SYSTEM VIBRATION

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Key words: testing, mechanical vibration, measurement by A/D card

Dynamic behaviour of a mechanical multibody system, especially if it contains elastic joining components, is very difficult to predict. There are methods suitable for its mathematical modelling. After computation it is very useful to compare the results and the real system parameters. One way of checking dynamic behaviour of a mechanical system is its excitation by a known and repeatable vibration and the measurement of the system's response in selected points. Easily, it can be done by measured accelerations of motions in the directions of the x, y, z, coordinates. A measurement and record can be done by a PC equipped with an A/D card. If simultaneous acceleration measurement of all points is impossible and accelerometers have to be transferred, it is necessary to measure in one reference point. Position has to be constant for all measurements. For the determination of a phase delay it is recommended to record the start of the excitation period too. After measurement, the record is submitted to the harmonic analysis. The accelerations in every direction for every harmonic order have a form of \( a = a_n \cos(\Omega t + \psi) \).

The accelerations in each direction have to be added into the resulting value for the order of a harmonic component in consideration. For two directions the task is simpler than for three ones. For coordinates x and y accelerations are

\[
\begin{align*}
  a_x &= a_{x_0} \cos(\Omega t + \psi_x) \\
  a_y &= a_{y_0} \cos(\Omega t + \psi_y)
\end{align*}
\]

These equations are parametric expressions of an ellipse. Acceleration is time derivative of velocity, however. Using this fact we can write expressions for a velocity ellipse as

\[
\begin{align*}
  v_x &= a_{x_0} \cos(\Omega t + \psi_x - 90^\circ)/\Omega \\
  v_y &= a_{y_0} \cos(\Omega t + \psi_y - 90^\circ)/\Omega
\end{align*}
\]

Similar consideration can be made for a movement too. The expressions are then in the form of

\[
\begin{align*}
  s_x &= a_{x_0} \cos(\Omega t + \psi_x - 180^\circ)/\Omega^2 \\
  s_y &= a_{y_0} \cos(\Omega t + \psi_y - 180^\circ)/\Omega^2
\end{align*}
\]

These equations are parametric expressions of an ellipse again, which is a trajectory of the point of the body as a part of the multibody system. This ellipse is similar to the
ellipses of velocity and acceleration. Only the begin of each one is moved by $$-90^\circ$$ in each step (with aspect to parameter $$f_t$$).

For finding a centre of rotation we can use a rule: a centre of rotation lies at the perpendicular line to the tangent of the trajectory. To find the centre of rotation we must use two points, which lie in the plane parallel to x-y plane. If a pair of points does not lie in a plane like that, the transformation of coordinates should be used.

Very often motions of each point of a pair are smaller than the distance between them. Then we can draw the perpendicular lines to the tangent of trajectories in these points. We can obtain angle of the tangent as

$$\tau = \arctan\left(\frac{v_y}{v_x}\right)$$

and the angle of the perpendicular line is $$\tau - 90^\circ$$. This way, doing through the whole excitation period, we can obtain poloide. For simplification we can substitute this curve by one point as a "mass-centre".

By addition of accelerations in three directions we can obtain axis of motion or axis of viration.

Very important is the dependence of the position of the centre/axis of the motion on the exciting frequency. When the position of the centre/axis is not changed by a changed frequency, that means that the form of vibration is not changed too. But if the position is changed, the form of vibration was changed. From it follows, that a subsystem containing a pair of solved points has its own frequency in the increase range of the exciting frequency.

References:


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COMPUTER AIDED FLEXIBLE MODELLING OF MULTIBODY SYSTEMS

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Key words: Multibody system in plane, Computer Aided Analysis, Kinematics, Statics, Dynamics, User interface

Introduction. This research deals with the computer aided modelling and analysis of multibody systems. Multibody systems are mechanical models of different technical systems consisting of rigid (now also deformable) bodies connected by kinematic pairs and massless force elements like springs, dampers, actuators etc. The kinematic pairs constrain the mutual motion of originally freely movable bodies.

The conducted research has concentrated in this year into two topics:

• further development of program called ASMER for computer aided flexible modelling of multibody systems

• development of new multibody formalisms dealing with flexible bodies.

The second topic is treated separately in another contribution to this Workshop.

Program ASMER. As being already reported (Valášek et al, 1993) the program ASMER (the acronym for Analysis and Synthesis of MEchanisms in planarR cases) has been developed. The flexible modelling means that the user can by the system formulate and solve a great variety of different mechanical problems. The system enables to solve direct and inverse kinematic, static and dynamic problems. Many different parameters (i.e. not only coordinates, but also forces, spring constants etc.) can be treated as unknown variables to be solved for.

The developed system has been tested on simple examples, errors have been corrected and a user-oriented documentation has been developed.

User Interface. ASMER has the primary interface based on the input description language. However, for the user convenient another interfaces have been developed. In order to enable the direct connection between ASMER and different CAD systems the possible generic and also specific graphical interface has been investigated. From the point of graphical interface it is useful for the user to enable the attachment of graphical objects from CAD system being used with the parts of multibody model. This makes easy the input of structural and other data and it will enable to animate the results in the future.

The generic solution is based on the object oriented approach towards the data description of the multibody models. The interface is divided into two parts. One is specific for the CAD system being used and the other is general. The first part takes the data from the
CAD geometry and user's other data (masses, forces etc.) and creates the internal database of these parameters. The second part translates the data from this internal database into the file with the ASMER input description language. This part can be reused.

A specific graphical interface as the application program in AutoCAD has been developed and now being tested. It enables that the user prepares the CAD geometric model (drawings) and by adding specific data this model can be analyzed as multibody model. The required added data are the structural description (or decomposition) of his pure geometric model, the characteristic dimensions of the connection of kinematic pairs and bodies, mass properties of particular bodies, forces and required task to be solved. The interface as a file with input description language is generated. The program ASMER can be run on these data.

Conclusions. There has been developed a powerful tool for computer aided modelling of multibody systems in plane. This system could to be incorporated within different CAD systems for connection between design and analysis. However, the system still require further development.

References:

This research has been conducted at the Department of Mechanics as part of the research project "ASMERP - Computer System for Analysis and Synthesis of Mechanisms in Plane and Space" and has been supported by CTU grant No. 8121.
ANALYSIS OF STATIC COMPLIANCE AND MODAL PROPERTIES OF A SU16 LATHE

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Key words: static compliance, analysis, modal analysis, machine tool, lathe, identification, FEM modelling, experiment

One of the aims of this work is to improve the methods of creation of machine tool calculated FEM models. The models are useful for evaluation of an influence of the individual structure parts on both the level of static deformation between an instrument and a workpiece, and the dynamic properties of a machine. Some static and dynamic experiments at a machine, which are done simultaneously with this calculations, are necessary to correlate and update properties of the FEM model, designed on the base of a drawing, with essential properties of the investigated machine structure, including the coupling properties of the individual structure parts. The comparison of the calculation and experimental results increase credibility of the FEM model and this makes possible some simulated calculations, not only at the current structure, but also at various modified structures. This approach is useful to optimize static as well as dynamic parameters of machine tools.

The above mentioned method was applied on a structure of a SU16 lathe with a milling super-structure. The super-structure consists of a cantilever, through this it is connected to the bed of the lathe, of a column, along which it is possible to move a chuck, which supports a milling head. A spindle is mounted in a tailstock barrel.

The software system COSMOS/M was used to design the FEM model. The Fig. 1. shows it together with one typical mode.
Regarding the complicated structure, many simplifications were applied. To the most significant one belongs the influence of contact stiffness in the moving couplings of any parts of the investigated structure. The only contact deformations applied were those of the rolling - contact bearings of the spindle. The static force loaded the structure in the three directions at the point of cutting instrument. The results of the comparison of the both models in the form of percentage differences are shown in the Tab. 1. The method of impact excitation was used to measure the experimental modal parameters. For illustration only some parameters are shown.

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The compared measured mode number 1 of natural frequency 179.5 Hz is shown on the Fig. 2.

References:

This research has been conducted at the Department of Machines & Equipments for Engineering Production. All FEM calculations has been done at the Department of Mechanics. The work is a part of the research project "Enhancement of Stiffness and Accuracy of Machine Tools" and has been supported by the grant of Czech Republic Grant Agency No.101/93/2412.
BEHAVIOUR OF LINEAR GUIDE SYSTEMS BY USING ADDITIVES FOR OILS

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Key words: linear guide systems, coefficient of friction

Many things influence the accuracy of machine tools. Among the most important influences are linear guide systems. Linear guide systems which are the most commonly used in machines tools include linear guides with rolling-element bearings, metallic sliding guides and guides with metal/PTFE guideways.

From the point of view of friction, the least effective guide system is the system having metallic sliding guides. In this system, one part is made of steel and the other of cast-iron. This combination of materials results in stick-slip effect in the low-velocity range. The stick-slip effect reduces the machine tool accuracy and results in poor quality of machined surface of the products. In spite of the use of various oils, the stick-slip effect still remains as a problem. There are additives, however, which can improve the capability of oils to decrease the coefficient of friction, especially in low-velocity range.

The useful additives include colloid dispersion of molybdenum disulphide (MoS2), produced by Molykote company.

Another type of useful additive is the solid PTFE lubricant. The lubricant contains particles that are smaller than 10 µm (in size).

Recently, Howe Laboratories have manufactured another type of useful additive called Duralube, made from crude oil. Homogeneous lubricant film is formed by individual molecules of Duralube (also referred to as SR3) which stick to a lubricated surface.

An extensive research on behaviour of metallic sliding guides and linear guides with metal/PTFE guideways has been performed on the experimental stand at Department of Engineering and Equipment for Mechanical Engineering Production. Comparison of Stribeck diagram for metallics sliding guides with P4A oil without additives and with additives, and guides with metal/PTFE guideways with Turcite B and P4A oil is shown in Fig. 1. To eliminate the stick-slip effect, especially for low velocities, the coefficient of friction must be constant over the range of velocities or slightly growing.
For these conditions, only P4A + Duralube and guides with metal/PTFE guideways with Turcite B are suitable. Additive Molykote in these conditions can only decrease the value of coefficient of friction.

This research has been conducted at the Department of Machines and Equipment for Engineering Production and has been supported by the grant of Czech Republic Grant Agency No. 101/93/2412.
MULTIPLE MODEL METHOD
IN EXPERIMENTAL MODAL ANALYSIS

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Key words: machine tools, modal analysis

Closely spaced modes (causing modal coupling) represent one of the significant error sources the Experimental Modal Analysis. Modes with close modal frequencies mutually affect each other which results in difficulties in determining the values of modal parameters from the measured spectra. The "degree of coupling" depends on how close the natural frequencies are and how high the dampings of the individual modes are. Modal parameters can be most accurately extracted from a spectrum containing only one mode (SDOF), or where the modal frequencies are sufficiently separated.

Sophisticated modal softwares extract the modal parameters from measured data using various MDOF curve-fitters. Those respecting modal coupling, however, are usually very complicated and not always accurate enough, mainly speaking of modal dampings and eigenvectors.

Multiple Exciter Method is still the best one from the point of view of accuracy but requires complicated and expensive instrumentation and is also very time consuming.

Multiple Model Method utilizes the possibility of physically isolating the adjacent modes by exciting the structure (or picking up the response) in their nodal points.

For example, if the task is to determine the modal parameters of the 1st bending mode in z direction of a beam with a rectangular cross section fixed at one end, the best point for excitation (reference DOF) will be the node of the 2nd bending mode in z direction. By placing the exciter to the z direction, all the bending modes in y direction are "physically" isolated (Fig. 1).

Procedure of accurate determination of modal parameters using MMM:
- Approximately determine the mode shapes using a traditional method with impact excitation.
- Isolate adjacent modes by exciting (or picking up the response) in their nodes. From SDOF spectra then accurately extract modal frequencies, dampings, and mode shape vectors - if it is physically possible!
Application of MMM to universal centre lathes. Accurate values of modal parameters are apart from other things important for stability analysis of machine tools. The oscillatory system of a workpiece in its clamping has, for majority of universal lathes, two distinctive modes 1 and 2 with the directions $\alpha_1$ and $\alpha_2$ respectively (fig. 2). Unfortunately, these two modes have very close natural frequencies resulting in high modal coupling. Conventional methods are therefore quite complicated to use.

**Multiple Model Method Procedure.**
- Using impact excitation, find the directions $A$ and $B$, perpendicular to the directions of the modes 2 and 1 respectively (Fig. 3).

![Fig. 2 - Directions of modes of centre lathes.](image)

- Measure the complex FRFs $H_{AA}(\omega)$ and $H_{BB}(\omega)$ by exciting the structure and picking up the response in the directions $A$ and $B$ respectively. The direct receptances can be calculated from the following equations:

$$H_{11}(\omega) = \frac{H_{AA}(\omega)}{\cos(\phi_1 - \phi_2 - 90)}$$

$$H_{22}(\omega) = \frac{H_{BB}(\omega)}{\cos(\phi_2 - \phi_1 - 90)}$$

If the task is to determine the mode shapes along the workpiece using MMM, the best reference point/direction would be the one perpendicular to the mode being isolated.

**Multiple Model Method** is an easy method for a relatively accurate determination of modal parameters using very simple instrumentation. It, however, cannot be effectively used to all the modes and dynamic structures. The method has been proved experimentally on a beam and a universal centre lathe SV32.

This research has been conducted at the Department of Machines and Equipment for Engineering Production and has been supported by the grant of Czech Republic Grant Agency No. 101/93/2412.
PROBLEMS OF THE DYNAMICS OF MACHINE AGGREGATES

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Key words: dynamics, machine aggregates, SW FAMULUS

Knowledge of the dynamic characteristics of machine aggregates is necessary for their design, construction and control. The Department of Mechanics and Materials Science of Electrical Engineering of the CTU in Prague is interested in the modelling of physical and mathematical models of machine aggregates for the requirements of control engineering. A method for the characterisation of a dynamic system has been developed, including non-linear elements with dissipation of energy and conditional bond. The computational system, Famulus SW, uses the numerical solution in order to solve mathematical models. This can be pinpointed by the system of non-linear differential equations of the second order. It also enables, besides tabular and graphical outputs, animation of the movement of the system.

A method for the construction of a mathematical model of machine aggregates is obtained using the Newton's second law or the Lagrangian equations of the second order. Five selected examples are presented in this paper. Model solutions of these examples are, from the program-making point of view realized as "open"; this means that no menu from DMENU libraries is used, so the parameters, and equations can be arranged by the Famula editor. So scientists have a chance to recognize this program step by step, which leads, in the end, to their independent work with it.

Example No. 1: The Solution of the Disk System Connected by Shafts with the Elasticity Constant k and Attenuation B. On the rotor No.1 operating driving torque $M_1 = M_0 \sin(\Omega t)$. This model is located in the EX1.FM file.

Example No. 2: The Solution of the Motion of Body System connected by Elastic Elements. On the rotor No.1 operating driving torque $M = M_0[1 + 0.2(1 - e^{-t/2})\sin(1t)]$, the value of the constant $M_0$ is made up from the condition of the statical balance of the system (Fig. 1). This model is located in the EX2.FM file.

Example No. 3: The Solution of the three-mass System. On the rotor No.1 operates driving torque $M_1$, which has a course done by equation $M_1 = M_0 - (C\omega)$, the rotors are connected by elastic shafts. On the rotor No. 3 in time $t_1$, after starting up operates loading torque $M_3 = M_3\sin(\Omega t)$. This model is located in the EX3.FM file.

Example No. 4: The Solution of the Motion of the body System, which is connected by non-elastic Elements. On the drum No.2 operates the torque $M_2$, which has the course $M_2 = M_2[1 - 0.1\sin(\Omega_2 t)/r_2]$. On the drum No.3 operates the torque $M_3$, which has the course $M_3 = M_3[1 + \sin(\Omega_3 t - \pi/3)/r_3]$. This model is located in the PR.7FM file.

Example No. 5: Solution of the body System replaced by the bi-mass System with the elastic and variable moment of inertia. The example is the system of bodies consisting of a driving motor, elastic connecting piece and crank mechanism. A method for the construction of the mathematical model of the system is used, taking into account the variable moment of inertia. This model is located in the PR10.FM file.
An example of the solution:

Model of the System

Dependence of Coordinates on Time

Dependence of Angular Speeds

Course of the Exciting Moment

Fig. 1:

References:


This research has been conducted at the Department of Mechanics and Materials Science, FEE CTU as part of the research project "Modern Methods of Modelling and Identification of Dynamical Systems" and has been supported by FRVŠ grant No.1133071.
STRENGTH MODELS OF LINEAR HYDROMOTORS

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Key words: strength, direct hydromotor

We have modelled a structure of direct hydromotor, see Fig. 1., assembled of cylinder-1; the piston-2; the seal-3; and the support-4. Using the exact mathematical models given in [1], we intend to assure a safe exploitation of hydromotor structures to be used for higher operational pressures and larger shifting lengths.

As a dominant loading of the shifted-out piston, the combination of pressure together with bending has been taken into account. The cylinder is assumed to be loaded by the combination of tension plus bending. In the piston with the seal there an extent deformation of the seal takes place causing a strong abrasive wear. We suppose that this contact influence will be expressed by means of a mathematical model describing the loading process after an experimental verification.

Further, frictional forces affecting the support behaviour will be introduced. A mathematical model based on the theory of the first degree has been derivated, Fig. 2a, which serves both for a first approach to the problem and for a modelling of the short linear motors. When taking into account the mutual displacements: piston-cylinder, the model based on the theory of the second degree has been defined. This theory can be applied to both long and short hydromotors, Fig. 2b. The solution of this more accurate model leads to an iterative computation of a non-linear equation system.
Fig. 2:

References:


This research has been conducted at the Department of Strength of Materials of the Faculty of Mechanical Engineering and has not been supported by any grant.
Section 8

THEORY

OF CONSTRUCTION
SERVICE LIFE PROLONGATION OF HARMONIC DRIVE UNITS

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

The former extensive theoretical and experimental results obtained from previous research works [1, 2, 3] led us to the project where the typification of the series of a shortened single stage HDU (Harmonic Drive Unit) were designed. The component set of such HDU consists of four basic parts, as it is shown in Fig. 1.

- 1 - Circular Spline
- 2 - Dynamic Spline
- 3 - Flexspline
- 4 - Wave Generator

E - flanged asynchronous electromotor

Fig. 1: Structural diagram of HDU component set installed in a universal test box, directly coupled with a driving electromotor

The series of HDU offers twenty one basic gear boxes, which size corresponds to the external diameter (from 16 to 80 mm) of the Wave Generator bearings, in a basic range of the output torques from 0.5 to 165 N.m at 1,500 input revolutions per minute and gear ratio from 70 to 201. The unique patented design of the the Wave Generator [4] enables a stepped assembly adjustment of a simultaneous gear mesh of the Flexspline with the Circular and Dynamic Splines.

The reliability and service life of HDU are firstly limited by a definite reduction of its kinematic accuracy. The reason is wear of HD-components and creation of initial tears and local pitting of the flexible ball HD-bearings. Correct and reliable design of HDU, verified assembly adjustment, repeated repairs or exchanges of the flexible HD-bearings (planned in time) will prolong a total HDU service life and reliability several times. A total HDU service life will be then finished by an excess wear of HD-gearings or by a fatigue failure of HD-Flexspline.
Experimental verification of the HDU (external diameter of the flexible bearings remained 80 mm) has been realized in the laboratories of our department (kinematic accuracy of HDU was measured in cooperation with the firm TOS, Čelákovice, CR) and brought the following results:

- after 4,000 hours of the long-run test at the rated torques and input revolutions, the initial local pitting of flexible ball bearings was observed and excess lost motion of the HDU was measured,
- a regrinding of the rolling surfaces and a tolerance enlargement of the ball diameter (realized on the damaged HD-bearings in the firm VÚVL, Brno, CR), together with a new verified adjustment of HDU led to a following long-run operation in conformity with the rated service conditions,
- the operating efficiency of HDU depends on the input revolutions, ratio, load level, temperature, type of lubrication, backlash between mating teeth of HD-gearings and working hours and can be reached up to 85 per cent,
- the torsional characteristic of HD-unit was measured on especially designed test stand and exhibits soft wind-up in the low torque region (about 70,000 N.m per radian) and hard wind-up in the rated torque region (about 150,000 N.m per radian),
- on the same test stand, a lost motion of HDU was measured; magnitude of the lost motion was kept up to 3 arc minutes in the case of new or re-adjustment HDU,
- HDU kinematic accuracy was measured by means of a single flank rolling method on the mobile equipment PEW 02 (from concern Klingelnberg, Germany); parameters of the maximum and local kinematic gearing deviations and the sum deviation of a gearing circular pitches were registered; these measured parameters certified the HDU to be a precise mechanical transmission during the duration of its total service life.

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. 28/71.
STRUCTURAL PERFORMANCE OF COMPOSITE REINFORCED CONCRETE SLABS WITH RESPECT TO CREEP AND SHRINKAGE OF CONCRETE

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

The term composite construction is usually applied to the combination of two dissimilar materials in a single structural member. The combination of concrete with structural steel which is capable of carrying loads if acting alone is now well established and recognized as an economical structural method. More recently, the precast concrete slabs have been designed both to act as permanent formwork and to behave compositely with the cast-in-situ slab for in-service loading.

The precast slabs are usually prestressed or reinforced with welded wire truss. They are easily and quickly laid on the supporting walls or on the floor beams. The bare precast slabs carry freshly poured concrete topping. After the concrete has hardened, the precast slabs and concrete topping act in composite sense in resisting additional superimposed dead and live loads. This type of construction became very favourite and it is being used for various types of floor structural systems including the most complicated ones. 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 is being performed in this research. In practice the structure is frequently used for the floor construction. It consists of a precast flat plate slab reinforced with bottom bars of a spatial welded wire truss and cast-in-place concrete topping. The precast slab is shored by temporary supports during the first construction stage, see Fig. 1.a. The weight of both slab and the concrete topping is carried by the welded wire truss. The composite cross-section is exposed to the effect of removing the shore and to the additional superimposed dead and live loads. The wire truss serves as the main tensile reinforcement for the whole slab, which is made continuous after the concrete topping has hardened, see Fig. 1.b. The change of structural system together with differential shrinkage and creep of old and new concretes cause the stress redistribution in the structure. The creep of concrete together with crack development tend to excessive deflection.

A sophisticated finite-element models are being developed in this research for both the analysis of spatial behaviour and creep behaviour of the structure. The methods used for the analyses are compared with the methods traditionally used in practice and they will be verified by results of the experiment. The scheme of experimental set-up and production schedule are shown in Fig. 1. The two span (3.6 m + 3.6 m) continuous beam is tested for a long term behaviour. The material properties are investigated through a series of accompanying experiments.
We intend to continue this research during next year to obtain the results of long-term experiments and to finish the comparisons with the results of theoretical analyses.

\[ \text{Fig. 1: Arrangement of the Experiment} \]

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, by Stamont Brno JSC, and by Hottinger Baldwin Messtechnik VUT-FS center.
NEW METHODS OF NONDESTRUCTIVE INSPECTION OF REINFORCEMENT IN FERROCONCRETE STRUCTURES

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Key words: ferroconcrete structures

1. An unusual effect was observed in September 1991 during the inspection of the reinforcement in ferroconcrete slab bridges near Zábršeh by the workers of the Main Center of the Radiation Crack Detection. In some parts of the lower face of the bridge slab the course of reinforcement was clearly visible from dark dust traces. Owing to the many coverage of the reinforcement (30 mm) and the excellent condition of the concrete the effect of penetrating rust of the corroded reinforcement was out of the question. A hypothesis was considered based on the fact that the geomagnetic field of the Earth has a shape which conforms with the course of the magnetic field of a dipole, the axis of which is a little inclined from the rotation axis of the Earth. The magnetic induction of this field reaches the value of the order of 20–50 μT. If the ferromagnetic material lies in the geomagnetic field for an extended time, a permanent magnetization of the material and superposition of the geomagnetic field with the magnetic field of the ferromagnetic material occur.

The iron reinforcements of concrete structures of bridges represent in principle ferromagnetic materials which easily magnetize in the geomagnetic field of the Earth. Their magnetic field is strangely deformed, e.g. by their different crosssections. This occurs e.g. with the reinforcements of the ROXOR typy which, for this reason, act as a magnet of a greater magnetic induction than the induction of the geomagnetic field and has the ability to attract ferromagnetic particles contained in smog and dust brought by air streaming into their close vicinity. The aim of this research task was to verify this theory, which required a detailed investigation of a series of bridge constructions, a series of laboratory and field measurements of the magnetic fields of reinforcements and, in case of confirmation of this hypothesis, an experiment of this phenomenon under artificial conditions which could result in the development of a completely new defectoscopic method in future. This could find a wide application in practice.

2. Procedure of the project solution Two bridges where the investigated phenomenon was observed earlier were taken as basis. This referred to bridge No. 31519-6 in Zábršeh and bridge No. 11-086 in Chromet. Both objects are ferroconcrete bridges, over a water stream, composed from an oblique connecting slab of constant cross-section with haunches for supports of 2 spans.

In both bridges, grey to black dust traces are clearly visible on the lower faces of the slabs (in both spans) copying the positions of the reinforcement. The dust traces have no sharp boundaries, THEIR individual parts are not connected (as it would be e.g. in the case of corrosion traces or efflorescence on cracks).

The position of the reinforcement was verified on selected areas with the aid of the Profometer 2 magnetic indicator of reinforcements made by the Proceq Co. and then radiographically by means of the Co 60 radiator of 0,85 TBq activity.
It was proved that the dust traces really copy exactly the path of the reinforcement, which was also confirmed in bridge No. 11-086 in Chromět in the defective areas of the lower face of the bridge slab where the reinforcement was exposed.

Samples of the surface in the area of dust traces were taken from both bridge objects, and with the object No. 11-086 we succeeded to in taking larger pieces of the plaster with a clearly visible boundary of the original light surface and dark traces which were later subjected to analysis by means of electron microscopy.

The analysis indicates that a higher content of sulphur and iron can be seen in the area of the dust trace, which supports our hypothesis that they refer to sediments of air pollution having the ability to sediment due to the effect of the magnetic field of the reinforcement.

A series of laboratory measurements of the magnetic field in the vicinity of ferromagnetic materials was made in situ. Then the magnetic field on the surface of the lower face of the bridge slab in Chromět was measured in the selected field of 1 m² area where dark traces are found.

Conclusion. The initial theory of the origin of dust traces was confirmed on the basis of the realized measurements. Unfortunately, all experiments including, among others, the artificial production of dust traces were not been completely finished at the time of writing this abstract. I will be able to acquire with the more extensive results of this research task at my defence on the occasion of WORKSHOP 95.
PUNCHING SHEAR FAILURE OF CONCRETE SLABS

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Key words: numerical analysis, punching shear, size effect, structural design, testing

The project consists of two different parts: experimental and numerical one. In the experimental part an investigation of the punching shear strength of reinforced concrete slabs was carried out. The numerical part contains a theoretical analysis of the problem.

The experimental specimens had an octagonal shape in plan view. They were cast in three different sizes in geometrically similar shapes and were designed at a scale of 1 : 10
All the specimens were made from concrete of nominally identical quality of mark B 20. Curing of the specimens was done in a standard way. The characteristics of concrete and reinforcing bars were proved by standard material tests [3].

The actual heights of the slabs were 45, 142 and 450 mm. For the experiment the specimens were simply supported in a horizontal position on circular supports. The span was equal to four heights of the slab and the circular punching disc had a diameter 0.8 of the slab height. The slabs were orthogonally reinforced at the bottom face.

The experiment was controlled by computer to total failure in a closed-loop testing machine. The complete force-displacement diagram was obtained. The nominal shear stress at a failure is not constant, significantly decreasing as the slab size increases [1]. This phenomenon is described by Bažant’s size effect expression [4].

The measured results were compared with the results of mathematical modelling and solved as an axi-symmetric problem. A triangular finite element was used, which enabled the smooth refinement of the mesh in places where cracks developed. A smeared crack approach based on the rotated cracked material model was used. The nonlocal damage concept was applied (by Bažant) [2]. The arc-length method was used to control the iteration process. Several experimental trials using specimens of different sizes were performed, in which the size effect was proved.

The numerical modelling of the behavior of this type of structure has certain difficulties and needs very robust algorithms. All the types of stress conditions occur - high compression, shear and tension. The general space stress conditions are very important to take into account. Cracks initiate in places where high compression in two perpendicular directions is present and where tension in the third direction occurs. The computational program is still under development.
Fig. 1: Large specimen prepared to test

References:
PUNCHING SHEAR FAILURE OF CONCRETE SLABS

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References:


Atmospheric Boundary Layer Wind Tunnel for Testing Building Structure

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Key words: boundary layer wind tunnel, wind simulation, wind effects

The Klokner Institute of The Czech Technical University in Prague (KÚ ČVUT) and The Aeronautical Research and Testing Institute (VZLÚ) are building jointly a new wind tunnel with a modelled atmospheric boundary layer, situated in the VZLÚ Letňany. The tunnel will be used particularly for research and tests in the field of wind effects on building structures, for the modelling of air flow in the environment of building structures, for the experimental studies of post-graduate students and for the teaching of Technical University students.

The fund to finance the construction originated in the amalgamation of the funds of the GACR (grant awarded to VZLÚ, with KÚ ČVUT and ÚTAM AV ČR as co-operating institutions), the Fund for Dynamic Development of Universities (KÚ ČVUT in 1993) and KÚ ČVUT.

The initial design of the wind tunnel was prepared by VZLÚ jointly with KÚ ČVUT. The technical design and its manufacture is assured by KÚ ČVUT, the fan, engine, control system and some special parts of the interior tunnel structure by VZLÚ.

The manufacture of the tunnel began at the end of 1993. The tunnel structure is scheduled for completion in January 1995. In 1995, optimisation of the basic and of the derived versions of the atmospheric boundary layer and the performance of comparative model tests will be investigated. From 1996 the tunnel will be fully available for research, students teaching, the experimental studies of post-graduated students and, on a business basis, for tests ordered by external customers.

Tunnel characteristics

The tunnel is an open circuit wind tunnel with a closed working section without temperature control. The working section is 1.5 m high and 1.8 m wide. Its overall length is 17 m, of which 2 m belong to the actual test section with a 1.5 m diameter turntable.

The removable built-in components for the generation of the boundary layer are installed in the 15 m long part of the working section. A barrier and triangular spires are situated after the entrance nozzle.

The possibility of eliminating the pressure gradient, originating from the pressure deviating effects of the boundary layer, is envisaged as well as additional measures for the maintenance of two-dimensional conditions for the development of a simulated boundary layer.

On the basis of computations, the height of the boundary layer at the beginning of the test section is expected to be 0.7-0.8 m. The fan should produce a free air flow with a highest velocity of some 20-22 m.s⁻².
The drive consists of a type ABP 1.8 m diameter axial fan, with a 55 kW DC motor ($n_{max}=985$ r.p.m.) and a thyristor converter.

**Fields of Application**

The principal field of application for the new wind tunnel will be the examination of the static and dynamic effects of wind on building structures. Further fields of wind tunnel use are envisaged in the study of air flow around or inside building structures (e.g. stadiums, airfields, etc.). It will be possible to study and solve problems of wind comfort, considering the functional properties, or the ventilation of built-up areas, etc.

The intended goal is to build a maximally universal facility for the field of applied industrial aerodynamics.

**References:**


*This research has been conducted at the Klokner Institute CVUT 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 GACR grant No. 105/99/0765.*
EXPERIMENTAL AND NUMERICAL INVESTIGATION OF STEEL SLENDER WEBs UNDER REPEATED SHEAR LOADING

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Key words: steel structures, numerical modelling, repeated shear loading, limit state, geometric nonlinear computation, linear buckling, fatigue

The objective of our investigations was to find the load-bearing capacity of slender steel webs subjected to repeated shear. In the past, a similar model was tested for a static loading. Post-buckling phenomena are very remarkable in this type of structural element. The buckling of elements occurs already at ca 40% of the post-buckling limit state. The post-buckling capacity of plated structures is very important from the point of view of reducing structural costs. In the case of repeated loading such an approach leads to many computational difficulties because of the fatigue due to buckling stresses.

Experimental and calculated results have been compared to get information about the failure mechanism. The experiments were carried out on 16 girders. The girder was supported at both ends and loaded by a concentrated force in the midspan, Fig.1.

Both low- and high-cycle fatigue phenomena were investigated. Several levels of load intensity were used to obtain the relationship between load intensity and the number of cycles. To evaluate the influence of the flange stiffness, two different thicknesses were introduced - 12 mm and 20 mm.

Numerical modelling was performed using the finite element system FEAT. The web was modelled by means of triangular shell elements, the flanges and vertical stiffeners by means of beam elements. To examine the influence of imperfections, several geometrically imperfect computational models were calculated. It was proved that an influence of imperfections on structural response does exist but that the loading capacity and the final limit state were practically identical in all cases.

Results of the geometrically nonlinear calculations and the results of the linear buckling modes were compared with the results from the experiments. The first mode corresponds to the loading of 423 kN. According to the geometrically nonlinear analysis, collapse occurs at loads over 750 kN. In Fig. 2 the calculated deformation shape at 90% of the limit state is depicted. The calculated results agree with the results of experiments quite well.
Fig. 1: General detail of test girders

Fig. 2: Deformed shape

References:


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HYPOTHESIS OF STRUCTURAL FAILURE OF MASONRY UNDER IMPACT LOAD

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Key words: dynamic response, brick masonry, shock failure

Numerical and experimental analysis of the dynamic response of a simple brick masonry structure is used for the derivation of a hypothesis of masonry failure under impact load.

Under this load the structure vibrates in one of its natural modes or in their superposition. Tensile and compressive stresses originate in the joints between the brick blocks in the direction perpendicular to the joint plane, naturally with the exception of the joint through which the nodal line passes. The magnitude of the tensile and the compressive stresses in the joint is not the same, for the masonry is actually pretensioned (in compression) by the dead weight of the structure.

Because the bearing capacity of the masonry in tension is very low, it is the principal tensile stress that is decisive for the failure of the mortar in the joint. In accordance with the conclusions of Chen [1] the process of masonry failure can be described by the stress/strain diagram shown in Fig. 1. The diagram shows that before the origin of the first cracks the stress/strain relation is almost linear (this linearity being confirmed also by the experiments executed). We have mentioned above that the tensile stress decides about failure under this type of load, and that this ultimate tensile stress for masonry is significantly lower than the
compressive bearing capacity. Consequently, then, the error resulting from the possible non-linearity of the stress-strain relation is small (unless the structure is pretensioned by its own large dead weight). Before the origin of the cracks in the joint, the structure is described with sufficient accuracy by its physical characteristics, corresponding with elastic deformation of the structure and, consequently, by the spectrum of natural frequencies. Experiments [3] have shown that the natural frequency varies with the increasing level (intensity) of impact load, even in the course of this "elastic" phase; this change corresponding with the origin of microcracks in the mortar between the brick blocks before a macrocrack originates in the joint. After the first macrocracks have originated in the joints, a sudden jump change in the magnitude of the natural frequencies takes place as a result of the change in the boundary conditions of the structure. Further a significant change of the modulus of elasticity takes place, its value dropping to about 20% of its initial value. This second step is repeated after the origin of another series of macrocracks until the structure collapses. Thanks to even a small pretensioning of the masonry by its own weight the origin of the first group of cracks does not result in the collapse of the structure. The envelope of this failure process is exponential.

Let us now compare the presented failure hypothesis with experimental results for impacts of a uniformly distributed, continuous load across the whole face of the wall. Fig. 1 shows the first doubling in amplitude of the measured displacements at the top of the wall during this transition process. The envelope of this phenomenon shows two practically symmetrical "triangles" about the zero position with equal maxima, of an order between 14 and 20 kPa of load, and further a very slow increase in the further loadability of the structure as a result of its retiming after the appearance of the cracks (the first macrocracks appeared under the pressure of some 14 MPa). Immediately after crack origin and the resulting response drop to the minimum, a change of boundary conditions takes place and, consequently, also a change of natural frequencies, a change of modulus of elasticity and a further strengthening of the structure and the possibility of its further loading. Analogously with Fig. 1 this response trend appears in the stresses, although the strength quality of the mortar in the joint plays a more significant role in this case.

References:

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ENVIRONMENTAL EFFECTS ON SHRINKAGE OF BRIDGE SEGMENTS

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Key words: analysis, bridge segment, environment, humidity, measured strain

Most creep and shrinkage studies have been carried out on specimens subjected to a range of constant temperature and relative humidity conditions. In reality, temperature and humidity vary during the day and also seasonally. Furthermore, the designer has little knowledge at the design stage of the probable date of manufacture of the concrete elements being designed. The research deals specifically with seasonal effects on shrinkage.

The experimental shrinkage data have been acquired during an extensive study of shrinkage and creep in two major glued segmental bridges in Cardiff (Wales U.K.). In the case of both bridges, three segments within a single half span (corresponding to mid-span, quarter span and support locations) were instrumented. Concrete strain was monitored by means of embedment type vibrating wire gauges placed at fourteen or eighteen locations around the cross-section of each segment. The segments, manufactured on site by the short-line match cast method, were stored up to 140 days on site before erection and shrinkage strains were monitored regularly throughout this period. The different shrinkage values have been observed in individual parts of the cross-sections (in the corners, in webs and in flanges) due to their different thicknesses, however, the environmental effects can be recognized in all the locations.

The segments of one of the bridges were cast in Spring whereas the segments for the second bridge were cast in late Summer. The shrinkage strains observed in the two sets of segments reflect the different environmental conditions prevailing after casting. One set of segments matured during the dry summer months (Fig. 1) whereas the other set matured when the weather was wet and colder (Fig. 2). The environmental conditions prevailing during these two seasons have been ascertained from information supplied by the Meteorological Office.

The predicted strains have been evaluated based on two different assumptions; the first taking variable humidity into account and the second assuming constant relative humidity according to the season. The predicted strains were evaluated by means of a simplified form of the BP Model. This type of formula has been used in the CEB-FIP Model Code 1990 and also in Eurocode 2. Close agreement between predicted and measured shrinkage strains was observed in all cases where the variable humidity of the air was taken into account. The effects of varying relative humidity influence the gradient of shrinkage strains and may result in the strains of an opposite sign, i.e. swelling due to localised increasing humidity. The shrinkage values predicted using the assumptions of constant relative humidity are also in good agreement with the measured shrinkage strains. This conclusion is very important for the practical use of the model used in this research in the design process.
References:


This research has been conducted at the Department of Concrete Structures and Bridges in cooperation with the University of Wales, College of Cardiff. The part carried out at CTU as part of the research project "Safety and Serviceability Analysis of Concrete Structures" has been supported by CTU grant No. 18164 (13920/94).
STUDS IN COMPOSITE BEAMS – SIMPLIFIED MODELLING

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Key words: anchors, composite beams, cracking, failure analysis, fracture mechanics, pull-out, size effect, stud connectors

The research briefly presented here deals with the load carrying capacity of the connection between the steel beam and concrete slab of composite beams. Specifically, attention is paid to the behaviour of welded stud connectors. The studs subjected to the action of the shear force fail either due to cracking of concrete or due to cracking of the shank of the stud. The failure mode depends on the length and diameter of the stud and on the quality of concrete. Assuming the failure is in the concrete, the load capacity can be regarded as the sum of the contributions of two actions: (1) a dowel action, which carries a substantial part of the load, and (2) resistance to pullout. The pullout is not too important for the stiffness of connection, however, it seems to be decisive for the ultimate load.

In front of the stud, there is a compression zone, in which the stresses are triaxial. An increasing shear displacement also results in progressive formation of two cracks: first crack, which is perpendicular to the direction of loading and, second crack which is a compression splitting crack. Both cracks decrease the stiffness of the connection but they are usually not the main cause of failure. The failure is caused by the formation of a conical crack (failure cone) similar to that known from pullout tests. The maximum (ultimate) load may be imagined to be a sum of the contributions carried by the compression zone and by the tension in the stud (Fig. 1).

After attaining the peak (ultimate) load, the cone surrounding the stud tends to be pulled out of the concrete slab. However, the front side of the cone is compressed and a significant friction opposes the movement of the cone. As the slip of the concrete plate versus the steel beam grows after reaching the peak load, the resistance of the stud decreases and the energy supplied is consumed by the growth of the fracture zone, by plasticity of the compressed concrete in front of the stud, and by friction on the front of the fracture zone. To explore this sophisticated mechanism in depth would require many experiments executed in very stiff loading frames. Since such experiments are lacking at present, only a simplified approach to the post peak behaviour makes sense.

The post peak slip of a concrete plate versus steel beam due to stud failure may be described as a sum of three components. The first one is the elastic displacement, which is the displacement that is recovered upon unloading. The second one represents the effect of fracturing. Until the ultimate load is reached this displacement equals zero, then the opening of a crack causes the force carried by the stud to decrease. The third component represents the effect of plasticity and friction in the damaged concrete, which may be observed in both the pre- and post-peak behaviour.

The diagram showing the post-peak behaviour is plotted in Fig. 1. Since the dependence $C_s(F)$ is not known, the dissipated energy $W_f$ may be roughly approximated by assuming

\[ W_f = \int \sigma d\varepsilon \]

where $\sigma$ is the stress and $d\varepsilon$ is the strain increment.
that the average fracture energy dissipated per unit fracture surface, \( G_f \), is about the same as in the usual pullout test. \( W_f = A_f \frac{G}{E_f} \) where \( A_f \) is the surface area of a fracture cone.

The effect of plasticity and friction may be taken into account in a similar way. The energy \( W_p \) can be related to the strain energy density corresponding to the nominal stress \( \sigma_N \). \( W_p = c_0 \frac{\sigma_N^3}{(2E)} \), where \( c_0 \) is an empirical constant and \( \sigma_N \) is defined on the basis of the peak load \( F_{max} \).

The proposed analysis was compared with the test results obtained by Eligehausen and Zhao in Stuttgart [2], where the studs of diameter 22mm and length from 50 to 115 mm were tested. The post peak behaviour was not directly tested, and thus the calculated values cannot be compared with the experimental values. To demonstrate the size effect, the load slip diagrams are plotted in terms of nominal stress versus slip (Fig. 2). The size effect may be observed, both in the peak load and in the descending branch of the diagrams.

![Fig. 1: Model of the post-peak behaviour of the stud](image1)

![Fig. 2: Nominal stress versus slip](image2)

References:


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INFLUENCING FACTORS ON DEFLECTIONS OF PRESTRESSED CONCRETE BRIDGES

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Key words: analysis, creep, dead load, environment, humidity, prestressing, shrinkage

The research deals with the problem of assessment of actual behaviour of prestressed concrete bridges, which includes the variation of deformations and the variation of internal forces during construction and during service life. The development of deflections in prestressed concrete bridges is a result of two opposing actions namely loading (dead and live) and prestressing forces. This is the reason why the deflections are extremely sensitive to the mutual development of loading and prestressing. In some structures deflections have been greater than expected. A comprehensive approach including the sensitivity analysis of the most important factors was necessary so that a realistic prediction of deflections would be obtained.

In this research the main influencing factors have been discussed. During construction the structure is loaded by dead load, by prestressing and by temporary loading due to the mechanisms needed for assembly or casting. The main factors influencing strain development are dead load, prestressing, and factors resulting from the material used. In the design procedure the elastic strain is defined by means of Young's modulus $E$, the delayed strain by means of the creep coefficient and shrinkage is usually described by a simple function of time and environmental humidity. During the service life the bridge is subjected to additional effects of traffic load and changing environmental conditions in daily as well as in yearly cycles.

The great uncertainty of the individual factors causes a major problem when predicting the deflections of bridges. The designer has a very limited knowledge concerning the concrete mix and environmental effects. Also minor changes in construction process may result in significant effects on deformations of the structure.

The effect of variation of input data on the development of deflections during construction has been investigated in the case of a prestressed concrete continuous beam erected by cantilever method. The three span beam (main span 125 m long) was cast in situ by cantilever method. The individual segments of the depth varying from 6.9 to 2.5 m were 5 m long, with exception of the segments close to the support which were shorter. The balanced cantilevers are prestressed by tendons placed in the top corners of the box cross-section. After completion of one cantilever, the formwork is moved to the second pier and the construction continues by erecting the second cantilever. Then the cantilevers are connected at the midspan by casting the closing joint. The development of deflections at the end of individual cantilevers is essential for successful completion of the bridge. Therefore the deflections were predicted under different conditions and different theoretical models were used. As an example the effect of variation of prestressing is shown here.
The prestressing force was considered as one of uncertain input parameters. The prestressing force in one tendon assumed by the designer (after short-term prestress losses) was 2.16 MN. Any higher value of prestressing may hardly be supposed, therefore the two lower values were assumed in the analysis. The initial decrement of the prestressing force was taken as 10% or 15% respectively. The total deflection at the end of the first cantilever at the time of casting of the closing joint was in the first case about 10 cm. In the case of lower prestressing the deflection increased up to 15.2 cm or 17.5 cm. These values represent a tremendous increase of deflections within the period of construction. Most of the deflection may be adjusted during the construction process by rectifying the formwork. However, that part of deflection, which appears after completion of the cantilever must be predicted very carefully, since no further correction is possible. The increment of deflection during 200 days after completion of the cantilever is plotted in Fig. 1. The three curves correspond to the three levels of prestressing force assumed in the analysis. The difference in prestressing force 15% results in the difference of the deflection increment 29%.

References:

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IDENTIFICATION OF ENGINEERING STRUCTURE MODEL

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Key words: identification, engineering structure model, modal analysis, static loading test

In order to create an accurate calculated model of a structure there is a need for a static and especially a dynamic design. It is necessary to comprehend the precise succession of the model's characterisations. For structures which we can model as a bar, it is above all important to calculate the flexural rigidity $EJ$ and the mass per unit length $m'l$. In the case of the calculation of loading capacity of the operated structures this situation is more complicated; it is necessary during the modelling of the structure to notice any evidence of defects, a damage to the structure, or aging of the structure's materials. When the engineering structures were put into operation a verification of the model of that static or dynamic design was conducted. After an experimental investigation a static or dynamic behaviour of the tracked structure was measured, results were compared with the results obtained from the calculated structure model. In most of the cases simply an agreement or disagreement of the calculated and measured quantities was noted. The disagreement is in most of the cases caused by a variety of factors that was evident in the differences in results. Another cases were carried out. A parametric study for an explanation of the unexpected results were carried out. In the case of agreement no further specification need be published. The method of identification of the engineering structure model based on the structure modal analysis results [1] engages not only measured circular frequency $\omega_{p\text{rep}}$ but also natural vibration modes $\{r(j)\}_{\text{exp}}$ to identify of the structure model. This allows for changes of tracked parameters which are more comprehensible. A process which was used in a working group of professor Bata for an experimental investigation of the natural frequencies and the modes of natural vibration is described in [2]. The identification process is based upon the deformation solution variant of the natural undamped vibration. The static stiffness matrix $[k]$ and the mass matrix $[m]$ are dependent on a parameter $p$, that can be generally considered as a variable. For the matrix $[m]$ as a variable parameter can be used to calculate for example the volume mass $r$, the mass per unit length $m$ and the individual parts dimension. The stiffness matrix $[k]$ produces for example the modulus of elasticity $E$ and the Poisson's ratio $\nu$ of the material, the section characteristics, and the dimension of individual parts of the actual structure had been distributed during the physical model creating. The increase $\Delta p_i$ of identified parameter number $i$ is determined from the following equations:

\[
\sum_{i=1}^{n} \left[ \frac{d[k(p)]}{dp_i} \right] - \alpha_{ii}^{[m]} \left[ \frac{d[m(p)]}{dp_i} \right] \Delta p_i \{r\}_{\text{exp}}^{[\Delta F]} = \{\Delta F\}^{[i]}, \quad (1)
\]
where \( \{\Delta F\}' \) is the force vector to express inequilibrium of the elastic force and the inertial force amplitudes, which arise during the natural undamped vibration of the identified model in the \( j \)-th natural mode by the \( j \)-th natural frequency. The method of identification of the engineering structure model based on the static loading test comes from the structure deformations measured during a static loading test. The static loading tests of bridges and other structures so far practised are in most of cases measured only by measuring a compression of bearings and on the deflection characteristic points of a transversal section in the middle of individual spans. The obtained data are improper in most of cases for the identification, because on their basis alone it is not possible to comprehend sufficiently an exact change of the resulting parameters along the length of the structure. More accurate results of measuring, suitable for the structure model identification, must also contain the deflections and as far as possible rotational displacements in places where the structure stiffness changes. The next measuring places of the structure deformation should arise from the condition of the solution stability. The increase vector of the identified parameter number \( \{\Delta p\} \) is determined from the following equations:

\[
\begin{bmatrix}
\left[ \frac{d[k(p)]}{dp_i} \right]_{(n,0)} \\
\vdots \\
\left[ \frac{d[k(p)]}{dp_i} \right]_{(n,n)}
\end{bmatrix}
\begin{bmatrix}
\{r\}'^T \\
\vdots \\
\{r\}'^T
\end{bmatrix}
\begin{bmatrix}
\{\Delta p\}_{(n,0)} \\
\vdots \\
\{\Delta p\}_{(n,n)}
\end{bmatrix} = \{\Delta F\}'_{(n,)}.
\]

In this equation \( n \) denotes the number of meditated deformation, unknowns \( p \) means number identified parameters of the structure model and \( \{\Delta F\}' \) is the vector of the unbalanced increment of an external loading. The identification (an introduction of the fixed reverse link between the calculation and the experiment) enables for an improvement of diagnostics of engineering structures for obtaining more exact input parameters of the structure model. For the calculation in a case of reconstruction, the identification can reveal new information about the accurateness of the modelling. This access can be a contribution to the methods of the continuous tracking structure condition during the structure's activity and in creation of a degradation model in a knowledge base in the Bridge Management System.

References:


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DYNAMIC BEHAVIOUR OF SYSTEM
RAILWAY BRIDGE-VEHICLE

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Key words: structural dynamics, railway bridge, railway vehicle, 3D-model, computer simulation, modal analysis, The Component Element Method

One of the most widespread means of transport is the rail transport. Nowadays with large demands of higher speeds a thorough understanding of the dynamic behaviour of a system railway vehicle/bridge structure becomes necessary [1], [2] and [3]. Computer simulations appear to be one of the most suitable means for this system analysis. Attention is concentrated on the 3-D model of the vehicle by the Component Element Method (CEM). Using the CEM physical space models of some Czech railway vehicles were created. Every model is described by a Vehicle Data File [3]. These Files make up a database of the railway vehicle models. The 3-D model of the bridge structure was built by the Finite Element Method and the models of railway upper structure with the unevennesses of the carriage way was built by the CEM. The solution algorithms and programs were created for analysis of the natural vibration, the bridge structure and the moving vehicle interaction and the response of the bridge structures to the moving vehicles [3]. The response of the bridge structure during the passage of the vehicle was calculated by the method of expansion with respect to the modes of natural vibration [2]. A response of the bridge structure is determined in characteristic points in a scale of deflections. A debugging and a verification of this software package still needs attention. A comparison of the computer simulation with measurements in situ were carried out. This took place at a railway bridge structure at km 22,140 in Kralice on the track Střelice Okříšky. A comparison of the frequencies and modes of natural vibration of the model and the real structure was carried out. The results of simulated and in-situ carried out dynamic loading test were compared as well. Parametrical studies of the influence of the unevennesses, vehicle passages in the velocity range of 80-500 km/h (Fig. 1) and passages of vehicle set in the velocity range of 70-180 km/h (Fig. 2) were carried out. We conclude that the maximal dynamic strain of the bridge is in the range of 140-160 km/h. This is the important result because there are streams in the Czech Republic which lead to the reconstruction and to modernization of the railway tracks and bridges in order to increase the transport velocity up to 160 km/h. Thus, the computer simulations could be used for a prediction of bridge behaviours under new conditions. Further use of the computer simulation is possible in an investigation of fatigue on the railway bridges.
Fig. 1: The dynamic ratio as a function of the vehicle speed, one railway engine

Fig. 2: The dynamic ratio as a function of the vehicle speed, a set of railway vehicles (one engine and four passenger vehicles)

References:


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CONCRETE REINFORCED WITH DIFFERENT KINDS OF FIBRES

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Key words: plain concrete, fibre reinforced concrete, steel fibers, polypropylene fibres, compression strength, splitting tensile strength, testing of slabs, load-deflection diagram, absorbed energy, toughness index, resistance to freezing and thawing

The aim of the research was to gain the information about the basic properties of concrete, structure of which is reinforced by randomly dispersed fibres. The authors focused their research on the question of influence of several types of fibre reinforcement (two types of steel fibre, polypropylene fibre and combination of steel and polypropylene fibres) on properties of concrete. All the kinds of fibreconcrete were produced on the basis of the same mixing formula, which has comprised the coincident amount of cement, water and aggregate. The difference, coming from the different amount of fibres was balanced by the usage of very fine indifferent aggregate (fraction 0-1).

This circumstance enables to adjudicate the determined influences only to a kind and amount of applied fibre. Test-pieces were subjected to the coincident conditions during their production and hardening.

The properties of concrete were tested on specimens:
- slab 600 x 600 x 40 mm (18 pieces),
- cube 150 x 150 x 150 mm (54 pieces),
- beam 100 x 100 x 400 mm (36 pieces).

The major point of this experiment was the testing of the slabs. The slab was simply supported along the whole perimeter and subjected to the load concentrated on the area 100 x 100 mm, placed in the centre of the slab.

The deformation-controlled regime was applied for testing of all the slab. The deformations of slab were measured at nine points and were read in 3sec interval.

On the basis of acquired records of deformation these data were evaluated:
- the dependance load-deflection derived from deformation controlled regime in the middle of slab.
- the dependance absorbed energy-deflection
- toughness index (by the principle described in (1), see Fig. 1)

Three slabs were tested for every kind of concrete.

The test of slabs were complemented with common tests of concrete properties (i.e. cubic strength test in 28 days and test of splitting tensile strength in 28 days). Three specimens were tested for determination of these properties.

Moreover, the frost resistance of concrete was examined. Three test-pieces were subjected to 75 cycles of intermittent freezing thawing. Another three specimens were used as comparative ones (in sense of CSN 731322).

The extent of annotation does not allow detailed presentation of results. Anyway, it is possible to state that:
- the usage of metal fibre increases both compressive and tensile strength of concrete.
- the application of polypropylene fibre does not bring significant increase of strength, if its influence is examined for well-cured concrete.
- toughness index is a quantity, which expresses the ability of concrete to resist the influence of loading after occurrence of crack. Its magnitude is significantly influenced not only with the material properties of applied fibre and its applied volume but even with its geometry.

\[ I_t = \frac{\text{area } ABDE}{\text{area } ABC} \]

Fig. 1: Definition of Toughness index

References:

This research has been conducted at the Department of Concrete Structures and Bridges of the Faculty of Civil Engineering CTU Prague as the research project “Concrete reinforced with different kinds of fibres” and has been supported by Faculty of Civil Engineering grant No. 19310.
A PROBABILISTIC APPROACH TO THE STEEL FRAME, FOUNDATION AND SOIL INTERACTION

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Key words: steel structures, semi-rigid design, column base, foundation, soil influence, probabilistic approach

A numerical FE model of structural behaviour has been developed including the probabilistic concept of basic structural parameters. From known subsoil behaviour the deformations and the internal forces were able to derive. The work was primarily used to check the serviceability limit state of the structure.

The stiffness of the column bases has a similar influence on the moment redistribution as the beam-to-column connection stiffness. The subsoil contribution significantly affect the overall frame behaviour. The current knowledge of subsoil interaction was based on an engineering simplified estimate [2]. The deformability of the column-bases consists of the deformability of the steel connection part (mostly of the plate and bolts), the deformability of the concrete block and the subsoil deformability. Fig. 1.

Fig. 1: The model of subsoil - foundation - frame interaction

The presented model includes firstly, the steel elements, then an analytical model of the semi rigid beam-to-column connections, also an analytical model of column base semi rigid behaviour and an analytical model of the interaction of the concrete foundation with the subsoil. Fig. 2. The beams and columns are represented with the elastic matrix including the large deformations. The beam-to-column connections are included by predicting the moment - rotational diagram of an extended end plate connection based on component
model [1]. The column bases strength and rigidity is predicted by an analytical "moment - normal force - rotation" model [3]. The concrete block to soil interaction is represented by a subsoil deformation estimation based on a homogenous continuum estimation including the depth of layers. A step by step solution is used with iteration on each step.

The model predicts the statistical distribution of deformations and internal forces based on a statistical distribution of a limited number of input parameters. The normal distribution is used. The soil is represented by five material variables with three statistically independent distributions. The concrete block quality and two geometrical imperfections represent structure variability.

The pilot search simulates the influence of five independent inputs on the horizontal drift of the frame.

The pilot study confirms the advantages of the complex solution in the particular complex calculation as well as in the simplified prediction. The expected high influence of soil quality could be strongly depressed by further knowledge of soil quality.

The study is affected by the range of soil parameters described in the standard classification.

References:

This research has been conducted at the Department of Steel Structures and at the Department of Mathematics as part of the research project "A Probabilistic Rigidity and Strength Model of the Steel Frame, Foundation, and" and has been supported by the Czech Grant Agency grant No. 103-93-2007.
THE INFLUENCE OF AXIAL FORCE ON THE COLUMN-BASE STIFFNESS

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Key words: steel structures, semi-rigid connection, column base tests

This paper is a summary of an experimental and theoretical program of research into column base behaviour held at the Czech Technical University. Full scale and component tests were performed for a typical column base with an H shaped column and an unstiffened base plate. The results have been used for numerical simulation and for the development of an analytical stiffness prediction model.

Fig. 1: The column base of full scale

During the test programme 12 experiments were performed this year. Firstly, six tests of T-stub in tension and compression were made to investigate the behaviour of tension and compression components in parts of the connection independently. Then, secondly, six tests of full scale column-base connection were performed to investigate the stiffness behaviour and the influence of axial forces, see Fig. 1.

Fig. 2: Displacement of the base plate obtained from tests

415
The test specimens were loaded with an axial force and bending moment (in four tests) or by a bending moment only (in two tests). The behaviour was observed by measuring the base plate deformations, see Fig. 2. The data from the measurements were used for evaluation of the moment - axial force - rotation curves.

The stiffness model is based on the assumption of elastic plastic stress distribution under the base plate, and elastic, plastic bolt and plate modelling. The model uses the effective area of the base plate and is compatible with the ultimate design proposed in [2], [3].

The experimental M-N-f curves were compared to curves derived from the complex model. Fig. 3 shows both the experimental and the calculated curves for test No. W08 and W10 [1]. It can be seen from the picture, that the model accurately predicts the initial stiffness.

Fig. 3: Experimental and analytical moment-rotation curve (experiment No. W08 and W10)

The model will enable a simple predication of stiffness. Further development of the prediction model is expected to be extended to base plates with stiffeners, etc. compatible with Eurocode 3, Annex J.

References:

This research has been conducted at the Department of Steel Structures as part of the research project "Flexibility of Column Bases" and has been supported by CTU No. 18118.
TRIANGULATION
OF 3D CAD SURFACES

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Key words: triangulation, 3D surface, advancing front

Mesh generation techniques have been given considerable attention in recent years. The reason is that the preparation of the model for analysis and other subtasks of the computer aided design procedure became the most significant part of the human labor involved.

The triangulation of surfaces in three-dimensional space is one of the more difficult meshing techniques. This is probably due to the fact that the surface description is in most cases quite complex, especially with respect to the continuity of the adjacent surfaces.

Most surfaces of practical value in CAD are based on parametric patches. The triangulation techniques used for 3D surfaces can be generally subdivided into two groups based on whether the generation of the triangles proceeds in the physical space or in the parameter space. The triangulation in the physical space is rather complex, especially for surfaces with non-negligible curvature. The triangulation in the parameter space on the other hand suffers from the lack of affinity between the parametric and physical spaces [3].

The present paper describes a procedure based on triangulation in the parameter space. The triangulation technique used is the advancing front method [1, 2]. The reasons for these choices are (i) the generator used for planar domains can be applied with only minor modifications; (ii) to triangulate 3D solids, only two generators are necessary  a generator for planar domains, and a generator for the solid; both can be based on the same technique and no special generator for surfaces is needed; (iii) the modified generator can be applied in other cases, e.g. in problems of boundary layers, where strongly stretched triangles (oriented meshes) are needed.

The adopted approach can be useful in practice if two essential conditions are met: (i) the generator for planar domains must be able to generate stretched meshes, and (ii) the quality of the surface parametrization must be taken into account. The first requirement is due to the fact that the parametrization is typically rather "bad" - equilateral triangles on the actual surface are distorted into poor quality triangles in the parameter space and vice versa. Therefore, to generate good quality triangles on the physical surface, stretched (distorted) triangles must be generated in the parameter space. Only a few triangulation techniques can produce stretched meshes, the advancing front methodology is one of them.

The generator developed by one of the authors was modified to include the anisotropic meshing. In opposition to the approaches documented in the literature, the present technique generates the triangles without applying the "local mapping" approach. It is believed that this can save non-negligible computation time.

The second condition relates to the fact that the parametrization of practically useful surface patches may be locally singular. This property leads to significant problems when the mesh is generated in the parameter space. A set of heuristic techniques has been developed to deal with poorly parametrized surfaces.
To test the proposed approach, the authors selected bicubic Bezier patches, as they are often used in CAD environments, and consequently of great practical value. The techniques sketched above will be illustrated here with a couple of figures. The meshed surface is an approximation of a hemisphere constituted by a single bicubic Bezier patch with two strong singularities. The Figure 1 shows the intrinsic coordinate curves. The Figure 3 depicts the mesh in the parameter space. Note the extremely stretched elements around the singularities. The final mesh on the surface is reproduced in Figure 2. The quality of generated triangles is very good despite the difficulties involved.

The presented technique seems to be promising with respect to its application in practical CAD problems of surface and solid meshing.

Fig. 1: Intrinsic coordinate curves on the surface patch.

Fig. 2: The final mesh on the surface.

Fig. 3: Mesh in the parameter space.

References:

This research has been conducted at the Department of Structural Mechanics and has been supported by GAČR grant No. 109/93/1175.

418
Steel-concrete composite structures have been used for several decades. In the last years very effective and economical design has been possible because a new shear connector – the headed stud was developed. The studs are welded with automatic guns and they have two big advantages: simplicity of execution and reliability. They also have disadvantages, the main one is the need for expensive equipment and for a very strong electricity power source. This disadvantage has stimulated research into new types of shear connector and so in the 1980's, the ILITI company from the Principality of Liechtenstein developed a bracket shear connector.

These connectors, whose trade mark is HVB, are fastened to a steel beam with two nails by a power-activated tool. They are made by the cold-forming process from a thin sheet with an ultimate tensile strength of 270-350 MPa and they are galvanized. At present five sizes of connectors are available, Fig. 1 shows their dimensions.

As HVB connectors represent a very new type of connection in composite structures within the Czech Republic, their behaviour is being verified by experimental analysis at the CTU, Faculty of Civil Engineering, Department of Steel Structures.

Twelve push-out tests were carried out as the first part of this research. A testing procedure according to Eurocode 4 was used and also specimens were prepared according to EC 4. They consist of a short steel beam that is sandwiched by two small concrete slabs, the connectors being fastened to the beam and embedded in the slabs (which are therefore
connected to the beam only through the connectors themselves). Four series of tests with three specimens were carried out always with connectors HVB 95.

The specimens in the first series, whose designation shall be S.1, were composed of a beam of type HEB 200 and slabs of 150 mm depth. The second series (N.2) contained specimens with metal profiled sheets of type Kovove profily TR 50/260, whose ribs ran transverse to a beam of type IPE 220, and the depth of the slabs were 100 mm. The specimens in the third series (N.3) had profiled sheets with ribs parallel to the beam. The other components were the same as in the series N.2. These three series had an arrangement of HVB 95 connectors parallel to axis of the beams. The fourth series contained three specimens (S4.1, N5.1, N6.1), one each from the previous series, but with an arrangement of HVB 95 connectors running transverse to the axis of the beams.

The measurements from the push-out tests included the maximum shear resistances of the connectors (see Tab. 1) and the dependence slip to load curves.

<table>
<thead>
<tr>
<th>specimen</th>
<th>load (kN)</th>
<th>number of connectors</th>
<th>max. shear resistance (kN)</th>
<th>mean of series (kN)</th>
<th>char. shear resistance (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1.1</td>
<td>339</td>
<td>8</td>
<td>42.4</td>
<td>40.6</td>
<td>35.0</td>
</tr>
<tr>
<td>S1.2</td>
<td>324</td>
<td>8</td>
<td>40.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1.3</td>
<td>311</td>
<td>8</td>
<td>38.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2.1</td>
<td>162</td>
<td>4</td>
<td>40.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2.2</td>
<td>178</td>
<td>4</td>
<td>44.5</td>
<td>42.4</td>
<td>36.5</td>
</tr>
<tr>
<td>N2.3</td>
<td>169</td>
<td>4</td>
<td>42.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N3.1</td>
<td>161</td>
<td>4</td>
<td>40.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N3.2</td>
<td>162</td>
<td>4</td>
<td>40.5</td>
<td>41.9</td>
<td>36.3</td>
</tr>
<tr>
<td>N3.3</td>
<td>180</td>
<td>4</td>
<td>45.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S4.1</td>
<td>340</td>
<td>8</td>
<td>42.5</td>
<td></td>
<td>38.3</td>
</tr>
<tr>
<td>N5.1</td>
<td>138</td>
<td>4</td>
<td>34.5</td>
<td></td>
<td>31.1</td>
</tr>
<tr>
<td>N6.1</td>
<td>162</td>
<td>4</td>
<td>40.5</td>
<td></td>
<td>36.5</td>
</tr>
</tbody>
</table>

Tab. 1: Maximum and characteristic shear resistance

The second part of the research is being prepared at present. In this part, three steel-concrete beams with 6 m span will be tested.

References:

This research has been conducted at the Department of Steel Structures as part of the research project "Composite structures" and has been supported by CTU grant No. 18162.
COUPLED MODELING SOLUTION OF STRESS IN ROCK MEDIUM

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Key words: coupled modeling, geotechnics

In the past, the coupled modeling (mutual influence of results from both the mathematical and the physical models from equivalent materials) proved several advantages when applied to geotechnical structures. In the paper, a new procedure is proposed for evaluation of internal parameters of the mathematical, physically nonlinear model using the partial results of the physical model. The procedure may be considered a special case of inverse analysis.

A number of numerical methods are now available. They are very often used for geotechnical problems solved under some simplifying assumptions. This is done because of a worse description of physical parameters of the trial model, incorrect input data, reduction of dimension from 3D to 2D due to the consumption of computer time, etc. Consequently, experimental physical methods are now being revived worldwide. The physical experiments can support the conceptional assumptions and results of the numerical methods and/or, on the contrary, the results of the mathematical treatment can influence the decision how to prepare the physical model. A combination of both methods and mutual use of their results enables one to restrict the disadvantages of both methods and to avoid results that do principally not agree with the reality, [1,2]. The coupling also significantly widen our current knowledge of rock mechanics.

The physical modeling method has been used for studying of various problems of rock mechanics associated with the underground and the surface mining of mineral raw materials, a construction of underground objects and problems of their stability. The paper by Stimpson [3], is a classical example. In comparison with mathematical solution, the advantage of such methods consists in a realistic simulation of the working processes in rock mass and their impact to it.

The advancement of the coupling of mathematical and physical modeling is very useful for an explanation of behavior of rock mass under consideration. This is very desirable for the basic research in geotechnics and geomechanics and also for practical use.

In the paper, a special case of inverse analysis is proposed. 2D plasticity is solved mathematically while the plastic law depends on some finite number of internal parameters. These parameters are to be stated from comparison of stresses obtained from both the physical and the mathematical models at a finite number of trial points from the domain describing the body of the simulated rock.

As from the physical model the values of stresses in a discrete set of points are given, the mathematical model has to be adjusted in such a way that the values from both the models in the points of comparison should be as close as possible. Say, the set
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\[ N = (A_1, ..., A_n) \]

consists of a finite number \( n \) of points of comparison \( A_i \). In these points, values of measured stresses \( \sigma_{\text{me}}(A_i) \) are provided from the physical model. There also is a finite number of parameters of the physical law considered in the mathematical model. This may be expressed in the form

\[ \sigma_y = \sigma_y(p_j), j = 1, ..., m \]

Our natural aim should now be to minimize the variance between both the computed and the measured values of stresses at the points from \( N \), i.e.

\[ I(p_i) = \sum_{j=1}^{m} (\sigma_y - \sigma_{\text{me}})^2 \]

 tends to its minimum

Obviously, the dependence of \( \sigma_y \) on \( p_i \) is not linear and the nonlinear minimization strategies have to be employed, i.e. the nonlinear programming algorithms have to be used. In this paper, the steepest descent type procedure was used. It consists in a numerical derivation of the last function with respect to \( p_j, j = 1, ..., n \) in such a way that \( I \) attains its minimum. The symmetric numerical derivatives were used. As a matter of fact, \( I \) need not possess a single minimum and an initial guess is necessary for attaining a successful result. This is a burden of the most optimization problems.

References:

This research has been conducted at the Technology Center as part of the research project “Underground nuclear construction” and has been supported by CTU (TU) grant No.19016.
Section 9

MATERIALS

ENGINEERING
Monte-Carlo Simulation in Electron Probe X-ray Microanalysis (EPMA)

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Key words: microanalysis, electron probe, Monte-Carlo simulation

In material sciences, the chemical analysis in microvolumes is provided by EPMA [1]. The Monte-Carlo simulation (MC) of the process of electron interaction with matter is currently used for the theoretical calculation of electron scattering as well as of the intensity of emitted X-ray radiation. MC gives the possibility to calculate and estimate the non- or hardly measurable parameters (e.g., the size of interaction volume [2] and composition of inclusions [3]).

We modeled the transmission of electrons through the thin layer (without substrate – the case similar to the conditions in the transmission electron microscope). From a large number of parameters we were looking for coefficient of electron backscattering, due to its importance for formation of one type of image and for a number of experimental data. For the check of validity of theoretical assumptions used in the MC, we compare results for three theoretical models of elastic collisions – screened Rutherford formula, Mott theory (used in [4]) and values from tables of differential cross-sections [5] – with experimental data [6]. Those models propose different values of differential cross-sections mainly for large angles (Fig. 1), what strongly influence the backscattering coefficient. The best agreement between MC calculation and these experimental data appeared for Mott theory (Fig. 2).

Thus we used this model for calculation of dependence of two quantities – the peak-to-background ratio (P/B) in the X-ray spectrum and the size of interaction volume – on the layer thickness. The P/B ratio is important for the quantitative analysis of inclusions, layers

Fig. 1: Electron scattering cross-section     Fig. 2: Comparison of MC with experiment
and rough surfaces; the calculated values depend on the layer thickness only very slightly. The size of interaction volume is characterized by the diameter of cylinder, containing 90% of excited X-ray radiation (D90). The results are in Fig. 3.

Finally, we calculate the energy dependence of D90 for 0.255 and 1.274 μm thick layer of Fe. The results are in Fig. 4.

![Fig. 3: Dependence of the interaction volume diameter D(90) on layer thickness](image1)

![Fig. 4: Dependence of the interaction volume diameter D(90) on electron energy](image2)

Conclusions: 1. For conditions used for calculation (electron energy 50 keV, Au layer of thickness 50±1000 μg.cm⁻² i.e., ≈ 25±500 nm), the Mott theory gives the best agreement of calculated and measured values of the electron backscattering coefficient. It should be valid for all the elements, because for lighter elements the differences of all the models decreases. For the other energy values, the check is to be done, but there is a lack of experimental data.

2. The dependences of D90 on the layer thickness and energy show the supposed shape; the numerical values give the estimation of the lateral resolution in layers of similar density.

References:


This research has been conducted at the Department of Material Sciences, as part of the research project “The influence of the surface layer and of the non-local effect on strength of bodies” and has been supported by grant of GA-CR No. 103/94/1708.
RELIABLE SURFACE
RECONSTRUCTION BASED ON
STEREO PAIRS OF SEM IMAGES

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Key words: surface analysis, electron microscopy, tree-dimensional reconstruction, correlation, disparity analysis

In order to determine the surface description (pixel vertical coordinates) of a microscopic sample, two images of the same area differing slightly by the angle of view must be provided. Though the primary purpose of it was to enable a stereoscopic view of the specimen, quantitative data on the surface description can be in principal obtained algorithmically on the basis of a geometrical model from the relative positions of corresponding points in both images. There are two main problems: reliable disparity analysis in the pair of images especially when there are no distinct details or when tilting of the sample changes the appearance of some details, and identification of the precise position and direction of the axis of tilt on the specimen surface needed for identification of the case geometry. The firmware of the used analytic complex provides totally chaotic results obviously due to imperfect pairing algorithms so that it is generally believed that the surface analysis is practically impossible. It is the purpose of the present project to develop algorithms that provide reliable surface description and to implement them in the available computing environment.

The first part of the analysis consists of pairing the points in both images, i.e. in determining two perpendicular components of the shift (disparity) vector \( d(p) \) for each position vector \( p \) in the image. Once the disparity matrices are determined the z-component (height) at the point \( p \) is [2]

\[
z(p) = -\frac{dz(p) - cx(p)}{\sin \beta}
\]

where \( dz(p) \) is the component of \( d(p) \) perpendicular to the axis of tilt, \( cx(p) \) is the component of \( dz(p) \) dependent only on the distance \( x(p) \) of the point \( p \) from the axis of tilt, \( cx(p) = x(p)(1 - \cos \beta) \) and \( \beta \) is the tilting angle.

Determining the exact correspondence between pixels of the normal and inclined images is the crucial and most difficult part of the calculation which needs a careful selection of the similarity criterion and the determination of realization details in order to insure a reasonable processing time with an acceptable error rate. The originally chosen criterion according to [2] that proved to be best as the reliability concerns is rather complex which led to extremely long computing times (over 10 hours per image) when used on simple grid of samples. One of the aims of the recent development was thus a more efficient sample sequence selection as described in the next paragraph. Criteria based on vectors of corresponding pixels in derived
parametric images according to [3] seem to be promising but no definitive conclusion has yet been arrived at.

Appreciable effort was devoted to finding reasonable parameters of pairing procedure, esp. a good sequence of filling the area of the image with paired points. The sequence should be designed in such a way as to enable the utilization of some of the already determined point correspondences as clues - initial estimates thus allowing to limit the extent of searched areas. The influence of the choice of sequences of the parameters determining the pairing procedure was estimated in greater detail in [6]. There is unfortunately no formalized clue to an optimum design of the sequence. Only a more or less intuitive approach supported by experiments was thus used to determine a reasonable alternative which proved to be substantially less demanding as to the computational complexity concerns.

The geometry of the real situation is rather complicated as the sample is usually shifted before acquisition of the “tilted” image, partly turned in the horizontal plane and also the axis of tilt is not in the expected position. A better axes position estimate than in the previous work [2, 5] can be based on the disparity vector field expressed in polar form. The formalism of the analysis concerning this problem is rather complex; a brief description of the main ideas can be found in [7].

The reported recent experimental research has led to the decrease in computational demands by more than one decimal order so that now the analysis became more practical and is already in the acceptable range (tens of minutes per couple of images on a 486/25 MHz machine). Also, the location of the tilt axes which is important for the heights calculation is more reliable using the approach based on the disparity matrix in polar coordinates. Localizing and correcting the falsely determined disparities by means of the disparity direction matrix seems to be promising. The intended interpolation of the values of similarity criteria may enable substantial refinement of the disparity field as its component values will not be constrained to integers any more and consequently the surface description should be less coarse. The program has been equipped for absolute calibration of the heights and for statistical analysis of the calculated surface.

References:

This research has been conducted at the Institute of Material Eng. as part of the research project “Reliable surface reconstruction based on stereo pairs of images provided by scanning electron microscope” and has been supported by TU grant No. C 29/94.
MATHEMATICAL MORPHOLOGY IN COMPUTER AIDED FRACTOGRAPHY

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Key words: image processing, mathematical morphology, fractographic analysis

One of the main tasks for the system of Computer Aided Fractography (CAF) was formulated as follows: to extend the facility of the current methods of fractographic reconstruction of fatigue crack growth based on the measurement of striation spacing. One of the possible ways could be the assessing of the geometry of the striation patches [1]. This approach to the fractographic analysis causes difficulties objections with detecting striation patches. Certain steps were taken in this problem by using image analysis methods, especially the segmentation by area growing method [2]. Unfortunately, the area growing algorithms are too time-consuming and high-dependent on image brightness and contrast. That is why a new approach based on mathematical morphology was introduced in [3].

Three basic demands were included to the algorithm:

1. Reasonable processing time on the PC computer.

2. The result of segmentation has to be independent of contrast and brightness of the microscope scan.

3. The results from one part of a crack surface must be as independent as possible of the magnification used.

The fast watersheds [3] algorithm was chosen to satisfy the demands presented above. Watersheds is the mathematical morphology transformation based on simulation of water flow through the brightness profile of the image. The character of the images analysed causes problems with image oversegmentation, because there is no apriori knowledge about the segmentation before processing. That is why new powerful techniques presented in [4] were used to remove image oversegmentation. Some results of watersheds segmentation are shown in the figures below.

References:


Original image of the fatigue fracture surface. Mag: 500x.

Final result of image segmentation.
(initial watersheds in grey, final segmentation in black)

*This research has been conducted at the Department of Materials as part of the development of the “Computer Aided Fractography” and has not been supported by any CTU grant.*
SCANNING TUNNELING MICROSCOPY

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Key words: Electron microscopy, Scanning microscopy, Tunneling microscopy, Surface topography, Surface spectroscopy, Atomic resolution

Since its introduction by Binning, Rohrer and collaborators [1] the Scanning Tunneling Microscope (STM) has engendered much excitement among surface scientists, not only for the atomically resolved surface topography it can achieve, but also for the range of surface spectroscopy possible.

Main advantages highlighting growing use of STM are:

• Atomic or submolecular resolution can be achieved in real space, i.e. there is no spatial periodicity of sample required (as e.g. in electron diffraction). The spatial resolution available with a good tip is about 0.2 nm in the sample plane, and 0.01 nm vertically (or even 0.001 nm using a.c. modulation of the tunnel current).

• Investigations using STM are possible in various environments such as ultra-high-vacuum, air or other gases, liquids or even gases, as well as electrolytic, cryogenic or high-temperature conditions among others.

• Besides a nondestructive analysis of the sample surface, the instrument can be used as a structure modifying tool in the nanometre and subnanometre scale (nanometre lithography, atomic and molecular manipulations) by changing tunneling (or field emission) parameters.

• STM has initiated the development of other scanning probe techniques such as Atomic Force Microscopy (AFM), including Magnetic (MFM) and Coulomb Force Microscopies (CFM), Near Field Optical Scanning Microscopy (NFOSM) and Photon Tunneling Microscopy (PTM), Near Field Thermal Scanning Microscopy (NFTSM), Scanning Ion Conductance Microscopy (SICM), Tunneling Acoustic Microscopy (TAM) and Ballistic Electron Emission Microscopy (BEEM).

In principle, the microscope (STM) is very simple. A sharp metal tip (usually W or Pt-Ir) is brought close to the (conducting) surface of interest, say within 1 nm. The physical quantity measured by STM is the tiny electrical current \( I_T \) which flows between the probing tip and the conductive sample surface through the very narrow gap between them. This current flows due to the quantum-mechanical tunnel effect and it is usually in the order of 1 nA for a gap width of 1 nm and an applied tip bias of 10 mV. Actually, an electrical current occurs only because there is a mutual penetration of the quantum-mechanical electron clouds surrounding the atomic cores and \( I_T \) reflects by its very nature the electronic properties of both the sample and the tip.

The tip is moved along the sample surface at a constant bias \( U_T \). A feedback loop adjusts the vertical (Z) position of the tip to keep the current (\( I_T \)) constant and, in consequence of this, to keep the gap width (tip-sample distance) constant, too. Thus, by monitoring the output of the feedback loop, it is possible to obtain the surface relief of the specimen.
Measuring the current-voltage characteristics $I(V)$ over each sample point of the scan raster (for $s = \text{const}$), one can find the considerable inhomogeneities of the local state density $N(E)$ as well as the tunneling barrier height $\Phi$ and thus judge about the local changes of electrical (or chemical) properties. This mode is called Scanning Tunneling Spectroscopy (STS).

Let us pick out only a few examples from the huge field of materials science applications of STM/STS (and related scanning probe techniques). Initial stages of fatigue cracks (nucleation, growth) were successfully investigated. Initial stages of epitaxial growth (GaAs on a Si(111)) [2] or topography of semiconductor surfaces [3] were observed with atomic resolution.

STM/STS was successfully applied for controlling of mirror surfaces, optical lattices, thin layers, magnetic and optic memory mediums (e.g. for quality control in magnetic disc production by IBM) or for hardness test. Also chemical and physical-chemical surface reactions (diffusion, sorption and so on) were observed in various gas or liquid environments through STM/STS.

We located our microscope TS 3130 (produced by TESCAN BRNO company) into the JEOL JSM-25S chamber. This combination of STM and SEM incidentally highly up-to-date, considering that it makes running of STM in vacuum environment possible enabled us first to find a place of interest on the SEM screen and, subsequently, to investigate it with STM. In addition, the spring mounting system of the JEOL JSM-25S proved to be excellent likewise for requirements of shock damping that is one of the most important factors affecting resolution of STM.

Before putting our microscope TS 3130 into operation we carried out a number of constructional modifications on the JEOL JSM-25S microscope: elimination of sample rotation, fitting the physical unit of the STM on instead of the specimen holder, adding 2 pcs of inlet bushings (left and right) in order to control the STM and replacing the micro-switch by a hand-switch detecting the working distance of the STM.

Our first investigations were carried out during the resolution test and calibration of the instrument. We were successful in attaining atomic resolution on the HOPG (highly oriented pyrolytic graphite) specimen. We obtained this micrograph at room temperature in the vacuum chamber. Optical lattice (with 1200 lines dug within 1 mm) was used to calibrate the microscope scale precisely.

References:

This research has been conducted at the Institute of Materials Engineering as part of the research project “Application of Scanning Tunneling Microscopy...” and has been supported by TU grant No. C 26/94.
MEASUREMENT OF THIN VARNISH LAYERS BY THE USE OF TUNNELLING SPECTROSCOPY

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Key words: varnish adhesion, varnish ageing, varnish ageing measurement

Inelastic electron tunnelling spectroscopy (IETS) is a very sensitive technique for measuring the vibrational spectra of organic molecules. Due to the high sensitivity, many applications are considered, such as studies of biomaterials or the study of ageing or adsorption mechanisms.

In our work the IETS has been used in analysis of adhesion mechanism and in the analysis of the ageing of electric insulation varnishes. Because any spectral bands caused by new bonds created as a consequence of the varnish adhesion can be found in the IR spectrum (the measured varnish layer is too thick for an analysis of such a type) the adhesion can be investigated by the comparison of the tunnelling and IR spectrum.

The basic assumptions in the adhesion study are as follows: every spectral band responds to vibration of specific chemical group and bond. In the case where a new bond has been created on the boundary-line varnish-metal a new spectral band ought to arise in tunnelling spectrum, if the sensitivity of the measuring method is sufficient. It is also probable that the spectral bands of the chemical groups present in the varnish could be influenced by the newly created groups or bonds, and therefore changes in the spectrum will occur.

The study of ageing has been based on a comparison of spectra of the varnish without and after ageing. However, the sensitivity of the IR spectroscopy is not sufficient for such a study in many cases, and therefore IET spectroscopy has also been used (one of the main advantages of IET spectroscopy in comparison with the IR one is a higher sensitivity to changes in the structure of molecules). The ageing occurs in the furnace at a high temperature.

The samples for the IETS measurement have been prepared by the evaporation of the bottom Al electrode on a Si or glass substrate, then by the pipeting of the varnish on this electrode and by the evaporation of the top Pb electrode across the first one. The slices must be perfectly clean before the evaporation, and the thickness of the varnish layer must be "tuned" by the viscosity of the varnish to achieve of the thickness of 2–3 nm.

The IET spectra have been recorded by the lock-in 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 a power supply which enables the setting of a smoothly growing voltage from zero to units of volts. The low amplitude pure sinus current has been connected to the junction. For the measurement of the 2nd harmonic voltage across the junction the Lock-In amplifier SR 830 (Standford Research) has been used. The data have been stored by the notebook IPC Porta (DX2/66 MHz, 8 MB RAM) and processed by the software developed at the university.
schematic diagram of the equipment is shown in the Fig. 1, where V ... dc voltmeter, LIA ... lock-in amplifier, C ... computer, S ... tunnelling sample).

The measurement of the spectra (Fig. 2) has been provided at the temperature of 4.2 K (liquid He) at the Physics Institute of the Czech Academy of Sciences. During the measurement the sample has been immersed directly into the liquid He. The equipment has been carefully grounded and screened, powering has been realized by the use of a voltage regulator. The IR spectra have been measured by the IR spectrometer Shimadzu at the State Research Institute of Protection of Materials.

The first type of the varnish measured in the way mentioned above has been the electric insulated varnish for surface insulation. The main spectral bands has been analyzed and their position, amplitude and width compared (IR vs. IETS bands). It has been found that some bands in the IETS spectra are shifted in comparison with the bands in the IR spectra. The basic ideas about the mechanism of the varnish adhesion has been obtained.

Fig. 1: Measuring equipment
Fig. 2: Tunnelling spectrum

References:

This research has been conducted at the Department of Electrotechnology of the Faculty of Electrical Engineering and has been supported by the Grant Agency of the Czech Republic, grant No. 102/94/1480.
THE CRYSTAL STRUCTURE OF THE SYNTHETIC NaX & ZK5 ZEOLITES DETERMINED FROM NEUTRON POWDER DIFFRACTION DATA

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Key words: neutron diffraction, X,Y zeolites, methyl groups, Rietveld analysis

Zeolites are a class of microporous molecular sieve materials having the general formula \( M_{n}Si_{(1-z)}Al_{z}O_{2}\cdot nH_{2}O \).

\( M \) represents some cation, required for charge balance, which resides in the channels formed by the aluminosilicate framework. It is the geometry of this framework, as well as the positions of cations within its channels and pores, that gives rise to the selective ion exchange, absorption and catalytic properties of these materials. A knowledge of the structures of the zeolites provides a basis for the understanding and prediction of these properties [1, 2].

Many zeolites have been synthesized only as crystalline powders and then we can determine the structure from X-ray or neutron powder diffraction data by means of the Rietveld method. There are some positive advantages to using powders together with neutron diffraction, where we can use the penetrating power in studies involving "in situ" dehydration, ion exchange, absorption and variation of temperature and pressure. The time required for data collection from powders can also be significantly less than that required for corresponding single crystal experiments, making feasible the collection of a number data sets to study the systematics of the structure zeolites under a variety of experimental conditions.

It has been shown recently that the pioneering studies [3, 4] of authors of this grant project found very good response in the literature [1, 2] where their results were discussed. Our conclusions on the distribution of protons and cations in Na-II,Y zeolites [3, 4] were fully confirmed on samples of similar nature but of different origin [1, 5]. Therefore, we started to continue our investigations on the NaX, NaY and ZK5 type of zeolites with chemisorbed methyl group.

The basic assumption for this work is the knowledge how to prepare the zeolitic samples with required properties. This is very important with respect to the decomposition of the methyl iodide inside the framework cavities. This process of the sample preparation was checked on the NaX samples. They were prepared for the neutron diffraction measurements in the following fashion. The laboratory-synthesized NaX or NaY samples were placed in an all-glass apparatus where each sample was first activated in a vacuum of 10 Torr at 400°C for 4-5 hours. The activated sample was sealed off under vacuum in a Si-glass ampule and it was placed on the KSN-2 neutron diffractometer.
Diffraction patterns for NaX (prepared by the Institute of Physical Chemistry) and ZK5 (prepared by [6]) were collected in the Laboratory of Neutron Diffraction at LVR-15 research reactor in Rež. The Cu(200) monochromator was produced $\lambda=0.1363$ nm and the resolution $\delta d/d=7.5\times10^{-3}$ was achieved. The diffraction patterns recorded were refined in the range of $20=57^\circ$ (about 150 diffraction lines) using the Rietveld profile analysis method (code RIETV-FN). In the same way we have measured this powder sample at the liquid helium temperature. The phase analysis were carried out on a diffractometer DRON-3 by using CuKα radiation. Structure refinement was carried out by using local modifications of the Rietveld procedure (code RIETV-FN), atomic shifts, occupation numbers, position of atoms and isotropic thermal coefficients were determined for both the samples. In case of the NaX sample, we reached discrepancy factors $R_w=11.1\%$ and $R_{exp}=9.9\%$ and we confirmed the cubic symmetry with the lattice parameter $a=24.935(3)$ in space group Fd$\overline{3}$m for this zeolite sample. In case of the ZK5 sample we obtained discrepancy factor $R_w=10.8\%$ and $R_{exp}=9.1\%$, respectively, and we confirmed the cubic symmetry and the space group Im$3$m with $a=18.618(3)$. Our results are in agreement with the parameters given in [1, 3, 5].

In conclusion we can say that we have prepared the conditions for the structural analysis of the NaX, NaY and ZK5 zeolites with the chemisorbed molecules. Now, we shall concentrate on measurements at the liquid helium temperature. It is assumed that by this way we can obtain important information concerning the structural properties of the methoxy group inside the cavities of the basic structural zeolitic framework. We expect to publish our results in 1995.

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 it has been supported by CTU grant No. 8216.
STRESS GRADIENT DUE TO
POLISHING AND SHOT-PEENING

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Key words: x-ray diffraction, residual stresses, gradient, quality control

X-ray diffraction methods of stress measurements are a reliable source of information about the deformation behaviour of surface layers the machine parts. Diffraction techniques become an effective means of the new system of quality control of industrial production. The principle of this control is that the checking of finished products must be replaced by the control of technological procedures. There is no other analytical technique that allows us to evaluate nonuniform stress fields in a nondestructive way.

The contribution deals with recent experiences of the authors concerning residual stress measurements in steel samples due to polishing and shot peening.

Samples investigated

a) Cylindrical steel specimens (POLDI 1-AK 1 TD) with the base area of 300 mm² were gently polished and bobbed with a special emulsion FEROGEN 2.

b) Squared steel samples (COR 13-6) with dimensions 50x50x10 mm³ were shot-peened by using a CLEMCO 2452 SCWB device.

Experimental techniques

a) Diffractometer DRON UM-1; an ω-goniometer was used to measure the diffraction line (310) centroid (2θa = 160.20°). The diffracted radiation CoKa was detected by scintillation counter with the step scan 0.2°(2θ) and constant time (20s) exposition.

b) Diffractometer Siemens; an ω-goniometer was used to measure the diffraction line (211) centroid (2θa = 155.48°). The diffracted radiation CrKa was detected by scintillation counter with the step scan of 0.2°(2θ) and constant time (40s) exposition.

Evaluation of non-homogeneous residual stress state

Basic equations of X-ray tensometry [1] have been used for description and evaluation of the residual stress tensor components. Typical courses ε²θ(±sin²ψ) were obtained for both types of investigated samples (Fig.1). An isotropic stress state was found from all measurements in the surface plane, i.e. σ11 = σ22 within the effective X-ray penetration depth T² [1], where σ11, σ22 are the mean values of stress tensor components.

Assuming that stresses σ11 and σ22 vary linearly with the distance T from the surface, σ11 = σ11(0) + g11T², σ22 = σ22T², where σ11(0), g11, g22 are unknown quantities, and T²(ψ) are calculated for the corresponding angles ψ [1], e.g. T²(ψ = 0, CoKa) = 11.1μm, T²(ψ = 0, CrKa) = 5.5μm.

Conclusions

• The non-uniform three-axial stress state was found in both cases of surface treatment of samples investigated.

• Evaluated values of σ11(0) and β11, β22 show a qualitative difference between both stress fields due to polishing and shot peening.

437
Tab. 1: Surface residual stresses $\sigma_{11}(0)$ [MPa] and stress gradients $g_{11}$, $g_{33}$ [MPa/um$^{-1}$] calculated from the experimental values in Fig. 1 by using the PFIT program [2]

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>$\sigma_{11}(0)$</th>
<th>$g_{11}$</th>
<th>$g_{33}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>polished</td>
<td>-595</td>
<td>+22</td>
<td>-9</td>
</tr>
<tr>
<td>shot-peened</td>
<td>-216</td>
<td>-23</td>
<td>-6</td>
</tr>
</tbody>
</table>

Fig. 1: Experimental values of lattice strains $\varepsilon$ vs $\sin^2\psi$ for polished (a) and shot-peened (b) sample

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.
EFFECT OF REMELTING ON MECHANICAL PROPERTIES OF WELDS IN Cr-Ni-Mo MARAGING STEELS

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Key words: stainless maraging steel, properties of welds, impurities, remelting

Stainless maraging steels with Cr-Ni-Mo alloying base belong among prospective materials. They have a good combination of strength and toughness, as well as good resistance to nonuniform corrosion. Mechanical properties of welded joints made up by conventional welding technologies are comparable to the properties of base metal [1].

Welding by high energy-beam processing (e.g. by electron beam processing) needs to decrease the content of impurities particularly phosphorus and sulphur below 0.005 wt.%.

Conventional concentrations of these impurities lead to their segregation into the narrow region along the fusion line, especially during electron-beam processing. Consequently, the notch toughness and fracture toughness diminish in that region significantly [2].

The objective of the current research was to evaluate the effect of vacuum arc remelting (VAR) and electroslag remelting (ESR) on strength and toughness of welds manufactured by electron beam (EB), metal inert gas (MIG) and submerged arc (SA) welding.

The original steel (not remelted) had the following chemical composition (in wt.%):

- 0.03%C - 0.37%Mn - 0.23%Si - 0.005%P - 0.014%S - 10.4%Cr - 10.3%Ni - 2.58%Mo -
- 1.23%Ti - 0.42%Al - 0.11%Cu - 0.03%Co - 0.02%Nb - 0.007%N - 0.005%O.

Remelting VAR made in SVUM Prague decreased the content of impurities to 0.005%N and 0.003%O, whereas remelting ESR performed at OVU Karlštejn lowered sulphur to min 0.005%.

The effect of remelting on notch-toughness of EB welded joints is shown in Fig.1 as compared with toughness of MIG and SA welds of the original steel. Remelting VAR almost did not change the toughness of EB welded joints. In contrast, remelting ESR increased the toughness of EB welded joints at the level of SA welds.

As far as yield strength is concerned, remelting ESR did not change its temperature dependence in the range of 20 to -60 °C for EB welded joints, whereas remelting VAR had a slightly negative effect.

For the evaluation of chemical microheterogeneity in weld metal (WM), heat affected zone (HAZ) and base metal (BM), the wave-dispersive X-ray microanalysis was applied. The concentration profiles across the welded joints were obtained from CAMEBAX micro-analyser. Quantitative analysis took ZAF correction into account. Statistical treatment of measured concentrations was based on the assumption of Student's t-distribution of the measured variable and the 95% confidence limit. The relative degree of heterogeneity is then [3]

\[ W_{95} = s_c \cdot t_{n-1} \cdot (N \cdot n^{-1/2})^{-1} \]  

\[ (1) \]
where \( s_c \) - standard deviation of the elemental concentration, \( t_{n-1}^{95} \) - Student's coefficient for \( n \) measurements, and \( N \) - mean value of experimentally determined variable.

Calculated values of \( W_{95} \) for selected chemical elements as related to the remelt processing and to the applied welding technology are presented in Fig. 2.

In accordance with the results obtained for further chemical elements, it can be said that for Cr, Ni, Mn and Mo the relation \( W_{95} < 0.1 \) is generally valid, hence their microheterogeneity is fairly low. In contrast, P and S obey the relation \( W_{95} > 0.2 \) except for ESR-EB processing, which means that the microheterogeneity for these elements is unsatisfactory. It follows that ESR-EB processing which lowered the sulphur content had also a very positive effect on its microheterogeneity.

In conclusion, electroslag remelting that particularly decreased the sulphur content in the tested type of steel, had also a positive effect on the microheterogeneity of both principal impurities (S and P) in welded joints manufactured by electron beam technology. It is suggested that this is the main reason for the increased toughness of ESR-EB welds.

References:


This research was conducted at the Department of Materials Science as part of the research project "Structure and Properties of Welds in HISS Maraging Steel" and was supported by CTU grant No. 8087.
MECHANICAL BEHAVIOUR
OF A STAINLESS MARAGING STEEL
AT ELEVATED TEMPERATURES

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Key words: mechanical behaviour, elevated temperature, tensile test, creep, stainless maraging steel

There are two major disadvantage of the classical ultra-high strength 18% Ni-9% Co-5%Mo-Ti maraging steels: poor corrosion resistance and poor elevated temperature resistance. The former disadvantage relates to the total absence of chromium, the latter disadvantage is caused by low reaustenitization temperature of about 500 °C and a consequent drop of hardness and strength. It has been shown recently that lowering the nickel content from 18% to 12% leads to an increase of reaustenitization temperature by 75 °C and further increase is possible by adding a considerable quantity of molybdenum [1].

The mechanical behaviour of 10% Cr-10% Ni-2% Mo-Ti-Al stainless maraging steel has been investigated extensively except for tensile loading at elevated temperatures [2]. This paper, attempts to determine the effect of ageing on both the short-time elevated-temperature tensile test characteristics and the creep rupture strength within the temperature range of 400 to 480 °C.

Two heats of the wrought steel type 10-10-2 were studied. For the sake of brevity, the chemical composition (in wt.%) only of the no.26 heat is presented: 0.018%C - 0.18%Mn - 0.20%Si - 0.011%P - 0.007%S - 10.42%Cr - 10.06%Ni - 2.25%Mo - 1.09%Ti - 0.46%Al - 0.01%Co - 0.06%Cu - 0.007%N - 0.005%O.

Specimens of 6 mm in diameter with threaded ends for gripping were machined from test blanks in as quenched state (930 °C, 1h/water). Afterwards the specimens were aged either at 520 °C or 560 °C or intercritically annealed at 650 °C for 3h and then cooled. The gage length was 30 mm. The tensile tests were conducted in electrical resistance furnaces in the air, where the temperatures were measured by means of chromel-alumel thermocouples. Generally spoken, the testing procedure and the testing equipment met the standardized requirements and recommended practice in accordance with CSN 420312 and CSN 420351.

The effects of ageing and testing temperature of the short-time tensile test on the ultimate strength is illustrated in Fig.1. The ultimate strength $R_u$ at 400 °C, similarly like hardness at ambient temperature, decreases with increasing ageing (annealing) temperature $T_a$. However, the values of $R_u$ at 480 °C are almost independent of $T_a$. It is also apparent that after annealing by 650 °C the ultimate strength is independent of testing temperature between 400 and 500 °C. The 0.2%-yield strength possesses a similar picture like the ultimate strength. The elongation increased with an increasing testing temperature. Values exhibited a large scatter at elevated temperatures.
The results of creep tests were rationalized by means of Larson-Miller parameter in the form

\[ 10^{-3}.T.(C + \log t) = b_1 + b_2 \cdot \log R_{mT} \]  

where \( R_{mT} \) is the creep rupture strength. In order to compute the constants \( b_1, b_2 \) and \( C \), the program Microsoft Excel was applied which lead to the following mean values: \( c=17.47, b_1=43.37 \) and \( b_2 = -10.20 \). Conventional statistical treatment of the given regression yielded the standard deviation and the 95% confidence limits shown in Fig. 2.

Metallographic examination of tensile specimens revealed bending in microstructure caused by titanium segregation. In the fracture area of the specimens many coagulated particles of the \( \gamma' - N_13 (Al, Ti) \) phase were observed in the specimens aged at 520 °C and crept at 480 °C.

It may be concluded that: (a) the investigated steel exhibited maximum short-time tensile strength at elevated temperatures of 400 to 480 °C in the peak age-hardened state; (b) plasticity (elongation) of the steel was mostly dependent on the temperature of a short-time test; (c) creep tests allowed to determine constants and confidence limits of Larson-Miller's regression in the linear form.

References:

This research was conducted at the Department of Materials Science a as part of the research project "Structure and Properties of Welds in HSS Maraging Steels " and was partially supported by CTU grant No. 8087.
INFLUENCE OF THE DEFORMATION CONDITIONS ON THE DYNAMIC AND POSTDYNAMIC DEHARDENING PROCESSES

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Key words: dynamic recrystallization, deformation rate, grain size, precipitation

In the presented contribution, the influence of the high deformation rate on the recrystallization and precipitation processes is analyzed in austenitic stainless steel. We studied two sets of samples of AISI 304 steel; these sets have different grain size ($d_1 = 400 \, \mu m$, $d_2 = 140 \, \mu m$) and the Ti content ($c_1 = 0.305\%$ and $c_2 = 0.55\%$). The cylindrical samples were deformed to 70% of initial height at 1050°C. The mean deformation rates were $\dot{\varepsilon}_1 = 2.7 \times 10^2 \, s^{-1}$ and $\dot{\varepsilon}_2 = 3.5 \times 10^3 \, s^{-1}$, respectively. Before deformation, the samples were annealed to dissolve the minor phases at 1200°C/45 min followed by water cooling. The recrystallization annealing was provided by holding up at the temperature of deformation or by new annealing with intermediate cooling.

The dehardening processes were observed by the metalographical methods, namely by light and electron microscopy, and the numbers of recrystallized grains were found.

At Fig. 1, the observed recrystallized fractions and their dependence on the experimental conditions are shown. Nearly at all the cases (except 1A, 1B), the strong dynamical recrystallization appeared.

In the observed range of the deformation rates, the dynamically recrystallized fraction increases with the deformation rate (the curves 1 and 2). This fact confirms the result that the dynamical recrystallization comes into play after hot deformation even at high deformation rates (approximately $10^2 - 10^3 \, s^{-1}$) [1, 2].

At lower value of deformation rate, the dynamical recrystallization is accelerated if the mean grain size decreases (see 1A, 1B, 1C) at higher one, the influence of the grain size magnitude diminishes (2A, 2B). The higher deformation rate, the finer and more homogeneous in size the dynamically recrystallized grains are created (Fig. 2). The recrystallization annealing after the hot deformation forces to the next growth of the recrystallized fraction, what is implied by metadynamic recrystallization (Fig. 1).

The growth rate of the recrystallized grains decreases with the time of recrystallizing annealing and it is higher for the samples deformed by a higher rate ($v \sim 1 \times 10^{-4} \, mm/s$ for $\dot{\varepsilon} \sim 10^3 \, s^{-1}$ and $v \sim 1 \times 10^{-5} \, mm/s$ for $\dot{\varepsilon} \sim 10^2 \, s^{-1}$). The values of the growth rate agree well with the results published in [3, 4].

Chemical element Ti inside the solid solution as well as in the form of fine minor phases breaks recrystallization processes. By the recrystallization annealing without intercooling the possibility of the fine precipitate appearing is depressed and the recrystallization is accelerated (see 1A, 1B).

Conclusions:
In the investigated range of deformation rates (~ $10^2$-$10^3\text{s}^{-1}$) intensity of dynamic recrystallization increases with the increase of deformation rate.

2. Influence of original grains size on recrystallization processes is more distinct for lower deformations rates.

3. Higher deformation rate leads to finer grains and more homogeneous structure.

4. Ti inside the solid solution as well as in the form of fine minor phase breaks the recrystallization processes.

5. Recrystallization is significantly slowed down by precipitates which are deposited in the period of intercooling and following reheating.

Fig. 1: Kinetic recrystallization curves of AISI 304 steel.

Fig. 2: Mean grain size distribution curves for samples after dynamical recrystallization.

References:


This research has been conducted at the Department of the Material Science as part of the research project “Dehardening processes in metallic materials” and has been supported by CTU grant No. 8181 (1994).
Ultra-high strength low-alloy steels (UHSLA) are the most effective heavy duty structural materials. The 300M steel of American provenance is successfully used in the aircraft industry. Czech firm Poldi Kladno has developed the analogous steel marked LDHA for the same application. In this paper, the determination of some substantial mechanical characteristics of the LDHA steel has been made as well as their comparison with the values of the American 300M steel. Chemical composition and the heat treatment of the steels are given in Tab. 1 and Tab. 2.

In Tab. 3 the values of some basic mechanical properties are shown. The data of the 300M steel were taken from literature [1–3]. Mechanical properties of the LDHA steel has been determined experimentally. A tensile test was done with the constant velocity of the cross beam motion of 0.01/s. Charpy V-notch test was carried out by using the instrumented pendulum impact testing machine according to ASTM E23. Fracture toughness test $K_I$ was done using the CT-specimens. The values of mechanical properties of the LDHA steel (Tab. III) are in good agreement with the American one.

The fatigue behaviour of the LDHA steel was evaluated using the smooth and notched cylindrical samples. In the low-cycle range, the durability values of all LDHA steel samples are comparable with those of 300 M steel. The fatigue diagrams of constant durability of the 300M and LDHA steels are illustrated in Fig. 1a,b (smooth samples).

In this study, the comparison between selected mechanical properties of the LDHA steel and the American 300M steel was made. It was shown that both steels are well comparable.

<table>
<thead>
<tr>
<th>STEEL</th>
<th>C</th>
<th>Mn</th>
<th>Pmax</th>
<th>Smax</th>
<th>Si</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Cu_max</th>
</tr>
</thead>
<tbody>
<tr>
<td>300M</td>
<td>0.40</td>
<td>0.65</td>
<td>0.010</td>
<td>0.010</td>
<td>1.45</td>
<td>1.65</td>
<td>0.70</td>
<td>0.35</td>
<td>0.05</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>0.50</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDHA</td>
<td>0.42</td>
<td>0.37</td>
<td>0.007</td>
<td>0.004</td>
<td>1.45</td>
<td>1.72</td>
<td>1.09</td>
<td>0.67</td>
<td>0.075</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Tab. 1: Chemical Composition, Wt Pct.
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PROCEDURE of HT

1. NORMALIZING 920°C/1h/air 927°C±14/1h/air
2. HARDENING 870°C/1h/oil 871°C±14/1h/oil
3. TEMPERING 300°C/2+2h/air 302°C±5/2+2h/air

Tab. 2: Heat treatment (HT).

<table>
<thead>
<tr>
<th>STEEL</th>
<th>H0.2 [MPa]</th>
<th>Rm [MPa]</th>
<th>A5 [%]</th>
<th>Z [%]</th>
<th>KCV [J/cm²]</th>
<th>KIC [MIPa.m¹/²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>300M</td>
<td>min. 1586</td>
<td>min. 1931</td>
<td>min. 7</td>
<td>min. 25</td>
<td>29⁺</td>
<td>57</td>
</tr>
<tr>
<td>LDHA</td>
<td>1659</td>
<td>1992</td>
<td>10</td>
<td>42</td>
<td>26</td>
<td>56</td>
</tr>
</tbody>
</table>

*CVN (Charpy V-notch data test) converted from [1] on the value KCV (notched-bar impact data test).

Tab. 3: Mechanical properties under uniform loading.

Fig. 1: Diagrams of constant durability (1 ksi = 6.895 MPa)

References:

This research has been conducted at the Institute of Physical Engineering 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. A6/94.
CYCLIC CREEP OF HIGH TEMPERED LDHA POLDI STEEL

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

The experimental results (obtained during the collaboration between the MTIP of Brno, TU of Brno and TU of Sofia) in connexion with the previous study [1] are published in this paper.

The LDHA steel worked out and heat treated by standard technology, is an ultra-high strength steel with values of $R_{p0.2} \approx 1700$ MPa and $R_{m} \approx 2000$ MPa. In this stage cyclic creep (further cc) may be expected which causes sudden instability. This is the reason why a model high tempered stage had been selected for the first period of the study because of the superposition of stable cc. The chemical composition of the studied steel is given in [1], for heat treatment see Tab. 1. Cylindrical specimens with diameter of 6.35 mm and active length $a_0 = 26$ mm were used.

It has been found [2, 3] that the cc under conditions of room temperature first arises when the limit value of plastic strain amplitude $\theta_e p$ appears (equal to a constant for used material and cyclic stress ratio $P$) even when there is symmetrical push-pull loading. Fig. 1a, b illustrates the dependence of cc on relative number of cycles $N/N_f$ ($N_f$ - cycles to failure) and corresponding dependence $e_{ap}$ for various $P$ of samples made from the steel studied. The critical threshold values of $\theta_e p(P)$ are marked where a heavy development of cc in the tension direction arises. Fig. 2 illustrates the curve in connexion with $P$ which gives the maximum value of plastic strain amplitude for specific material at which the cc does not exists below this value. The last mentioned curve is called the cc threshold curve [4].

Assumption of intensive and stable cc has been proved in the model stage of developed LDHA steel. For this material the limit dependence of plastic strain amplitude on stress ratio has been estimated, which determinates the extreme cc acceleration (the cc threshold curve). Moreover, it has been established the cc could also rise in the case of symmetrical push-pull loading.

Fig. 1
The authors wish to thank Dr. K. Staevski (University of Sofia), Ing. O. Kyša, Mr. J. Novák (both MTIP of Brno) and Dr. P. Sandera (TU of Brno) for their technical help.

1. NORMALIZING 920°C/1h/air
2. HARDENING 870°C/1h/oil
3. TEMPERING 630°C/2h/air

Tab. 1: Heat treatment (MTIP of Brno)

<table>
<thead>
<tr>
<th>SAMPLE No.</th>
<th>$\sigma_s$ [MPa]</th>
<th>$\sigma_m$ [MPa]</th>
<th>$\rho$</th>
<th>$f$ [Hz]</th>
<th>$N_f$</th>
<th>$\varepsilon_{ap}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>M 19</td>
<td>700</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>9999</td>
<td>$\approx 5 \times 10^{-5}$</td>
</tr>
<tr>
<td>M 20</td>
<td>700</td>
<td>100</td>
<td>1.143</td>
<td>0.5</td>
<td>5619</td>
<td>$1.65 \times 10^{-4}$</td>
</tr>
<tr>
<td>M 21</td>
<td>800</td>
<td>0</td>
<td>1</td>
<td>0.3</td>
<td>705</td>
<td>$1.68 \times 10^{-5}$</td>
</tr>
<tr>
<td>M 22</td>
<td>800</td>
<td>100</td>
<td>1.125</td>
<td>0.3</td>
<td>160</td>
<td>$1.75 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

*) value of $\varepsilon_{ap}$, no $\frac{d\varepsilon_{ap}}{dt}$

Tab. 2: Experimental conditions and results of tests

Fig. 2: The cyclic creep threshold curve

References:

This research has been conducted at the Institute of Physical Engineering 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. A6/94.
STUDY OF MATERIALS FOR MULTIPHASE ELECTRO-CHEMICAL SYSTEMS


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Key words: multiphase systems, homogeneous precipitation, size of particles, primary cells, fuel cells

The project deals with the study of physical and electro-chemical properties of multiphase systems applicable in the form of electrode mass of alkaline accumulators and primary cells. The aim of the project is to attain a substantially finer structure of the multiphase systems being studied which will enable us to increase the specific surface and porosity of prepared electrode mass with the purpose to increase their current carrying capacity both at normal and also at low temperature. It will be possible to attain this target by using the method of homogeneous precipitation which yields a super-fine structure having "nano" size particles, i.e. "nanophase" materials as initial components of the electrode mass studied.

This year our work has been focused on preparing a material system on the base of silver oxide which can be used as electro-chemical system in primary cells and also in type Ag-Zn accumulators. At the same time the material system on the base of silver oxide will be used for the preparation of oxygen electrode of fuel cell.

The use of homogeneous precipitation of silver salt solutions in alkaline medium has enabled a substantial decrease of size of silver oxide particles when compared with the material used till now.

The existing silver oxide used for the preparation of silver electrode of primary and also secondary Ag-Zn system contains particles of about 10 μm in size. By means of using the method of homogeneous precipitation it was possible to prepare silver oxide having the medium size of particles ranging from 0.35 to 0.37 μm. The largest volume portion of four laboratory charges of silver oxide was in the range from 0.34 to 0.45 μm. At present the prepared average sample containing all four charges of silver oxide is subjected to long-term testing in systems of primary Ag-Zn cells in the third world largest firm RENATA in Switzerland, which produces these primary cells. On the basis of results gained at the firm RENATA further research will be continued of silver oxide application in primary or possibly secondary Ag-Zn cells.

By means of the same technology of homogeneous precipitation every time 10 charges of silver oxide were prepared as well as 10 charges of silver oxide containing also zinc oxide,
by simultaneous precipitation of silver salt and zinc salt solutions. The prepared charges were of medium size of particles in the range from 0.33 to 0.42 µm, with the largest volume portion in the range from 0.34 to 0.45 µm. The above charges will gradually be used for the preparation of oxygen electrodes for the system of oxygen-hydrogen fuel cell in cooperation with the firm Astris Ltd., Benešov. The above work will be a follow-up on the research of the Department of Electrotechnology, Faculty of Electrical Engineering and Computer Science, Technical University Brno, carried out from 1969 to 1972. Also the structure of prepared laboratory charges has been evaluated by means of a scanning electron microscope.

An integral part of the laboratory for the evaluation of electrical and electro-chemical properties of the systems studied is the automatic measuring and regulating system. The designed laboratory enables us to measure properties and to test conditions of the studied systems in long-term automatic, free programmable cycle, namely:

- to measure continuously the value of voltage of separate systems (cells),
- to measure or possibly regulate charging and discharging current,
- to connect and disconnect the measured objects in programmable cycle,
- to determine the capacity of the systems (cells) studied and ampere-hour and watt-hour efficiency of the charging process,
- to ensure further auxiliary functions, to control break-down state and to evaluate the whole measuring cycle inclusive of working out the records.

From three basic possibilities of solution i.e. the use of standard industrial design built on modern processors with extension modules or the design of single-purpose equipment built on single-chip microcomputer connected by serial line with PC, the third consistently PC oriented possibility has been selected. The control system is provided with digital and analog inputs and outputs and with a communication subsystem with superior PC for the control and exchange of information. The equipment is built on PC 286 or a higher-grade PC with modules produced by firm Advantech, series ADAM 4000. Converter 232/485 enables the use of the line for object control to a distance of up to 1200 m and supports up to 256 modules. Digital input/output module ADAM 4050, module of multiplexer IDK 9010 in connection with module of A/D converters with isolation amplifiers ADAM 4012 and further digital output module IDK 9020 form the core of the system controlled by PC with appropriate software. The system is equipped with a driver for modules ADAM 4000 and with a Control Panel program from the firm Alcor Ltd. Moravské přístroje (Moravian Instruments).

References:


This research has been conducted at the Department of Electrotechnology as part of the research project “Study of materials for multiphase electro-chemical systems” and has been supported by TU Brno grant No. 991/39.
NEW MAGNETIC MATERIALS FOR MEASUREMENT TECHNOLOGY

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Key words: magnetic materials, instrumentation, magnetic measurement

Amorphous and nanocrystalline soft magnetic materials are serious candidates to replace traditional crystalline materials in magnetic circuits used for instrument transformers, power chokes, magnetic sensors, magnetic shields and other devices. The magnetic and electrical parameters of these materials allow us to decrease the core volumes, increase the operating frequency, decrease power losses, and increase precision. The specific mechanical and magnetic properties of the above mentioned materials have led to new constructions of magnetic circuits and accompanying electronics, and also to new methods of measurement of their magnetic properties.

The latest version of the Dynamic hysteresigraph is described in [1]. The instrument uses a digital oscilloscope for simultaneous sampling and averaging; the induced voltage is numerically integrated; and the hysteresis loop and sample parameters including power losses are calculated. The instrument software, written in Turbo Pascal and C languages in the MS Windows environment, allows easy modifications and graphic data handling. Another version of the virtual instrument was created in the LabView environment [2]. The improved version of the instrument, which is under development, is using 16-bit/1 MHz IOtecho model ADC 488/SSA synchronous sampling unit; the aim is to increase the instrument precision, especially for the evaluation of power losses. The excitation arbitrary waveform will be automatically adjusted so that the sinusoidal magnetic induction waveform will be reached as required by the standard IEC methodology. The high-frequency instrument power amplifier necessary for core excitation is under development. The aforementioned instrument will allow us to measure precisely the magnetic parameters of the toroidal samples at high frequencies, as required for the design of power chokes for switch-mode power supplies.

The concepts used in software packages created for magnetic measuring instruments are discussed in [3]. The innovative Complex permeability meter is created as a virtual instrument in the LabWindows CVI environment. The hardware consists of a Digital Signal Processing Lock-in Amplifier, a V-MOS excitation power amplifier and computer-controlled high-frequency resistor, and a switching box of novel construction. The instrument frequency range has been extended up to 100 kHz.

The industrial Initial Permeability Meter was developed on a contract basis for ABB Brno. The instrument is used for input quality checks of the toroidal and C cores. In order to eliminate the time-consuming winding of each measured sample, industrial permeability meters usually use special measuring fixtures. Both the excitation and measuring windings are created by a single multi-conductor cable; the multi-pole connector allows us to break the winding loop and easily insert the sample. Errors caused by a non-uniformity in the winding have to be taken into account in case of low permeability. Studies regarding the
errors created by desaccommodation effect and non-sinusoidal magnetization condition have been conducted [4]. The total instrument error achieved is well below 5%.

Amorphous foils may be used for shielding purposes, because, unlike the permalloys, they may be formed without subsequent high-temperature annealing. Circular 1.2 m Helmholtz coil pair for shielding efficiency tests are being designed and fabricated in collaboration with Development Laboratories in Poděbrady.

Magnetic field and field gradient sensors using amorphous magnetic materials exhibit excellent properties. Race-track fluxgate sensors developed at CTU have a noise level below 7 pH rms (100 mHz to 10 Hz) [5]. Miniature sensors working on the same principle have even larger sensitivity than Hall and anisotropic magnetoresistance sensors [6]. The high electrical resistivity of the alloy used, allows us to increase the excitation frequency and also use the fluxgate magnetometer to measure AC magnetic fields [7]. Technology for producing the annular sensor cores from nanocrystalline material is under development.

Design and error analysis of the amorphous core instrument current transformer proved another field of use for these materials. Preliminary measurements of the nanocrystalline toroidal cores have shown that the almost constant and relatively high permeability of these materials allow us to build instrument transformers with a large dynamic range. Because the saturation induction of nanocrystalline materials is much larger than that of both cobalt-based amorphous materials and permalloys, the resulting core volume may be significantly lower. Another advantage of iron-based nanocrystalline materials is the low cost of the raw materials used in their production.

References:


This research has been conducted at the Department of Measurement as part of the research project "Amorphous and nanocrystalline materials in electrical engineering" and has been supported by GACR grant No. 102/93/1197.
THE INFLUENCE OF THE PALLADIUM DIFFUSION ON CARRIER LIFETIME IN POWER DIODE STRUCTURES

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Key words: palladium diffusion, deep energy levels, carrier lifetime

Characteristics of semiconductor devices (esp. bipolar power devices) can be seriously influenced by impurities creating deep energy levels in the band gap and enhancing the recombination rate of excess carriers (decreasing the excess carrier lifetime). Some of these impurities (Au, Pt) are used often for lifetime control in the device fabrication process.

Palladium is an impurity in silicon having a very high diffusivity and it influences the carrier lifetime. In our research, the influence of palladium diffusion in structures of power silicon diodes has been investigated.

These diodes were prepared by a conventional diffusion technology where Al, B and P were diffused into N-type silicon wafers of $\rho = 80\ \Omega\cdot\text{cm}$ in order to prepare power diodes of a P$^+$PNN$^+$ structure. A very thin layer of palladium was deposited on the P$^+$-type side of the structure P$^+$PNN$^+$ by vacuum evaporation. Diffusion of palladium was performed at temperatures of 820, 860, 900 and 940 °C during 4 minutes (50 seconds is the minimum time of diffusion according to data published in [1] for homogenous distribution of palladium in silicon wafers of thickness $d = 300 \ \mu\text{m}$ and temperature 820 °C). Then one series of power diodes where palladium was diffused at the temperature of 860 °C during 20 minutes was made.

On these prepared diodes some fundamental parameters, for example lifetime, were measured. It was discovered that palladium in silicon, like many other transition metals, forms active recombination centers. In comparison with diodes without palladium, in Tab. 1, a big difference in lifetime can be seen. From this table the difference between diodes with palladium diffused at the temperature of 860 °C for 4 minutes and 20 minutes can be seen also. This fact demonstrates the "kick-out" mechanism of diffusion palladium in silicon, which is not mentioned in [1].

Energy levels related to palladium in silicon were measured by using DLTS and TSC techniques. As we have mentioned above, palladium exists in silicon as a substitutional and interstitial atom. By the DLTS technique acceptor levels at $E_C - 0.18 \ \text{eV}$ and $E_C - 0.28 \ \text{eV}$ were discovered. By the TSC technique also an acceptor level at $E_C - 0.28 \ \text{eV}$ and another acceptor level at $E_C - 0.22 \ \text{eV}$ were observed. The dominant recombinant level is at the acceptor level of $E_C - 0.28 \ \text{eV}$. Owing to these deep energy levels of palladium in silicon there is the crucial influence on the lifetime.

From the experimental results, it follows that the palladium diffusion into the silicon device structures allows effective control of the minority carrier lifetime. The increase in the leakage current, caused by the charge generated in the depletion layer, is similar to the values obtained with platinum doping and smaller to those obtained with gold doping. In
view of these facts, palladium in silicon might be applied for carrier lifetime control in silicon device fabrication technology.

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**Tab. 1**
Effective carrier lifetime [ns] measured at the room temperature

group: 1...Pd diffusion, 820 °C, 4 minutes
2...Pd diffusion, 960 °C, 4 minutes
3...Pd diffusion, 900 °C, 4 minutes
4...Pd diffusion, 940 °C, 4 minutes
5...Pd diffusion, 860 °C, 20 minutes
6...reference samples without Pd diffusion

References:

*This research has been conducted at the Department of Electrotechnology as part of the research project “Recombination in power semiconductor devices” and has been supported by GAČR grant No. 102/94/1968.*
The fatigue behaviour of AlZnMg alloy (7010 T7651) was under investigation in the framework of a development of new materials for the airframe components. Flat CCT specimens were manufactured from a semi-finished plate with recrystallized structure (the plate was supplied by the Pechiney Centre de Recherches de Vereppe, France). Two structure/crack orientations of CCT specimens were under study:

TL/L - direction of lamination is parallel to the crack growth direction;

TL/TC - direction of lamination is perpendicular to the crack growth direction.

Fatigue tests were performed at room temperature, loading frequency \( f = 7 \) Hz, constant stress range \( \Delta \sigma = 56 \) MPa or \( 40 \) MPa and constant stress ratio \( R = 0.1 \). Specimens were tested in air and vacuum. During the fatigue tests, an investigation of a near-threshold behaviour was performed for both structure/crack orientations. The results of high-cycle fatigue test were presented in the form of macroscopic crack growth rate as a function of stress intensity factor range \( \Delta K \) (or its effective value \( \Delta K_{eff} \)), see [1]. By means of statistical processing [2], the experimental data were fitted by regression functions, the parameters of which are presented in [1]. The comparison of macroscopic crack growth data (see Fig. 1 and 2) results in the following conclusions:

1. The specimens in TL/L orientation tested in air and vacuum: The difference between the macroscopic crack growth rates in air and vacuum is negligible (from the practical point of view) in the range of \( 4.5 \) MPa.m\(^{1/2} \) < \( \Delta K < 10 \) MPa.m\(^{1/2} \), while for \( \Delta K > 10 \) MPa.m\(^{1/2} \) the macroscopic crack growth rate in vacuum is rather higher than in air.

2. The specimens in TL/TC orientation tested in air and in vacuum: The macroscopic crack growth rates in both the environments are almost the same in the range of \( 5 \) MPa.m\(^{1/2} \) < \( \Delta K < 23 \) MPa.m\(^{1/2} \), while for \( \Delta K < 5 \) MPa.m\(^{1/2} \) the macroscopic crack growth rate in vacuum is lower than in air.

3. The specimens tested in air: The macroscopic crack growth rate in TL/TC orientation is higher than in TL/L orientation, however the higher the \( \Delta K \), the lower the difference. The estimated fatigue threshold value \( \Delta K_{th} \) (for \( v = 10^{-12} \) m/cycle) is approximately two times higher for the orientation TL/L than for the orientation TL/TC.
4. The specimens tested in vacuum: Because of the limited macroscopic data set, it is impossible to decide whether the fatigue crack growth rate differences between the orientation TL/L and TL/TC are significant or not.

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) and by the grant No. 106/94/0985 of the GA of the Czech Republic.
INFLUENCE OF ENVIRONMENT AND STRUCTURE ORIENTATION ON FATIGUE CRACK GROWTH IN AlZnMg ALLOY (Part II)

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Key words: fatigue, structure/crack orientation, environment, quantitative fractography, striation spacing, aluminium alloy

In the first part of our contribution [1], the results of fatigue tests were summarized. The investigation of AlZnMg alloy (7010 T7651) was completed by quantitative fractography. The main goal of the fractographic analysis was the measurement of striation spacing $s$ as a function of stress intensity factor range $\Delta K$ (or its effective value $\Delta K_{eff}$) for both the structure/crack orientations studied and for both the environments. The fractographic analysis results in the following conclusions:

1. The specimens tested in air: A variability of the striation spacing data in log-log coordinates is approximately constant in the whole range of $\Delta K$ in orientation TL/L, while in orientation TL/TC it depends on $\Delta K$ (compare Figs. 1 and 2). The difference is due to an interaction between the fatigue crack front and microstructure, the orientation of which is considerably different in the two cases under study. The differences in the fractographic data in both orientations lead to regression lines (parameters of regression lines are described in [2]) with different slopes.

2. The specimens tested in vacuum: Both the mean value and the variability of striation spacing increase with the increasing value of $\Delta K$ (or $\Delta K_{eff}$). The variability of striation spacing is much more accentuated in TL/TC than in TL/L orientation (compare Figs. 3 and 4). Similarly as in air, the differences in the fractographic data lead to the regression lines with different slopes.

References:


This research has been conducted at the Department of Materials as a part of the joint research project "Properties of Al-Alloy 7010" and has been supported by Pechiney Centre de Recherches de Voreppe (France) and by the grant No. 106/94/0985 of the GA of the Czech Republic.
FATIGUE CRACK GROWTH UNDER HIGH STRESS RATIO

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Key words: fatigue, stress ratio, fatigue crack growth, crack growth modelling, crack tip deformation mechanics, finite element method

In order to study fatigue crack behaviour under high value of stress ratio $R=P_{\text{min}}/P_{\text{max}}$, a computer simulation of fatigue crack growth in a CT-specimen (Fig. 1) was performed. The final length of the modelled crack was $a=8.84$ mm. The cracked specimen made from the 7010 Al-alloy ($\sigma_t=400$ MPa) was loaded by pulsating tensile loading $P$ ($P_{\text{max}}=12$ kN, $R=0.7$). The parameters of the computer simulation were chosen in such a way that the theoretical results were directly comparable with the experiments performed at the École Centrale Paris and at our laboratory. The special two-dimensional FEM program used for the modelling was described in [1]. The fatigue crack, growing in the same specimen under low stress ratio ($P_{\text{max}}=9.3$ kN, $R=0.1$) had already been modelled in [2].

The plane stress simulation describes the behaviour of the crack in a thin-walled body. The crack tip plastic deformation in the load direction is very intensive due to easy local transverse contraction in the $x$ direction, and, therefore high incompatible plastic strains remain in the wake of the growing crack. In spite of this, the crack closing is much less intensive than the closing under repeated tensile loading ($R=0$). This is due to high values of the crack tip opening displacement (CTOD) under highly asymmetric loading. The theoretical value of the crack opening load is only $P_{\text{op}} = 0.74 P_{\text{max}}$, and almost the whole loading cycle is thus effective. This conclusion agrees well with the experimental data, for example, Eller's equation $(P_{\text{max}} - P_{\text{op}})/(P_{\text{max}} - P_{\text{min}}) = 0.5+0.4R$ gives $P_{\text{op}} = 0.767 P_{\text{max}}$ for $R=0.7$. The theoretical crack growth rate predicted directly from the critical plastic strain energy density accumulated ahead of the crack is $0.094 \mu m/\text{cycle}$. The rate estimated from experimental relation $da/dN = \Delta K/\Pi$ is $0.072 \mu m/\text{cycle}$; the agreement is also quite good.

An interpretation of plane strain results with respect to the behaviour of the crack in the thick wall is much more complicated. The crack tip plastic deformation under local plane strain conditions can be covered only from a difficult contraction in crack growth direction $x$. Moreover, the specific plastic deformation mechanism leads to further reduction of low residual plastic strains created ahead of the tip during the preceding growth. Therefore the resulting incompatible plastic deformations that remain at the crack faces and induce crack closing are much lower than in the plane stress case (Fig. 2). According to Fig. 3, the plane strain value of CTOD is higher (the current crack tip position in Figs 2, 3 is indicated by a vertical line). The theoretical value of $P_{\text{op}}$ is thus lower than $P_{\text{min}}$ and the fatigue crack through the thick wall should remain fully open during the whole cycle at $R=0.7$. This result agrees with the direct measurements [3] on the thick CT-specimens ($t=25$ mm).

However, the relatively high experimental crack rate ($0.089 \mu m/\text{cycle}$) does not correspond with the FEM simulation of the low cycle fatigue at the crack tip because the theoretical cyclic plasticity under plane strain conditions is very low. This discrepancy had already been observed in [2]. There are two possible explanations: 1) The fatigue fracture under
plane strain conditions at the crack tip demands a specific criterion for the elementary crack advance. Probably the high value of $\sigma_u$ has to be taken into account. 2) The plane strain state does not exist nor in a close vicinity of the crack front in the middle part of the thick wall.

Fig. 1: Modelled CT-specimen symmetric according to the x-axis.

Fig. 2: Residual plastic elongation of the layer adjacent to the crack face.

Fig. 3: Crack profile under maximum and minimum load.

References:

This research has been conducted at the Department of Materials as part of the research project “Computer Modelling of Fatigue Crack Growth in Aluminium Alloys” and has been supported by grant No. 106/94/0985 of Grant Agency of the Czech Republic.
COMPUTATIONAL ANALYSIS OF THE FATIGUE FRACTURE SURFACE (COMPUTER AIDED FRACTOGRAPHY)

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Key words: fatigue fracture, quantitative fractography, scanning electron microscopy (SEM), image analysis

The key point of the fractographic reconstitution of the fatigue crack growth (FCG) is the quantification of changes of any selected fractographic features depending on the fatigue crack growth rate (FCGR) and fatigue crack growth direction (FCGD). The method of fractographic reconstitution of FCG, based on the measurement of striation spacing s, was developed in the Fractographic Laboratory of the Department of Materials FNSPE CTU [1]. In the last years, many experiments were made here with different fractographic features, using the facilities of the Computer Aided Fractography (CAF). This CAF system is linked to the Scanning Electron Microscope JEOL 840A.

The first results obtained by CAF were presented in [2]. The results indicate that some of the geometrical characteristics of interactively detected striation patches may have correlations with the FCGR.

The extension of the CAF system by the automatic detection of the striation patches is essential for verifying these first results. The method of region growth, which was developed to detect the striation patches, was presented in [3]. The speed and accuracy of this algorithm were not acceptable for practical use. In the last year we concentrated on the procedures of grey-scale morphology. The algorithm, based on the rain-flow approach (watersheds, waterpartings), was developed and built into the existing system of CAF. The more detailed description of this optimized algorithm is presented in [4].

The further analysis of the geometry of the segmented areas should provide two main information outputs about the FCGD and about the FCGR. We tried to integrate the ways of assessing FCGD and FCGR. For this purpose, the following methods of fractal geometry and planar anisotropy were tested:

1. The fractal characteristic of the segmented areas. This $f_c$ characteristic is influenced by the changes of FCGR. The experimentally estimated dependence $f_c$ vs. FCGR seems to be nonmonotonous and therefore not useful in practice.

2. The characteristics of the rectangles circumscribed around the detected areas. This approach was described in [2]. The direction of the longer axis of the rectangle is related with the FCGD, while the ratio $c/b$ of the rectangle's sides is related with the FCGR. The results obtained by this approach are presented in Fig. 1. The $c/b$ characteristic follows the changes of the FCGR measured during the fatigue test.
3. The quantitative characterization of the planar anisotropy by the Steiner Compact. This approach is based on the analysis of the Steiner Compact, created on the rose of intersections [5]. The dispersion of the distances between the Steiner Compact and its circumscribed circle can be used as an essential characteristic of planar anisotropy. The analysis of the shape of the Steiner Compact can estimate the rose of directions (containing the information about FCGD). This research is still going on.

Fig.1: Comparison of results of the planar anisotropy approach (c/b characteristic) and the curve of FCGR measured during the fatigue test. The data sets were obtained on the fracture surface of a 2024-T3 aluminum alloy specimen.

References:

This research has been conducted at the Department of Materials as part of the development of "Computer Aided Fractography" and has not been supported by any CTU grant.
INJECTION Moulding of Alumina Ceramics for Medical Applications

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Key words: bioceramics, ceramic suspension, mechanical properties

Injection moulding is a principal method for the production of complex net-shape ceramic parts [1]. This process provides an economic and quick production of high-quality and accurate ceramic parts with mechanical properties that are of the same level as with other ceramic shaping methods [2]. The above characteristic of injection moulding shows that it is suitable for the production of such parts as e.g. ceramic dental implants. The aim of the work is to assess injection moulded ceramic specimens made of different Al2O3 powders from the view of requirements made on ceramic implants, and to establish the properties of individual ceramic powders used for injection moulding of dental implants. Alumina ceramics was prepared by injection moulding of a ceramic mixture made up of 63 vol.% Al2O3 powder and 37 vol.% thermoplastic binder. Four types of ceramic powder were studied: Martoxid CS 400M (Martinwerk), AKP 15 (Sumitomo), Alumina M calcine (Ceraver), and RC-HP DBM (Reynolds Chemicals). Powder purity was better than 99.7% Al2O3, the size of medium grain ranged from 0.55 μm (RC-HP DBM) to 0.88 μm (Alumina M). Powder materials contained precursors of MgO, which served as a grain growth inhibitor during the sintering of ceramics. The powders were dry-ground in a ball mill, with an addition of oleic and stearic acids or magnesium stearate. The binder system was formed by 85 wt.% paraffin and 15 wt.% ethylenevinylacetate copolymer.

All types of powder alumina studied sintered well at 1550°C and relative density was close to or higher than 99% theoretical density (with the exception of Martoxid). The shape and size of particles had no pronounced effect on these physical properties. Characteristic bending strength reached 400 MPa (Alumina M, 1550°C/2 h, three-point bending), which for this type of material is considered to be a very good value [3,4]. Alumina M ceramics also display the highest value of the Weibull modulus (m>8). With polished specimens the value of characteristic three-point bending increased to about 450 MPa. The same parameters, including the same Weibull modulus, were obtained for polished ceramics prepared from RC-HP DBM material. Fracture toughness for Martoxid, Alumina M and RC-HP DBM was determined by several different methods. The highest values were obtained for ceramics prepared from Martoxid: 4.3 MPa m1/2 by the method of chevron notch made by V-shaped diamond-charged grinding wheel (CVN), and 5.0 MPa m1/2 by the bridge-indentation method (SEPB). For the other types of ceramics (Alumina M, RC-HP DBM) fracture toughness ranged from 3.2 to 3.5 MPa m1/2 and was similar for both methods (CVN, SEPB). The V-notch method (SEVNB) yielded unreliable overrated values. The fracture toughness of ceramics prepared from Martoxid can be regarded as high [5,6,7] and this was the result of higher porosity of these specimens (3%). From the microphotographs of the structure of Martoxid ceramics the size of pores could be estimated; it ranged from 1 to
The pores were of irregular shapes with acute angles. The other ceramics displayed only minute spherical pores of 1 to 2 μm in size. In all the types of ceramics the grain size ranged from 3 to 10 μm, with a frequent occurrence of larger grains of up to 30 μm in size. Grain size increased with increasing temperature of firing. The most regular structure was found in the ceramics prepared from Alumina M fired at 1550°C/2h, i.e. ceramic with the maximum strength obtained. The specimen was made up of grains that did not exceed 10 μm. Most grains ranged from 3 to 7 μm. The microstructure of the ceramics revealed the necessity of homogenous distribution of the inhibitor (MgO) of grain growth.

The parameters established for the ceramics under study have shown that ceramic products prepared from these materials by injection moulding can be applied in practice. It can be expected, however, that physical and mechanical properties, especially the Weibull modulus, could further be increased by hot isostatic pressing.

References:

This research has been conducted at the Department of Ceramics as part of the research project "Study of preparing structural ceramic materials and bioceramic materials by injection moulding method" and has been supported by TU grant No. A-7/94.
THERMOPLASTIC BINDERS FOR INJECTION MOULDED CERAMIC SUSPENSIONS

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Key words: rheology, injection moulding, alumina

Transitory binder for injection moulding of ceramics is a temporary means providing uniform distribution of powder into desired shape and a fixation of particles in this shape till the beginning of sintering. The binder under study was a three-component system with the components: polyethylene (Bralen SA-200, Slovnaft Bratislava), ethylenevinylacete copolymer (Elvax 210, Du Pont) and paraffin (S2/54, Koramo Kolín). The demands made on binders include not only suitable rheological properties of ceramic suspensions but also the possibility of extracting these binders from ceramic green bodies. On the basis of earlier work [1] and literary sources [2,3] the content of low-molecular component of the proposed binder system was therefore limited from 10 to 50% paraffin. Ceramic suspensions were prepared from alumina powder (RC-IIP DBM, Reynolds Chemicals), which was dry-ground in a ball mill with an addition of oleic and stearic acids. A type Brabender rheometer was used in experimental measuring. The torque values were established which were necessary for kneading ceramic suspension and which characterized its viscous behaviour. The measurements were made for three levels of filling the suspension with ceramic powder (60, 55, 50 vol.%) and for four values of kneader revolutions. Six binders were proposed with different contents of individual components (Fig. 1), which made it possible to describe the region under study by a second-order polynomial, where the independent variables represented the content of individual components and the dependent variables was the torque of the ceramic suspension prepared with this binder. For the system with 60 vol.% ceramic powder and for 20 r.p.m. of the rheometer the regression function was in the form

\[ \tilde{g} = -21.0 z_1 + 15.2 z_2 + 16.2 z_3 + 19.9 z_1 z_2 + 18.4 z_1 z_3 + 110.8 z_2 z_3 \]

where pseudocomponents \( z_i \) were linked with the initial components \( x_i \) (paraffin), \( x_2 \) (copolymer EVA) and \( x_3 \) (polyethylene) by the equation

\[ Z = A \cdot X \]

where matrix \( A \) was in the form

\[
A = \begin{pmatrix}
1 & 0.1 & 0.1 \\
0 & 1 & 0 \\
0 & 0 & 1
\end{pmatrix}
\]
Fig. 1: Scheme of three-component binder system with limited low-molecular component and points representing experimental binders (PAR=paraffin, EVA=polyethylenevinylacetate, PE=polyethylene)

Regression function for the other levels of filling were of the same nature, i.e. minimum torque values were established for suspensions with two-component binders containing 50% paraffin, while maximum values were found for suspensions formed by 50% polyethylene and 50% copolymer EVA. Maximum concentrations ($\phi_m$) of ceramic powder in invidual experimentally examined binders were determined with the help of the relation

$$\lim_{\phi \to \phi_m} M_k(\phi) = \infty$$

where $\phi$ is the volume fraction of powder, and $M_k(\phi)$ is the function describing the course of suspension torque in dependance on filling. The values calculated ranged from 0.75 to 0.85 depending on the regression function used and they were roughly the same for all types of suspension. The temperature dependence of the torque was not very pronounced, which was of course due to considerable heat dissipation during kneading at higher revolution, especially in the case of binders with a small proportion of paraffin.

References:


This research has been conducted at the Department of Ceramics and Department of Rubber and Plastic Technology as part of the research project “Thermoplastic binders for high pressure injection moulding of ceramic suspensions” and has been supported by TU grant No. A 11/94.
INTERACTIONS OF NICKEL AND TITANIUM ALLOYS WITH SINGLE-CRYSTAL ALUMINA

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Key words: ceramics-metal interaction, Ni-alloys, Ti-alloys, alumina, diffusion

The interaction of ceramic moulds and cores with reactive nickel and titanium alloys depends not only on the chemical composition of the ceramics but also on its structure, on the chemical composition of molten alloy, on interaction temperature and time, and on the pressure of furnace atmosphere. From the viewpoint of further development of precision casting and unidirectional solidification of refractory alloys it is necessary to describe the mechanism of interaction between this alloys and ceramic materials. The most recent works have shown the suitability of studying this problem on physically and chemically defined systems.

The subject of study in the present work were the interactions of single-crystal alumina plates with type Ni-Cr, Ni-CrAl, Ni-CrTi, Ni-CrTiAl, Ti, Ti-AlV alloys at temperatures from 1500 to 1720°C for periods from 5min to 16h. The interactions took place at a pressure of 1.2 standard atmosphere of protective Ar atmosphere.

The interaction between Ni-19.1Cr alloy and Al2O3 began by the redox reaction of Al3+ ions with Cr and continued with interdiffusion of Al3+ and Cr3+ ions through the layer of reaction products. The products of interaction had a grainy structure and they were formed by the solid solution Cr2O3xAl2O3. The growth of reaction products was controlled by Al3+ and Cr3+ interdiffusion through this layer. Al and Cr concentrations in the interaction layer were measured by X-ray microanalysis; their dependence on the distance from interaction interface was fitted by regression analysis methods to a suitable physical model. The diffusion coefficient values were calculated from regression coefficients. The diffusion coefficients of Cr and Al at 1600°C were of the order of 10^{-12} cm^2/s, the activation energy was 180kJ/mol. Thin metallographic specimens of interaction interface were prepared for TEM but due to the great similarity of lattice parameters of the same crystallographic structures of Al2O3 and Cr2O3 neither the dependence of the magnitude of lattice parameters on the distance from interaction interface (and thus on the composition of interaction layer) nor the crystallographic orientation of individual subgrains of interaction layer could be established.

After the interaction between Ni-19.7Cr4.7Al alloy and single-crystal alumina it was found that an addition of 4.7wgt.% Al to Ni-19.7Cr alloy completely prevented the interaction between the ceramics and the molten metal. This result is in keeping with thermodynamic calculations.

During the interaction of Ni-20.0Cr4.6Ti alloy with Al2O3 a layer of reaction products was formed which consisted of Ti2O3 (95wgt.%) with additions of Al, Cr and Ni oxides. The layer was separated from both the alloy and the single-crystal by a sharp interface and its composition was practically the same over the whole volume. The growth of layer was...
controlled by the diffusion of Al\(^{3+}\) and Ti\(^{3+}\) ions through this layer. By means of the parabolic law the diffusion coefficient of the above ions through the layer of Ti\(_2\)O\(_3\) was calculated from growth kinetics. For a temperature of 1600°C its value was 4.10\(^{-9}\)cm\(^2\)/s.

Similar to Ni-CrAl, Ni-20.6Cr5.6Ti4.9Al alloy did not react with single-crystal aluminia. This experimental result was not supported by any theoretical calculation since the activities of individual elements in the Ni-CrTiAl alloy could not be found in the literature.

The maximum reactivity among all the metals under study could be observed in the case of pure Ti. During interactions of Ti with single-crystal aluminia at a temperature of 1720°C heavy erosion of Al\(_2\)O\(_3\) appeared after a holding time of 30 min already. According to thermodynamic calculations\(^\text{7}\) it is probable that at this temperature Al\(_2\)O\(_3\) will be reduced by Ti, accompanied by the formation of either TiO (the change in the standard Gibbs energy in this reaction is \(\Delta G=14.1\) kJ/mol of Ti) or Ti\(_2\)O\(_3\) (\(\Delta G=23.1\) kJ/mol of Ti). After the redox reaction Al diffused into molten metal. The detailed results of the TEM examination significantly showed that Ti\(_3\)Al phases in Ti matrix were formed in the area adjacent to the interface as a result of this diffusion.

There was a similar reaction between Ti-6Al4V alloy and single-crystal aluminia. Under identical conditions, however, the intensity of this reaction was lower than in the case of pure Ti.

In all the experiments single-crystal plates were used whose outer surface orientations were parallel with crystallographic planes "A" (1 1 -2 0), "R" (1 0 -1 2), or "C" (0 0 0 1). The effect of orientation of single-crystal aluminia on the nature and intensity of the interaction between Al\(_2\)O\(_3\) and molten metal was not observed in any of the cases investigated.

References:


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STRENGTH OF CERAMICS

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Key words: alumina, injection moulding, fracture toughness

The strength of structural ceramics could be expressed by equation:

\[ R_m = \frac{K_c}{\sqrt{a}} \]

where \( a \) is the largest dimension of suitably oriented defect in volume under load in the component, and \( K_c \) is the fracture toughness of the material. Thus, there are two possible ways how to improve structural ceramics strength. First is the elimination of defects, the second is the increase of its fracture toughness. At present, there is neither commonly accepted procedures for experimental evaluation of ceramics strength and fracture toughness nor generally approved standard for measurement of \( R_m \) and \( K_c \). Therefore, the main aim of our work was to make an inventory of different experimental methods, introduce them in our laboratory and make their mutual comparison. This contribution contains experience acquired during the measurement of strength and toughness on structural ceramics produced by IME TU in Brno.

Experimental material

Test pieces were made from crude pieces of materials produced by injection moulding. The mixture for injection moulding contained 90.5 wt.% of \( \text{Al}_2\text{O}_3 \) powder and 9.5 wt.% of thermoplastic binder. Since four different powders and two sintering regimes were used, eight different structures were available. Specimen surface was either left as fired or it was ground on emery papers with 40 \( \mu \)m grain. Test pieces were 4 mm high, 3 mm wide and 50 mm long. Due to the limited space, table contains experimentally determined values of strength and toughness for two materials only. Powder Martoxid CS 400M (producer Martinwerk), material (1). The material was sintered at 1600 °C for 1.5 hour. Parameters of the structure: average grain size 4-8 \( \mu \)m, occasionally coarser grains 20-30 \( \mu \)m were encountered, sharp irregular pores, average size 1-10 \( \mu \)m occupy 3% of the volume. Powder Alumine M (Ceraver), material (2). Compactation at 1550 °C for 2 hours. The structure: average grain size 3-7 \( \mu \)m, largest dimension of coarse grains does not exceed 10 \( \mu \)m, pores are oval and they appear only sporadically.

Strength

The attachment was designed for 3 or 4 point bending in testing machine TIRAtest. Its span is \( L_1 = 16 \) mm for 3 point or \( L_1 = 16 \) mm (inner span) and \( L_2 = 32 \) mm (outer span) for four point bending. Experimental results of strength measurement (\( R_m \)) were evaluated using Weibull probabilistic model in the form:

\[ P_j = 1 - \exp\left[-\left(\frac{R_m}{\text{MOR}_0}\right)^m\right] \]
where $P_f$ is the probability of failure, $m$ Weibull modulus, and $\text{MOR}_0$ stress at which 63% of bars fail. The results (Tab.) show that values of $\text{MOR}_0$ depend on the type of test, while the $m$ values do not. It was shown [1] that the differences are caused by the changing size of loaded volume. Designer needs the values of unit volume characteristic strength $\sigma_0$. The $\sigma_0$ values calculated from $m$ and $\text{MOR}_0$ data are also given in table.

Fracture toughness

Generally accepted method for fracture toughness measurement is the ASTM E 399. Unfortunately, it is difficult to introduce the fatigue crack into structural ceramics. Thus, we tested and applied in our laboratory following procedures:

a) Single edge V-notch beam (SEVNB). The crack is replaced in test piece by sharp straight through notch made by diamond wheel with small radius. In our case the radius of the notch was 45 μm. Thus, the test procedure is in accord with E 399, taking into account that the crack was replaced by notch.

b) Single edge precracked beam (SEPB)[2]. The crack is produced by special device with a groove. Stress concentrator is made on the specimen surface (notch or hardness indentation). The specimen with stress concentrator is placed into the device against the groove and pressure is applied. A crack is nucleated from the stress concentrator. Crack stops its propagation in the middle of the specimen. The measurement of fracture toughness is thus in agreement with E 399.

c) Chevron V-notch (CVN). The Chevron notch method for toughness measurement was developed for extremely brittle materials - ASTM E 1304 - 89. It was modified for bend tests of structure ceramics - see [3].

The results presented in table and results on other ceramic materials showed that the values obtained by SEPB and CVN methods are similar and both methods yield lower values than SEVNB.

<table>
<thead>
<tr>
<th>Mat.</th>
<th>3 point bend</th>
<th>4 point bend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MOR₀ m σ₀</td>
<td>MOR₀ m σ₀</td>
</tr>
<tr>
<td>(1)</td>
<td>327 6.1 362  5.7 386</td>
<td>-</td>
</tr>
<tr>
<td>(1)-gr.</td>
<td>311 7.9 311  7.7 343</td>
<td>-</td>
</tr>
<tr>
<td>(2)</td>
<td>402 8.1 408  8.2 410</td>
<td>4.82</td>
</tr>
</tbody>
</table>

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
MICROWAVE QUALITY TESTING OF CERAMIC MATERIALS

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Key words: dielectric measurement, ceramic materials, microwaves

This equipment enables one to find, by a non-destructive method, more conductive spots in insulators, especially in ceramic materials. Such spots, often enclosed in the insulator mass, are difficult to identify by current testing checking methods. Their appearance causes low quality of the insulator, resulting in inferior quality, or breakdowns and high losses, of the final products.

Insufficient quality, in ceramic materials especially, is the result of an imperfect technology, where the ceramic mass is polluted by metals or their oxides, which after the burning cause the rise of areas with low specific conductivity and high loss factor in the ceramic mass.

The principle of the described measuring method is the measuring of the dielectric losses of the dielectric at very high frequencies in a high quality resonator. The measurement conditions must be so arranged that the electromagnetic field be concentrated to a small part of the sample. The presence occurrence of a defect area in the dielectric manifests itself by a sharp decrease of the Q-factor of the measuring resonator.

The realised equipment was designed for the measuring of cylindric ceramic tubes. The basic component of the equipment is a coaxial resonator, operating with TEM wave. The same is composed of two quarter-wave resonators, placed opposite to each other, shorted at the outer ends and oscillating in opposite phases. A measured in the hollow, crossected central conductor of the resonator ceramic tube is placed which may be longitudinally shifted. The dimensions of the resonator and its operating frequency must be selected with respect to the dimensions of the object. It is especially important that there does not occur a radiation of the HF power from the resonator through the hollow central conductor. This condition may be fulfilled by choosing an operating frequency of the resonator at which the central hollow conductor of the resonator, considered as a subcritical waveguide, will have a very high damping.

For identification of the conductive spots in the measured object, the Q-factor of the resonator is evaluated. Evaluation of the resonator frequency does not give the required information, as the resonance frequency is influenced, especially, by variations of the dimensions of the object (unexactnesses) which cause the change of capacity between the central conductors of the resonator.

The Q-factor of the resonator is evaluated by means of the transfer function of a filter, formed by the resonator with two very low couplings. In the case of suitably chosen couplings and feeling mode, the transmission of the resonator in a certain range is approximately proportional to its Q-factor.

For suppressing the influence of the resonance frequency, there is, for the exciting of the resonator, applied a wobler which generates frequencies in the whole supposed range of the resonance frequencies of the resonator. The output signal of the resonator is evaluated
by a peak detector, whose output signal corresponds to the maximum output signal of the resonator at an arbitrary resonance frequency.

For easier tracing of the inhomogeneities in the measured object the equipment is completed by a driving unit, ensuring the longitudinal movement perpendicularly to the measuring slot between the central conductors. The output voltage of the peak detector, which is the measure of the Q-factor of the resonator, is processed by a recorder, connected to the driving unit which plots a curve, showing the dependence of the Q-factor or the position of the object.

The areas of decrease of the Q-factor show the presence appearance of conductive spots in the dielectric. An inferior quality is also signalled by a constantly low Q-factor. The limit values may be set by comparison with an etalon, tested by a different method.

The equipment is suitable for a fast and reliable testing of semifabricates, which enables defective parts to be removed, in due time, from the production process. Thus, it prevents the much greater losses that would occur during the expedition checking or operation in eliminating finished parts after their breakdown. The described equipment is the object of a patent application and is protected by a trade mark.

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Germ-Grain Model of Short Fibre Composites

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Key words: stochastic geometry, random sets, germ-grain models, composites, distances

One technically important group of composite materials is that of short-fibre composites, in which particles of fibre-like shape are more or less randomly distributed in the bulk of material. Examples of such types of materials are polymer filled with glass, graphite or metallic particles, ceramics materials with whiskers or metals strengthened by elongated particles. Strength, toughness and other mechanical and/or physical properties of such materials depend on the size, shape and spatial arrangement of particles, in particular on the size and shape of particle-free regions in the matrix. A suitable characteristic of these regions is the spherical contact distribution function (SCDF) \( F(l) \). Its form is well known for several theoretical models like Boolean or lattice models [1, 4, 6]. For real materials such models are not very realistic and we must use some germ-grain models, e.g. the simple sequential inhibition (SSI) model of composite material. For these models the SCDF must be estimated on the basis of computer simulations [2, 7]. The comparison of obtained estimates with the theoretical results for selected germ-grain models is the main goal of the present paper.

The starting point for all examined models is the germ-grain model of a random closed set. Three basic arrangements of germs will be investigated:

a) points of a Poisson point process of intensity \( \lambda \),

b) points of a translation lattice,

c) reference points of an SSI model obtained by a simulation.

The uniform primary grains will be considered in all cases. The basic shape is a cylinder of height \( s \) and radius \( R \) with hemispherical caps. Simulation of the SSI model was accomplished using the "simple rejection" algorithm [3].

The geometrical properties of the matrix will be characterized by the spherical contact distribution function (SCDF) which can be interpreted as the conditional probability that a ball of radius \( l \) centred in a point of matrix chosen uniformly at random hits the boundary of the matrix. The knowledge of the SCDF enables us to calculate its moments and related quantities describing the distribution of spherical distances and hence also the geometry of free volumes between particles. For example, the first moment of is the expected distance of a typical point of the matrix from its boundary. The SCDF estimation for the SSI model must be based on the simulation, in the remaining cases is evident from the theory.

Five realisations of the SSI model (Fig. 1) with a different volume content \( p \) were investigated in detail. For each of them, \( 5 \times 10^5 \) distances from uniform random matrix points to the closest particles were computed and used to estimate the shape of the p.d.f.'s \( f(l) \) and the values of moments. For Boolean and lattice models with the same basal parameters

473
(Fig. 2), the distribution functions and the moments were computed from the formulae given in [3, 5]. The comparison of SCDP for SSI and theoretical models is given in Fig. 2.

These comparisons open the possibility to replace in physical models a random particle arrangement by a simple lattice or Boolean models with suitably modified parameters. Moreover, the simulated models of particle spatial arrangement can be used in computer models of selected physical processes in composite materials. Models of electrical conductivity and/or fracture processes are in progress.

References:


This research has been conducted at the Department of Physics and Material Engineering as part of the research project "Computer simulation of composite materials structure" and has been supported by TU grant No. VUT 88/93.
In composite materials we can control structure formation with the aim of reaching the set of suitable properties. The inner structure of these materials is composed of matrix and particles of various form and spatial arrangement. A very frequent type of composite is that of materials filled with short-fibre particles. One type of modern short-fibre composite materials is that of materials with polymeric matrix and conductive fibres. The efficiency of particles consists in the strengthening effect as well as in changes in electrical properties, first of all in conductivity.

In the past few years, modern computers allow us to simulate the inner structure of short-fibre composites. From the point of view of stochastic geometry [1,2] the inner structure of this material is so called germ-grain model. The model consists in the setting of grains into points of space (germs). The positions of germs as well as parameters of grains (size, shape and orientation) fulfill some prescribed statistical rules. The most popular germ-grain model is the Boolean model, based on the statistically independent position of germs. The advantage of this model is the detailed theoretical description of the model and its geometrical parameters. On the other hand, this model admits intersection between particles and so can be used for the small volume contents of particles only.

For non-overlapping particles of nontrivial shape the computer simulation is the only way to obtain detailed information concerning the inner structure of model.

For our computer simulations in 3D space, the simple sequential inhibition (SSI) model was used [3]. This model consists in the sequentional filling of structure with non-overlapping particles of cylindrical shape with hemispheres at the ends. The length-to-width ratio of particles is one of the initial conditions of the simulation and varies in range from 1 (ball) to about 100. For higher values only a low volume content of particles can be simulated.

This computer simulated model of inner structure was used for simulation of conductivity and percolation effect [4] in composite material. The simulation schedule was as follows:

1) The distances to the near particles was computed for every particle. Two particles closer then the given limit are considered as belonging to the same cluster. The whole set of particles is sorted into separate clusters.

2) The most extensive cluster is selected. The cluster is investigated as network of resistances (necks between particles) connected by conductors (particles).

3) This network is then maximally simplified (cutting blind branches, association of parallel and serial pairs of resistance)

4) Kirchhoff's equations were then automatically formulated and solved as a system of linear algebraic equations.
5) Total electrical resistance of the system was calculated. The structures can be simulated for given distribution of space orientation and length distribution. The effect of these input parameters as well as the effect of volume content on the percolation threshold can be studied. The various types of resistance-distance functions can be implanted into the model.

A comparison with experimental results of percolation threshold and conductivity is being planned.

Fig. 1: Plane projection of the three most extensive clusters for the volume content of 19% (19 000 simulated particles), uniform random distribution of directions, length/width is 10). Maximum distance of interaction is a 0.11 diameter.

Fig. 2: Plane projection of the most extensive cluster for volume content 19% (19 000 simulated particles), uniform random distribution of directions, length/width is 10). Maximum distance of interaction is a 0.12 diameter.

References:


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FIBRE LENGTH REDUCTION IN THE POLYMER MATRIX DURING EXTRUSION

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Key words: extrusion, glass fibre, PP, screw geometry, fibre reduction

Introduction. The fibre length distribution is one of the major aspects in characterizing the composites made from thermoplastic materials. The fibre length during extrusion dramatically reduces its size to only a fraction of its initial value and homogenization in a molten polymer depends on processing parameters.

Experimental results and discussion. In this study we investigated the fibre degradation during single screw extrusion in PP Mosten 58 412, PP Novolen 1100 HX (granules) and we used 6mm length fibre from E-glass. The fibre length was reported to reduce always its size down depending on polymer viscosity and an amount of shear the material sustains [1]. The fibre breakage mechanism was evaluated relating to the solid and melt conveying in the extruder. The simulation of the extrusion process in the geometries was performed and an estimate of the shear was obtained. The simulation was performed under ideal conditions assuming shear dependent viscosity, however the fluctuation of the fibre concentration along the screw length influencing the viscosity of the material seems to be important as well.

Experiments were carried out using three different geometries. The first geometry was with a constant channel depth. The fibre shortening is low mainly due to low shear forces in the molten material. The absence of the sufficient shear caused the unacceptability of the product due to low homogenization.

The pressure and intensive shear loading occurring mainly in a thin fluid layer between the solid bed and the barrel in the standard shape extruder with long compression zone increased the destruction of the fibre significantly. The fibre shortening continues until the final solid bed break-up. Under these conditions the extrudate was partly acceptable for relatively low fibre contents.

The third geometry tested was the screw with a rather short compression section. We observed that the homogenization in the polymer matrix was good and the original fibre length was reduced to the average fibre length 2.1 mm and about 5 percent of the fibres retained its original size. The fast solid bed destruction and following low shear homogenization in the metering zone gives acceptable results. The extrudates remained smooth up to 30 percent filling level. At higher levels of filling the fibre reduction increases dramatically.
Conclusion. The glass fibres used to reinforce thermoplastic materials are degraded to a high degree which can negatively influence the mechanical properties of the resulting composites. The three screw geometries tested confirmed that the fibre length reduction occurs mainly in the transition zone. The typical screw design with a step transition zone can under certain conditions such as the fibre filling percentage or the processing parameters produce extrudates with satisfactory homogeneity at moderate fibre degradation.

Fig. 1: Effect of different screw geometries on solid bed reduction (circles) and amount of non-damaged fibres (filled circles) as functions of position along the screw.

Fig. 2: Influence of filling level on glass fibre length reduction (Δ) and solid bed reduction in the third screw as functions of the position along the screw.

References:

This research has been conducted at the Department of Plastics and Rubber Technology, Faculty of Technology Zlín, Technical University Brno as part of the research project “Fibre Length Reduction in the Polymer Matrix during Extrusion” and has been supported by VUT Brno grant No. A 15/94.
THE EFFECT OF WATER ABSORPTION ON THE DYNAMIC PROPERTIES OF KEVLAR-EPOXY COMPOSITE

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Key words: composite, dynamic properties, water absorption, Kevlar, epoxy, degradation

It has been established that when fibre-reinforced epoxy resins are exposed to hot wet conditions, they absorb moisture [1]. These environmental conditions may cause degradation in the mechanical and physical properties because of one or more of the following reasons: a) physical or chemical degradation of the polymeric matrix, b) loss of adhesion or debonding at the fibre-matrix interface, c) reduction in fibre strength and modulus.

The objective of our research is to experimentally determine the effect of water on the dynamic properties and impact resistance of Kevlar49-tetrafunctional epoxy resin composite where both matrix and fibres are hygroscopic. This composite material may be used for aircraft components where impact damage tolerance and radiotransparency are required (for example a nose radome).

Kevlar-epoxy composite laminate has been manufactured from commercial Kevlar 49 fabric prepreg VICOTEX 913/60K 120 and K 285 (Brochier, France) based on tetraglycidal-diaminodiphenyl-methane (TGDDM) epoxy cured with dicyandiamide (DICY). The laminate was constructed by stacking code [0/0/-45/+45/+45/-45/0/0]. The water absorption [2], desorption and re-absorption plots were determined by monitoring weight gains of rectangular specimens (2.3×50×50 mm) which were immersed under water or dried at room and elevated temperatures (65 °C). An apparent diffusion coefficient $D$ of water through the thickness of the specimens were calculated from initial slopes of the integral absorption curves assuming Fickian behaviour. Dynamic elasticity modulus $E$ and damping loss factor $\tan \delta$ data were obtained on beams 2.3×10×210 mm by forced flexural vibration technique. Both the rectangular and beam specimens were subjected to the same hygrothermal history.

The values of the apparent diffusion coefficient $D$ for absorption and re-absorption of water in Kevlar-epoxy laminates are shown in Fig.1. The initial absorption rate in virgin specimens is much lower than water re-absorption rate, both at room and elevated temperatures. Since Kevlar fibre diffusivity is low compared to matrix diffusivity [3], the water re-absorption must be accelerated owing to capillary action at the resin and interfacial microcracks. Fig. 2 show how the flexural damping of composite varies with the treatment of specimens. Clearly, water absorption at elevated temperature produces an irreversible changes of the composite damping factors. The absolute increase in the damping of dry specimens after water exposure at elevated temperature could be related to increasing relative motion between fibres and matrix at the interface. The effect of structure changes on impact resistance is currently being tested on instrumented pendulum hammer.
**Fig. 1:** Comparison of diffusion coefficients in Kevlar-epoxy composite

**Fig. 2:** Changes of damping factor in Kevlar-epoxy composite

**References:**


*This research has been conducted at the Department of Materials as 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.*
THERMAL FATIGUE SPALLING OF YPSZ PLASMA SPRAY COATINGS

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Key words: zirconia, plasma spray, fatigue spalling, microstructure investigation, X-ray diffraction, scanning el. microscopy

Quality criteria of thermal barrier coatings (TBC) to withstand in service the local conditions can be characterized by many factors depending on structure design, environments, quality of the material used etc. It is evident that in consequence of continuous quality TBC degradation due to operating conditions some critical event can be recognize as a spalling and/or peel off mechanism. A total number of life thermal cycles applied is than taken for assessment of the particular TBC's quality. There are three main factors controlling the cyclic life, (i) thermal shock stresses, (ii) thermal expansion mismatch stresses and (iii) stress generated by volume expansion in virtue of the bond coat oxidation processes. When cycles at higher temperature and more severe oxidising environment are operating the third factor, mentioned above, and quality of bond coat material will be prevailing as recently reported. On the other hand, at substantially lower temperature the quality of ceramic TBC and its internal microstructure design influence will increase their role.

The aim of this work based on experimental evidences, was to elucidate the more characteristic damage processes and their relationship with the given TBC heterogeneous microstructure.

Experimental conditions. Yttria 8% partially stabilized Zirconia plasma sprayed coating as the main experimental material was used. As the bond coat between ceramic and substrate the Ni22Cr6Al1Y (NiCrAlY) alloy was chosen. The thickness of the bond coat and top ceramic layer was made in 0.1 mm and 0.4 mm, respectively. Thermal cycling in range of 200-840°C were then applied up to an event of resolved damage of ceramic layer due to some kind of spalling mechanism, described below. X-ray diffraction and scanning el. microscopy were the main methods elaborating the tested specimens.

Results. From macroscopic point of view the distinct peel off damage process of all TBC tested has occurred. Fractures, edded by a sudden peel off event have run in surface parallel planes without any measured residual deformations as would be expected when macroscopic residual stresses would be mainly affected. The fracture plane and substrate normal distances were different, however, with a possibility to distinct approximately five main characteristic positions of the major fracture surface according to TBC's structure design particularly along their normal cross section, listed in TAB.1. Microstructure investigations by SEM has revealed the characteristic features of fracture surfaces controlled mainly by the coating heterogeneous microstructure and defect distribution along with an unstable fracture starting event. It was observed that the parallel through ceramic fracture


| A | Boundary between substrate and NiCrAlY bond coat |
| B | Boundary between NiCrAlY bond and YPSZ layer |
| C | Plane in a distance of a few YPSZ grains from coat bond |
| D | YPSZ boundary with occurrence of spalling steps |
| E | Through YPSZ layer parallel fracture |

surfaces pertinent to the C, D, E classes were nearly equivalent. A typical fracture surface morphology consist of fractured bridges in between welded on particles, smooth flakes corresponding to solidified free surface of as-deposited particles, small unmelted cores of origin particles and network of microcracks. The origin of the microcracks is believed to be mainly due to the after deposition thermal dilatation stresses. The observed fracture micromorphology of zirconia particles or bridges between them are clearly consistent with primary solidification crystal structure i.e. that of controlled by heat take off direction. It is evident, here, that such a character of TBC's is very far from any simple assumed existence of homogeneous rigid body so that any mechanical stability of this system ought to result in delicate balance of complex factors under influence. The specimens fractured following B class, mentioned in the above TAB.1, exhibit a surface of NiCrAlY bond coat with some anchored ceramic particles. There were no indication of through metal fractures, here.

X-ray diffraction measurement made on the both relevant sides of the specimens tested has revealed the changes in major phases content, i.e. tetragonal to cubic crystal structure transformation and consequently decrease in microstress level as the effect of thermal cycles applied. These were more characteristic processes for A, B, C classes defined above. The remaining, i.e. D, E classes were mainly influenced by oxidation processes of bond coat material forming NiOx oxides and thermal instability the bond coat material itself which undergone different intermetallic compound formation along with various volume changes effects. The arising stresses are then responsible for sudden peel of damage mechanism in these cases.

**Conclusion.** It can be concluded that the spalling process, observed in YPSZ thermal barrier coatings due to thermal cycles applied is affected by complex of factors influenced by the quality of all material used, design TBC's layers and plasma spray technology. It is evident, therefore, that each different kind of TBC must be qualified with respect to the relevant service conditions in order to reveal the particular features of critical reliability.

**References:**


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ION BEAM TECHNOLOGIES

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Key words: Ion beam, surfaces, etching, deposition thin films, ion source

Ion beams have been widely used for technological purposes, e.g. in electronic, engineering and optical industries. In addition to focused ion beams the broad beams of ions with diameters of a few centimetres have been applied in surface and thin film technologies.

The Kaufman ion source with a beam diameter of 15 cm designed at the department of Physical Engineering [1, 2] was used in a study of the application of ions for cleaning, etching and deposition technologies. In all experiments the beam of Ar ions with energy of 400 - 1000 eV was used.

Polycrystalline samples of the stainless steel and copper were exposed to the ion beam in order to sputter off the residual impurities on their surface and so to increase the quality of the chemical analysis carried out in the scanning electron microscope equipped with an X-ray microprobe. The samples had to be bombarded by the ions for short time intervals (typically below 1 minute) only this way was it possible to avoid revealing a grain structure of materials treated. In the case of polycrystalline materials the grain structure possesses always steps due to high anisotropy of the ion beam etching process. Thus the intensity of the X-ray emitted from the etched surface of the sample into the microprobe is decreased significantly by this step topography (wave dispersion analysis) and brings a systematic error into the analytical method. The amount of carbon, the most critical surface impurity, was decreased in the case of stainless steel and copper on average by 15 % and 25 % respectively. The X-ray signal generated by the electron beam goes mainly from sub-surface layers where the concentration of “bulk” carbon cannot be considerably influenced by the ion beam. So we may conclude the yield of the carbon impurities on the surface was high in comparison with the bulk concentration of carbon and it was decreased by the ion beam substantially.

To get information about homogeneity of the etching process Si samples with a check marks prepared by electron lithography were etched. The maps of the etching velocity distribution in the plane of samples (obtained by profilometer Talystep) were compared with the theoretical and experimental beam profiles.

Contrary to “classical” technologies (e.g. wet etching, plasma etching) the intensive beam of energetic ions is able to modify and to etch some refractory materials — ceramics, synthetic minerals, diamond — like thin films, etc. YAl garnet was etched in order to prepare steps with a smooth surface suitable for a growth of epitaxial layers (Josephson junction). The etch rates obtained at 600 eV ion beam was 30 nm/min \( \text{cm}^2/\text{mA} \) and the roughness of the surface was monitored by the profilometer and STM.

The capability of the ion beam to “erode” ceramic was used for deposition of thin films by sputtering of the Al2O3 ceramic target on the Si substrate. RBS analysis carried out
revealed the thin film composition was close to Al oxides with a few heavy metal impurities (Fe, Cr), C and Ar. To decrease the concentration of the metal impurities considerably it is necessary to cover the target holder disc made of the stainless steel by the target material very carefully.

Additionally the design of the “Saddle field” ion source suitable both for technological and analytical applications was designed. The shape of the electrode was optimized by means of computer simulation of electron trajectories.

References:


This research has been conducted at the Institute of Physical Engineering as part of the research project “Ion Beam Technologies — Etching and Deposition of Thin Films” and has been supported by TU grant No. E14/93.
INFLUENCE OF THE SURFACE LAYER AND OF THE NON-LOCAL EFFECT ON THE STRENGTH OF BODIES

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Key words: surface layer, coating, strength, non-local effect, stainless steel

The significant influence of the surface layer and the stress field in the neighbourhood of the fracturing locus were described by a simple criterion in the earlier published papers [1-3]. The surface layer is modelled by this criterion as a surface plane, the influence of the deviatoric part of the stress tensor is described as local, and the influence of the isotropic part as non-local. The criterion formulated in this way was verified to some extent (for some brittle materials, bodies and loading processes), but some other experimental data received from materials with more rough structure indicate that for them the criterion should probably be generalized by introducing also the influence of the deviatoric part as non-local (with a smaller reach than for the isotropic part) and that the shielding effect of the deviatoric part upon the influence of the isotropic part should be studied with care (parallel with the "crack shielding effect") [4]. The aim of the work is the formulation and experimental verification of such a criterion, but the gathered experimental data are expected to be meaningful by themselves, not only in relation to the criterion.

The martensitic stainless steel of supposed approximate composition (in wt.%) Cr 17%, Ni 4%, Mn 3%, Al 1% and C 0.1%) will be used for the preliminary experiments. This steel is in brittle state after suitable thermal treatment. The chemical composition is supported by the electron probe X-ray microanalysis. The experiments will be aimed predominantly to the influence of the surface itself and of the added surface layer. The samples used for the measurement have three types of surface:

1. that untreated after the manufacturing process;
2. that coated by Ti$_x$N$_y$ layer deposited by PVD method;
3. that treated by chemical-thermal process (nitridation).

Mechanical properties will be analyzed after the bending and tensile tests. The other methods (especially optical and electron microscopy and X-ray microanalysis) will be used for investigation of material structures and fractography as well.
Fig. 1: X-ray spectrum at the area microanalysis of steel in SEM, electron energy 20 keV

References:

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EQUIPMENT FOR DIAGNOSTICS
OF THE CONTACTS QUALITY

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Key words: contacts, contacts quality measurement, contacts nonlinearity

The quality of contacts is an essential parameter that strongly influences the possibility of the use of contacting components. Materials that presently play evergrowing role in the technology of electronic components (especially in the area of microwave integrated circuits) are high temperature superconductors. Therefore the technology of contacting of these materials is continuously being developed. Our work is focused on the quality evaluation of the metal contacts prepared on the layers of the high temperature superconductors. The presented method and equipment has a general use and can be applied, with small adjustments, in the measurement of all metal contacts.

In the article [1] the method of the nonlinearity measurement has been presented. This method makes the measurement of the contacts' nonlinearity possible, however, we have discovered some imperfections and limits during its use. The odd nonlinearity measurement (investigated as a value of the third harmonics voltage) was realized by the application of a growing ac current (frequency of 10 kHz). The third harmonics voltage was measured by the selective voltmeter tuned at the frequency of 30 kHz. The even nonlinearity (investigated as a voltage of the second harmonics) was measured by the use of a constant low level ac current (frequency of 2.0 kHz) together with a fluently growing dc voltage. The second harmonics voltage was measured by a lock-in amplifier at the frequency of 5.2 kHz. When the results obtained by the measurement of the second and third harmonics voltages were analyzed the odd nonlinearity and a break point of the voltage vs. current curve were found. However, the determination of even nonlinearity as a complement to the third one was impossible. The direct measurement of the even nonlinearity was not possible. Also the accuracy of the odd nonlinearity measurement provided by the use of the CLT meter was low. Therefore a general reconstruction of the equipment was realized.

The block diagram of the newly developed equipment is shown in the Fig. 1 (here \( R_s \) represents a contact resistance between the contact layer \( C \) and the superconductor, LIA lock-in amplifier). Generally, the nonlinearity measurement can be provided in the arrangement with three or two contact points. Mostly the three point arrangement is used. The superconductor is supported through the contacts by a growing ac current which is given by the sinus generator and amplifier. The use of the amplifier is very significant in this arrangement because the sufficient current for powering of the samples is obtained this way. The level of the basic ac signal distortion has to be very low, because the accuracy of the nonlinearity evaluation is strongly limited by the distortion of the input signal. Therefore a low distortion sinus generator and amplifier are used. A higher reduction of the input signal distortion is achieved by connecting a proper low pass or band pass filter between the amplifier and measured sample.

The arrangement also makes the analysis of the break points of current vs. voltage curve possible. For this type of measurement the ac signal is stabilized on a low level and the c-v
curve is measured by dc voltage (the sample is powered together with the ac and dc signal) step by step for the whole range of maximum input current (with regard to the technology of contacts the maximum input current has been 50 or 100 mA). A dc supply that supports the sample can be realized as an independent source (a multturn potentiometer Aripot powered by dry batteries), or, if the lock-in amplifier is computer controlled equipment, by the use of D/A card installed into the computer. The separation of sources is realized by the capacitor C and inductance L.

The equipment described has been used for the measurement of the contacts prepared on the YBaCuO layers by the evaporation of silver. By the analysis of the second and third harmonics the quality of contacts has been evaluated. The method is also applicable for the evaluation of the quality of the HTS layer preparation. This layer has in normal (nonsuperconducting) state a high nonlinearity that can be measured by the developed equipment.

Fig. 1: Measuring equipment

References:

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METHODOLOGY OF ELECTRIC INSULATING VARNISHES TESTING

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Key words: electric insulating varnish, testing of varnishes, methodology of testing

Electric insulating varnishes are an integral part of the insulating system of electric machines and equipment. These varnishes can be used as paint for surface insulation, impregnating varnish, varnishes for the insulation of wires, and varnishes for the surface insulation of PC boards (printed circuit boards) and electronic components. This paper is focused on the first three groups of varnishes mentioned above, however, the conclusions can be applied in many other cases too.

The realization of electrical tests of varnishes is prescribed by standards. In spite of the fact that many Czechoslovak state standards are being replaced by the standards of international validity, it is possible to find one's bearings in them very well. However, these standards describe the test and its realization without giving an outline of which types of tests should be chosen for solving a concrete problem. Usually, the producer describes the properties of a varnish in standard conditions. This information is in many cases insufficient because the insulating system will work in a special climate or special working conditions. Therefore, the properties of a varnish must be tested in these conditions. In the case of the realization of all tests described by the standards, the number of samples would be very high and the tests would make unrealistic claims. Therefore, at the start of the testing suitable types of tests should be chosen. The results from the selected tests have to answer the question of whether the varnish is or is not acceptable for the given application.

With respect to the type of varnishes, the electrical properties will be considered as basic ones. Therefore, the electrical resistivity and the breakdown strength will be measured in all cases. In many cases, too, the dissipation factor or some of the complex parameters that describe the properties of the insulation system (e.g., critical voltage) is measured. As for the nonelectric properties the measurement of the thickness of the film of varnish, its adhesion, testing the resistivity against bend and pull-off tests are mostly applied. The combination of the tests depends strongly on the type of varnish. Always, the thickness of the varnish film is measured. In the case of the varnishes for surface insulation, the measurement of adhesion, the resistivity against bend, and Ericsson test are usually applied. The varnishes for the insulation of wires should be tested for the resistivity against bending and the pull-off test, the varnishes for the impregnation should be tested for the resistance against bend, but their properties are usually evaluated by the use of complex parameters that include different electrical and nonelectrical properties.

All the presented tests are described by the standards where the realization of samples and usually the method of evaluating the results are also prescribed. The samples are measured at the beginning of the test, and again after aging in real operating conditions or climate. In cases where the samples can not be tested in such conditions, the election of a convenient type of climate or combined exertion has to be found. These conditions should imitate the real operating conditions.
The strategy of the test has to be chosen with respect to the method of mathematical processing of the results. The extent of the test (the number of the samples being tested) is greatly affected by the probability of the right result. In case more complex information is required, the results of different tests could be correlated. It is possible to find out in this way whether there are some relationships between different electrical and nonelectrical properties. This information could be very important as then the user obtains information about the probable complex state of the insulation despite the complete group of tests not having been realized.

Very useful in results evaluation is the method of one factorial experiments. This method makes it possible to find out the level of a factor (e.g., temperature) at which the properties of the insulation change is statistically significant.

If the external conditions change within some limits (for example temperature from $t_1$ to $t_2$ and humidity from $h_1$ to $h_2$), the method of factorial experiments can be used for the construction of a mathematical model that describes the behaviour of the varnish within this area of conditions. However, in this case the volume of the experimental work is usually substantially higher in comparison with the methods mentioned previously. There are many tests that are provided during the testing of the electric insulating varnish. Sometimes we have to decide which varnish from the tested group is the best for a prescribed application. We often meet the situation where some different varnishes are better in some types of tests. Therefore, the election of the best sample is not simple. We have developed a method that is based on the establishment of weight coefficients that reflect the significance of different properties for a considered application.

The methodology of the testing is an essential part of research work. We have applied the methodology mentioned above to the testing of different types of electric insulating varnishes and to the comparison of their properties from different points of view. The methods of correlation and method of weight coefficients have mostly been used.

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SULPHUR CONCRETE

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Key words: sulphur concrete, modifications, 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 aggregate of suitable granulometry. After cooling, this mixture turns to a firm matter with good mechanical properties and very high resistance to a variety of aggressive materials.

Sulphur, in its solid state, exists in four modifications. These vary in crystalline structure and other physical properties. From a practical point of view, only two modifications are important: alpha and beta, as the other two modifications are not stable and, relative to temperature, transform into these two stable modifications. Melted sulphur hardens at 119°C; this solid state should consist only of monoclinic beta sulphur of 1960 kg/m³ of specific mass. After further cooling to less than 95°C beta sulphur transforms to orthorombic alpha sulphur with 2070 kg/m³ specific mass, unchanging even after further cooling. As alpha modification has higher density than the beta one, sulphur volume reduces by about 5%, with inner tention. Without removing this property, sulphur could not be used as a binding agent.

Therefore, modified sulphur is to be used. Olefinic polysulphides may be used, however their price is too high for mass production. Another option is a mixture of oligomer of cyclopentadiene and dicyclopentadiene. Due to financial aspects, experiments are focused on the verification of the latter option, i.e. a mixture of cyclopentadiene (CPD) and dicyclopentadiene (DCPD). The experiments used commercial sulphur with addition of 1, 3 and also 5 weight per cent of the CPD and DCPD mixture. Samples were made also without the addition of modifiers. Their shape was a 40 x 40 x 160 mm prism. The role of the modifier was tested in the following way: each series of 9 testing bodies were heated in a water bath to 100°C and after one hour left to cool to the standard laboratory temperature of 20°C. All the bodies in all series were exposed to 30 temperature cycles. This was followed by tests of compression bending strength and compression strength, where the rate of reduction of these parameters indicated the efficiency of the modifier. The test results show that the proposed CPD and DCPD modifiers at 3% of sulphur mass give optimum effect and significant stabilization of hardened sulphur structure when compared with bodies without a modifier.

In the next stage the optimum structure of sulphur concrete was proposed with an aggregate of 0/8 and 8/16 mm. The best dose of modified sulphur in this case equals 14% to 16% of the overall aggregate mass. Basic physical and mechanical properties of sulphur concrete were defined for this formula. Compression strength goes up to 50 MPa, volume mass is 2350 kg/m³ and absorption capacity is 0.1%.

Corrosion tests have been started, to monitor during at least a one year period the corrosion resistance of the above mentioned formula of sulphur concrete to sulphuric acid and hydrochloric acid.
In 1995 the experiments will focus on a sulphur concrete formula utilizing waste sulphur, corrosion tests will be extended to further inorganic and organic corrosion media, with special semi-operation verification of sulphur concrete as a special corrosion-resistant hydroinsulating layer.

The ultimate goal of the research will be to gain all the information necessary for the practical application of sulphur concrete in civil engineering where the inexpensive waste sulphur could be used as a binding agent.

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.
REASONS FOR THE IMPROVEMENT OF CONCRETE STRUCTURES

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Key words: concrete structures, strengthening, fatigue, adhesive layers, reinforced joints

During recent years more and more concrete structures are being repaired. The main reason for reconstructions and repairs is for improving the serviceability of structures, including structures with dynamic load.

One problem, which is solved during reconstructions, is the strengthening of structures, improving their load bearing capacity. This can be done with added concrete layers and enlarging of the cross section of concrete elements. The weakest part of this kind of repair is the connection between the old and the new concrete. Adhesive layers are used to create joints with required characteristics. The second step for improving the connection between the old and new concrete layers is the use of reinforced joints, where steel bars are connecting both concrete parts. The problem of joints without reinforcement (their bearing capacity and durability under cyclic load) was solved in the last research program. Within this research program we solved the problem of the durability of reinforced concrete joints. For the first part of the research we had made twenty concrete samples, the adhesive layer was made from polymer cement composition, prepared as follows:

- 100 weight parts of PC 325 cement
- 100 weight parts of 0-1.0 mm sand
- 100 weight parts of SOKRAT 2804

Immediately before the casting of the new concrete part this composition was applied on the surface of the old concrete part. The new concrete was applied immediately, into the fresh connecting layer. The same adhesive layer was used in the research of plain joints, so now we are able, comparing obtained results for plain and reinforced joints, to evaluate the influence of reinforcement. First the static strength tests were done and then the durability of this type of joints was evaluated. For this purpose the Wöhler curve was determined, using the equation

\[ \frac{f_{\text{max}}}{f_0} = 1 - \beta \star (1 - R) \star \log_{10} N \]

where \( f_{\text{max}} \) denotes the highest level of loading, \( f_0 \) denotes the static strength, \( R = f_{\text{min}}/f_{\text{max}}, f_{\text{min}} \) denotes the lowest level of loading, \( N \) denotes the number of cycles to failure and \( \beta \) depends on the rate of the drop in strength.

The second aim of repairs of concrete structures is the restoration of the properties of concrete elements. The loading of concrete structures results in cracks in concrete and then in changes in stiffness parameters. The main aim of this kind of repair is the restoration of these stiffness parameters. This problem was solved with the use of 2 m long reinforced concrete beams. These beams were subjected to static load and cracks occurred. Then the
stiffness parameters of these damaged beams were evaluated using the method of Ing. J. Bayer. The cracks in concrete were repaired with an injection with epoxy resin and the repaired beams were again subjected to evaluation of stiffness parameters. Comparing the results obtained before and after repairs we can evaluate the effectiveness of these kind of repairs.

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This research has been conducted at the Klokner Institute as part of the research project "Service Life of Some Kinds of Repairs of Dynamically Loaded Concrete Structures" and has been supported by CTU (TU) grant No. 8221.
EFFECT OF CLOSELY-SPACED REINFORCEMENT ON CRACK RESISTANCE OF CONCRETE

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Key words: concrete, reinforcement, crack, fracture, energy, unloading, straining, bond

The favourable effect of closely-spaced reinforcements on the crack resistance of concrete was explained using the Griffith's energy approach. The energy balance of a critical structure crack is substantially enhanced by the energy absorbed within small segments of reinforcing elements (wires, fibres) if stressed due to the unloading of the limited adjacent regions of concrete, despite the relatively low stresses and strains induced in these segments since the energy absorbed here is not negligible compared to the fracture energy of concrete [1].

It is obvious that our derived formulae can be roughly applied also assuming the more pertinent non-linear fracture mechanics approach for (macro)crack formation because it can occur only if preceded by the development of structure cracks ("microcracks") whose equilibrium is improved by reinforcement as just stated above. Nevertheless, we shall try to treat this problem in more detail.

The Bazant's non-linear fracture mechanics solution both for plain and reinforced concrete is well known [e.g. 2]. Considering the action of reinforcement, he supposes that bond in the fracture process zone and in the adjacent parts of unloaded regions failed while the energy balance is enhanced by reduction of the energy released from concrete in the remaining, more distant parts of the unloaded regions as well as by the energy absorption due to slip of the reinforcement along the segments with failed bond to concrete.

Let us assess the energy effect of the reinforcement more accurately. The first of the mentioned energy contributions is rather low for usual percentages of reinforcement at usual elastic moduli of both components. The second energy contribution plays a decisive role only in composites made of a ductile matrix where large shifts between the matrix and reinforcement are possible; when considering quasi-brittle matrices like concrete, the slip movements induced by rather small forces at developing structure cracks prior to the formation of running cracks are very limited and, therefore, cannot lead to a substantial energy consumption. For the latter class of materials, the most important energy contribution of the reinforcement consists in its local straining due to the unloading of the regions at the fracture process zone, in a similar way to the equilibrium of a simple critical structure crack.

Regarding the rather wide fracture process zone, the average strain (and, of course, also stress) within segments of reinforcement within this strained zone are only slightly higher than the original values prior to the development of the fracture process zone. Thus, the energy coming from the total amount of energy released from the unloaded regions and caught by the average straining of the reinforcing segments within the fracture process zone plays no substantial role. Nevertheless, the average increase in strain and stress is only fictitious; really, as just noted above, bond between reinforcement and matrix is here still working over major parts of the segments between individual structure cracks even within...
the fracture process zone. Hence, the total deformation executed by the unloaded regions onto the fracture process zone is mainly concentrated into the small segments over the openings of individual structure cracks. The energy absorbed by these peak strains and stresses is, naturally, rather high and can cover a substantial portion of the released energy. So, an improvement of the energy balance and of the corresponding crack resistance given by the start of the first running crack can be very important.

The peak levels of the strains and stresses depend on the equilibrium which is established between the force transmitted into the reinforcing element by bond and the induced tensile force in this element, the total length of the respective strained segments of the reinforcing element being determined by this equilibrium at the total deformation from the unloaded regions. As just noted above, bond is acting over the major parts of both the fracture process zone and the unloaded regions. Thus, the total length of the strained segments of the reinforcing element is still the same whether there is a system of structure cracks or only one critical crack. Further, we can accept that the shape of the whole unloaded region at the fracture process zone is elliptical, as in our previous solution considering a simple structure crack, whereas Bazant supposes triangular unloaded regions with slopes of 1 on both sides of the fracture process zone. However, using these two different assumptions, we obtain very close results.

Hence, our old solution for a single critical structure crack [1] is fully usable also for the energy balance of a fracture process zone from where a failure by propagation of a running (macro)crack begins. The only difference is given by the rather greater size of a fracture process zone, compared to the size of a critical structure crack. Since the energy balance directly depends on this size (i.e. is directly proportional to its $3/2$ power [1]), the effect of the closely-spaced reinforcement on (tensile) strength and extensibility of the matrix is even more favourable than according to the simple Griffith's approach.

One more favourable effect which improves the energy balance of the fracture process zone can be mentioned here. A dispersed reinforcement makes the stress and strain field in a heterogeneous matrix to be more uniform and, in such a way, delays the formation of structure cracks. That is the reason why structure cracks arise more numerous, similarly like (macro)cracks in the ordinary reinforced concrete, and, therefore, absorb a higher amount of the released strain energy from the unloaded regions at the fracture process zone. Hence, the array of structure cracks becomes more dense and, probably, also the size of the fracture process zone can somewhat increase. However, this last described effect can be preliminarily evaluated only as a secondary-one; it is surely influenced by the heterogeneity of the matrix and needs to be subjected to further investigations using statistical methods.

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THE DEVELOPMENT OF EXPANSION MATERIAL

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Key words: expansion

The development of new building materials stresses considerably the need for new masses that might be used in the building industry and that would satisfy the requirements of reaching a high quality at low acceptable prices. In that research at work we have developed an expansion material that may be used for filling excavated areas in mines. The application in the mining areas is necessary to prevent the spontaneous combustion that may occur at given moisture of coal in mines. From the economic and ecologic points of view it would be possible to use waste raw materials e.g. power plant ashes.

The properties of expansion filling material that are mainly produced on the basis of inorganic raw materials are as follows:

• the mass expands in the area its application only and without the necessity of supplying thermal energy
• for the production of the expansion mass waste raw materials are used
• the mass has the ability to expand at least three times, the time of a gel formation must not be higher than ten minutes and the self-supporting ability of the gel is reached after 15 minutes
• the expansion mass satisfies the current safety prescriptions and hygienic standards, in contact with fire it does not release harmful substances that would threaten the health.

For the development of the expansion material these raw materials have been used:

• cement
• ashes
• quickly solidifying gypsum
• chlorinated lime
• acrylate water dispersion Sokrat 2804
• hydrogen peroxide

The three basic ingredients of the expansion material consist of the following basic raw materials.
Ingredient A:
- cement SVPC 325 ................. 40% of the weight
- power plant ashes ............... 20% of the weight
- quickly solidifying gypsum .... 25% of the weight
- chlorinated lime ................. 15% of the weight

Ingredient B:
consists of water and the acrylate dispersion Sokrat 2804. The water coefficient \( W = 0.65 \) (water/(cement + ashes and gypsum)), i.e. the batch of water for 1 kg of the ingredient A is 0.55 litre of water.

The batching of the acrylate dispersion is carried out in volume. The weight ratio of dry material of the dispersion (50% dry material) to the ingredient A is 1:8.

This means that for 1 kg of dry ingredients we use 0.25 litre of acrylate dispersion SOKRAT 2804 containing 50% of dry material mixed in 0.55 litre of water.

- Sokrat 2804 ........................ 31.3%
- water ................................ 68.7%

Ingredient C:
- hydrogen peroxide – its batch amounts to 0.4 litre for 1 kg of raw material A.

For a quicker consolidation and hardening of the mix we use the allowance of calcium chloride \( \text{CaCl}_2 \cdot 6\text{H}_2\text{O} \), i.e. 6% of the weight of cement.

The total ratio of mixing individual ingredients is as follows:

\[
\text{INGREDIENT A : INGREDIENT B : INGREDIENT C} = 5 : 4 : 2
\]

In the preparation of the mix a perfect homogenization occurs especially. A good mixing is especially necessary with hydrogen peroxide. The degree of the expansion of the mass and its hardening depends on the perfect mixing and homogenization of ingredients.

Conclusion – application:
With regard to the properties of the expansion material, its wide application – e.g. for filling excavated areas of mines – is possible.

References:

This research has been conducted at the Department of The Building Materials as part of the research project “The Development of Expansion Material” and has been supported by CTU grant No. D 53/93.
EVALUATION OF IMPERIABILITY OF CONCRETE WITH SURFACE TREATMENT BY IMPREGNATION COATING

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Key words: liquid media, environment, impregnation agent, impermiability of concrete

During technological processes of many branches there harmful liquid media are used, such as oil products, products of agricultural and the food industry, etc., endangering the environment in the case of their leakage. The protection of the outward environment is made by impregnation coating of concrete. Recently a new line of foreign impregnation products has come to our market, but they are not suitable from the ecological point of view.

Considering that there is no norm scoring the quality of impregnation for evaluating the efficiency of impregnation agents either in our country or abroad, it is not possible to use any rational parameters.

Another important feature connected with using the impregnation agents for concrete is the fact that in ours as well as in special foreign literature, there is a minimum of information on physico-chemical characteristics of the concrete - impregnation system. It is probably caused by the relatively high price of these experiments. Another reason can be that the limited number of firms dealing with this problem on a high level protect established results as certain part of their know-how.

By the reasons given above it is very difficult to compare our indications with foreign or inland ones, which is usually done during all types of research-developing or experimental activities.

The goal of our research is enlightening the influence of impregnation agents combined with concrete upon the increase of the tightness of concrete or upon the increase of the impermeabillity of concrete against various liquid media.

The goals of the single stages of the research can be divided:

- assembling of the apparatus which would enable measuring of the penetration of various types of liquid media through concrete with impregnation layer,
- enlightening the influence of an impregnation agents upon the porous structure of the superficial parts of concrete.

Test of impermeability and resistance of coating materials against the effect of various liquid media are not, as it has already been stated above, given by any technical standard valid in the Czech Republic. In Klokner Institute there the testing method, certified by C1A, for tracking of impermeability of surface treatment of concrete has been elaborated. The test is based on the tracking of the penetration of liquid media through specimens with
the pressure developed by a column of tested liquid with the height level of 1.4 m. The specimens have a cylindrical shape with a diameter of 100 mm and a height of 50 mm. During the test itself specimens are put into a special jig connected with a glass tube by a hose; an appurtenant liquid medium is then poured into the glass tube. The level of the liquid is controlled and refilled regularly. The test result is the comparison of the time needed for the penetration of the liquid medium through the specimen with coating and without coating or the comparison of the resistance of the specimen against penetration of a liquid medium after some time on a fracture of the specimen.

A lot of impregnation agents, such as composite XYPEX, create secondary hydration in capillary solutions by means of active chemicals and clog transport ways for liquid media permanently. To prove this assertion we made a porosimetric analysis on the specimens prepared in the laboratory by means of high-pressure porosimeter working in the range 0 - 100 MPa, i.e. it is possible to determine the size of pores 7.5 - 7 500 nm on it. In very small pores, so-called micropores, the transport of either water or other liquid media cannot occur. This transport occurs at so-called capillary pores, i.e. at pores with a diameter larger than 100 nm. From measured values of porosity of concrete cured and noncured by coating XYPEX is seen the positive influence of the coating on decreasing of transport ways for liquid media by decreasing global and particularly capillary porosity is seen.

Experimental measurement was done with these liquids:

- petrol
- diesel oil
- transformer oil
- ensilage juice
- phenol

As impregnation agents, the coating materials XYPEX Concentrate and XYPEX Modified made by the Canadian firm XYPEX CHEMICAL CORPORATION and MAXSEAL made by the Spanish firm DRIZORI S.A. were used.

Research work on this subject continues permanently, focusing on the research of transport ways in concrete in various layers under the surface, and the testing of other impregnation agents. Further work is done on gradual improvement of the apparatus for testing the transport of liquid media through concrete.

References:


This research has been conducted at the Department of Experimental & Measurement Methods as part of the research project "Evaluation of Safety of Emergency Sump at Action of Harmful Liquid" and has been supported by CTU grant No. 78220.
APPLICABILITY OF THE SURFACE HARDNESS METHOD FOR STRENGTH DETERMINATION OF CONCRETE EXPOSED TO ENVIRONMENT

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Key words: concrete structures, Schmidt hammer, carbonation

Determination of concrete strength in structures is an important part of the estimation of structural reliability and serviceability of reinforced concrete structures. For testing of concrete is very often used surface hardness method (Schmidt hammer).

The results of the surface hardness method are influenced by many factors. Some are standardized (e.g. age and humidity of tested concrete in ČSN 73 13 73), others must be eliminated by proper preparation of the tested surface of the concrete. In the diagnostics of actual structures it is very often necessary to ascertain the in-situ concrete strength of inaccessible structures (cooling towers, chimneys), where only mountaineers can operate the testing equipment. Concrete on such structures exposed to the atmosphere will usually form a hard carbonated skin, the thickness of which can exceed 20 mm. It is very difficult to remove such a thick concrete layer, especially on inaccessible structures. Such requirements also reduce the advantages of the surface hardness method.

The influence of concrete carbonation on the surface hardness method is very complicated and it is difficult to describe these phenomena theoretically. The solution to this problem can be based mainly on the results of test programs.

However, the testing program used in KI consisted of comparative testing on different types of real concrete structures. On each testing site two Schmidt hammer measurements were taken, together with determination of the depth of concrete carbonation. The first Schmidt hammer measurement was taken on the original surface of the concrete, which was only cleaned by hand grinding. The second Schmidt hammer measurement was accomplished on the same site, but the carbonated skin of concrete was completely removed by an electrical grinding machine. Both sets of rebound numbers were processed according to ČSN 73 13 73 and two values of the concrete cube strength were established. For every testing site coefficient \( \alpha_c \) was computed.

\[
\alpha_c = \frac{R_b}{R_{b,\text{carb}}}
\]

where:
- \( R_b \) – concrete cube strength measured on a surface without carbonated skin,
- \( R_{b,\text{carb}} \) – concrete cube strength measured on a surface with carbonated skin.

The thickness of carbonated skin (depth of carbonation) was determined by a phenolphthalein test on four sites close to the Schmidt hammer measurement site. The coefficient \( \alpha_c \) was related to the depth of carbonation.
Conclusions: (1) The hard carbonated skin on a concrete surface affects the results of the surface hardness test and can cause an overestimation of the concrete strength by more than 50 per cent. (2) In the measured range of concrete carbonation (1 to 20 mm), the rate of this effect depends proportionally on the depth of concrete carbonation.

References:

This research has been conducted at the Klokner Institute of CTU and has been supported by CTU grant No. 8221.
GENERALIZED RELATIONSHIP BETWEEN TENSILE SPLITTING STRENGTH OF CONCRETE AND FRACTURE AREA SIZE

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Key words: tensile splitting strength, fracture area, testing specimen shape and size

At the present time the tensile splitting strength is considered as representative of the tensile strength of concrete. According to CS 73 1318 the "arbitrate tensile strength" is the tensile splitting strength determined on the 150 mm cube. Therefore, a knowledge of the relationship between this strength and other sizes and shapes of test specimens becomes very important. That is why the question of the size effect in the tensile splitting strength test of concrete was systematically studied.

The experimental program consisted of test specimens of different shapes (cubes, cylinders, prisms - loaded transversaly or longitudinally) and sizes. For casting, concrete mixes of variable composition were used (e.g. with different water/cement ratios, different types, grading and volume of coarse aggregate). The mean values of the compressive strength of the tested concretes varied approximately from 25 to 55 MPa and the mean values of the tensile splitting strength varied from 2,5 to 5,2 MPa (both determined on 150 mm cubes).

The test results which were obtained according to the theory of elasticity were evaluated with the aid of mathematical and statistical methods. However, for this purpose the volume of the test specimens was substituted either by the size of the corresponding fracture area or by the size of the highly stressed volume in their loaded cross-section (HSV-see [1]).

Further, the absolute values of the tensile splitting strength were converted into relative ones (depending on the basic size of the fracture area or on the highly stressed volume). It was shown that the adjusted relative values of the tensile splitting strengths were for both quantities practically identical.

For mathematical expression of the relationships between the mentioned quantities, an exponential function was used. This function fits to the experimentally obtained results very closely. However, the higher values of the correlation coefficients show, that the relationship between the tensile splitting strength of concrete and the size of the fracture area of the tested specimens was more favourable. This fact made it possible to formulate their general relation by the expression given in [2]. This relation allows conversion of the test results obtained on specimens of different shape and size to the strength of the basic sized specimen. This is important for the test results obtained on samples taken from finished structures; as these samples are usually of different sizes. For this purpose a set of corresponding conversion factors was also summarized (see [2]).
The investigation into the problem mentioned above with the use of the specimens usually used in laboratory tests has shown, that for these sizes the tensile splitting strength of concrete decreases as the size of the specimen increases. The obtained results also prove the existence of a size effect in this way.

References:


This research has been conducted at the Department of Building Materials and has not been supported by any grant.
STRAINS OF STEEL FIBRE REINFORCED CONCRETE UNDER LONG-TERM LOAD

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Key words: fibre reinforced concrete, creep, shrinkage

The effect of steel fibre in a standard concrete matrix has been investigated. The practical applications of the material - fibre reinforced concrete (FRC) - will be possible if we know physical-mechanical properties of the material and its behaviour under a long-term load.

The experimental research programme of the measuring strains of FRC under a long-term load has been carried out for several years, in cooperation between the Faculty of Civil Engineering in Prague and the Politechnic of Warsaw.

Typical concrete used in design practice was tested - see Table 1.

<table>
<thead>
<tr>
<th>Components</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>cement</td>
<td>491</td>
</tr>
<tr>
<td>water</td>
<td>167</td>
</tr>
<tr>
<td>aggregate 0-8</td>
<td>989</td>
</tr>
<tr>
<td>aggregate 8-20</td>
<td>745</td>
</tr>
<tr>
<td>plasticizer Klutan</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Tab. 1: Composition of basic matrix (plain concrete)

Design of tested series are in Table 2.

<table>
<thead>
<tr>
<th>Series</th>
<th>Volume % of fibres</th>
<th>Ratio d/l of fibres [mm/mm]</th>
<th>Age of concrete at loading [days]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>—</td>
<td>28</td>
</tr>
<tr>
<td>B</td>
<td>0.05</td>
<td>0.6/63</td>
<td>28</td>
</tr>
<tr>
<td>C</td>
<td>0.5</td>
<td>0.4/40</td>
<td>28</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>0.4/40</td>
<td>28</td>
</tr>
</tbody>
</table>

Tab. 2: Characteristics of tested concretes

The strains (creep test) are shown in Fig. 1.
The strains were measured on prisms 150 x 150 x 150 mm. The specimens were placed in the room with the relative humidity of 98% and an average temperature of 20°C. At the age of concrete 28 days the samples were moved into the laboratory. From the total number of 24 specimens the 12 prisms were subjected to long-term loading (creep test). Of the remaining 12 specimens, shrinkage was measured.

The long-term load was adjusted to 21% of the ultimate cube strength. The cubes were made of the same concrete as the prisms.

The results in Fig. 1 confirm the theory that the total creep of FRC is lower than the total creep of plain concrete. The results also confirm the total creep depends on the amount and type of fibres which are used. An extremely significant factor is always the technology of manufacturing.

Fig. 1 Elastic and creep strain - time development

References:


The research has been conducted at the Faculty of Civil Engineering of CTU Prague in cooperation with the Politechnic Warsaw and has been supported by the CTU grant No. 2043/94.
CONTRIBUTION TO THE RESEARCH OF AGEING OF NPP’S CONTAINMENTS

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Key words: concrete, ageing, containment

As part of the IAEA Vienna "Management of Aging of Concrete Containment Structures" Coordinated Research Program we had to find and choose the main leading condition indicators i.e. a minimal but "complete" set of parameters characterizing the aging of a concrete structure, such that their values could be measured and evaluated during tens of years. We will present our preliminary conclusions.

In this direction we distinguish the following sorts of concrete condition indicators (selected with regard to containment structures):

- indicators measurable on the surface layer of the concrete
- bulk condition indicators
- structural condition indicators

Slow acting changes in the bulk condition parameters (except moisture) can be omitted with regard to the ageing, since ageing especially in the case of high quality concretes, is largely determined by external effects acting on the surface.

Firstly we will define the parameters which we now consider optimal for a long time evaluation and why:

- Changes in the surface layer, which covers the reinforcement.
- Changes in the thickness and the surface quality of the cover layer due to dissolving or due to etching by acid rains. The critical parameter would be the "roughness"; defined by the mean depth of filling.
- Chemical changes leading to decreases in the pH value and in the loss of the alkali passivation the reinforcement. The parameter would be pH in the wet layer changing with the depth in the layer.
- The velocity of carbonation is influenced by the depth of the microcracks and by the porosity of the surface layer. The parameter would be the permeability of fluids through the cover layer of the concrete reinforcement.
- Occurrence of surface defects, caused by the repeated volume changes of liquid/solid phase transitions in the moisture.
- Occurrence of large cracks or defects caused by the act of external forces (explosions, earthquakes etc.) or by large temperature changes (fires).
Currently the setting and leakage rate of the containment structure are the most measured and evaluated structural indicators.

This research will be continued by a programme for evaluating the changes of the main condition indicators of aging processes in the concrete cover of reinforcement (supported by measurements of the bulk moisture) and by an evaluation of the data collected for some containment structures using different methods of measurement.

References:

[1] VYDRA, V. – TYDLITÁT, V.: Condition Indicators of Concrete Containment Ageing Report presented on The 2nd Research Coordinating Meeting as a part of the programme “Mamagement of Ageing of Concrete Containment Structures” organised by IAEA (Toronto 1994)


This research has been conducted at the Department of Physics of the Faculty of Civil Engineering, CTU in Prague and has been supported by the International Atomic Energy Agency, Vienna under agreement No. 7296/RB (1993).
MEASURING THE WATER VAPOR DIFFUSION IN DEKALUX

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Key words: diffusion coefficient, diffusion permeability, steady-state method

There are several Czech standards dealing with the water-vapor diffusion coefficient. The basic definition can be found in [1], where the "diffusion coefficient" $\delta$ is understood as a factor of proportionality between the water-vapor flux and the pressure gradient, $j = -\delta \operatorname{grad} p$. The same definitions are also used in the standards describing the principles of measuring the water-vapor diffusion, such as Refs. 2-4.

Comparing this terminology with some of the basic terminology of thermodynamics textbooks (see, e.g., [5]), one can see serious discrepancies. In common physical terminology, the diffusion coefficient is a proportionality constant between the mass flux and the concentration gradient, $j = -\rho D \operatorname{grad} c$, where $\rho$ is the density, while the mass flux due to the pressure gradient can be expressed by the barodiffusion coefficient $D_{II}$, $j = -\frac{1}{\rho} D_{II} \operatorname{grad} p$.

Comparing the two relations containing the pressure gradient, formulated above, we immediately obtain that $\delta = \frac{1}{\rho} D_{II}$, and the coefficient $\delta$ cannot be called the diffusion coefficient, within the frame of linear irreversible thermodynamics.

Only a few building physicists have noticed this discrepancy. For instance, Binko [6] calls the coefficient $\delta$ the "diffusion permeability", while Kašpar [7] and Mrlik [8] call it "diffusion conductivity". In this paper, we follow the correct physical terminology and employ the definition formula $j = -\rho D \operatorname{grad} c$ for the diffusion coefficient, while for the coefficient $\delta$ we use Binko's name of "diffusion permeability".

Our measuring apparatus (developed at our Department) consists of two airtight glass chambers separated by the sample of the measured material (see Fig. 1). In the first chamber, a state of 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 desiccation material, such as silica gel). After a certain time, measurement is interrupted, and the changes in the mass of water in the cup, $\Delta m_w$, and of the silica gel, $\Delta m_s$, are determined. If $|\Delta m_w| \sim |\Delta m_s|$, 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.

Assuming the water vapor to be an ideal gas, the diffusion coefficient in our experimental setup can be calculated using the formula

$$D = \frac{|\Delta m_w(\tau)| R T_0 d}{p_w(T_0) S T_0},$$

where $\tau$ is the time from the start of the experiment, $R$ is the universal gas constant, $T_0$ is the constant measuring temperature, $d$ the thickness of the board sample, $p_w(T_0)$ the partial pressure of water vapor at the temperature $T_0$, $S$ the cross section (surface area) of the board sample.
Comparing the definition formulae for the diffusion coefficient $D$ and the diffusion permeability $\delta$, and using the equation of state of an ideal gas, we obtain the isothermal relation between these two quantities, $D = \frac{\delta}{\rho}$, where $M$ is the molar mass of water vapor.

Measurements to determine the water-vapor diffusion coefficient in Dekalux (environmental friendly cellulose-based replacement material for the asbestos-cement products, producer: EZA Šumperk, $\rho = 1800 \text{ kg.m}^{-3}$) were performed on 5.5 mm thick material boards. Some of the samples were measured "as is", some were provided with waterproof coatings on the surface which was in contact with the 100% relative-humidity environment. The mean values of diffusion coefficients determined by the steady-state method from 10 measurements at the temperature $T=296 \text{ K}$ were: 1.89 $\times 10^{-7}$ m$^2$s$^{-1}$ for Dekalux without any coating, 1.47 $\times 10^{-7}$ m$^2$s$^{-1}$ for Dekalux with Rudicolor, 1.31 $\times 10^{-7}$ m$^2$s$^{-1}$ for Dekalux with Aquafob, and 1.12 $\times 10^{-8}$ m$^2$s$^{-1}$ for Dekalux with Coronyl. These results show that from the three studied coatings, only Coronyl can be considered to be effectively waterproof.

References:
[2] ČSN 727030 Stanovení součinitele difúze vodní páry v stavebních materiálech
[3] ČSN 727031 Měření součinitele difúze vodní páry v stavebních materiálech metodou bez teplotního spádu
[4] ČSN 673093 Stanovení propustnosti volného nátěrového filmu pro vodní páru

This research has been conducted at the Department of Physics and has been supported by the grants of the Grant Agency of the Czech Republic No. 103/94/0140 and 103/94/0595.
Section 10

POWER SYSTEMS,
ELECTRICAL ENGINEERING
&
POWER SUPPLY
THE OPERATION
OF INTERCONNECTED SYSTEMS

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Key words: interconnected systems, island state, emergency state

The results of scientific activities dealing with the behaviour of the Czech Power energy system operating together with power energy systems of West European countries UCPTE were presented in the year 1993. The philosophy of the UCPTE recommendations is to avoid spreading to the neighbouring system a disturbance which has arisen in one partner system.

Separating network which has arisen into small islands represents one important possibility in designing a defense plan against major disruptions and for a re-energizing plan. Criteria for dividing parts of the 110 kV network were checked and a suitable locality in Southern Bohemia was chosen.

This year the research continued in following ways:

- analysis is performed to identify actions that can be taken to prevent major disruptions and to identify measures that can be taken to restore the normal state
- the preparation of a simplified mathematical model to describe the behavior of the network in the island states

We can define the main principle for operation in separated distribution networks:

a) A balance between the sources of electric energy and the demand in selected islands must be established
b) The limited current and voltage conditions of elements in the selected island state must be observed
c) The stability of the parallel operation of generators
d) The magnitude of The demand for electric energy is the main indicator of operation in selected island states. There is where priorities are defined in the supply of electric energy to consumers.

The description of models. It is not possible to prepare only the linear model for the emergency states. The power energy system or some of its elements have the limited values of the state quantities and therefore it is necessary to respect important physical limitations. On the other hand we cannot use detailed models because it is very difficult to obtain input data from a real network. The aim of our work was to prepare a compromise model, which is comparatively simple and which respects existing physical limitations with the basic static and dynamic relationships between input and output.
The model contains two basic parts:

- the model of the electric part of the power station and the transportation of electric energy
- the model of the technological part of the power station

The technological part of the power station contains basic models for regulation steam values (pressure, flow, power) and the transition qualities of boilers and turbines. The limitations of the active power of the turbine and the speed of increasing power, the pressure of steam, and the limited values of current were respected.

The electric part is divided into two parts i.e. the model of generators, and the transmission system with lines, protections, circuit breakers, and transformers.

The present situation in transmission lines is very important for the modeling of behaviour during the transition of the network from a normal to an emergency state. The accurate starting conditions for the normal state were counted, and the same was worked out for the system automatic devices. The simulations showed the way for the transition to the island states and time data for the development of the system automatic devices.

The described model can be used in the real network of the Czech Power Energy companies. The results of these scientific activities were presented in two studies, three times at conferences and seminars, and three papers in international conferences were called for.

References:


This research has been conducted at the Department of Power engineering as part of the research project “The interconnection of power energy systems” and has been supported by CTU grant No. 38199
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, alternator

We have continued with fulfilling the team project goals which have dealt with research and development of the headlined topic. Our project was supported at first by a CTU grant in 1992 and we referred the results to Workshop 93 in five papers. The project was funded also for 1993 and we referred the results to CTU Seminar 94 in five papers, as well, and six papers at other conferences. There was no chance to be supported by a CTU grant in 1994 without formulating a new project. We decided to apply our project to the Grant Agency of the Czech Republic, and the innovated project in the CTU committee for grants. Both of the applications became successful.


After initial experiments (see [9], [10]), the group from Dept. of Physics proved the possibility of PD-detection and measurement by ultrasound, with respect to problems of the method in the case of oil-insulated transformers, and so new acoustoelectric converters have been prepared. The transducers must be both broad-band and highly sensitive, thus a transducer with a built-in preamplifier has proved to be the best solution. These transducers allow multisensor detection and the comparison of time delays between transducers. This is the way to the PD-location.

Our accredited High Voltage Laboratory obtained 4 sets of voltage instrument transformers of 400 kV which were removed from the substation after tens of years service for the Czech Power Company in order to perform all routine tests and review their remaining lifetime. We have performed the joint PD-measuring by both the acoustic and the routine electric global method on these transformers.

The analysis of PD-activity measurement methodologies with respect to the possibility of on-line measurement and expert-deciding, respectively. The parameters and properties of different measuring equipments have been proved in on-site service with respect to measurement effectiveness and data processing possibilities. As a result, the decision about the methodology of on-line and off-line measurements and the design of measuring equipment have been proved.

Initial experiments with on-site measurement of transient overvoltages have been provided and a new approach to the mathematical evaluation of overvoltages caused by ferromagnetic resonance has been studied.

The authors of the frequent characteristic method (FCHM) provided the verifying FCHM-measurements of winding state on the tested transformers (both oil- and dry-type) in the short-circuit testing laboratory in Běchovice, with the aim of detecting a winding distortion eventually caused during the tests, and to innovate the method, e.g. to reach the
fast and lucid evaluation of the obtained results. The special apparatus for FCIIM application has been developed, and its production is almost finished. The new verifying program based on the agreement with the enterprise Hydro Power Plants has been opened. The program concerns the repeatability of measurements on transformers in power plants and switchgears.

The program for controlling pulse-frequency-technique measuring stands has been created by the group from Dept. of Electrotechnology. Further, the set of measurements (on two different types of transformers) has been completed, which deal with the transformer aging impact to the frequency domains. For more information see [1].

The research group from the accredited Testing Laboratory of Electrical Machines followed up with the topic of the program-equipment for oscilloscope-computer communication and data processing. Experimental work concerned the on-line instantaneous values recording of voltages and currents on transformers or reactors, with the goal of providing the processing of these values in off-line mode. This way allows the possibility of transient phenomena evaluations on a higher level of accuracy. The program to check magnetic field distribution in transformer- or reactor-core has been created, as well. It is based on the FEM.

References:


This research has been conducted at the Department of Power Engineering as a part of the research projects “Reliability of Insulating systems of Power Equipments” and “Reliability of Insulation in Power System”; it has been supported by GACR grant No.102/94/1958 and CTU grant No. 38200. In this research, Department of Physics, Department of Electrotechnology and Department of Electrical Drives and Traction have taken part, as well.
ECONOMICS AND MANAGEMENT OF ELECTROENERGETICS

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J. Vastl, J. Vašíček, M. Vítek, B. Wilmann

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Key words: economics, energetics, competition, market

This paper summarizes partial results of the project which was funded by the ČVUT-grant for the year 1994.

Like countries of the European community, the Czech Republic also needs to build up market for electricity with competitive elements, which results from the privatization processes. Regulation and legislative scopes of electro-energetics have changed. Economics and management that include competitive elements on the side of production as well as consumption call for new principles and new procedures.

In the first phase, the economic model of transmission system operations with central dispatching was devised. The main procedures of management of these problems in foreign countries have been surveyed. The analyzed procedures in the study had to do with particular conditions in the Czech Republic. The result was the proposition of an independent organisation for transmission system operations in the form of a commercial organisation. The economic model has been theoretically formulated and practically implemented with basic numerical and financial indicators. Two basic variants have been compared. The present stage without independent organisation and the projected stage with the proposed organisation.

The purpose of the study is to produce, from the scientific as well as from the practical point of view, a high quality working plan for the decision making of the relevant offices. At the same time, it tries to direct attention to risks connected with new organisation which can be considered in time to prepare for the decision making process.

Further, the problems of the redistribution of differential rent in the area of electricity distribution have been analyzed. One of the results of the study is, that the process of redistribution of differential rent among regional electricity distribution stock companies (REAS), implemented for many years during the dominance of nation-wide united consumption electricity prices, must be realized also after the privatization of the mentioned companies (i.e. after 1.1.1994) before regional electricity prices will be established.

In contrast to the period when these companies were completely state owned, the emergence of new privatized REAS necessitates institutionalization of the above-mentioned rent redistribution. The most suitable form appears to be the formation of a specific commercial company whose property, according to state provision, will be shared by all eight REAS. Except for obligatory rent redistribution, the proposed company could also fulfill other activities, which according to agreement of participating companies may be efficiently fulfilled by a single committee, i.e. by the proposed company.

An integral part of the study is also the methodology of the differential rent calculation. However, it must be stated that because of complicated cost differences among individual REAS, the making of unambiguous solutions with use of any methodology is hardly possible.
The final solution is the introduction of different regional electricity prices (tariffs) with permanent protections against monopolistic behavior.

The possibilities of application in the Czech Republic of the British model of licensing in energetics have been analysed. One main contribution of this research study was a detailed acquaintance with the division of tasks in the new British organisation model in electroenergetics with competitive elements, especially in the production part of the electroenergetic system. Another contribution of this study was acquaintance with detailed prescriptions for state regulation of monopolies in the new British organisation model.

This research has been conducted at the Department of Economics, Management and Humanities as part of the research project No. 38 183 “Economics and Power Engineering Control in a Competition Environment” and has been supported by CTU grant No. 38 183.
NEW TECHNOLOGIES OF ENERGY PRODUCTION AND CONSUMPTION WITH MINIMUM IMPACT ON ENVIRONMENT

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Key words: energy production, environment, primary measures, fluid bed boilers, cogeneration plants, combined cycle, gas turbine, district heating, solar energy, energy consumption, thermal demands of buildings, electric heating and lighting

Rationalisation of production and consumption of electrical energy and heat with minimal impact on environment are the results of this research work.

Energy production. Theoretical analysis of primary measures to lowering NO\textsubscript{x} content in flue gases of boilers, operational measurements and proposal for the above mentioned measures.

Realisation of this measures in five boilers is the practical result. Modification of air duct and dampers allows a 40-50% decrease of NO\textsubscript{x} content in the flue gas and emission limits are fulfilled.

Analysis and use of results of operational measurements of fluid bed boilers burning a bituminous and sub-bituminous coal. This result was obtained and applied in two cogeneration plants. Fluid boilers will be built in co-gen plant and by this means will be decreased SO\textsubscript{2} content in flue gas more than 90%.

Special attention has been given to the thermodynamic analysis and optimization of multi-pressure combined cycles. The optimum pressure ratio in the 1-pressure and 2-pressure gas turbine and the optimum distribution of the expansion pressure ratio in the 2-pressure gas turbine has been derived. The possibilities of the steam cycles efficiency in the dependence on the gas turbine before the steam boiler has been evaluated. It has been shown that the complications with the design of 2-pressure gas turbines with high pressure ratio and high gas inlet temperature can substantially reduce the expected combined cycle plant efficiency in comparison with increasing efficiency of the combine plant with 1-pressure gas turbine. It appears that the efficiency of combine cycle power plants with the inlet gas turbine temperature about 1300°C can reach nearly 58 and perhaps 60% even with the 1-pressure gas turbine.

Reconstruction of the existing municipal CHP plant by use of coal gasification. Combined heat and power (CHP) plant for district heating, where coal is gasified, purified and burnt in combine cycle unit was designed for reconstruction of existing municipal plant. This technology increased energy efficiency, contributed to a reduction in the use of fossil.
fuels and through this to environmental improvements. Two integrated gasification combined cycle (IGCC) units can operate up to 5000 hours per year in the case which has been effectively solved. In these operating conditions designed CHP equipment can economically compete with other types of CHP or heat plants. The work showed that the use of IGCC units could very successfully replace the equipment of coal fired CHP plants after their useful life.

Model solution of thermal demands of buildings with consideration of thermal gains from solar energy and from the use of the buildings while keeping the interior temperature comfortable. Based on the results of an analysis of the current state of this problem solution in other countries I proposed, a statistically proved and tested mathematical model, which will help to assess the building from the view of energy consumption. In the course of solving this problem (in 1994) there were input value modifications incorporated into the model. These values correspond to NIVEAU, the new regulation basis in this country and abroad. By test - measuring selected school buildings there was established an authoritative divergence of theoretical and real results. Results of the solution will be continually published in professional magazines and included in technical thermal standard updates.

Energy consumption. This part, in its entirety, represents the indirect reduction of negative consequences of the electric energy generation upon the environment as well as the direct reduction of the demands on energy in both the production and non-production sphere during electric heating and lighting.

The broadly distributed publication of the results has aroused an unusually great interest of users. Within this project a number of suitable users has been suggested, who due to their financial resources were willing to realize such systems which would most reliably show the results of the theoretical part of the solution of the scientific and research task. First of all, the realization of the lighting system can be mentioned, which together with the application of the most up-to-date low-pressure sources and the program-controlled voltage multipliers proves these efforts.

Secondly, the system of heating of the production room characterized by an extreme height of rooms have been realized. Even here, by applying theoretically proved IR radiators considerable savings of energy have been reached.

Because of considerable time demands it is not possible now to determine exact values but in both cases they will represent more than 60% of the original demands on energy in both the systems.

This research has been conducted at the Department of Heat and Nuclear Power Energy Equipment, Department of Electroenergetics and Faculty of Architecture as part of the research project “New technologies of energy production and energy consumption with minimum impact on environment” and has been supported by TU grant No. C2.
The use of alternative energy sources and water savings in school buildings

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Key words: alternative energy sources, energy savings, water savings, heating, heat pump

This project consists of two parts. The first one is “Development and Optimization of the Thermal Cycle of Absorption Heat Pum with Auxiliary Compressor” (so called “hybrid” heat pump). In the Czech Republic, there are still a lot of waste heat sources. Big group of them are warm waste waters from technologies and from residential buildings. For instance, new Prague sewage disposal plant will produce (after completion) 6 m$^3$ cleaned water per second. Its average yearly temperature will be 18-20 °C. Cooling it in the winter period to the water temperature in the river (5-3 °C or also less), we gain a heat output of hundreds MW at our disposal. This energy could be turned back to the district heating system. We propose to use the “hybrid” heat pump for that purpose. The heat output of one such machine could be 10 MW or more.

Fig. 1: The principle of hybrid heat pump

A - absorber, D - desorber, E - heat exchanger, K - compressor, T - throttling valve, a - ammonia vapour flow, b - enriched liquid flow, c - poor liquid flow (liquid = mixture of water and ammonia)

"Twin" refrigerant should be applied there: water - ammonia. This mixture has several advantages.
• ammonia does exist in nature and (very probably) is not harmful for the Earth’s ozone layer
• the mixture enables to reach comparatively high temperature (90°C or more) at the heat pump outlet under a conveniently high heating factor ($\epsilon = 3-4$). The parameters of the heat cycle of this heat pump were investigated and optimised. The idea of heat pump is shown in Fig. 1.

If we implemented this pumping for a whole new sewage disposal plant in Prague we could save total equivalent of $10^6$ MWh energy in fuel a year.

The second part of the project is investigation on water consumption in showers. Different shower heads were measured and tested. The best of the shower heads give better cleaning effects under twice lower water consumption than the elder ones. Money savings are not only caused by lower water consumption but also by heat savings. In this way, for instance, warm water consumption in the CTU Fitness Center would be decreased from $1100 \text{ m}^3$ to $580 \text{ m}^3$ per year which means savings of Kč 25,000 per year.

This research has been conducted at the Department of Environmental Engineering as a part of the research project “Energy Savings in School Buildings”, and has been supported by High Education Development Grant (FRVS) grant No. 11 21004.
OPTIMUM ENERGY UTILIZATION OF THE BROWN COAL

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Key words: combustion stability, mathematical modelling, ecological combustion, optimization, prediction, reconstruction

Project “Optimum Energy Utilization of the Brown Coal” includes the measures for the optimum utilization of the brown coal by combustion in the steam and hot water boilers for reaching the maximum transformation efficiency of the coal chemical energy to heat while keeping the ecological limits of pollutions in combustion products.

1. Combustion Safety (J. Karták). Some serious operational problems can arise during combustion of low grade brown coal:
   - pressure fluctuations in the furnace causing flame going out or resulting in an explosion
   - flue gas penetration into a boiler room
   - higher minimum output of a boiler

   Up to date, the combustion stability of a new boiler has not been controlled during the design, so the instability can occur in any new boiler.

   A mathematical model of combustion dynamics and a model of total mass of air and flue gas flow through the boiler dynamics have been developed.

Mathematical Model of a Boiler (F. Jirouš, T. Dlouhý). Every boiler is designed for a definite fuel and mode of operation. The changes of fuel or mode of operation affect the economy of operation. The limits for pollutant emission in many boilers are not satisfied. It is possible to reduce the NOx production by changes in combustion process or by retrofitting the combustion device. But retrofit changes the operational properties of a boiler and its economy. At present, there are no suitable calculation methods for predicting the efficiency of these changes. Thermal calculation of a furnace with respect to primary measures of lowering NOx production is developed. The calculation of the furnace temperature profile is made by means of zone calculation. Volatile combustion and C/Sr combustion are considered separately.

Expert System for the Support of Boiler Operator (F. Jirouš, T. Dlouhý). The combustion quality during boiler operation depends on operator's conscientiousness. Not even the modern control systems solve the question of optimal combustion control respecting the changes of the fuel and the characteristics of combustion devices. Current mode of boiler operation is more complicated because air pollution limits must be respected. An expert system, i.e. philosophy of continual control of combustion quality, calculation of heat losses
Optimization of Power Plants Operation (F. Hrdlička). Optimization of power plants operation will solve the environmental effects of operation by decreasing the power plant power output with regard to weather conditions. Pollutant diffusion model for the one point large source within the area of significance has been developed.

Small Capacity Combustion Equipment (B. Janeba, L. Dvořák). Brown coal is utilized as the fuel in many small and middle-size thermal plants in the Czech Republic. The technical level and the mode of operation of these plants are the main factors influencing the emissions in their vicinity and especially in the dwelling areas. A mathematical model for the analysis of emission effects on the local emission situation for various types of plants has been created.

This research is conducted at the Department of Thermal and Nuclear Power Plants under the research project "Optimum Energy Utilization of the Brown Coal" supported by the Grant Agency of the Czech Republic (Grant No. 101/94/1500).
The term Alternative Sources is used for generators of electrical energy which employ ecologically-friendly local sources of renewable primary energy - the energy of the sun, wind, water, etc. Their importance is not in influencing the global energy balance, because they have little or medium power capability, but in reducing the nonrenewable energy supply and improving the local energy situation. They serve sometimes as autonomous energy sources for remote nonelectrified localities, but in our country, they support, in most cases, the local main electric energy supply.

The uncertainty of the electric energy supply is the key problem with alternative energy sources. This uncertainty results in fluctuations in the electrical energy parameters, namely power, voltage and frequency. These parameters must be stabilised either by modifying the generating equipment, e.g. wind-generator, or by building a power converter, which is the more effective way. The structure of a typical system with converters is shown in Fig. 1.

The main component of such a converter is the inverter INV which performs the d.c./a.c. conversion, synchronized with the voltage of the main supply MS, and is able to control the flow of electrical energy produced by alternative sources AS. State-of-the-art power semiconductor devices, especially IGB transistors, make it possible to build inverters which generate sinusoidal output current with a unity power factor.

The research reported here is concerned with the design of one promising type of inverter, called a PWM voltage stiff inverter (see Fig. 2). An analysis of the converter has been made, and this report will discuss both the simulation and experimental results. The converter is bidirectional; it can operate both as an inverter and as a rectifier - [Žáček 1994].
(1) **Feedback current modulation with hysteresis.** By this method the real phase current is compared to a reference sinusoidal wave of a demanded phase current using a comparator with hysteresis. The output signal of the comparator controls the switching of the corresponding power phase switch (a transistor twin with antiparallel diodes). The minimum width of the hysteresis band is limited by minimum switching time of applied power transistors.

(2) **Feedback current modulation with sampling.** By this method the hysteresis of the comparator is negligible, and the current difference is sampled only at discrete time intervals. The sampling period must be greater than the minimum allowed switching on/off time of power transistors.

(3) **Sinusoidal voltage modulation.** Here a reference sinusoidal voltage wave is compared to a triangular wave of a different modulating frequency. This frequency is limited by the minimum switching on/off time of power transistors.

The results of computer simulation of feedback current modulation with sampling are illustrated by Fig. 3, where all three phase currents supplied to a.c. mains and their step-down transient are shown.

The research effort for the realisation of a transistorised voltage stiff inverter with pulse width modulation and its microprocessor control is continuing.

![Fig. 3: Current modulation with sampling](image)

**References:**


This research has been conducted at the Department of Electrotechnology, Faculty of Electrical Engineering CTU Prague, as part of the research project "Technical Equipment for Parameters Conversion of Alternative Sources of Electrical Energy" and has been supported by CTU grant No. 282383.
ELECTRIC GENERATORS
FOR WIND POWER STATIONS

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Key words: wind power station, electric generators

The commercial use of wind energy for electricity production is in the present time based on series produced wind energy power stations with power ratings up to approximately 500 kW. Very large wind energy converters in the megawatt range were developed, but as yet their commercial commitment is small.

The speed of wind turbine rotors is typically 30 to 50 rpm and the generator is coupled to the turbine via the gear box so that it can rotate at 1500 rpm.

The generator rated voltage 400 V is used up to approximately power 300 kW, voltage 690 V up to 750 kW and the suitable high voltage for higher power.

The induction generators are usually used in the whole range of powers and for the most part with cage rotors. The induction generator with a higher resistance of cage rotor (Tjaereborg Wind Turbine 2 MW), or induction wound rotor generator in oversynchronous cascade (AWEC-60 1,2 MW), are tested for the modification of the speed-power curves. For a better service of wind power stations with a low velocity of wind, two generators with different speeds \(2p = 4/6\) are used. Only one generator, with poles changed by Prof. Rawcliffe pole amplitude modulation (Richborough 1 MW Wind Turbine), has also been tested.

The synchronous generators, usually of power 500 kW, are operated at constant speed, or at variable speed and variable voltage with a semiconductor convertor.

Direct driven generators, without gear box are being developed with the aim of decreasing the noise and increasing the time of life of the wind power stations. Low speed synchronous or induction generators rated more than 100 kW for typical wind turbine rotors must have more than 150 poles. This causes difficulties in the design of these generators. Because the size of generator increases with the number of poles, and the minimum practicable pole pitch may be about 50 mm, generators have a large diameter and are weightly.

High speed induction generators are usually used in wind power stations because they are simple and robust. We studied the possibilities of the design of the squirrel cage induction generator for direct driven wind power stations. We chose the generator rated 630 kW, 690 V and 50 Hz for the design. We chose the synchronous speed 33,3 rpm, and the corresponding number of poles was \(2p = 180\).

We designed the stator of the generator with the minimal number of slots per pole per phase regarding sinusoidal voltage on the machine terminals, and the minimal width of slots and minimal workable width of teeth. The large number of poles results in a relatively large inner diameter of the stator, which requires a relatively large air gap between stator and rotor. The large air gap and large number of poles leads in the usual electromagnetic design of the magnetic circuit, to a large magnetizing current and to a low power factor. A design with a longer magnetic circuit results in a large mass, and such a machine is not serviceable.
in comparison with e.g. synchronous generator. We were not successful in the design of an
induction generator for the chosen parameters that could be realized in praxis.

The basic design of the synchronous generator was easier, but similar difficulties to those
for the induction generator were met in the detailed design (large diameter, nonsinusoidal
voltage on the terminals due to the small number of slots per pole per phase). Further more
the poles on the rotor were too narrow to use the amortisseur winding.

The solution of these difficulties was found in the synchronous or induction generator
for direct driven wind power stations with a lower number of pole pairs. In this way the
generator has a smaller appropriate diameter, but the produced electric energy has a lower
frequency than the grid. Therefore a semiconductor frequency converter must be used.

In comparison with the synchronous generator the induction generator must be con­
ected to the power grid by a frequency converter with phase controlled rectifier. The rated
frequency of the induction generator and the poles number is chosen as low as possible.
Nevertheless the induction generator has lower power factor and is substantially weighty.

The firm Enercon GmbH is the only manufacture up to now which delivers the wind
power stations with direct driven generators. This unit is rated 500 kW, 18 - 40 rpm and
has an AC/DC/AC converter and a synchronous generator with a rotor diameter of 4 m
and an external diameter of stator covers 5 m.

Attempts have been made to solve the problems of direct drive of generators by the new
operational principles of wind turbines and generators. The firm Heidelberg motor GmbH
produces vertical axis wind turbines with integrated permanent magnet ring producing the
rotating field. The maximum rated power is 1,2 MW.

Many other new operational principles of electric generators are being tested. We may
introduce for example a variable reluctance generator, an induction generator with a stator
formed only by a segment and with axial air gap and disc rotor, a generator with axial air
gap and with a wound rotor between two disc rotors with permanent magnets etc.

From the study made we may recommend the concept with a high speed induction
generator and gear box from a proved manufacture or the concept with a low speed syn­
chronous generator and frequency converter. Both products are available on the European
market at nearly the same price.

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This research has been conducted at the Department of Electrical Drives and Traction
as part of the research project “Wind Power Generators for the use in the Czech Republic”
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FIRST EXPERIENCE WITH MAGNETIC BEARING

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Key words: magnetic bearing, control, testing

The idea of using magnetic force for bearings originates in the last century but dynamic development in this field started in the 1970's, especially in space research.

The basic principle of the magnetic bearings appears to be simple. Two electromagnets in each controlled axis act upon the rotor so that equilibrium of forces is achieved and the rotor is stabilized in its required position. This equilibrium can only be obtained by the active control of the exiting currents of the two electromagnets.

It was decided to build a theoretical and experimental workplace of magnetic bearings at the Department of Electrical Drives and Traction at the beginning of 1992 and a technical project was prepared.

This workplace is composed of a mechanical set consisting of a long rotor supported by one conventional bearing and one radial magnetic bearing. The whole system is driven by a DC machine. The power electronics which energizes the magnetic bearing consists of a diod rectifier with a voltage DC link and four transistor choppers. The control part of the equipment is designed by the use of analog technic devices.

All parts of the workplace were designed in the first period of this research [1]. The second period was conducted on a temporal construction of the mechanical part. This construction allowed only a testing of the bearing behavior in stillstand and enabled the basic tuning of controllers. The design of the electromagnetic part of the bearing was also controlled in this period. The results of measured force led to the necessity of changing the design methodology [2], [3].

The control part of the bearing splits into current controllers and position controllers. The aim of current controllers is to ensure the required value of exiting currents of all four electromagnets. It follows that there are four current control loops - two for every axis. The two current controllers receive the required value of current as an output of the same position controller. Since the solving of the current control loop is a standard problem, the structure of controller is also standard. The PI controller was chosen and tuned experimentally. The design of the two position controllers is more complex and complicated. The use of PD or PID controllers appears to be the easiest solution for realization with analog circuits. The PID controller was chosen.

The behavior of the controller was simulated in cooperation with the Department of Control Technic on computer by program MATLAB and the approximate parameters of the controller were set up. Experimental optimisation followed. The method used for optimisation was based on system response to external force impulse [4].

It showed that the parameters set theoretically were not correct because the original values in the mathematical description used here were incorrect. But this simulation gave some answers about the properties of the control loop.
Another part of the research was concerned with the formulation of the mathematical
description of the whole system leading to a detailed mathematical model of both current
and position control loops. The accuracy of this model was proved by a computer simulation
of experiments conducted during controllers optimisation. Both current control loop and
position control loop were described and simulated.

The construction of the workplace was finished recently by the installation of the testing
stand, which was made free of charge in the CKD Elektrotechnika company. This new
configuration required the new optimisation of controllers parameters due to the different
parameters of the system (the mass of the rotor is significantly different here).

It was possible to run the equipment then and check the performance of the magnetic
bearing during rotation. Although low speed was applied it appeared that the bearing is
capable of functioning in the range up to 3000 rpm, at least.

The failure of a position sensor at that time prevented further investigation. It is
supposed that the bearing should be able to operate even at speed several times higher.

The break down of the position sensor caused delay in all work conducted on the
equipment. Another supplier of the inductive sensors was found at that time. SCHENCK
IN-81 sensors should be replaced by sensors IS 2 made at STU Bratislava. These offer
similar parameters but their price is lower.

As soon as those new sensors are mounted on the bearing testing of the dynamic be­

havior can be continued. The next period in the project will be measuring the mechanical
parameters of the system dependant on the controllers parameters. Also, the ability to run
the magnetic bearing at speed close to, and above, the critical speed of the system can be
tested.

The article presented above shows that the aim of the Internal grant of CTU for 1994
was successfully fulfilled.

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This research has been conducted at the Department of Electrical Drives and Traction
as part of the research project “Theoretical & experimental workplace of magnetic bearings”
and has been supported by CTU grant No. 38149.
DYNAMICAL CHARACTERISTICS
OF A FLEXIBLE ROTOR
SUPPORTED BY MAGNETIC BEARING

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Key words: magnetic bearing, control, critical shaft speed

The design of machines often requires the rotor is supported by bearings exploited in extreme conditions, e.g. high speed revolutions, low temperatures, vacuum or special gas. Application of frequently used bearings is in such conditions very limited or excluded. In the present time, there is a possibility to use magnetic bearings. There are several well-known research centers, that develop magnetic bearings. There is also a number of practical applications especially to machines with rotating parts and a number of publications has been devoted to this topic.

The idea to create a theoretical and experimental laboratory of magnetic bearing was materialized by Department of Electric Machines and Drives (K314) at the Faculty of Electrotechnical Engineering of CTU. Our Department of Mechanics K231 participated on this project. A subsidy was obtained after winning internal grants No. 28149 and 38149 during 1993 and 1994. The coordinator of both grants was professor Pavelka at Dept. K314.

The research activities in 1994 continued the results achieved in 1993, they have been already presented in two papers on CTU Workshop 94. In can be quoted, that the aims we have stated in the grant in 1994, were achieved. The experimental device for testing the characteristics of the magnetic bearing, the different feeding and control systems has been already assembled and put into operation. This experimental device, the most important part of the laboratory of magnetic bearings, also offers an experimental measurement of the dynamical behavior of a rotor supported by one magnetic bearing and one swivel ball bearing. More detailed information about the experimental device and its characteristics are presented in another paper on this Workshop 95.

Our research group from Dept. K231 during 1994 devoted, besides participation on the last workshop operations and assembly of the mechanical part of the device devoted, a great deal of research activities to theoretical investigation of the dynamical behavior of the flexible rotor supported by one active magnetic bearing. First of all, we had created an appropriate mathematical model describing the electromechanical system consisting of magnetic bearing and its feeding and control system. On the basis of the mathematical model a program for simulation of the electromechanical system was created. The program was used for considering the stability of the system, simulation of the system's response on a jump of the loading force and for simulation of the system's behavior when running through critical revolutions. The obtained results are now used for theoretical research of the dynamic characteristics of a rotor supported by two magnetic bearings. The problem of such supported rotor is now theoretically considered, too. The results obtained from numerical simulations will be compared with values measured on the experimental device. The results of our research work during 1994 are presented in the research report [4]. The
problem of a rotor supported by two magnetic bearings is also dealt with in the diploma work [5] defeated in our Department in 1994.

References:


This research has been conducted at the Department of Electrical Machines, Apparatus and Drives and at the Department of Mechanics as a part of the research project “Theoretical and Experimental Workplace of Magnetic Bearings” and has been supported by CTU grant No. 28149.
THEORY AND DESIGN OF MAGNETIC POWDER SHAFT SEAL

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Key words: magnetic powder shaft seal, rotation heat engines, pressure difference, experimental device, magnetic circuit

This paper presents a contribution for designing of the ferromagnetic shaft seal with powder packing. The shaft seals for rotation heat engines make an important construction knot of these devices. It must suit the demanding conditions of rotation heat engines operation while accomplishing often antagonistic design and operation requirements.

In technical practice two basic arrangements of the shaft seals for the rotation heat engines are used: contact and noncontact seal. There is a connecting link which partly removes the disadvantages of both arrangements while the full function of the seal is preserved: the ferromagnetic shaft seal with powder packing.

This topic presents a theoretical value of pressure difference across 1° shaft seal device for the rotation heat engines and it also presents the design and construction of a single-purpose testing device for the theoretical results verification.

The design of the magnetic ferro-fluid seal is known from laboratory and vacuum instrument devices. It is necessary to specify some basic differences for rotation heat engines seals: design limit of circuit velocity in a gap (revolutions, shaft diameter), temperature limit (loss of magnetic property), radial seal gap (abs. size of the gap and non-alignment during shaft rotation in journal bearings) etc. By reason of the work reliability the seals are commonly designed with the permanent magnets. The theoretical calculation and the designed experimental device consider the creating of a magnetic circuit with an electromagnet (a quick change of circuit parameters – could be possible).

A physical principle for the solution starts from the Maxwell equations for a statical magnetic field. The equations have been applied to annular coil settled in ferromagnetical stator. One closed magnetic circuit of the seal consists of a stator with two radial edges and a rotor. Magnetic circuit is thus closed across these mentioned above elements. The radial gaps below the edges are filled with ferromagnetic powder (middle size of grain to 0,001 mm).

By calculating the I and IV Maxwell equations in an integral form for a magnetic induction and field intensity for known geometrical dimensions and magnetomotive voltage will be the size of the energy density in a gap filled with powder.

It is also possible to calculate the force which makes the energy change in the gap when a very small powder shifting happened by raising different pressures across the seal. The result is the theoretical pressure difference across the seal proportional to this force.

The experimental device: the stator dimensions have been designated on the basis of the preliminary calculations. On the assumption of max. circuit velocity have been given the shaft diameter (100 mm) and the revolutions (10 000 1/min). For the verification of the theoretical results the device enables: to change revolutions, a torsional moment, current
and voltage at coils, medium pressure inside a stator, radial gap on an edge and radial non-alignment within the range of hypothetical boundary conditions for the calculation.

Description of the experimental device (Fig. 1): the device consists of a stator (1) centring horizontal and vertical adjusting screw (2). A cylindrical rotor (3) supported between the ball bearings in the pedestals (4) and joined by a clutch to an electric motor. The whole device is mounted on the base - plate (5). Inside the stator there are two conforming mag. seals (6) in opposite polarization with an annular coil (7), fed from a stabilized el. source. The pressure medium is connected to a hole (8). Seal edges (9) create polarized the polepieces an together with the mag. powder (10) the magnetic circuit is closed.

This research has been conducted at the Department of Heat and Nuclear Power Energy Equipment as part of the research project "Theory and Design of Magnetic Powder Shaft Seal" and has been supported by TU grant No. A 7/94.

![Fig. 1](image-url)
RECENT PROGRESS IN ENGINEERING THERMODYNAMICS RESEARCH

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Key words: thermodynamics, experimental research, velocity of sound, computer simulation, thermophysical property

Introduction. A General outline of the research program in the field of engineering thermodynamics was presented in [1]. The last year scheme of activities contributing to better understanding of thermodynamics phenomena via combination of simulation and experiment is presented in Fig. 1.

Fig. 1: Scheme of the research activities

Experimental Research: (a) The final evaluation of the sonic measurements in R123 was performed and the publication is in progress. (b) The study of the new experimental equipment for the velocity of sound measurements in liquid phase was completed [2].

Computer Simulations of Thermodynamics Problem: (a) THERMODYNAMIC PROPERTIES OF LIQUID CHLORINE AND CARBON DIOXIDE MODELED BY '2-LENNARD-JONES CENTERS' PAIR POTENTIALS AND BY QUADRUPLE MOMENT. Computer simulations using molecular dynamics calculations were carried out for model liquid systems of 108 Cl₂ and CO₂ molecules interacting through two Lennard-Jones (12-6) centers coinciding with the positions of the atomic masses (the 'atom-atom' pair potential). In the case of CO₂ the quadruple moment was included. Thermodynamically consistent expressions for the energy and the pressure as functions of density and temperature were obtained for each systems. The introduction of CO₂ quadruple moment slightly improved the agreement between calculated thermodynamic quantities and experimental data [submitted to Acta Polytechnica].
(b) THE SECOND VIRIAL COEFFICIENTS OF REFRIGERANTS HFC-32: $CH_2F_2$, HFC-23: $CHF_3$ AND HCFC-22: $CHClF_2$. The second virial coefficients of the three refrigerants were calculated on the basis of site-site model potential and compared with experimental results. Molecular interactions consisted of van der Waals and electrostatic parts. The van der Waals interactions were described by a distance-buffered potential: Buf-14-7($\delta$, $\gamma$). Electrostatic interactions were approximated by a Coulombic potential. The interaction sites were considered at the atom nuclei and molecules were assumed as mechanically-rigid bodies. It was found that a satisfactory agreement between measured and calculated second virial coefficients (see Fig. 2) could be achieved only by a change of buffering constant of Buf-14-7($\delta$, $\gamma$) potential and by a slight increase in experimentally determined dipole moment value. A subsequent sound velocity calculation from the calculated second virial coefficients was also discussed for gaseous refrigerants.

Information transfer. The activity in the field continued under the scheme of small databases on PC platform and also on Macintosh platform ($H_2O$, new refrigerants).

References:

This research has been conducted at the Department of Fluid Dynamics and Thermodynamics as part of the research project “Engineering Thermodynamics-Experiment and Simulation” and has been supported via co-operation with Cornell University, Keio and Kyoto University by financial support of the Monbusho.
START OF A RAIL VEHICLE
RIDING ON A MAGNETIC CUSHION
AND DRIVEN BY
A LINEAR INDUCTION MOTOR

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Key words: partial differential equations of parabolic type, quasi-stationary electromagnetic field, linear induction motor

The paper presented constitutes a continuation of the author's papers on finite difference electrodynamics and on transient eddy currents presented at the Czech Technical University Workshops in 1992 and 1993, as well as of a paper written together with Nguyen Van Nhac, entitled "Finite difference, finite element and boundary element formulae as a language of physics" and presented at the Computational Physics '90 meeting in Amsterdam.

We shall concentrate on the interaction between the moving part of the linear induction motor and the rail and shall not describe the mechanism of magnetic levitation.

We shall concentrate on the two-dimensional quasistationary electromagnetic field. In this case, only one component of the electrical field intensity $E$ is different from zero and the original vector problem degenerates to a scalar problem. From various possible two-dimensional problems, we are quoting the following two:

1. the planar problem: both the rail and the moving part of the linear induction motor are infinitely broad, but they can be of finite length. The winding is composed of doublets of infinitely long wires (Fig. 1). Note: The occurrence of insulating layers sandwiched between the magnetic sheets forming the magnetic core of the linear induction motor is respected by taking a low average electrical conductivity of the magnetic material.

2. the cylindrically symmetrical problem: the rail is a cylinder of circular cross-section of finite length. The moving part of the linear induction motor is constituted by a hollow cylinder concentrical of the previous. The winding is composed of doublets of circular meshes lying in circular groves (Fig. 2 and 3).

Principle of violated cylindrical symmetry: The ideal cylindrical symmetry requires the rail to float in the air. We are violating this symmetry by cutting the moving part of the linear induction motor, connecting the circular loops by straight line segments and by joining the rail by means of a thin plate having a negligible magnetic resistance to the foundation.

In order to oversimplify the problem, we use rectangular alternating current instead of a sinusoidal one and we are taking the number of phases greater than three, e.g. four, six, etc.
In this stage of research, we study the so-called "initial tendencies", i.e., we calculate the electromagnetic field and the mechanical forces while the moving part of the linear induction motor stays at rest.

This research has been conducted at the Departments of Mathematics of the Faculty of Nuclear Sciences and Physical Engineering as a part of a long term research on numerical methods for the solution of partial differential equations and has not been supported by any grant.
EVALUATION OF SPACE QUALITY
LIGHTING THROUGH
A NEW INTEGRAL CHARACTERISTIC

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Key words: integral characteristic, average spherical illumination, average cubic illumination, light flow vector

A light field can be described by various integral characteristic. The well known ones are the average spherical illumination ($E_4$), the illumination of the plane surface ($E$), the average cylindrical illumination ($E_c$), the direction of the flow of light ($E$), etc. The advantage of integral characteristics is the simplification of the light field description. In comparison with the general light field characteristics, which describe the field in each point by an infinite amount of values, these integral characteristics provide the possibility to appreciate quantitatively the particular property of an illumination in the point of space using one value of this quality only.

The integral characteristic is in general equal to the mean value of the basic model of the illumination receiver and it is defined by the equation in integral form

$$C = \int_0^{2\pi} f_c \cdot L(\alpha, \delta) \cdot d\Omega(\alpha, \delta)$$

where

- $C$ is the general integral characteristic,
- $L(\alpha, \delta)$ is the luminance of beams of spherical co-ordinates $\alpha, \delta$ bellowing to the spherical angle element $d\Omega(\alpha, \delta)$
- $f_c$ is the receiving function of the model receiver, defining the degree of reaction of the receiver on the impacting radiation. For example, for $E_4$, the receiving function is $f_c = 0.25$, for illumination $E$, $f_c = \cos \beta$, where $\beta$ is the angle between the normal of the receiver surface and the direction $(\alpha, \delta)$.

Also the average cubic illumination $E_{c0}$ can be derived from equations (1), (2). The receiving function of the elementary cubic receiver is then

$$f_c = \frac{1}{6} \sum_{j=1}^{6} \cos \beta_j$$

where

- $\beta_j$ is the angle between the normal to the one from 6 surface of the elementary cube and the direction of the light beam characterized by the angle co-ordinates $\alpha, \delta$.

Some of the equations can be simplified in practice, because the point source of light can illuminate not more than 3 walls, the linear source illuminates not more then 4 walls, and the planar one illuminates, at most 5, cube walls.
To verify the usability of the characteristic E6 model calculations of different types of fields of light sources were performed. Evaluation of measured data shows the analogous distribution of both values $E_{44}$ and $E_{40}$ though their absolute values are different. The values of the cubic illumination $E_{40}$ were from 0 to 14% higher than the values of the spherical illumination $E_{44}$ in the same points. The average divergence was less than 10%. This conclusion shows that for the average cubic illumination, the recommended values for the average spherical illumination could be use.

The calculus of $E_{40}$ is not complicated, because it deals with the illumination of planes. Simultaneously both 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 projectives of the direction of the light flow vector into a given co-ordinate axis, signifying the difference of illumination of opposite walls of the cubic.

In the same way, these procedures offer the whole statement of the light vector, and additionally, the further parameters analoqous with known average cylindrical illumination and both hemispherical and hemicylindrical illumination values.

*This research has been conducted at the Department of Power Engineering.*
FREQUENCY PROPERTIES OF POWER TRANSFORMERS

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Key words: electromagnetic interference, power transformer, frequency characteristics

The power transformer is one of the most important parts of the supply system of many electronic devices. Its main role of changing voltage to desired level is being extended with respect to electromagnetic interferences (EMI), spreading along power networks. This EMI may cause undesirable defects in control systems supplied through the transformer. In this connection, the transmitting parameters of a power transformer have an important role, which may be significant for dealing with EMI effects. Our analyses deal with frequency transmitting characteristics of several types of low power transformers. A schematic diagram of a power transformer was synthesised for a usable wide frequency range (see Fig. 1). For calculation of frequency characteristics, parameters of individual element in the schematic diagram were measured. To achieve high accuracy, these parameters were measured in wide frequency range from 10 kHz to 30 MHz, and their frequency dependence was taken into account.

![Fig. 1: Schematic diagram of a power transformer for wide frequency range.](image)

The transmission frequency characteristics were calculated for loaded and unloaded transformers. Theoretical and experimental results are in good correspondence. Significant resonant swings are observed in unloaded transformers. These swings are damped when the transformer is under load (see Fig. 2). But, in a frequency range of several MHz the effect of primary and secondary capacitance will arise. Therefore, an additional HF filter must be used.
Fig. 2: Calculated (a) and measured (b) transmission frequency characteristic of an unloaded (full line) and of a loaded (dash line) power transformer.

References:

This research has been conducted at the Department of Electrical Drives and Traction and has not been supported by any grant.
MODELLING OF AN ARC BEHAVIOUR

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Key words: arc, arc modelling, arc plasma

Introduction. Information about electric arc behaviour in technical systems which include circuit breakers is of great present importance. Quantities for the arc plasma shape and temperature distribution in the arc column are particularly wanted. In principle, these quantities could be obtained by the simultaneous solution of the differential equations describing mass, momentum and energy conservation together with Ohm's law and Maxwell's equations. However, this straightforward solution is impossible in practice, even with modern computers, because the equations are highly non-linear and some of the complicated arc conditions such as radiation heat transfer (particularly for a contaminated plasma) are very difficult to define mathematically. Consequently, arc modelling still involves the need to make some simplifications. In our study, the switching arc in a model of the quenching chamber of a self-pressuring rotary arc SF₆ interrupter was subjected to an optical diagnostics process to obtain information about arc plasma shape during arcing. The experimental data thus obtained were used in a simplified theoretical calculation of the arc temperature and electric field.

Theory. The results of recent experiments [1-3] have been used in theoretical calculations of the arc plasma temperature in the plasma column. Optical diagnostics of the switching arc in the quenching chamber of a circuit breaker with SF₆ have made it possible to determine the arc shape in space. The shape of the arc column is very irregular, the arc radius varies very much with vertical direction.

For further calculations we used the arc radii measured in the lower part of the arc column near the insulation nozzle, where the arc can be assumed to be relatively stabilised by the gas flow. Upper part of the arc column is forced to rotate along the coil due to the relatively strong magnetic field near the coil.

Arc radii have been used as input data in solution of an energy balance equation to obtain approximate values of the arc plasma temperature and electric field. Several simplifications have been taken into account:

- the arc is assumed to be an infinite cylinder
- there is no interaction between arc plasma and electrodes
- local thermodynamic equilibrium is assumed
- convection is neglected
- electric field is assumed to be uniform in the arc column
- no contamination is taken into account.

Because this description is very simplified and the assumed approximations are very rough for switching arcs, it serves only to illustrate approximate values of the arc plasma temperature and electric field, and their behaviour during arcing. Our next step will be...
to make some spectroscopy measurements of the arc plasma temperature which will be compared to the theoretical one.

The equation of energy balance is solved by a relaxation method based on a solution of a time dependent energy balance equation [5]. Radiative heat transfer was treated by the method of partial characteristics [4].

Conclusions. Experiments with model of quenching chamber of self-presurising and rotary-arc SF₆ interrupter were made [1-3]. All measurements were accomplished by using optical diagnostics of the switching arc. Experimental data were used in a simplified theoretical calculation of the arc temperature and electric field. Even if the theoretical model of the arc is too simplistic to describe all processes during the arcing in circuit breaker, we think it can give approximate values of temperature and electric field which are needed for further analysis of the switching process.

References:


This research has been carried out at the Department of Electrical Machines and Apparatuses as a part of the research project "The modelling of the electric arc in the quenching chamber of circuit breaker and the checking of results by experiments" and has been supported by TU grant No. A 2/94.
SWITCHING ARC DIAGNOSTICS

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Key words: arc, switching arc, plasma diagnostic, arc modelling

Introduction. Information about electrical arc behavior in the technical systems including circuit breakers is of a great importance in the present state of the art. The method of optical diagnostics of the switching arc in the physical model of quenching chamber of a one-pressure 11kV power circuit breaker with SF$_6$ gas of the 'self-blast' type with rotation of the switching arc in the magnetic field of an installed three-turn coil is presented. Data obtained are used for the computer reconstruction and animation of the arc image in the quenching chamber space.

Experiments were carried out in a testing circuit of switching current 2.8 kA (7.2 kV). SF$_6$ overpressure in the chamber was of 0.4 MPa, the moving contact speed and diameter 2.4 m/s and 13 mm, respectively [1].

The switching arc in the quenching chamber was simultaneously photographed from two fixed rectangular directions using a set of mirrors by a high speed camera (4000 frames per second) [2].

The negative film with pairs of the arc records was digitized on microdensitometer and equidensitometrically analyzed for further processing. AutoCAD package was used for the computer spatial reconstruction of the switching arc image in the quenching chamber space. A sequence of spatial reconstructed arc images made it possible to animate the arc behavior in the quenching chamber during the switching process [3].

Results. The animation of the reconstructed arc images gives a unique opportunity for the studying of the arc behavior in confrontation with electrical and mechanical quantities usually measured [4]. It is possible to monitor the changes of the arc shape in time and space, and furthermore, to determine hardly accessible arc characteristics such are the arc surface, volume and diameter and the length of the central filament of the arc column. The rate of the arc root movement along the contact, the erosion of which is closely connected with the rupturing capability and life of the circuit breaker, can be also determined.

Two spatial reconstructed arc images at moments corresponding to the time of 4.15 ms and 0.65 ms before the arc extinction are shown in Fig. 1 and 2. The experimental model of the quenching chamber allowed the monitoring of only a part of the arc in the so called accumulation space, i.e. approximately between the coil (upper contact) and the bottom teflon nozzle which separates the accumulation and expansion space of the quenching chamber. The moving contact, which is not illustrated in the figures, is underneath the nozzle in the expansion space.

Conclusions. Computer techniques offer a new possibility of analyzing and processing experimental data in an accessible and inspiring form. Numerically evaluated and equidensitometrically processed photographs of the arc in the environment of AutoCAD and its superstructures enable the spatial reconstruction of the arc image and open new possibilities for the analysis of experimental data. The sequence of the reconstructed arc images and
their animation provide information about the switching arc in a form readily understandable to students and inspiring research and development workers in the plasma technology field.

References:


This research has been carried out at the Department of Electrical Machines and Apparatuses as part of the research project "The modelling of the electric arc in the quenching chamber of circuit breaker and the checking of results by experiments" and has been supported by TU grant No. A 2/94.
APPLICATION OF ALKALINE ACCUMULATORS FOR PROTECTION OF ENVIRONMENT

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Key words: alkaline accumulators, wind-power plants, photovoltaic batteries, electromobiles, capacity of accumulators

This project is devoted to application of alkaline accumulators in two ecological programs. One of them includes the application of alkaline accumulators for accumulation of electric energy from renewable resources (wind-power plants, photovoltaic batteries), the other is given over to the use of alkaline accumulator batteries as the resources of electric energy in electromobiles. The targets of the project are both short- and long-term measurements (the latter in particular) of the electro-chemical parameters in the nickel-cadmium and nickel-iron accumulators, mainly those under operation by their users.

The results obtained from our assessments over a period of one year and three quarters of operation revealed that a 12V Ni-Cd battery having the capacity of 120 Ah in the system with a wind-power plant, type AVE 500 with an output of 500 W, manufacturer AVECO Brno Ltd. in the town of Letovice near Brno, brought about minimum decrease in the capacity of these accumulators. The capacity decrease in the Ni-Cd traction accumulators, type KPM 120 P, amounted to 0.2 % only. At the same time the influence exerted by the electrolyte carbonization on the capacity of aforesaid accumulators was established as minimum, the decrease being 0.8 % only.

Measurements were made of the of the charging efficiency in a 12 V Ni-Cd battery having the capacity of 48 Ah and consisting of cells, type KPM 48 P; when charged from a solar panel from TRIMEX TESLA Ltd., the peak output being 159 W up to 16 V unless the charging current value did drop under 500 mA.

When the value of 16 V had been attained the accumulator battery was discharged via loading up to the final discharging value of 10.5 V and then switched over to charging. In course of the long-term measurement the charge 134 Ah was supplied to the battery and the total charge drain had a value of 92 Ah. The ampere-hour efficiency of the accumulator battery in the set regime was 68.8 %.

The operation of a photovoltaic battery having the capacity 25 W, producer SOLARGLAS Ltd. Treboň, was subject to verification. The photovoltaic panel was used for charging 12 V alkaline Ni-Cd battery with a capacity of 45 Ah. The used Ni-Cd accumulator battery served for feeding a TV set, the current supplied being 1.5 A. The experimental operation was underway from June 1st till September 1993. Two working regimes of the photovoltaic battery - electric consumer system were applied: Regime I represented permanent connection of the Ni-Cd battery with the photovoltaic panel for a period of three weeks without any limitation of its overcharging. During the whole period this operation was going on the photovoltaic panel was manually turned, the reason being to retain perpendicularity of incident radiation with a maximum error of 15 degrees. The weather at that time was
sunny with occasional intervals of slight cloudiness. Discharging the battery that was safeguarding the TV set feeding was carried out daily for a period of 140 to 270 minutes and until the final value of 10 V, which corresponded to the value of 1.0 V per one cell. The aforesaid time of the TV feeding corresponded to the power consumption ranging from 3.4 up to 6.8 Ah from the Ni-Cd battery. Regime II was subject to verification over the July - September period in 1993, the respective durations of sunshine being 7.7 hours, 8.7 hours and 6.1 hours daily. The battery charging from photovoltaic panel was carried out five days a week continually and with no discharging. On Saturdays and Sundays the discharging was performed using the current of 1.5 A for a period ranging from 8 hours (sunny weather) to 4 hours (cloudy weather). During the month of September the accumulated energy was capable of feeding TV set for two hours only. In this Regime II the panel was adjusted to the position that the solar radiation was impinging it perpendicularly at the noon time.

To verify the possibility of applying the nickel-cadmium and nickel-iron accumulators, type KPM 120P of the pocket design and a capacity of 120 Ah, measurements were made of their capacity in relation to the value of discharging current within the range C5 up to C1. The purpose of these measurements was seen in verification of the possibility of using these batteries in electromobiles. The results obtained from the measurements brought evidence that the capacity of Ni-Cd and Ni-Fe accumulators was comparable within the range of discharging by means of the C5 - C1.5 currents. When discharged with the use of C1.2 and C1 currents the capacity of Ni-Fe accumulators was 26.7 % lower.

References:


This research has been conducted at the Department of Electrotechnology as part of the research project “Application of Alkaline Accumulators for Protection of Environment” and has been supported by TU Brno grant No. 994-C/4.
STUDIES OF THE COLLECTOR/ACTIVE MASS INTERFACE IN THE LEAD–ACID BATTERIES

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Key words: lead-acid batteries, collector/active mass interface, contact resistance, time effect, grid alloys

Lead–acid batteries have been used in technical practice for more than one hundred years; yet their development is still far from being finished. The effort to improve their use properties encounters so far a shortage of reliable information about the properties of complex, highly porous and non-equilibrium systems, which the electrodes of lead–acid batteries are.

Our research work dealing with the investigation of contact resistances within the electrode systems of lead–acid batteries significantly contributes to the knowledge and understanding of the electrode system. The changes of these resistances, as a matter of fact, clearly reflect physical and chemical processes taking place in the electrodes in the course of their service. The analysis is made possible by our original method of the direct in situ measurement of the resistance of the interface (i.e. contact layer) between the grid (i.e. collector) and the active mass [1]. This method allows a long-term continuous measurement and a detailed study of a number of phenomena, whose identification is by means of other methods not feasible. The very first applications of this method yielded new interesting and very useful findings [2].

Under normal circumstances the resistance of the contact layer on the positive electrode contributes only about 4 to 5% towards the total resistance of the battery. However, under certain unfavourable circumstances passivation of the electrode may occur for various reasons. This results in a significant increase of the resistance of the contact layer in some cases by as much as several orders of magnitude. The solution of this problem is particularly topical in the development of high–density–energy batteries [3]. The study of the contact layer may also greatly contribute to the solution of the PCL (Premature Capacity Loss) problem, which is currently intensively being studied, particularly in the context with the transition towards the low–antimon or antimon–free grids for sealed batteries [4]. The resistances of the contact layer on the negative electrodes are – when compared with those of the positive electrodes – by about two orders of magnitude lower. The fact that at these electrodes it is possible to ascertain changes of the contact resistances reliably as low as the tenths of milliohms, testifies to the high sensitivity of our measuring method.

The very first measurements on the positive electrodes showed considerable differences in the behaviour of the contact layer on collectors of different composition. In order to investigate this phenomenon more closely, a long-term investigation – in the framework of the current research project – was carried out. Its aim was to monitor seven types of
positive electrodes having collectors from different lead alloys, under different conditions occurring in the course of the battery service. These collectors were made from industrially manufactured grids supplied by various battery manufacturers.

The measurements at the positive electrodes confirmed considerable differences in the behaviour of the contact layer on collectors of different composition, no matter whether the electrode was on duty or off duty [5, 6]. The time changes of the resistance immediately after the end of charging confirm that they are the result of different, often contradictory, mechanisms. This so called time effect has been repeatedly studied with the aim to guarantee the reproducibility of the results of measurements of contact resistances. This is of great importance for the research on the PCL origin, which is being initiated (in close cooperation with the research group at CSIRO, Australia) at the present time.

The alternating temperature changes at positive electrodes bring about the irreversible changes (increase) of the contact layer resistance. This is probably due to the mechanical damage of the contact layer arising as the consequence of the very different thermal expansion coefficients of lead alloys on one side and of the lead dioxide on the other side. The increase of the contact layer resistance becomes higher as the antimon content in the grid alloy increases [6].

It was rather surprising to find non-negligible differences between the resistances of the contact layer of individual collector ribs of the same electrode. These differences become substantially greater as the time off duty (e.g. after charging) and a charge passed during discharge increase [7]. This phenomenon may in practice cause a non-uniform exploitation of different parts of the active mass of the same electrode, with all ensuing negative consequences for the use properties of the battery. A detailed study of the causes of this phenomenon will be a subject of our future work, too.

References:

This research has been conducted at the Department of Electrotechnology of TU Brno as part of the research project "Studies of the collector/active mass interface in the lead-acid batteries" and has been supported by TU grant No. 99/99.
USING OF NOREG CONVERTORS
FOR TEACHING OF ELECTRICAL DRIVES AND MECHATRONICS

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Key words: control, asynchronous motor, NOREG convertor, rectifier

NOREG is a three-phase AC voltage convertor. Each phase of the convertor circuit consists of two antiparallel thyristors, so the effective value of the output voltage can be varied between 0 and 380 VAC. The convertors are designed for power control of medium-size loads, for instance heaters or light fixtures.

The control part of the convertor consists of the control loop of the power circuit, driving the source of current firing pulses. The control circuit is an analog design, using operational amplifiers.

The advantage of this type of mass-produced convertors is a simple design and construction for a given power range (the thyristor module used is 80A/1200V) and relatively low price (when compared to to frequency convertors). Their disadvantage is that they are not possible to use them for electric drives.

The Department of Electrotechnics of Faculty of Mechanical Engineering CTU modified two convertors NOREG for purpose of teaching the students the electric drives oriented applications and the applications involving mechatronics.

The power circuit of the first convertor was left unchanged and its control circuit was modified to enable the soft-start of asynchronous motors by means of lower voltage. The soft-start modification can operate in three modes. The configuration of the system is performed manually by changing connection leads on the control panel, according to the circuit diagram.

The first mode represents a manual, low-voltage control of an asynchronous motor by a potentiometer controlling the phase angle of the convertor, thus the effective output voltage of the convertor.

The second mode enables the soft-start of asynchronous motor by a constant magnitude of the start current. The required phase angle is in this mode controlled by a PI current control circuit. The actual current value is set by a potentiometer located on the control panel. The advantage of this configuration is in already running, does not allow the current to exceed the present current value.

The third mode of operation represent the soft-start of asynchronous motor with a constant acceleration. In this type of control, the acceleration loop is superior to the above described current control. The actual value of acceleration is derived from analog differentiation of the signal of tachodynamo.

The second NOREG convertor was modified into a reversed rectifier. The convertor was populated by three additional pairs of thyristors and the power diagram was modified to emulate the antiparallel reverse control rectifier. The control circuits were enhanced to contain circuits for current reversal. The generator of firing pulses had to have three
synchronization transformers for phase shift of synchronization voltage added. This rectifier can operate in three modes, set manually by means of the control panel.

In the first mode, the angle (and, therefore, the output voltage) is set directly by a potentiometer.

In the second mode of operation, the current is controlled by an analog PI regulator. This mode is often used for loading the tested motors by a constant torque.

The third mode enables RPM control via a revolution-control loop by a PI regulator, superior to current control loop.

The Department of Electrotechnics intends to use the above-described systems with current control for the test equipment purposes, in which different types of loads (constant, linear, quadratic, large moment of inertia and/or their combination) can be modelled.

The concept of control structure of both modified NOREG converters is modular, enabling to replace individual components of the control diagram by a device/component, other than the standard configuration of the NOREG converter (which includes microprocessors).

This research has been conducted at the Department of Electrotechnical Engineering of Faculty of Mechanical Engineering CTU as part of the research project “Laboratory Exercises for Mechatronics” and has been supported by Ministry of Education grant No. 11-21001.
NEW CONTROL METHODS UNDER DEVELOPMENT AT DEPT. K-314

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Key words: electrical drive, vector control, direct self control, parameter identification

At the Department of Electrical Drives and Traction (K-314), emphasis is placed on the use of microcomputer techniques for the control of electric drives and converters. Problems are solved in a complex manner, which means that particular control algorithms are processed, and, simultaneously, supporting software devices are developed for facilitation of research and development work and for final appliance maintenance.

Field-oriented control is the most popular method for controlling high performance induction machine drives. Both of the two basic categories of field-oriented control, the indirect and the direct methods, have been analyzed. For indirect field-oriented controllers the sine wave modulation PWM strategy is assumed. Both transistor converters with a switching frequency order of kHz and GTO converters, where emphasis is placed on exact control of the switching frequency, are used in these techniques. The latter type of converter is prepared for use as the traction drive for Škoda Plzeň.

Currently IGBT inverters allow an improved direct self control with fuzzy-logic features [1]. First in this process, the magnitude of the stator flux space vector is checked. The actual stator flux components can be calculated from the armature voltage and current signals in the stationary reference frame. Then the angle between the stator flux and the reference axis can be calculated. The electrical torque is estimated from the flux and current information as

\[ m_e = K_p (\psi_{as} i_{bs} - \psi_{bs} i_{as}) \]

The table below shows the influence of the converter switching state on the behavior of induction machines. States I, V, VI are used when the stator flux is to increase. States II, III, IV cause a decrease of the stator flux. States I, II, VI are used for increasing electric torque. At given trajectory of \(|\psi_s|\), state I has the biggest influence and state VI has the smallest. If the torque is to be decreased, states II, IV, V are used. State IV should be used at the biggest torque error and state III at the smallest.

<table>
<thead>
<tr>
<th>Torque</th>
<th>Flux error</th>
<th>Negative</th>
<th>Zero</th>
<th>Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Large</td>
<td>IV</td>
<td>IV</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Negative Small</td>
<td>III</td>
<td>0</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Positive Small</td>
<td>II</td>
<td>1</td>
<td>VI</td>
<td></td>
</tr>
<tr>
<td>Positive Large</td>
<td>II</td>
<td>1</td>
<td>I</td>
<td></td>
</tr>
</tbody>
</table>
The analysis given in [3] contains the requirement for high performance induction drive control algorithms. It shows that the commonly used indirect vector control technique is strongly dependent on the accuracy of the motor parameters used in the computation model. The way of overcoming this dependency is to build an adaptive control system — nowadays, in full digital environment.

For the induction motor drive, the equivalent model takes various types of descriptions (\(T'\)-form, \(T''\)-form, \(T''\>-form, etc.). The aim of the identification procedure is to set-up the values of the equivalent model parameters. The proposed method of identification (inherited from [2]) is based on the fact that the equivalent scheme of the induction motor could be taken as frequency dependent impedance circuit. By controlling the inverter switches 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 the computing procedure. The output of this is the first estimation of the system parameters. Then, the process continues, by the iterative procedure, to reach estimation stability. The resulting values come to the controller algorithms according to standard rules (e.g., symmetrical optimum). The second part of this complex system forms the adaptation features of the control algorithm. There are many ways to fulfill the requirements for the high performance drive. We intend to use the MRAC (Model Reference Adaptive Control) method.

Most of our department research activities have close connections with Czech enterprises. For those purposes, industrial control means are used, for example the one-board control computer D 8201-N3 manufactured by Škoda Plzeň. This unit is constituted by an autonomous microcontroller, the monolithic circuit Intel 196KR, operating with a clock frequency of 16 MHz, which makes use of all on-chip peripheral blocks and also provides further options. For very fast applications the use of DSP is required. It was designed as an optional board operating on the clock cycle of 40 MHz, based on the microprocessor TMS 320C25. Communication between both processors (180C196KR and TMS 320C25) uses a dual-port RAM. The DSP is connected via A/D and D/A converters with a controlled drive. The circuit AD 7874, which consists of 4 fast 12 bit A/D converters with simultaneous conversion on all channels in time 32.5 \(\mu\)s is used. The characteristics of this design are very useful for an electric drives control based on a machine’s model.

References:


This research has been conducted at the Department of Electrical Drives and Traction as part of the research project “Microprocessor and Adaptive Control of Electrical Drives” and has been supported by GA ČR grant No.102/94/1541.
THE ELECTRICAL DRIVE
WITH A RELUCTANCE MOTOR

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Key words: reluctance motor, axially laminated rotor, vector control, observer

The synchronous reluctance motor (SynRM) is an AC machine with the three phase stator which is identical to the stator used in an induction motor and with a rotor that has a different reluctance in the d-axis and q-axis. The simplest rotor of this type used before 1960s had salient poles, with unfavourable ratio of $L_d/L_q$ (2-3) and thus with a substantially lower torque than a comparable induction motor. A construction with the axially laminated (AL) rotor is more advantegous. Fig. 1 shows a cross-section of the AL rotor manufactured for this project. It's a four-pole machine, the nonmagnetic material between the laminations being aluminium. The ratio of $L_d/L_q$ for that AL rotor equals to 7-8. This type of SynRM can achieve a torque and efficiency approaching to the values of a comparable induction machine. The torque of a SynRM is expressed by the equation

$$M = \frac{3}{2} p (1 - \frac{L_q}{L_d}) (L_d i_d^i) i_q^1$$

Fig. 1: Axially laminated rotor structure

The SynRM is fed into the stator windings by three-phase sinusoidal current waveforms from a voltage-fed inverter with PWM. The motor is furnished with a position sensor.

The mathematical model of a SynRM, including iron losses and leakage inductances is expressed by the set of equations

$$u_{ds} = R_s i_{ds} + L_d i_d^i - \omega \Psi_d + L_d i_d^i$$
$$u_{qs} = R_s i_{qs} + L_d i_q^i + \omega \Psi_q + L_q i_q^i$$

From an equivalent circuit of the SynRM (Fig. 2) the following applies

$$(i_d - i_d) R_{Fe} = u_{ds} - R_s i_{ds} - L_d i_d^i$$
$$(i_q - i_q) R_{Fe} = u_{qs} - R_s i_{qs} - L_q i_q^i$$
The torque \[ \frac{3}{2p}(\Psi_{q}\dot{i}_d - \Psi_{d}\dot{i}_q) = J\omega' + M_0 \]

![Fig. 2: The equivalent circuit of a SynRM](image)

An algorithm of a vector control is based on two current controllers: in the q-axis and in the d-axis. Reconstructed values of \( i_d \) and \( i_q \) from an observer are used for the feedback. The structure of the vector control of a SynRM is in Fig. 3

![Fig. 3: The structure of the vector control of a SynRM](image)

The experimental verification was performed with a SynRM of a rated torque of 8.5 Nm, 1500 rev/min, 380 V, 4.2 A. The SynRM was supplied from a voltage-fed inverter with IGBTs, sinusoidal PWM was performed by a programmable logic array Xilinx, the control system was based on a Motorola 56001 DSP.

![Fig. 4: The experimental system](image)

References:

[1] SKALICKÝ, J.: Rizení synchronního reluktančního motoru s pozorovatelem Sborník konf. EPVE '93, Brno, str. 12-17


This research has been conducted at the Department of Electrical Drives and Power Electronics as a part of the research project "The Intelligent Servodrives with Reluctance Motors" and has been supported by TU grant No. E74/93.
EXPERT SYSTEM FOR DIAGNOSTICS OF HV ELECTRICAL MACHINES

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Key words: expert system, insulation, diagnosis, high-voltage, electrical machines, database, reliability, measurement, evaluation, partial discharges, data processing, discharge activity

The aim of our research is to estimate the state of aging of the HV insulation, and to estimate both the safety of operation and the reliability of HV electric machines. The results of the project should help increase the reliability and safety of operation of large power generators and transformers working in the power system of the Czech Republic. That is, to realize a complex diagnostic and expert system of hard- and software facilities needed for the measuring and data processing of diagnostic measurements of electric machine insulation. Measurement of partial discharges (PD), i.e. discharge activity, is an important modern non-destructive method for testing high-voltage (HV) equipment which leads to increased reliability and operational safety of power system equipment. The advantage of the global method of PD-measurement consists, above all, in its completeness (i.e. all kinds of PD are measured in the complete phase of the alternator stator simultaneously), in its great sensitivity, its ability to measure with no complex adaptations on the machine to be measured, and in the relatively short measuring and result evaluation time. In the first step of this project, the computer program enabling the evaluation of data from the diagnostic measurement of discharge activity in HV insulation was made. The computer program is based on PARADOX and enables the input of data, and the evaluation and editing and saving of measured values of discharge activity including information and notes about the equipment (the machine, the HV electrical equipment, the sample of insulation, etc.) and measuring conditions. The evaluation of entered data and the calculation of parameters (maximum apparent charge q and sum charge Q in a half-cycle of supply voltage and power of PD) is performed automatically. Evaluated values can be corrected by several means. Output is displayed in the form of tables and graphs on the monitor of the computer or on the printer. The saving of values is performed for later evaluation. The input of measuring values can be done via the keyboard of a computer or directly from the PD-measuring equipment (PD-measuring unit). The interconnection was made between the computer and the measuring unit for the direct input measuring data into the computer [6]. It is done via I/O PC-card with 12-bit A/D converters. The detected analog signals are transmitted to the A/D conversion units; thence they are digitized and applied to the computer unit. There are two ways to take the PD-pulses from the PD-measuring unit (the user can choose). The first is the “classical” method of taking analog signals of apparent charge and sum charge from the pointer's indicators of the PD-measuring unit. The better and progressive method is to take a “raw”, unformed signal from the integrator of the sum charge of PD. This signal is then digitized and statistically processed. This method gives more information about the behavior of insulation under the HV stress. This procedure will make it possible to evaluate the diagnostic parameters immediately and to use the global method as an on-line
(monitoring) measuring method. The next step of our research activity in this project will be to create an expert system for evaluating discharge activity in IIV equipment and the monitoring of the state of insulation in the operation.

References:

This research has been conducted at the Department of Electrical Engineering as part of the research project "The Expert System for Diagnostics of IIV Electrical Machines" and has been supported by GACR grant No. 102/94/1411.
EXPERT SYSTEM FOR AN INCREASE IN THE RELIABILITY OF POWER-ENGINEERING SYSTEMS

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Key words: expert system, insulation, diagnosis, diagnostics, high-voltage, electrical machines, database, reliability, measurement, evaluation, data processing

The dielectric diagnostics and prophylaxis of electrical machines and equipment are very important factors in the increase of reliability and stability of the electrical supply network. There are many diagnostic methods to monitor the real state of an insulation system and the estimation of the insulation lifetime. That's why any separate method does not solve the problem completely, a complex of diagnostic methods is usually used for this purpose. The evaluation of many diagnostic methods and the interpretation of evaluated data for the estimation of the real state of insulation is very complicated, and a lot of specialists and experts are interested in it solving this problem. Many database and evaluating systems have been created for the processing of measured data, but only the expert system for dielectric diagnosis, i.e. the expert system for the evaluation of diagnostic methods, solves problems by evaluating measuring data from other diagnostics methods, and produces quality decision, and recommendation, for the future operation of equipment.

The first step in the construction of this expert system was to choose an empty expert system and also choose a diagnostic methods for off-line diagnostics of electrical machines, apparatus and systems. Because most experts decide according to directives, limit values and rules, we chose the rule-based expert system. Several empty expert systems were tested and finally the rule-based expert system SPEL-EXPERT was chosen, because it was the best for our purpose, was user-friendly and has the best service (hot line). The criteria for the diagnostic method were: a declare-ability of the method, the common-use of the method and whether the results of this method can be quantified. According to these criteria 40 diagnostic methods (18 methods for electrical rotating machines, 8 for non-rotating machines and 8 methods for insulating oils) have been chosen for the diagnostic expert system. This expert system is named IZOLEX and was created on the empty rule-based expert system SPEL-EXPERT.

Currently, the construction of the network of the expert system (nodes, connections taxonomies etc.) is finished. The IZOLEX has 366 nodes, 495 rules, 9 context links, 84 priority links, 3 taxonomies (45 taxonomy classes) and 82 goals. The base of knowledge is filling according to international and national standards and directives, commonly used rules, and according to the experiences and knowledge of specialists (experts). Problems with creating and testing the base of knowledge and the structure of the expert system were solved with the cooperation of several laboratories, research institutes, universities and manufacturers. Experts from these working places supported it with their knowledge, experiences, measuring and evaluating directives and limit values.
Our goal was to realize a complex diagnostic and expert system needed for the measuring and data processing of diagnostic measurements of electric machine insulation. The results of our work have increased the reliability and safety of the operation of large H2V power machines working in the Czech Republic National Power system.

References:


This research has been conducted at the Department of Power Engineering as part of the research project “Expert System for an Increase in the Reliability of Power-Engineering Systems” and has been supported by CTU grant No. 8201.
A STUDY OF THE DYNAMIC BEHAVIOUR OF VOLTAGE CONTROLLED POWER DEVICES EXTEMME CONDITIONS

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Key words: voltage controlled devices, IGBT, power MOSFET, dynamic parameters, low temperature measurement

At present, the voltage controlled power semiconductor devices have become the "working horses" or power electronic equipment. These devices, especially power MOSFETs and IGBTs are normally operated in a range of junction temperatures from room temperature (exceptionally from —40 °C) up to 130 °C. The parameters of the devices are usually published in this temperature range[1, 2]. Less information concerning device parameters can be obtained for the region of lower temperatures. On the other hand, applications of voltage controlled power semiconductor devices in circuits with superconductors may be expected and in this case the devices should operate at temperatures not much higher than that of liquid nitrogen. About the functions of power devices under such extreme conditions there is not much information, especially about the behaviour of IGBTs.

For the study of the dynamic behaviour of voltage controlled devices (MOSFETs and IGBTs) an apparatus for measuring has been developed. The apparatus enables measuring courses of gate and collector currents and voltages, from which may be determined turn-on and turn-off times, power losses, and other important parameters (e.g. the threshold voltage) in the temperature range from —190 °C to 200 °C under defined load conditions. Measurements may be performed in the range of the collector voltage Vce up to 600 V with the collector current Ice in the range up to 50 A, the gate voltage Vge can be changed from 7 V to 20 V and the width of the gate signal can be changed from 1 to 10 µs.

The central component of the apparatus is a thermostat with a device holder. The device holder may be cooled to liquid nitrogen temperature and heated (using the DC current to avoid disturbances) up to 200 °C. The holder temperature can be measured in the interval from —200 °C to 200 °C with an accuracy of 0.1 °C. The basic measuring circuit has been realized at the outer side of the thermostat in such a way as to minimize parasitic inductances in the circuit. The load in the measuring circuit could be changed, and measurements of the parameters of voltage controlled power devices performed under conditions of both resistive and inductive load, or under other defined conditions. All the measurements can be performed at very broad intervals of temperature, providing research of device behaviour at extreme temperatures, especially at temperatures below —40 °C. The device can also be used for diagnostics of irreversible changes in the characteristics of the device, which may be caused by temperature cycling.

References:


This research has been conducted at the Department of Electrotechnology as part of the research project "Diagnostic methods in electrotechnology" and has been supported by CTU grant No. 8130.
MONITORING
OF TRANSFORMERS AGEING
BY PULSE FREQUENCY TECHNIQUE

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Key words: diagnostics, transformer, ageing of materials, pulse frequency technique

The ageing process of transformers can be checked using the pulse frequency technique. The resonance phenomena of their winding systems effected by the higher temperature are measured according to time in this case. The configuration of the transformer winding system has its own frequency characteristic at a given state of the system. Any defects or qualitative changes, either of transformer windings or of the insulation system, due to ageing can be detected as a changes in the frequency characteristics.

The monitoring workplace is controlled by a PC/AT computer and own control programme is used. Voltage pulses of symmetric oblong form, voltage $U = 10 \, \text{V}$, frequency range from $1 \, \text{kHz}$ to $10 \, \text{MHz}$, were used in our experiments. The source of the voltage pulses is connected between primary and secondary windings. A mean value of the voltage response signal is measured on a resistor connected in series into a circuit created by the windings, the insulating system and this resistor as a function of the frequency. Frequency characteristics are typical for a given resistor, type and condition of the transformer. The measuring method mentioned above was verified for the temperature ageing process of the two small-power transformers (1 kVA and 2.5 kVA). The ageing process was made at temperature $160 \, ^\circ\text{C}$ for 200 hours. The measurements of the dissipation factor, capacity and insulation resistivity have been realised in parallel with the pulse frequency method in order to compare them.

It was observed that the pulse frequency method can indicate dissipation factor changes or the insulation resistivity and capacity changes as well. This method is most sensitive in the case of capacity changes between the windings. The mean values of the voltage signal as a function of the frequency before (a) and past (b) ageing process are shown in Fig. 1. — for bigger changes in the dissipation factor and in Fig. 2. — for bigger changes in the capacity.
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 CTU grant No. 38200, 102/94/1358.
UNIFIED SPECIFIC UNIT OF VIBRATING WIRE GAUGE FOR EXTREME DEMANDS FOR LONG-TERM STABILITY AND RESISTANCE IN AGRESSIVE ENVIRONMENT

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Key words: gauge, vibrating wire, conditions "in situ"

The wire method of measuring mechanical or physical quantities is based on the relation between the tension of the steel measuring wire and one frequency of its transverse oscillation. Influences characterizing available measuring accuracy have been analyzed theoretically. We can quote the influence of stiffness in motion of the measuring wire, the influence of support of the wire, the influence of the central line, of amplitude, temperature, environment and damping. Disturbing influences were described that can cause hysteresis and deviations from linearity. The mathematic model of the wire was worked out for the engineering model of wire systems. That model emerges from the solution of quartic non-homogeneous equation of motion for the wire which describes its oscillation under a static axial force and attenuation in proportion of motional speed. The mathematical model of wire was obtained by the solution with the Fourier method in the form of cascade matrix. The wire demonstrates a non-autonomic two-way device. The cascade model of electromechanical parameters and the gyroratory transmitting agent of the converter was solved in a similar way. The complete model of the wire vibrating gauge was achieved which enables a simulation of the late electromechanical oscillating system and an analysis of transient effects.

Tracing measuring method is characterized by the feature that all measurements in range of following quantities especially under "ins instu" conditions the conditions found during measuring in difficult operational conditions, terrain, constructions sites building sites, etc., have got ensured long-term accuracy or data stability.

That method with oscillating wire starts to be standard for its perfect engineering solution of issues.

The design of the precise unified unit of vibrating wire gauge, which is being verified at present and a patent applications is being considered, shall fulfill the following exacting demands:

1) stability of zero reference reading in the extent of 0.4% of measuring range for the intervals longer than 20 years
2) accuracy of measurement in class 0.2
3) resistance in aggressive environment complying with CSN standards, series 7302, and with ISO standards for air, water, concrete, and soil under ambient temperature fluctuation between —20 and +60 C

non-sensitivity against electromagnetic interference at the level of interference fields in neighbourhood of electrified rail traction, in electric power and distribution plants and around emitters of telecommunication facilities.

4) possible application in local and foreign systems

5) application in unit-built systems for the measuring of base series of mechanical quantities with concentration on tencometers intended for concrete and steel constructions, pressure gauges with minimal changes of volume, sensing units for high-pressure devices, sensing units for pore pressure, dynamometers, thermometers with quick response etc..

The principle of solution is intended to be applied as in electromagnetic polarized system respectively its various modifications under arrangement of the unified unit with support body of tubular shape. The wire is located in a suitable medium to ensure long-term quality of steel wire that cannot be surface finished due to metrology reasons.

References:

This research has been conducted at the Department of Electrotechnical Engineering of CTU Prague and at Kloíner Institut as part of the research project "Vibrating Wire Gauge for Measurement of Quantity" and has been supported by CTU Fac. of Mechanical Engineering grant No. 288/.
Section 11

COMMUNICATION
ENGINEERING
DIGITAL AUDIO BROADCASTING
SUMMARY OF THE PRESENT STATE
OF THE ART

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Key words: digital audio broadcasting, DAB

Digital Audio Broadcasting (DAB) is a system supporting digital transmission of broadcast signals through the whole distribution path (from the studio to the user's receiver). DAB also provides a high quality stereophonic service to mobile receivers.

Main user features of DAB [R1], [R2]:
- optional transmitted sound quality (normal distribution quality corresponds to that of commercial the Compact Disc recording),
- excellent reception with portable and moving receivers,
- efficient frequency spectrum utilization,
- transmission of data associated to the programme (programme journal, traffic information ...),
- it is possible to split the digital audio channel into data channels (16/32 kb/s) and transmit data to user groups.

Main technical features of DAB [R1]:
- Musicam (ISO/IEC MPEG Layer II) source signal coding,
- COFDM (Coded Orthogonal Frequency Division Multiplex) transmission technique.

Musicam source coding was developed by the IRT research institute in Munich. Musicam (Masking pattern adapted Universal Subband Integrated Coding And Multiplexing) considerably reduces the data rate of the digital sound signal while the sound quality (as it is perceived by the human ear) does not change. The COFDM transmission technique was developed by the CCETT research institute in Rennes. COFDM comprises channel modulation and coding techniques.

At present, four variants of DAB are under consideration: T-DAB (Terrestrial DAB), S-DAB (Satellite DAB), Hybrid Satellite/Terrestrial DAB and Complementary DAB. There are three different modes of DAB supporting matching technical features of the system to the corresponding variant of DAB.

History and future prospects of DAB:

1988: - Eureka (EU 147) DAB research programme,
- 1st experimental network in Rennes (France),
- DAB demonstration during the WARC-ORB conference in Geneva.
1991: - foundation of the DAB-Plattform (Germany) and the Club DAB (France), associations for co-ordination and establishment of DAB.
1992: – 1st international symposium on DAB in Montreux,
   – international experimental network DAB (Germany- France- Switzerland), Rheingraben region (Strasbourg, Baden-Baden, Basel).
1994: – 2nd international symposium on DAB on Toronto.
1995: – launching DAB receivers to the market,
   – DAB receivers will be distributed to selected users,
   – experimental DAB broadcasting in Germany, France and Great Britain.
1997: – regular experimental DAB transmission in Germany.

After 2000 – spread of DAB in Europe and in Canada is anticipated.

The main problems currently under investigation in the world in this area [R2]:
1. frequency planning and frequency allocation,
2. choice of suitable DAB variants for covering national areas,
3. choice of DAB distribution network and distribution requirement,
4. coverage of a region with a DAB signal,
5. configuration and management of the programme multiplex,
6. definition of measuring methods, development of measuring devices,
7. development of DAB receivers, development of ICs for DAB,
8. In-Band Systems.

The main institutions concentrating on these problems include EBU, CEPT, ITU and ESA. In the Czech Republic research in the above-mentioned fields is performed at the Testcom P&T Research Institute in Prague [R5].

Our department has been working on DAB problems since 1992. We work closely with Testcom. Up to now, we have focused on transmission channel study, the COFDM transmission technique, DAB distribution network [R3], DAB link budget [R4] and the MUSICAM source coding method. In spring 1994, our department submitted an application for a DAB grant. The application was sent to the Grant Agency of the Czech Republic and it contained our anticipated future activities in the DAB field. Our project will support the expansion of DAB in the Czech Republic.

References:

This research has been conducted at the Department of Radioelectronics as part of the "Digital Audio Broadcasting" research project.
SPEECH RECOGNITION SYSTEMS

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Key words: speech recognition, expert system, phonetical elements

In this paper a general mechanism for merging hypotheses coming from multiple modules of a phonetically-oriented continuous speech recognition system, e.g., a vowel analyser, a plosiva analyser, hidden Markov models, a dictionary, etc. is proposed. The structure of this general mechanism was implemented as a program called Hypothesis Manager, which also serves as an integrated development environment for design and tests of recognition systems. We designed an easy-to-use standard interface for connecting new modules to this central block. The method used for hypotheses management is blackboard-based data-driven forward-chaining, and highly specialised for use in signal processing, and allows the combination of bottom-up and top-down analysis.

Hypothesis manager. Hypothesis manager is a program, which can be used as a central part of the speech recognition system. This program calls other programs (so called 'authors of hypotheses'), merges their results, and estimates credibility of the individual 'authors'. It also serves as an integrated developing environment, which offers windowed user interface for development and testing of speech recognition systems.

All the authors look at the central database of information already gathered about the speech signal and propose new information to be added to it. The role of Hypothesis Manager is to serve as a moderator in this process.

The information in the database is structured into an individual hypothesis. Some hypotheses can be generated only when other hypotheses are already present in the database.

A crucial part (in the algorithm of hypotheses generation) is step, which must be based on computation of the quality of the hypotheses. This computation is based on the estimation of the credibility of the authors gathered by the statistical analysis of authors' performance done during the training phase.

Another problem which has to be solved is that of merging two hypotheses concerning the same subject. There are a lot of variants of this operation (usually called 'consensus') described by various authors. Our approach is based on statistical analysis. Having two authors providing their opinions about the same subject, we can merge their opinions using statistics of their previous opinions.

'AUTHORS'

Speech/pause detector for noisy speech signal. The basic idea of energy based algorithms is the assumption that the presence of speech means an increase of energy. Since the signal energy $E$ is compared with the given energy threshold $E_p$, speech is detected in the speech signal segment if $E$ is above $E_p$. Differences between several algorithms are usually in the definition of the energy threshold $E_p$.

Our new algorithm not only tries to apply energy dependence but also detects changes in the spectrum of signal. As a parameter for the speech detection is used cepstral distance $C_D$ between spectrum of current signal segment and spectrum of noisy environment.

In the speech/pause procedure the vector of cepstral coefficients is computed for each segment. Then cepstral distance $C_D$ from the noisy environment is computed. Speech is
detected if $C_D$ is greater than 3dB. If $C_D$ is less than 3 dB speech pause is supposed and cepstral coefficients of noise spectrum are updated.

**Formant extractor.** The basis of the formant extraction process is as follows:

Using the AR model we find twelve LPC coefficients, because six formant frequencies and formant bandwidths for each segment are usually sufficient. Next, we reduce the number of frequencies to five by removing the frequency with the maximal bandwidth. Then, we identify frequencies $F_{1\text{poss}}, F_{2\text{poss}}, F_{3\text{poss}}, F_{4\text{poss}}$ which are close to frequencies $F_{1\text{ref}} = 499$ Hz, $F_{2\text{ref}} = 1440$ Hz, $F_{3\text{ref}} = 2760$ Hz, $F_{4\text{ref}} = 3200$ Hz. These frequencies were chosen based on our experiments using male speakers. (Different frequencies are chosen for female speakers). As a reference formant frequency we use the frequencies $F_{\text{poss}}$ which match the predefined frequencies in the best way. Thus we eliminate one more 'formant' frequency and, finally, have four selected formant frequencies $F_{1p}, F_{2p}, F_{3p}, F_{4p}$. Next, we compute the average value of these frequencies for the stationary part of the speech signal. These frequencies are used as frequencies characterising the whole phonetical element of speech.

**Segment classifier based on Time Delayed Neural Net (TDNN).** The TDNN classifier can be used as an 'author' of hypotheses derived from signal descriptors in the continuous recognition system based on expert system principles. Particularly, it could eliminate the incomplete coverage of the chunk classes in this application. The TDNN is not asked for a recognition of the complete utterance; rather it is asked to generate hypotheses about trained chunks as well as possible.

To recognize the speech signal, the sampled utterance must be segmented into frames, and the vector of descriptors must be computed for all frames. The sequence of descriptors has a matrix form. A number of columns is fixed (e.g. LPC model order), and the row matrix dimension depends on the frame length and the phrase duration.

This speech representation can serve as a multi-layer perceptron (MLP) input data. It is necessary to have several vectors in the same time for an input layer to make short-term spectrum analysis (e.g. formant frequencies moving, moving in cepstral space) possible. In this case the first hidden layer plays the role of the low-level acoustic detector.

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 Recognition Systems” and has been supported by CTU grant No.38128.
SUB-BAND SPEECH CODER 16 KBIT/S

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Key words: speech coding, signal processing

Sub-band speech coding belongs to speech-coding techniques working at medium bit-rates. This article presents the sub-band coder 14 kbit/s with error-protecting scheme (2 kbit/s) developed in cooperation with the French company SECMAT N.T. The coding includes splitting of signal by 5-channel filter-bank, ADPCM with adaptive quantizers based on CCITT Recommendation G.726 in each channel and dynamic bit allocation according to the RMS-values of 20 ms segments. For error protection of part of the information, the Hamming code (13,9) and bit interlacing are employed. The entire coder and decoder were implemented in real-time on the signal processor TMS 320C50 (Texas Instruments).

Structure of Coder and Decoder. The coder works with a telephone-quality signal (sampling rate 8 kHz, 8 bits log. PCM). At the coder input, the signal is splitted to 5 channels using decimated polyphase filter-bank. Only the information of 4 channels is coded and transmitted. ADPCM blocks as well as the filters work with the sampling frequency of 1.6 kHz thanks to decimation at the coder input. The coder output frame is created from quantized ADPCM outputs and side information and protected against channel errors before transmission. In the decoder, the frame passes through the error correction, then the channel signals are proceeded by inverse ADPCM blocks and put together in the synthesis filter-bank.

Filter-Banks. The polyphase filter-banks with perfect reconstruction were used. Thanks to their structure, the decimators could be moved before the analysis filters and the interpolators after the synthesis ones, so that the sampling frequency of the filters (and all other blocks between the filters) is 5-times lower than the original one. In both the analysis and the synthesis filter-banks, the 10 polyphase components and cosine transform-matrices are used. The coefficients of filter components were found using the Optimization Toolbox functions of MATLAB.

ADPCM, Quantizers and Dynamic Bit Allocation. For adaptive predictive coding of channel signals the backward ADPCM of G.726 was chosen. The signal is predicted using a 6-th order all-pole and a 2-nd order all-zero filter. The residual is coded with 1 to 5 bits using adaptive quantizers. For 2 to 5 bits the quantizers proposed by the Recommendation G.726 were used, for 1 bit it was necessary to employ forward adaptation (1 bit gives only the information about the sign of residual). For corresponding channels, the RMS-value of 20 ms frame is found and converted to the scaling constant of quantizer. The RMS-values of channel signals are used for dynamic bit allocation, too. In the beginning of the iterative procedure, 1 bit is assigned to each channel (the case of 0 bits/channel is not possible). Then the maximal RMS-value is found and one bit is assigned to a corresponding channel. This value is halved and the procedure is repeated until all available bits are
allocated. To be able to perform the same allocation on the decoder side, the RMS-values are logarithmically coded and transmitted as “side-information”.

**Error Correcting Code.** The coder is designed for telecommunication channels with bit error ratio $BER = 10^{-4}$ and maximal length of error sequences 20. Therefore it is necessary to protect the most important part of information against channel errors and interlace the protected bits. For this, the standard Hamming Code (15,11) punctured to (13,9) was used. In the 313-bit frame, 32 bits are available for protection so that 72 most important bits of the frame can be protected. The “side-information” and MSB of the channel with maximal RMS-value were chosen. The interlacing against error sequences is performed using “line-wise” writing with consequent “column-wise” reading of a bit table.

**Implementation and Results.** The software of the coder/decoder was implemented in real-time on the fixed-point DSP TMS 320C50 where 7 MIPS were at our disposal. The DSP was a part of a PC extension card, its fast serial port was used for communication with A/D and D/A converters. The results were compared using a digital tape recorder.

The sub-band coder offers a good quality of resulting speech signal with complexity much lower than that of methods LPC, CELP, etc. The error correcting code was found suitable for given channels, when the simulations were performed, the distortion of resulting signal was not audible.

**References:**


*This research has been conducted at the Department of Radioelectronics as part of the research project “Speech Coding for the Transmission on HF and VHF channels” and has been supported by TU Brno grant No. A 1/94.*
FREQUENCY SHIFT OF 2-D REAL COEFFICIENT ZERO PHASE FIR DIGITAL FILTERS

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Key words: digital filtering, frequency shift

The paper concerns with the frequency shift of the frequency response of 2-dimensional (2-D) real coefficient zero phase finite impulse response (FIR) digital filters. The frequency shift allows to move the passband of the filter in the frequency plane. By this way useful frequency transformations, e.g., lowpass to bandpass or lowpass to highpass filter are easily achievable. The frequency shift is performed in purely analytical form. Formula describing the mutual relation between the original impulse response and the transformed one is derived. The frequency shift is used in fast (re)design of 2-D FIR filters. The application in adaptive filtering is advantageous.

Introduction. Frequency transformations are a useful tool in filter design. A number of frequency transformations in the real coefficient zero phase digital FIR filter design are known today, e.g., [1-4]. However the described frequency shift of real coefficient FIR filters was not found in references, neither 1-D nor 2-D case. While the method of the frequency shift of 2-D real coefficient zero phase FIR digital filters is novel not published up to now, the fashion of computation of the impulse response of the frequency shifted filter is similar to the one introduced in [4] for rotation, expansion, shrinking and change of the shape of the frequency response of a 2-D FIR filter. The frequency shift method is applicable also in the 1-D case.

Frequency shift. A real coefficient zero phase 2-D FIR digital filter is represented by its impulse response \( h(m,n) \). Let us assume the real valued impulse response of odd length in both directions with central term \( h(0,0) \) and with symmetry \( h(m,n) = h(|m|,|n|) \). In order to obtain a frequency shifted real coefficient filter, some type of symmetry of the frequency response \( H_T(\omega_1,\omega_2) \) of the frequency shifted filter has to be satisfied. For quadrantal symmetry

\[
H_T(\omega_1,\omega_2) = H(|\omega_1| - \delta_1, |\omega_2| - \delta_2)
\]

(1)

the relation between the original impulse response and the shifted one reads as follows:

\[
h_T(p,q) = \frac{1}{(2\pi)^2} \sum_{m=-M}^{M} \sum_{n=-N}^{N} h(m,n) K_1(m,p,\delta_1) K_2(n,q,\delta_2)
\]

(2)

for \( m = -M ... M, \quad n = -N ... N \)
where

\[
K_1(m, p, 0) = \begin{cases} 
\frac{4}{m-p} \sin(m\delta_1) & \text{if } m \neq p, \ |m-p| \text{ is odd} \\
0 & \text{if } m \neq p, \ |m-p| \text{ is even} \\
2\pi \cos(m\delta_1) & \text{if } m = p
\end{cases}
\]

and

\[
K_2(n, q, 0) = \begin{cases} 
\frac{4}{n-q} \sin(n\delta_2) & \text{if } n \neq q, \ |n-q| \text{ is odd} \\
0 & \text{if } n \neq q, \ |n-q| \text{ is even} \\
2\pi \cos(n\delta_2) & \text{if } n = q
\end{cases}
\]

Concluding remarks. An important feature of the frequency shift is the speed of computation. Redesign of an existing 2-D FIR filter using the described frequency shift is faster than a new design of the filter from the very beginning using Remez exchange algorithm combined with McClellan transform. The frequency shift of a filter with impulse response coefficients of size 7x7, 15x15, 27x27 resp. takes on 386/387 (40 MHz) personal computer 0.02 s, 0.4 s, 3 s respectively.

References:


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LOW-SENSITIVITY
NON-RECIPROCAL LOSSLESS FILTERS

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Key words: filters, switched capacitors

The recent development in the field of analog circuits and systems was oriented to
achieve better quality, higher speed and better compatibility with “digital technology”.
Our contribution to this trend was research oriented to the development of new structures
suitable for continuous- and discrete-time working active filters. These structures are based
on the non-reciprocal lossless principle, which has not been published before. Such structures
have excellent sensitivity properties and an application flexibility. The first information was
given at the ECCTD’93 [1], where we presented the basic LP and HP filter structure and
the synthesis algorithm.

The following work has concerned with improving a direct synthesis algorithm and op­
timization procedure with respect to the non-ideal properties of OpAmp used. The results
of this part of our work were presented in detail in [2], [3], especially the improved synthesis
procedure for non-standard BP all-pole filters and an application of a developed “prewarping”
optimization procedure for Cauer LP filter design. In connection with the mentioned
topics it another important problem emerged: How to obtain the starting circuit param­
ters for both-port resistively terminated lossless non-reciprocal circuit. This problem led
to the solving of a more general form of the basic Feldtkeller’s equation. The result has
brought not only the solution to the desirable parameters, but also a new view of derivation
and computing of the two-port parameters of reciprocal circuits with unequal load. The
derivation of the above mentioned equation has been described in detail in the Proceedings
of STO-5 [4] together with an example of the synthesis of both-port loaded non-reciprocal
LP Cauer filter.

Simultaneously there have been studies on how to transform the basic structure to the
discrete-working switch capacitor equivalent circuit. As a result a set of modified structures
of LP, HP and BP filters, containing the minimum number of resistors have been found.
The structures have been obtained by using a general direct synthesis algorithm described
in [2] and can be used as a prototype for low-sensitivity SC filter design. An example of
this procedure has been published in detail in [5].

An important question in deriving the SC-filter design was the optimization procedure
involving non-accuracy of p-z transformation, parasitic effects including parasitic capacitors,
limited OpAmp gain and the real properties of switches. For this purpose an original
algorithm has been created, derived from the aforementioned “prewarping” optimization
procedure. The results are presented in another contribution of these Proceedings and have
led to the design of a tuned BP filter for "HDO" receivers, produced by ZPA Trutnov.

An important improvement in the behaviour of presented filters with respect to the
active devices nonidealiites can be achieved by using an “adjoint transformation” of the
original circuit. The transformation changes the voltage-mode to the current-mode, and
leads to a decrease in the influence of the frequency dependent OpAmp gain to the resultant
frequency response of the final circuit, and an important improvement in the dynamic conditions. The first results in this field have been presented in [6]. An example of the 6-th order Cauer LP filter transformed to the current-mode showed a minimal distortion of the pass-band frequency response and about a 15 dB increased dynamic range in comparison with the original filter.

References:


This research has been conducted at the Department of the Circuits Theory K331 as part of the research project "Discrete-Time Analog Filters" and has been supported by CTU grant No. 8187.
SC FILTERS OPTIMALIZATION

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Key words: switched capacitors, filters, biquadratic cells, filter optimization

Working on grant No. 8137 at the CTU, the optimized design of switched capacitor filters was solved.

There are a lot of optimization methods for switched capacitor filters described in foreign literature, which are used to eliminate the influence of first order parasitic effects, like:

- inaccuracies caused by the p-to-z transformation
- parasitic capacitances
- finite dc gain of OpAmp’s
- On-resistances of the switches

and so on. Some of these methods are slightly complicated.

We focused on the application of the method described in Ref [1] because of its efficiency and easy algorithmization. The method was originally developed for the optimization of the continuous-time analog filters with respect to the losses. The optimization algorithm consists of three basis steps:

1. Synthesis of the idealized filter
2. Analysis of the obtained circuit with respect to the losses.
3. Comparing with the given transfer function, and if necessary, pre-warping and a new synthesis.

There are two basic ways of applying the above mentioned schedule for switched capacitor filters.

A. Using the analog prototype and pre-warping in the p-domain. This approach was tested before and published in Ref [2,3]. Problems with the accuracy and backward z-p transformation were noted.

B. Carrying out the whole optimization to the z-domain. This approach will be described here.

The above mentioned approach was tested on the second order biquadratic cells (Fig. 1) designed in Ref [4] for the tunable band-pass filter for the reciever HDO (ZPA Trutnov). The influence of the OpAmp’s finite gain was corrected for the passband in this case, which corresponds well with the actually used OpAmp’s. After rewriting the optimized transfer function into a more suitable form, the described method gives a slightly faster convergency and good numerical accuracy. Filters which have been designed and optimized in this way are being realized by the CMOS technology at present.
In this example as well as in the case of parasitic capacitances, the real transfer function can be obtained by the charge conservation equations, which are easy to handle both manually and by the analytic programs. For optimizing effects like On-resistance or finite OpAmp transconductance a more generalized analytic method is needed which respects the transient effects in the switching process. Such a method was described in the Ref [4] and will be used in the next step of the optimizing process development.

References:

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DESIGN OF FIR NOTCH FILTERS

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Key words: maximally flat approximation, IIR and FIR notch filter, recursive formulae

Based on the symmetry of the maximally flat frequency response of a FIR notch filter the new design procedure is developed. The closed form solution provides direct computation of the frequency response, recursive computation of the impulse response coefficients, simple windowing technique, and an access to new implementation.

Introduction. In order to remove a single frequency component from the signal spectrum the IIR notch filter is frequently used. It consists of an abridged all-pass second-order section and allows independent tuning of the notch frequency \( \omega_0 \) and the 3-dB attenuation bandwidth [2]. Therefore the design of a digital IIR notch filter is rather simple. Such a filter also possesses infinite impulse and step responses consequently which can produce spurious signal components unwanted in various applications (as in ECG signal processing).

A few procedures for the design of linear phase FIR notch filters are recently available. The methods which lead to feasible filters are generally derived by iterative approximation techniques or by noniterative but still numerical procedures, e.g. the window technique.

Design algorithms. In our paper [1] we were primarily concerned with a completely analytical approach to the FIR notch filter design. The solution is partially based on exact formula for the frequency response of a FIR notch filter symmetrical about \( \omega T = \pi/2 \). Emphasizing simplicity of form for monotonic frequency response we derive the polynomials

\[
N_{l,m}(w) = \left[ \frac{m+l}{2l}(1-w) \right]^l \left[ \frac{m+l}{2m}(1+w) \right]^m
\]  

in sum of Chebyshev polynomials of the first kind \( T_n(w) \) through which the transfer function \( H(z) \) is expressed. Here and in the following we use the transformed variable \( w \)

\[
w = \frac{1}{2}(z + z^{-1}) \rightarrow \frac{1}{2} (z + z^{-1}) \big|_{\text{imag} \cdot \omega T} = \cos \omega T, \tag{2}
\]

which transforms the \( z \)-plane onto a two-leaved \( w \)-plane. We introduce the formula for degree of a notch filter which is related to the notch frequency, the recursion formulae for polynomials \( N_{l,m}(w) \) and the impulse response coefficients of a moveable notch filter.

The notch frequency \( \omega_0 \) is expressed from the minimum value of \( |H(e^{j\omega T})H(e^{-j\omega T})| \) as

\[
\omega_0 = \cos \omega_0 T = \frac{m-l}{m+l}. \tag{3}
\]

The recursive formula for \( N_{l,m}(w) \) offers recursive evaluation of the transfer function \( H(z) \) and consequently, an alternative implementation of maximally flat FIR notch filters by a structure with the multipliers coefficients of limited dynamic range.
In order to evaluate any off-diagonal polynomial

\[ N_{i,m}(w) = \left( \frac{m+l}{2l} \right)^{m-l} N_{l,m}(w) \]

(4)

it is advantageous to drop the normalization factor and employ the polynomials \( N_{i,m}(w) \). Using repeatedly recurrence for the Chebyshev polynomials we have deduced simple recursive formula for an arbitrary off-diagonal polynomial \( N_{i,m}(w) \)

\[ N_{i,m+1}(w) = 2N_{l,m}(w) - N_{i+1,m}(w), \]

(5)

which form a new algorithm for the evaluation of the impulse response coefficients \( a(n) \) of a FIR notch filter specified by the notch frequency (3).

Concluding remarks. The rectangular windowing of the large extent impulse response is presented which leads to the frequency responses comparable to those designed by standard windowing technique. The main disadvantage of these filters is that the required filter order is approximately inversely proportional to the square of the stopband bandwidth. The design procedure usually leads to the filters of a much higher order than those with equiripple frequency response and it means that the number of multiplication required per computed output sample is quite large. The economization of Chebyshev polynomial expansion of \( H(z) \) is then equivalent to the square windowing of a finite but large extent impulse response. We can use even severe abridging of the filter order \( N \rightarrow N_r \sim \sqrt{N} \) to obtain comparable results and computational complexity with the standard windowing technique. It is worth noting that abridging the large extent impulse response does not affect the position of the notch frequency and the width of the notch. Rectangular windowing is responsible for the ripple in the passband and the finite attenuation of the notch frequency only.

Note that the whole design process is a recursive one and it does not require any DFT algorithm nor we need any iterative technique. The degree equation (3) is the simplest formula ever available in filter design which relates a critical frequency with the filter order \( N = m+l+1 \).

References:


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FILTRERS WITH SYNTHETIC ELEMENTS OF HIGHER ORDER USING TRANSIMPEDEANCE OPAMP

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Key words: higher order synthetic element, transimpedance opamp, filter.

It is possible to use synthetic elements of higher order for development and design of new filter structures [1]. These elements include:

a) n-th order two-terminal network type X with impedance

\[ Z_X(s) = X_0 + X_1s + X_2s^2 + \ldots + X_n s^n \]

b) n-th order two-terminal network type D with admittance

\[ Y_D(s) = D_0 + D_1s + \ldots + D_n s^n \]

We exploited transimpedance OpAmp (TIOA) for synthesis of these elements. TIOA was originally designed to be a wide-band amplifier up to 60 MHz. Thanks to the Analog Devices company, this building block is currently available as the monolithic trans impedance OpAmp AD844-5 [2]. The model of TIOA and its schematic symbol are shown in Fig. 1.

![Model of TIOA](image1)

![Schematic symbol of TIOA](image2)

CCCS - current controlled current source
VCVS - voltage controlled voltage source

Fig. 1 a) model of TIOA, b) TIOA’s schematic symbol.

We used this model in the simulation program MicroCap [3].

Fabre [4] exploited the PZ pin for a filter design. This pin is presented by the manufacturer as a compensating pin and is not frequently used. We analyzed and extended a new circuit structure applying TIOA that was published by A. Fabre in 1993.

We designed two new methods to increase the order of the type X impedance and the type D admittance. These methods are shown in Fig. 2.
Fig. 2. Principle methods to increase the order of the imittance a) type X, b) type D.

Example: The realization of a fifth order low-pass filter with decreased tolerance sensitivity is illustrated in Fig. 3.

Fig. 3. Low-pass filter.

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. I-991/05.
ARTIFICIAL HEAD FOR
MEASUREMENT OF HEARING
PROTECTORS BASED ON THE ANC

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Key words: artificial head, active noise control, hearing protectors

For the purpose of objective measurements of active hearing protectors we developed an artificial measuring head, because existing measuring heads didn't meet the requirements of our research. The aim of the design was to enable us to measure various types of protectors with the highest accuracy and performance of psychoacoustical measurements possible.

The design had to meet the following requirements:

1) The auricle and concha must be the precise model of a human ear so that removable types of hearing protectors can be measured.

2) The compliance of an ear-drum and the middle-ear system adjacent to the ear-drum models must correspond with human ear parameters according to IEC recommendations [1].

3) Basic dimensions of the head, esp. the distance between the ears must correspond to the average human head.

The model was designed on the basis of the requirement to meet principal anthropometric data for the average human ear. It is made of plywood, cross-sections correspond to respective cross-sections of a human head (Fig. 1a). Since layers are stuck together along the length of their entire surfaces there are only tiny cavities in the volume of the artificial head and, thus, the required stiffness is ensured.

Fig. 1: a) Overall view of measuring head   b) Detail of auricle and middle-ear simulator
The surface of the head is provided with a layer of soft silicon resin which models the skin. At the ears there is a space for insertion of models of auricles and microphone cables.

Models of auricle and concha are cast from the real human ear and are made of elastic silicon resin. At the end of the concha is a thin layer of plexiglass resin, where the simulator of the middle-ear system is connected (Fig. 1b).

Most commercially available artificial heads solve the problem of sound detection at the end of concha by using a microphone instead of an ear-drum. However, that cause different impedance and resonance characteristics of the concha. That's why we decided to model the impedance of the ear-drum and inner ear more precisely.

The end of the concha we use is based on the simulator for headphones measurement [2]. This simulator models the concha in its cylindrical volume and the impedance of the ear-drum and inner ear by way of the Helmholtz resonator.

Since the concha in the artificial head is the exact copy of a human one, we use only the part of the simulator that models the impedance of a middle-ear system (Fig. 2). The Helmholtz resonator is composed of an acoustical compliance of volume V and an annular slit between the concha and volume V. The mass of the ear is characterized by the acoustic mass and acoustic resistance. Since the input impedance of the measuring microphone is superior to the impedance of the resonator we can neglect the former. We use an electret microphone.

Fig. 2: Scheme of middle-ear simulator

The goal of this work is to obtain a device for measuring of insert and classical types of hearing protectors. We can also use the artificial head for measurements of directional properties of the human head. These measurements will be important for the research of localization abilities under the conditions of active noise control protection.

References:

This research has been conducted at the Department of Radioelectronics.
THE ANTENNA CHARACTERISTICS
MEASUREMENT SYSTEM

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Key words: antenna measurement

Many microwave antenna far-field measurements have been done on the antenna characteristics measurement system built in 1993 at the Department. This system is being improved.

The 1 kHz AM modulated signal generated by Hewlett Packard oscillator is transmitted by a stable horn. Frequencies from 1 GHz to 26 GHz can be transmitted so far. Measured antenna located on a rotating turntable receives the signal. The signal is detected by a quadratic detector and is then amplified and rectified by two selective amplifiers with a different gain. The PC computer 386DX/33 with MS-DOS program EMAN v.1.2 collects measured data using a 12 bit A/D converter (PC Bus Data Acquisition & Control Board AX5411). The program automatically sets a scale of A/D converter and selects the more appropriate amplifier gain to increase dynamics. The dynamics of 60 dB can be reached theoretically. A user friendly graphical environment of the program provides maintaining, evaluation and graphical processing of the measured data.

Fig. 1: Graphical output of horn
Completely new software for antenna measurement system is being developed these days. After the installation of the IIPIB communication card, the new program will control the generator, counter and other possible devices in the system, such as attenuator for calibration of detector and so on. It will help users to speed up the measurement itself and the time to learn to handle the system. Controlling the transmitted frequencies allows one to sweep the frequency. And so, antenna characteristics in a wide frequency range will be easily measured in one revolution of the turntable. Various correction methods will significantly increase precision. A wide frequency detector calibration and follow-up data correction is an example. Both transmitted and receiving power are measured to avoid generating power fluctuations on different frequencies. The new software is being written with the MS-Windows 3.1 environment to obtain a maximally user friendly control, adjustable according to users' system knowledge. The use of both the MS Windows text and graphical outputs can be easily transferred to other applications, such as text editor and spreadsheet. Open software architecture will subsequently allow the inclusion of new controls and additional measuring and evaluating methods subsequently.

To build both a far-field and near-field antenna characteristics measurement system in an anechoic chamber, controlled and evaluated by one software product, is the goal for the near future.

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 use of acoustooptical effects in the testing of piezoelectric transducers

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Key words: piezoelectric transducers, acoustooptics

This paper deals with the use of acoustooptical effects in simple contactless testing of piezoelectric transducers.

Let us consider a plane monochromatic light wave passing through a homogenous isotropic transparent medium which is disturbed by an ultrasonic wave propagating in a direction perpendicular to the light propagation. The harmonic longitudinal ultrasonic wave induce the changes of the refractive index of the medium.

The acoustooptical effect is described exactly by the Raman-Nath system of equations [1]. The general solution is rather complicated [1]. When the Bragg boundary condition is satisfied, it is possible to take the light intensity proportional to the square of the Bessel function [2] as described by the equation:

\[ I_{\nu}(\nu) \approx J_{\nu}^2(\nu) \]  
\[ \nu = \frac{2\pi \Delta \mu L}{\lambda} \]

where
- \( \nu \) represents the Raman-Nath parameter;
- \( \Delta \mu \) represents the amplitude of the change of refractive index;
- \( L \) represents the width of interaction; and
- \( n \) represents the order of the diffracted light maximum

We can determine the following equations for \( \Delta \mu \) [3]:

\[ \Delta \mu_H = \frac{1}{2} \mu_0^2 p_{11} - p_0 \]  
\[ \Delta \mu_V = \frac{1}{2} \mu_0^2 p_{12} - p_0 \]
where

$P_0$ represents the amplitude of acoustic wave and
$P_{ij}$ represents piezooptic coefficients,

We can calculate the amplitude of the acoustic wave ($P_0$) by means of measuring of the light intensity. We can also determine the transfer function of the piezoelectric transducer in this way.

Further, we can compute, by the signal processing method, other behaviour of the piezoelectric transducer. (e.g. impulse response, which is very important for many practical applications).

We can determine exact values of elements in the frame of the transducer model.

First measurements taken by this method indicate that the method provides good results.

The principle schema of the method is shown in Fig. 1.

![Fig. 1: The principle scheme of measuring procedure](image)

References:
MODEL OF ELECTROSTATIC TRANSDUCER BASED ON COUPLED SYSTEM DESCRIPTION

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Key words: electrostatic transducer, circular membrane, rectangular membrane, coupled systems

The trend towards miniaturization of electrostatic transducers fabricated on silicon chips has made necessary the development more accurate models of these systems. New models are based, in part, on the fact that vibrations of a membrane and fluid in the air gap are coupled. This coupling is described by the set of coupled differential equations for the displacement of the membrane and the pressure in the air gap (w is the general surface coordinate):

\[ \Delta \xi + k_{M}^{2} \xi = -\frac{p_{i} - p_{e}}{\nu} \quad (1) \]

\[ \Delta p_{e} + k_{p}^{2} p_{e} = \frac{(j\omega)^{2} \rho \xi}{h} \quad (2) \]

where \( k \) is the wavenumber in the air, \( k_{M} \) the wavenumber on the membrane, \( h \) the z-dimension of the air gap, \( \rho \) the density of the air, \( p_{i} \) the incident pressure, \( p_{e} \) the pressure in the air gap, \( \nu \) the tension of the membrane per one meter, and \( \xi \) the displacement of the membrane.

This system can be resolved generally for any type of geometry with the help of a general orthogonal function series. In circular coordinates these functions take the form of Bessel functions, in cartesian coordinates we use goniometric functions. The assumed solution for displacement is projected onto this orthogonal base:

\[ \xi (w) = \sum_{n} \xi_{n} \Psi_{n} (k_{wn} w) \quad (3) \]

where \( k_{wn} \) is the series of eigenvalues associated with appropriate orthogonal functions. After the substitution of this solution in the differential equation (1) we obtain:

\[ \xi_{n} = \frac{1}{\nu (k_{M}^{2} - k_{wn}^{2})} \int_{S} (p_{i} - p_{e}) \Psi_{n} (k_{wn} w) \, dw \quad (4) \]

where \( S \) is the surface of the membrane.

The solution for pressure in the air gap is obtained by the addition of two series, the first having the same base as the solution for the displacement, the second being the solution of the homogenous equation (2):

\[ p_{e} (w) = p_{n} \Psi_{n} (k_{wn} w) + C \psi (kw) \quad (5) \]
C is the constant that we obtain from the boundary condition where \( w \) designates the coordinate of the membrane and air gap peripherics and \( Z(w) \) the specific impedance at the periphery of the air gap. Acoustic velocity at the periphery is obtained from the Navier-Stokes equation.

\[
\rho (w) = Z(w) v (w) \quad (6)
\]

\[
v (w) = -\frac{1}{j\omega \rho} \text{grad} p_e (w) \quad (7)
\]

The \( n \)-th amplitude of the pressure is obtained in the same manner as is displacement:

\[
p_n = \frac{(j\omega)^n \rho \xi_n}{h} \quad (8)
\]

Now we can calculate the solution for the displacement of the membrane. The equivalent circuit of this system is derived from the basis of acoustic admittance:

\[
Y = \frac{j\omega \xi}{\rho} \quad (9)
\]

The final form of the equivalent circuit of the coupled membrane-air gap system takes the form of the parallel combination of circuits. These circuits are composed of one series resonant mass-compliance circuit, representing the membrane, and four parallel resonant mass-compliance circuits, representing the air gap. If the peripheral impedance at the periphery \( Z \) is zero, the equivalent circuit of the air gap reduces to one parallel circuit only.

References:


This research has been conducted at the Department of Radioelectronics and has not been supported.
The measurement arrangement can be seen from Fig. 1. Computer simulation has proven that the perturbation two-port (PTP) should possess such parameters that 1) it will cause a measurable change in the measured SWR; 2) it must not be pure resistive; 3) it will not change the impedance seen from DUT port rather far from usual 50Ω. As a result of satisfying these demands 1) the phase of the DUT reflection is measured accurately; 2) there is no ambiguity during phase evaluation; 3) potentially unstable devices do not tend to oscillate during measurement. At least two different PTPs resulting in two different measured SWRs are used for each reflection coefficient. A computer controlled PTP (CPTP) can be used for this purpose. For convenience, Fig. 2. shows corresponding traces plotted in a Smith impedance chart.
Fig. 2: Illustration of the key idea on top of a Smith chart

Full knowledge of CPTP vector two-port scattering parameters is necessary. It must be determined in a calibration step.

A CPTP based vector analyzer is expected to cost less than other vector measurement arrangements providing comparable bandwidth.

This research has been conducted by the authors, who are members of the Department of Electromagnetic Field, and has not been supported by CTU yet.
PROPERTIES OF SLOT LINE
AT HIGH FREQUENCIES

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Key words: modelling, microwaves, slot line

Results obtained in 1994 within the frame of the grant for “Analysis of uniplanar waveguiding structures” are summarised below. The objective was to analyse properties of uniplanar homogeneous transmission lines, particularly of the slot line. This transmission line is widely used in various complex uniplanar structures. Precise knowledge of its properties is a necessary basis for the design of microwave integrated circuits.

The spectral domain method is effectively used in the analysis of uniplanar transmission lines [1]. The wave equation is converted into an ordinary differential equation by the Fourier transformation, and boundary conditions are applied. The field in the slot is approximated by expansion of the proper basis functions. Using Galerkin’s method, a set of linear algebraic equations for coefficients of these functions is derived. A root of the determinant of these equations’ system matrix provides the unknown propagation constant. This root, being real, determines the propagation constant of bound guided wave. However, there are also complex roots. They can be detected above the cut-off frequency and will equal the propagation constants of leaky waves.

Planar transmission lines have been investigated, for the most part, only in the frequency range where leaky waves are not excited [2, 3]. Our results agree with those given in [2, 3], both for lossless and lossy substrates. We can determine also the cut-off frequency mentioned above. Below it the wave propagating along the line is purely bound and its phase constant $\beta$ is greater than $k_{TM0}$, which belongs to the TM0 substrate mode. The condition for surface wave excitation $\beta$ less or equal $k_{TM0}$ is met above this cut-off frequency.

Leaky wave in the substrate far from the slot can be represented by a superposition of two waves propagating oblique to the right and to the left of the slot. The resulting wave propagates along the line and behaves like a standing wave with increasing amplitude in the transversal direction. The amplitude decreases along the line due to radiation into the substrate, even if the line itself is lossless.

In lines with a wide slot manufactured on the thick substrate higher order modes can propagate. In specific frequency ranges even leaky waves are excited. Their phase constants can be lower than $k_{0}$, which stands for propagation constant in free space. These modes are space leaky waves radiating into the space above and below the substrate.

Using our own codes, we are able to compute propagation constants of bound waves, as well as leaky dominant and higher order modes. The field distribution in transversal directions parallel and perpendicular to the substrate are determined together with radiation patterns. Radiation patterns for an odd space leaky mode above as well as in the plane of the substrate are plotted in Fig. 1 and Fig. 2. All these results have been presented in [4, 5].
Preliminary work on the analysis of more complex structures exploiting slot line has begun. Slot lines terminated by short and open ends have been chosen. Such stubs are often used in uniplanar circuits. Investigation of these structures will be the contents of the second stage of our work.

![Fig. 1](image1.png)  ![Fig. 2](image2.png)

**Fig. 1:** Radiation pattern of the odd space leaky wave above the substrate  
**Fig. 2:** Radiation pattern of the odd space leaky wave in the plane of the substrate

**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. 8202.
IONOSPHERIC DELAY PREDICTION
FOR WIDE AREA DGPS USERS

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Key words: position determination, global positioning system, ionosphere delay prediction

Introduction. Global Navigation Satellite Systems (like GPS) are expected to greatly improve the accuracy and reduce the cost and complexity of navigation for land, marine and aircraft users. However, real accuracy is not sufficient for some applications. Differential GPS (DGPS) is a means that uses local correlation of position errors for improving the accuracy of navigation. Ref. [3]. Wide Area Differential GPS (WADGPS) is a system that sends a vector of error corrections instead of scalar range error corrections to users.

A possible method of ionospheric time delay correction for single frequency users is discussed in this paper. Users receiving both GPS frequencies can compute the ionospheric time delay without any other models. WADGPS monitor stations use this method.

Ionosphere Corrections. The ionosphere is an important source of range errors for single frequency GPS users. The state of the ionosphere at a certain point depends on many variables. The construction of a simple and precise enough model of the ionosphere is impossible because of the difficulty of describing the physical behaviour of the ionosphere.

A method based on transmitting information about the ionosphere directly to users provides better quality computation of ionospheric errors. The ionosphere is divided into a net and ionospheric time delays at the nodes of this net are broadcast to users.

Information about the state of the ionosphere is obtained by one master station and several monitoring stations. Each monitoring station measures the slant ionospheric time delay at the pierce points at a height of 350 km. The vertical time delay at the nodes of the net is computed by the master station. The computation is based on an analytical model of the ionosphere and data measured by monitoring stations.

Geostationary satellites are used for the broadcasting of data (vertical time delay at the nodes of the net) to users. These data are used for the time delay inside cells made by the net at real pierce points.

This paper deals with the possibility of dividing an imaginary ionosphere into cells and the precision of interpolation of the state of the ionosphere inside these cells, based on knowledge of the real state of the ionosphere in or at the nodes (corners) of the cells.

Division of the Ionosphere into Cells. The division of the ionosphere into cells is supposed to ensure the creation of a net covering the area used by WADGPS users. Information about the vertical time delay at the nodes of this net is broadcast to WADGPS users.

It is obvious that precision of time delay interpolation inside cells depends on the layout and size of the cells. Two styles of ionosphere division are used in the simulations described below. The first style involves division by meridians and parallels with constant step. Steps 5, 10, 15 and 20 degrees were used in our case. This very simple style has an disadvantage due to the shrinking of cells towards both geographic poles. It increases the amount of
information broadcast to WADGPS users, which depends on the number of nodes of a certain net. However the precision of interpolation, where the greatest errors are near the equator, does not increase. The second style of net involves division with variable step in longitude. This is a modification of the previous method. The division step is constant in longitude but not in latitude.

Precision of Interpolation. One of the main methods for the point of usability is precision interpolation of the ionospheric delay inside the cells. Ionospheric precision depends both on cell sizes and on division styles. The precision of interpolation is evaluated from the differences between the value of the ionospheric delay and the real value of the ionospheric delay at a certain point. The impossibility of obtaining a description of the actual state of the ionosphere led to one of the complex models of the ionosphere (Bent model) being used for obtaining the real values of ionospheric delays. The Bent model (Ref. [2]) is an empirical model of the ionosphere. It was derived from known data of ionospheric behaviour.

Results of Simulations. Simulation was carried out with different size of cells and with both constant and variable step. It is obvious that the greatest errors of the interpolation are in the equatorial area and they decrease toward both geographic poles. The introduction of the variable step style merely tends to slightly worse precision in the higher latitude area, but it reduces the amount of information broadcast to users.

Conclusions. Model precision depends on two factors. The first of these is the size of the cells building up the ionosphere net. The cells should not exceed 10x10 degrees in size. The error in this case is up to 5 meters. Further increase of cell size leads to a rapid decrease in interpolation precision.

The second factor is the dependence of interpolation precision on latitude. Errors are significantly greater at the equatorial area where there are the greatest values of time delays. The same is also true for a variable step net of cells, where the ratio of size of different cells is more favourable. One possible solution is to decrease the cell sizes in the equatorial area and to increase their sizes at higher latitudes. More uniform distribution of errors in the ionosphere limit could be achieved in this way with the same upper error limit and the capacity of the informational channel for users would decrease at the same time.

References:

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MM WAVE PROPAGATION EXPERIMENT

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Key words: propagation, mm wave

The experimental setup which is also suitable for the measurement of transmission in the different layered media in mm wave bands was designed and developed. It represents the transmitter - receiver setup; their distance is changeable due to different experiments which can be supported by these instruments. The experimental system consists of 10mW transmitter (polarisation vertical or/and horizontal), and double polarised receiver - both vertical and horizontal polarisation. The transmitted power information is transmitted by the fibre optic line (or directly, in short distance arrangement) and recorded together with other data. In one of the arrangements this system can be used for a propagation of mm wave experiment (the length of the experimental link which was build is 60 m, 35 m above the terrain (top roof position, walls on both sides)).

The system for the transmission of supplement information between transmitter and receiver is a part of the measuring system. It contains two optical fibres with supplement circuits. One fibre serves for the transmission of information about the level of transmitted power, and the other one for switching transmitted polarisation.

The source of the microwave power for the transmitter is an oscillator with Gunn diode. Its output power level is 10 dBm. This microwave power is guided through the insulator, the adjustable attenuator and is finally transmitted by the horn antenna with a gain of 20 dB (EIRP is 1 W). Part of the power entering the antenna is coupled to the detector, where the microwave signal is rectified. The output DC voltage is transferred to a pulse-width modulation and led along the optical fibre to the receiver (see arrangement in the Fig. 1).

Two horn antennas with a gain of 20 dB (the same as with the transmitter) are used at the receiver input. Each of them receives one of the horizontal and vertical polarisations of the electromagnetic wave. The signal from these antennas is switched and modulated with a rectangular waveform of frequency 1 kHz in a PIN diode switch. The modulated signal is led to a mixer, and the output mixing product with frequency 200 MHz is amplified in the IF amplifier with a gain of 30 dB. The amplified signal is detected on the quadratic detector and the remaining modulation is amplified in the AC amplifier and then rectified in a synchronous detector. The output DC voltage, proportional to the received power, is converted to digital form at the A/D converter in IBM-PC computer. The system of the receiver is shown in Fig. 2.

In the system of the receiver is also a detector of pulse-width modulation carrying information about transmitter output power. This modulation is led to the receiver along the optical fibre. By detecting this modulation, a DC voltage proportional to the transmitted power is obtained, which is also converted in the A/D converter in the IBM-PC computer. The receiver switches the transmitted polarisation using optical pulses in the next optical fibre. If the transmitter is switched off after the first optical pulse this transmitter will
operate. The measuring time of each combination of received and transmitted polarisations is about 500 ms. The transmitted polarisation is switched by half the frequency of the received one. The microcontroller Intel S7C51 has been chosen for the controlling of the experiment.

The results of the experiment are the components of the transmission matrix, which for polarisation measurement, includes the received copolar level \( \text{CPA} \) [dB] as well as the received crosspolar level \( \text{XPD} \) [dB], generally in orthogonally polarised system.

The experimental setup was build during Spring-Summer 1994 at the Czech Technical University in Prague. The first results taken in the period were for the propagation of mm wave length use. Interesting results included relatively deep fluctuations, probably due to the temperature distribution on transmission line, especially the "wall reflection temperature effect" which creates the unhomogenous regions just in front of the antennas.

References:


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ATM SWITCHING NETWORKS

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Key words: ATM, switching element, switching network

The long-term objective of the future BISDN (Broadband Integrated Services Digital Network) is to integrate narrowband and broadband services in a single public network based on the ATM (asynchronous transfer mode). This decision was made by the CCITT in 1987, and since then, many switching architectures were proposed. This intervention aims to give a concise summary of existing ATM switching networks and the principles of their development.

The switching architectures for STM (synchronous transfer mode) or for pure packet switching are not directly applicable to broadband ATM for two major reasons:
- The high transmission speed at which the switch has to operate (from 150 up to 600 Mb/s).
- The statistical behaviour of the ATM streams passing through the switching systems.

An ATM switch's core is a switching network, also known as switching fabric in some publications. It is composed of identical basic switching building blocks, interconnected in a specific topology. These switching elements combine two functional components: buffer memory to store the cells and an interconnection mechanism to transfer them from the inlets to selected outlets.

Many possible architectures can be conceived based on different combinations of buffering and interconnection options. In the case of buffering, these options include individual or shared buffers, with or without feedback, at inlet and/or outlet level. In addition, contention arbitration techniques may be combined with the buffer control to improve performance. This abstract is not a proper place for describing the suggested architectures. Nevertheless, I would like to highlight typical advantages and drawbacks of the possible buffering schemes. Pure input queuing is generally easier to implement; on the other hand, it suffers from severe throughput degradation. Much better results are obtained with output queuing or shared queuing schemes. The latter considerably reduces the required queue size, although the memory management is more complex than in the previous cases. Generally, more popular queuing disciplines are the combined ones, namely input-shared and output-shared queuing.

A switching network, as explained earlier, contains a certain number of switching elements (typically a very large number of switching elements which are arranged in several stages) and has hundreds or thousands of inlets and outlets. When choosing a switching network architecture, there are several more key factors to be taken into account than those mentioned above. Among the most essential ones are the internal routing technique and the internal transfer mode.

A fundamental choice in the asynchronous digital switch architectures depends on whether or not a connection path is preset when the communication is set up. In switches using the preset path routing method, an initial routing process is performed per connection to select and set up a switching path with sufficient available bandwidth on each internal link for the duration of the communication. For each cell to be transferred over this path, a
The second routing process uses a virtual connection label to retrieve the preset path addresses marked in memory. This label translation can take place either in each switching element to identify the outlet(s) to be used, or only once at the switch input port to identify the outlet(s) to be taken in each switching element. In the latter case, the addresses are attached to the cell in a path address tag.

The second choice is the self-routing method, in which no initial routing process takes place because no connection is set up. The only routing process finds a suitable path for each individual cell by analysing, in each switching element, the identity of the destination switch output port which is contained in the self-routing tag attached to that cell. The basic advantage of a self-routing method is that it is significantly simpler because it does not require connections to be controlled within the switch and there is no need for bandwidth management on each internal link between switching stages.

Another important difference lies in the number of switching paths available at each stage for transferring an individual cell to the requested output port(s). When only one path is set up (preset path routing) or can be used (self-routing with a single path), the flow of cells corresponding to the given communication is deterministic - cells use the same path. This ensures cell sequence integrity, but any failure on this single switching path directly affects the communications which are using it. When multiple paths are available, the flow of cells for a communication can be statistically distributed over all available paths. This makes it possible to significantly reduce the internal bit rate through the switch. If a failure occurs, fast self-isolation mechanisms at each switching matrix level indicate which internal links should be avoided. One drawback of this method is the need for resequencing mechanisms at the output, as the cells belonging to the same connections generally have do not reach the destination switch port in the same sequence in which they entered the switch.

Internal transfer mode is the choice of the internal format of switched units. In fact, the ATM cell size and the possible ATM link bit rates (initially 150 and 600 Mb/s) result in a buffering capacity and operating speed requirements which are far from optimal for the realisation of switching elements and modules. Therefore, some solutions suggest a multislot transfer mode, in which the external ATM cell is mapped into a chain of elementary slots, known as a multislot cell. The first slot contains a header and all the successive slots in a multislot cell are transferred consecutively through the same switching elements and links. A few bits in each slot are used to indicate the cell slot sequence, as well as the presence of idle slots that do not carry the significant data. This approach allows for a reduced buffering capacity and a tradeoff between speed and parallelism. Besides this, internal transfer based on multislot cells facilitates adaptation to different external cell sizes at the edge of the switching network.

References:
PIECEWISE-LINEAR MODELLING AND CIRCUIT DESIGN

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Key words: piecewise-linear, nonlinear, modelling, synthesis

Piecewise-linear (PWL) approximation can be used for both analysis and synthesis of nonlinear dynamic systems.

A nonlinear characteristic approximated by a set of linear sections is expressed in compact form by a piecewise linear model. The so-called state model firstly introduced in [1] seems to be the most suitable for this purpose. Unfortunately, a universal algorithm for its design has not been known yet. The problem can be simplified by using the decomposed modification of basic state model in the form [2]

\[
\begin{align*}
  y &= A u + B j + f \\
  x &= C u + D j + g \\
  0 &= M u + N j + Q \\
  u &\geq 0, j \geq 0, u^T j = 0
\end{align*}
\]

where \( x, y \) are external variables and \( u, j \) are state variables satisfying the linear complementary condition (4). Equations (1) and (2) form an external part of the model and eqn (3) is an internal part. The main task is to derive model parameters from a given piecewise linear relation between \( x \) and \( y \) variables. The decomposed model provides the possibility of solving the problem of relation structure and the problem of its particular form separately.

Model design. This chapter deals mostly with a one-dimensional model design. The \( x \) variable is a scalar and the system modelled is a nonlinear one-port. Then the \( x \) and \( y \) variables form \( \mathbb{R}^2 \) plane and PWL relations can be divided into single (open, close) and multiple groups. The open relation is a continuous curve whose outer segments are half-lines. The close relation does not contain such segments. Two different algorithms have been developed for one-dimensional model design:

- exact solution
- numeric solution

The **exact algorithm** for single open PWL relations was published in [3]. It is based on utilization of hierarchical procedure. Matrices of the internal block are created using the algorithm according to the number of breakpoints and state variables. Parameters of the external block are obtained by solving of linear equations system. An entirely new algorithm for close types is presented. The result PWL relation is "sewed up" from polyhedral elements that are abscissas in the one-dimensional case. Matrices of the internal block are known in common form for any number of state variables. Parameters of the external block are just mere coordinates of the individual breakpoints in an \( x \)-\( y \) plane.
The method can be generalized for two-dimensional system where the result relation is "sewed up" from triangular elements.

The numeric solution allows to design a decomposed model with lower number of state variables than that designed by the exact algorithm. The main reason for this effort is to increase the speed of simulators using state description. The model designed by the exact algorithm has limited the number of free parameters, so we have to choose a high number of state variables. To overcome the limitation it is necessary to modify both the external and the internal block simultaneously. The method is based on the numerical iterating procedure. The initial point plays a very important role in this procedure. An algorithm for initial solution has been developed. It is based on modified hierarchical procedure and allows to generate the initial point in general case. Pascal subroutines for algorithm verification and simulators have been written.

PWL circuit design. The state model is also suitable for piecewise linear circuit design. The model equation (1), (2), and (3) are linear. The nonlinear properties are introduced by linear complementary condition (4). The circuit consists of linear multiport corresponding to the model equations loaded by a block of ideal diodes corresponding to state variables [4]. The number of ideal diodes is given by the dimension of state vectors \( \mathbf{u} \) and \( \mathbf{j} \). Only the linear multiport is to be designed. The method is described in literature but usually the circuits are based on ideal memoryless amplifiers. Practical realization has to take into account a stability condition. As the synthesis has not a unique solution certain additional criteria can be chosen for the circuit optimization. The circuit structure obtained by this method is not minimal. On the other hand they are universal and especially suitable for nonlinear dynamic system investigation.

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HIGH-FREQUENCY LINEAR TRANSCONDUCTOR

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Key words: analog circuits, transconductance amplifier, current-mode, continuous-time filters, integrated circuits

The current trend in MOS VLSI is to perform more signal processing in the digital domain, although the interface between the analog outside world and the digital processor will remain analog in nature. Another reason for employing analog circuits in modern digital systems is to maintain basic signal processing, which is required for the proper operation of the digital core (input anti-aliasing filtering and output smoothing filtering). Continuous-time integrated filters have an important role in mixed analog/digital MOS VLSI systems such as high-speed communication chips, storage systems and analog interface circuits in general. Filters operating in continuous-time do not use any switching, and thus have none of the disadvantages associated with sampled-data filters. There is no need for anti-aliasing or smoothing operations, no potential for operational amplifier high-frequency noise being aliased into the baseband, and no additional components at the output due to clock feedthrough. Several circuit techniques are available for implementing monolithic continuous-time filters and can be found in several realizations from recent time: Active-RC, MOSFET-C and Transconductance-C. Because transconductance-C filters use an integrator built from an open-loop one-stage transconductance amplifier driving a capacitance load, they can reach a high speed. Such filters have a limited signal-to-total-harmonic-distortion (THD) ratio. The major reason is due to the nonlinearities of the voltage-to-current converter. To minimize even-order nonlinearities, fully-differential structures are preferred [1]. This solution also improves the dynamic range of the circuit. Reduction of the remaining odd-order nonlinearities has to be carried out using some linearization techniques [2]. Unfortunately, linearization circuits exhibit a limitation of speed of the whole filter. It is straightforward that a resulting filter will be designed according to opposite requirements for the speed and the THD. Due to the process variation and the temperature influence, a tuning circuitry has to be included into the filter concept. This demand is even more important in high-frequency circuits because of the use of small-size devices, which leads to a higher limitation of the filter performance (especially the stability of the cut-off frequency) due to eventual changes in the technological process. Therefore, the designed transconductance element is thus required to comprise the transconductance controlling. This paper was oriented towards the development of the transconductance amplifier for high-frequency filter synthesis where low-distortion performance is a priority. Also, the demand for the low-voltage operation, a common trend for down-scaled VLSI's, was considered as an important standpoint for the design strategy. The basic differential (source-coupled) pair, which represents a simple transconductor, possesses a superior high-frequency performance due to its single-stage structure. Even-order nonlinearities are canceled by the differential nature of the structure, but the remaining odd-order nonlinearities still seriously degrade its performance [3]. The dominant third-order harmonic distortion can be reduced by applying...
some linearization techniques discussed for example in [1]. The current-differencing principle realized by the proper scaling of the transistors of cross-coupled pairs exhibits fully cancellation of the 3rd harmonic component of the THD. A disadvantage of this solution consists in the difficult control of the transconductance which is required for tuning the filters. This shortcoming can be overcome by employing a novel principle where the transconductance is linearly proportional to the voltage [4]. The transconductor is constituted by two unequally biased cross-coupled differential pairs operating in saturation. In the proposed structure, an improved biased scheme permits a low-voltage operation. Applying simple square-law characteristics of transistors, following a simple relationship for an output differential current, can be derived:

\[ I_o = I_1 - I_2 = -2KV_0(V_1 - V_2) \]

It is clearly seen that the value of the transconductance is linearly adjustable by a control voltage. A test circuit has been simulated for a typical 1.5 \( \mu \)m n-well CMOS process. High-frequency operation will be limited due to the non-linear behavior of capacitances associated with the bias shifters. According to simulations by SPICE, the frequency operation up to 4 MHz, can be expected for the input voltage range of 0.5 V with an acceptable value of THD.

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DESIGN AND CHARACTERISATION OF FUNDAMENTAL ANALOG FUNCTIONAL BLOCKS FOR CMOS DIGITAL-ANALOG ASIC


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Key words: application specific integrated circuits, CMOS analog circuits design, analog functional block

Recently, an increasing demand for application specific analog and mixed-mode integrated circuits has emerged [1]. Thus a library of analog functional blocks, and well-characterized analog devices are a necessity for all IC producers.

The target of this project is to create a library of analog functional blocks using the CMOS process (5μm, poly-Si gate, single metal, digital) available in the ICM company (Innovation Center of Micronics, a successor of TESLA VUST) in Prague. The project has continued since autumn 1993 [2,3] and is supposed to finish in 1995.

The main goals of this project are as follows:
- to create a library of fundamental analog functional blocks for the CMOS technology provided by ICM
- to characterize this technology from the viewpoint of analog circuits design
- to build a measuring system including software for functional and parametric tests of analog circuits.

In the year 1994 the activity was concentrated on two major tasks. The first was the characterization of the test multichip that was designed in the end of the year 1993 [3] and processed in ICM in the beginning of the year 1994. The test structures were measured first in ICM to obtain the results of routine parametric tests. Later on, detailed device characteristics were measured in the diagnostics laboratory of the department of microelectronics, e.g. output and transfer NMOS and PMOS I-V characteristics including the subthreshold region, C-V characteristics of MOS capacitors, C-V and I-V characteristics of PN junctions, and parasitic bipolar transistors etc. The functional analog blocks were evaluated by the use of a 40MHz gain and impedance analyzer. Some blocks were cut out of the wafer, encapsulated and then measured. The measured data were analyzed and the device parameters for SPICE simulation extracted. The SPICE model library, which is technology dependent, has been updated. All the analog cells except two (current amplifier OCA-2, bandgap reference BANDGAP-H) were proven to work. Nine analog functional blocks achieve expected specifications (comparators COMP-B, COMP-C, operational amplifiers OPAMP-B, C, E, operational transadmittance amplifier OTA-C, multiplexor MUX-C, bandgap reference voltage...
source BANDGAP-K, switched capacitor filter FILTERSC-1) and will be included in the library. The second task was the design of a new set of analog functional blocks and test structures. 12 new 8-pad test structures for a more detailed device characterization were designed. The set of the designed analog circuits consists of:

- OPA-CP operational amplifier with P-channel input transistors and a CMOS output buffer
- OPA-CPQ operational amplifier with P-channel input transistors and an output buffer with vertical NPN transistor
- OTA-BN, CDN improved general purpose operational transadmittance amplifiers (OTA)
- OTA-BM, CN improved OTAs for switched capacitor filters
- CHOTA-C simple low offset chopped OTA
- CHOTA-B precise low offset chopped OTA
- MUX-E improved multiplexer for switched-capacitor filters
- FILTERSC 3 improved second order switched-capacitor filter for mains transmitted remote control
- I-SRC-8c new version of the 8-channel current source with band-gap reference for an 8-channel thermometer.
- NEURO-1 analog artificial neuron cell

Both the test structures and functional blocks were arranged in one multichip (7.6x7.7mm in size). The arrangement of the multichip is similar to the previous test chip [3]. The multichip incorporates two types of cells, 78 8-pad unified test cells and 16 large 22-pad cells. The 8 pad cells are used for the technological and device test structures and for simple functional blocks. The large cells contain the analog functional blocks listed above. Each cell usually contains two functional blocks and biasing circuitry.

A measuring setup for automated parametric and functional testing of the analog blocks designed is currently under development.

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DESIGN AUTOMATION OF PASSIVE COMPONENTS FOR ANALOG INTEGRATED CIRCUITS

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Key words: analog integrated circuits, design automation, passive components

Recently, CAD tools for digital integrated circuit design have reached a considerably advanced stage and are widely used for industrial purposes. On the other hand, the tools for the automation of analog integrated circuit (AIC) design are rather in their infancy. This contrast has recently provoked considerable attention from researchers to this field [1]. Recently some specialized AIC design tools have appeared [2, 3]. These tools are devoted to the design of active components or a particular class of circuits. In a lot of applications it is not possible to avoid the passive components and often these components determine the final properties of designed circuits. According to our knowledge, there are no tools for design automation of passive components. This project is to fill this gap.

The aim of the project is to create a set of programs for design automation of passive components for AIC's. The input of the program will be a set of required component parameters (specified by the designer or calculated using another design program) and the output will be the overall mask topology of the designed component. The project started in September 1993 and is planned for three years. This contribution describes current project achievements.

Fig. 1 shows the importance and the specific place of designed programs in the AIC design process. The developed programs are divided into three hierarchical levels. The programs of the first level will select according to the specified parameters a suitable type of realization for required component (e.g. diffused resistor, polysilicon resistor, more complex transistor realization of resistor, etc.). Possibly, the system will announce that there is no way to realize the component through the required technology. The program of the second level will calculate the size of elements for the chosen type of passive component realization and also specify an additional design rules for layout generation. The program will also generate the model of suggested circuitry. This model will be used instead of the original ideal component for the resimulation of the overall circuitry. The programs at the third level will carry out the design of the masks.

Up to now our attention was focused on the design of integrated resistors. The activities were concentrated into four tasks. The first was the review of possible realizations of passive components in AIC's and their description. The reviewed realizations comprise common strip resistors as well as a comprehensive set of active realizations of passive components (there are solutions with different complexity, starting from single transistor up to 10 to 20 transistors). A parameter set describing each type of component was selected and the relations between the parameters were defined. Each manner of realization is characterized by the range of obtainable values, precision, linearity, frequency and temperature properties.
The second task was the development of passive component models suitable for AIC design. The models for diffused and poly-Si strip resistors have been developed. Models consider the nonlinear phenomena in these types of resistors and their frequency and temperature properties.

The third task was the design and measurement of test structures for resistor parameter extraction and model verification. The first set of structures was designed, processed and measured. The second set of test structures was designed based on the measurement results and with respect to model and program requirements. The second set of structures is currently in process.

The fourth task is the creation of the first version of the first and second level programs. The created programs R_SELECT and R_CALCUL exploit the results of the above mentioned tasks. The programs transform the set of input specifications to the description of the selected resistor realization.

![Diagram of resistor design process](image)

**Fig. 1: Position of tools for resistor design in IC design process.**

**References:**


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VLSI DESIGN OF ANALOG NEURAL NETWORKS

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Artificial neural networks (ANN) are massively parallel computational systems, inspired by the function of the human brain [1]. They consist of large number of identical processing elements called neurons. Each neuron performs fixed non-linear input-output mapping by applying an activation function to the sum of inputs. Inputs and outputs of neuron are connected to other neurons through an interconnection network. The strength of connection between every two neurons is determined by a factor called synaptic weight. The ANN can be made to perform arbitrary function by finding an appropriate set of synaptic weight values through learning.

![Figure 1](image1.png)

![Figure 2](image2.png)

The fact, that ANN can realise any function without the need for system design or programming makes them suitable for the fast and cost effective development of general applications. Moreover, the modular structure of neural networks supports their implementation in analog neurochips [2]. Our work deals with the design of a system, enabling optimal automatic implementation of feedforward multi-layer neural networks into analog VLSI neurochips. For that purpose we have designed the block of synaptic weight and the block of neuron as CMOS analog circuits. The synaptic weight was realised as a four-quadrant transconductor [3] because of the need for both positive and negative synaptic weight values. The block of neuron consists of I/V converter and non-linear V/V circuit, implementing the neuron activation function. ANN can then be readily constructed by assembling neuron blocks and parametrizable synapses in a meander structure.

The analog implementation of ANN's has several important advantages over the digital ones. Those are first of all: high speed, small chip area and physical parallelism (i.e. high fault tolerance [4]). However there are severe limitations in accuracy, which is a common problem of analog circuits [5]. Therefore we have paid great attention to problems
of tolerances, sensitivity, and optimisation in neural networks [5,6]. The main source of
error in ANN proved to be weight deviations in the neighbourhood of their nominal values
caused by technological process imperfections. Luckily, it is the nature of neural networks
that their sensitivity to single parameter deviation decreases with the robustness of the net­
work. Fig. 1 illustrates the relation between network error and weight deviation for 5, 7 and
10 neuron ANN. A novel approach that we propose for improving ANN accuracy is using
the measured or simulated neuron characteristics for learning the network, instead of its
mathematical prototype. That enables us to take into account manufacturing imperfections
already in the learning phase and reduce the influence of inaccurate MOS device models.
We have proved that for modelling of both neuron and single MOS devices it is possible to
build reliable models from the measured data by using neural networks.
To maximise the tolerances of learned network parameters and preserve the proper
function of ANN we perform further design centering over the set of these nominal param­
eters [5-7]. For this purpose we have used methods of statistical estimation of yield gradient,
that belong to the class of stochastic optimisation [6, 7]. The above described methodology
at the end enables us to build reliable ANN systems from inaccurate elements. Fig. 2 shows
the computed decrease of yield with growing weights error.

References:

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