RESEARCH ON NONDESTRUCTIVE EXAMINATION METHODS FOR CANDU FUEL CHANNEL INSPECTION

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ABSTRACT

The requirements of the 1994 edition of CAN/CSA-N285.4 Periodic Inspection Standard, which address all known and postulated degradation mechanisms and introduce material surveillance demands, involve a growing need for improved nondestructive examination (NDE) methods and technologies.

In order to have a proper technical support in its decisions concerning fuel channel inspections at Cernavoda NPP, the Romanian Power Authority (RENEL) initiated a Research Program regarding the nondestructive characterization of the fuel channels structural integrity.

The paper presents the most significant results obtained on this Research Program: the ENDUS experimental system for Laboratory simulation of the fuel channel inspection, ultrasonic Rayleigh-Lamb waves technique for pressure tubes examination, phase analysis technique for near-surface flaws, influence of the metallurgical state of the pressure tube material on the eddy current defectoscopic signals, characterization of plastic deformation and fracture of zirconium alloys by acoustic emission.

1. INTRODUCTION

For the safe and efficient operation of CANDU reactors, the structural integrity of some critical components, mainly fuel channels, is essential.

Zr-2.5%Nb of the pressure tubes is not particularly damage-tolerant, even in normal operational conditions. Both manufacturing (e.g., lap-type flaws) and in-service defects (e.g., debris and bearing pad fretting, delayed hydride cracking, hydride blisters) have occurred. For detection and characterization of such defects, a number of nondestructive examination (NDE) methods and inspection tools have been developed.

However, the requirements of the new edition of CAN/CSA-N285.4 Periodic Inspection Standard, which address all known and postulated degradation mechanisms and introduce material surveillance demands, involve a growing need for improved NDE methods and technologies.

Some years ago, The Romanian Power Authority (RENEL) initiate a Research Program [1] concerning experimental and theoretical studies on NDE methods for characterization of the fuel channels structural integrity. The main output of this Program are:

(1) To ensure technical support for RENEL decisions concerning inaugural, base-line and periodic inspections for Cernavoda NPP.

(2) To provide technical assistance for equipments procurement and personnel training for inspection activities at Cernavoda NPP.

(3) To develop the necessary knowledge infrastructure for inspection data interpretation/evaluation.

The paper presents the most significant results obtained on this Research Program: the ENDUS experimental systems for laboratory simulation of the fuel channels inspection, Rayleigh-Lamb waves technique for ultrasonic examination of the pressure tubes, phase analysis technique for depth determination of the near-surface flaws, effects of the pressure tubes metallurgical microstructure on the eddy current flaw signals, characterization of plastic deformation and fracture of zirconium alloys by acoustic emission.

2. ENDUS EXPERIMENTAL SYSTEM

ENDUS is a laboratory system for experimental studies on the NDE of the pressure tubes, by ultrasonics and eddy current techniques. It was developed as experimental basis for our Research Program. Also, it will be used for laboratory simulation of various complex situations encountered during the real inspections at Cernavoda NPP.

The block-diagram of this very flexible and performant system is presented in fig.1. It consist of tree major parts [10]:

(1) **Automatic Scanning Device (ASD)**

It perform the controlled movement of the **Modular Examination Head (MEH)** inside the **Pressure Tube Sample (PTS).** The main characteristics of **MSD** are:

- Maximum scanning resolution on the **axial** direction (vertical): 0.002 mm/step
- Maximum scanning resolution on the **circumferential** direction: 0.2 mm/step
- Length of the **PTS**: 885 mm
- Scanning range on the axial direction:650 mm

The mechanical scanning is made by the independent (but synchronous) action of two stepping motors (type SLO-SYN with 1.8°/step).

(2) **Real-time Control and Data Acquisition /Processing Unit (RCD)**

It ensures the real-time command and control of **MSD**, the ANALOG to DIGITAL conversion of the defectoscopic signals, synchronization of the entire system, the data storage and processing facilities.

The hardware support of the **RCD** Unit consist of the VME DEVSYS process computer with VM20 processor and specialized interfaces for linking with the NDE devices. The basic software support is developed on the OS-9 operating system using C^{++} language as programming medium; this configuration provide for a unique combination of high performance multitasking facilities with high-speed real time control and processing [13].

In order to have a powerful but still easy to use **operator interface**, an IBM PC AT486 DX computer is included in the hardware configuration of the **RCD** Unit, which run various user interfaces as Windows applications. The AT486 DX computer ensure, also, others NDE Functions of the system like, for example, the **frequency analysis** of the ultrasonic signals.

(3) **Multichannels defectoscopic unit (MDU)**

Consist of analogic ultrasonic and eddy current instruments specific to each NDE function/channel..

The basic configuration of the MDU is presented in fig.1. Depending on the NDE method or technique under study, specially designed modular examination heads are used, with various transducers/ probes instrumentations or different geometries, etc.

Also, on the ENDUS system, it is possible to work with different Pressure Tube Samples having specific reference defects, or artificial defects or even natural defects (e.g., samples with various manufacturing defects).

Specialized techniques and devices were developed for machining artificial defects with different shapes and dimensions. Replica method and high-frequency ultrasonic images techniques are used for characterization of the machined defects ([2],[5]).

3. ULTRASONIC METHODS

In this field, our Research Program is focused on three main objectives:

(1) Development of new techniques complementary to the usually ultrasonic techniques currently applied in the wet technologies for pressure tube inspection, in order to improve their performance in some limit cases. A number of studies are now in progress related to:

- excitation and propagation of the Rayleigh-Lamb waves in the pressure tube wall; applications to detection of surface-breaking-cracks and of hydride blisters
- time of flight diffraction (TOFD), phase and frequency analysis techniques for detection and characterization of the near-surface flaws and of the unfavorable oriented flaws

(2) Development of NDE methods for acousto-elastic characterization of the pressure tube, in order to answer to the material surveillance requirements of the 1994 edition of the CAN/CSA-N285.4 Standard. Here, our works are related to:

- determination of the hydrogen (deuterium) distribution on the pressure tube
- evaluation of the fracture toughness

(3) Development of an Ultrasonic Goniometry technique for measurement of the residual stresses profile in the rolled-joint zones of the pressure tubes. Ultrasonic Goniometry is a powerful method, based on ultrasonic reflectivity near the critical angles, which was developed in our Laboratory, for the acousto-elastic characterization of materials [17]. It was applied for characterization of the elasto-plastic properties of zircaloy-4 thin wall tubes and now, our goal is to use a special designed ultrasonic goniometer as a tool for post-installation verification of the pressure tube rolled joints.

In the following, we shall summarize some of our results concerning ultrasonic examination and characterization of the pressure tubes.

Pressure tubes examination with Rayleigh-Lamb waves ([3],[6]).

Usually, Rayleigh-Lamb oscillation modes are lightly excited and are extensively used for NDE in the case of the thin-wall components.

However, at sufficient low frequencies, it is possible to excite Rayleigh-Lamb waves in moderate thickness plates or tubes.

In fig.2, it can be seen the calculated Rayleigh-Lamb dispersion relations for Zr-2.5%Nb pressure tubes [3], experimentally verified by ultrasonic goniometry. The symmetric and asymmetric branches which correspond to different oscillation modes are expressed as frequency dependencies of the incidence angle at the water/pressure tube interface. It is obvious that for frequency values around 2 MHz, a significant dispersion effect is manifest.

The measurements performed with a specially designed examination head (fig.3) have demonstrated a linear dependence of the reflected and, also, of the transmitted amplitude of the A_1 and S_1 oscillation modes on the defect de pth, up to approximately 0.1 * (wall thickness) ≅ 0.4 mm, from both inside or outside pressure tube surfaces. For a high depth, this dependence is rapidly saturated [6].

Therefore, examination with Rayleigh-Lamb waves is very useful for detection of surface-breaking-cracks type of flaws or for detection of hydride blisters, despite of the disadvantage of a poor localization resolution.

An other interesting application of the Rayleigh-Lamb waves excited in the pressure tube wall is the possibility of the hydrogen content measurement by a modified velocity ratio method [16].

Depth determination of the near-surface flaws by phase analysis of ultrasonic composite signals

The standard procedure of evaluation of the flaws size and position from the amplitude and time of flight corresponding to the echo signals, cannot be applied in the case of the near-surface flaws for which an overlap exist between the surface echo and the flaw echo.

A number of deconvolution algorithms are described in literature ([20],[21]) for reconstruction of the flaw echo signal.

The technique developed and experimentally verified in our works ([4],[9]) concerning the pressure tube examination with longitudinal waves on the radial direction, is based on the linear frequency dependence of the phase function

$W(f) = (1/2\pi)\ \mathrm{arctg}\ [-\mathrm{Im}\ Z(f)/\mathrm{Re}\ Z(f)]$

where $Z(f) = X(f)/Y(f)$, $X(f)$ being the complex Fourier Transform of the surface echo, and $Y(f)$ the complex Fourier Transform of the composite echo (overlap of surface and flaw echoes). The slope of the linear dependence $W = W(f)$ is proportional with the flaw depth.

Figure 4 illustrate the surface echo the composite echo and the frequency dependence of the phase function $W = W(f)$ in the case of a rectangular flaw machined from the outside surface up to 1 mm depth from the internal (incidence) surface. The phase function $W(f)$ was constructed by real-time digital processing using the Fast Fourier Transform routine of the ASYSTANT software package.

In order to obtain a good signal to noise ratio, broadband high frequency ultrasonic transducers must be used.

Acousto-elastic characterization of the pressure-tube material

Three types of high accuracy methods for the measurement of the ultrasonic phase velocity and attenuation were developed and currently used in our Laboratory ([7],[16]):

(1) **Sing-Around Method** for measurement of very small sound velocity changes [22]. Our home-designed and constructed MPUS-01 system can measure variations of the order of $\delta V/V \sim 10^{-7}$ and is used for experimental studies on acousto-magnetic effects, temperature effects, non-linear elastic effects in different materials, specially in zirconium alloys [8]; in certain conditions, the MPUS-01 system permits, also, the simultaneous velocity and attenuation measurements, under the influence of some controllers external parameters of the sample state.

(2) **Ultrasonic Goniometry** for experimental determination of the Rayleigh-Lamb dispersion relations. This is a new technique developed in our Laboratory, based on the frequency-angle double scanning [23]; using powerful mathematical methods, this technique lead to complete characterization, in a certain spectral range, of the acousto-elastic properties of the investigated sample.

(3) **Acoustic Microscopy Method** for obtaining high-resolution B-scan and C-scan ultrasonic images of the acousto-elastic discontinuities in metallic and ceramic materials. The MICROSCAN-03 equipment, designed and constructed in our Laboratory are used for obtaining 3-dimensional acoustic images of microstructure details at magnification factors comparable with the usual metallography (x 50 and, in special conditions, up to x 100).

All these methods are extensively used for the understanding of the complex microstructure properties of Zr-2.5%Nb pressure tube material.

In fig.5, we present the texture dependence of the ultrasonic longitudinal wave velocity in Zr-2.5%Nb pressure tube. Calculus of the longitudinal phase velocity on different propagation directions in monocrystaline zirconium, demonstrate that the maximum value correspond to the propagation in the - axis direction the minimum value correspond to the propagation in an arbitrary direction in the basal plane Therefore, in polycrystalline zirconium the phase velocity v_L will be dependent on the effective fraction of elementary cells aligned with the - axis (the f - factor).

Our ultrasonic velocity measurements have confirmed that, in the metallurgical state specific for the CANDU pressure tube, the most great fraction of the alpha grains are orientated with the - axis around the circumferential axis. The acousto-elastic anisotropy is very pronounced and is described by the function:

where β is the propagation direction in the axial-circumferential plane (β=0 is the axial direction) and:

a = 4.6805	c = 0.005283
b = 0.042448	d = 0.072768

In order to elaborate an ultrasonic NDE method for measurement of hydride concentration in the pressure tube, detailed experimental and theoretical studies are in progress in order to establish the acousto-elastic effects of the hydrogen ingress.

It is interesting to note that the influence of the hydride precipitation on the ultrasonic phase velocities is determinated not only by the hydrogen content but, also, by the internal stresses developed during the precipitation process.

This significant effect can be seen in the fig.6 in which the dependencies of the longitudinal phase velocity on the hydrogen concentration are shown for two different hydriding method:

- **slow hydriding method** by gas-solid equilibrium reaction; in this case, the ultrasonic longitudinal velocity is slightly increased, in accord with others experimental studies [19];
- **fast hydriding method** by non-equilibrium hydrogen plasma-metal interaction process; in this case, the dominant effect is the longitudinal velocity decrease under the influence of the high-level internal stresses developed by the fast hydrogen precipitation [16].

The ultrasonic 3-dimensional images of pressure tube samples with different hydrogen contents, prove that the hydrogen distribution is relatively nonuniform, even in the case of slow hydrided samples [16]. This can be seen in fig.7: the δ hydride pellets form long "filaments" parallel with the axial-circumferential plane (the XY plan, in the specified figure); in accord with the known fact that the basal plane is the habit plane for this type of hydrides.

The Acoustic Microscopy studies on zirconium-hydrogen system are very recent, but they already demonstrate the remarkable utility of this method in understanding the complex phenomenon of hydrogen ingress and precipitation in metallic materials.

High frequency ultrasonic imaging techniques, similar to the Acoustic Microscopy techniques, will be, also, applied for examination of the

offcuts samples of the pressure tubes at Cernavoda NPP/Unit 1, in order to establish if the rolled-joints are free of lap-type manufacturing flaws [25].

4. EDDY CURRENT METHODS

Three main problems are under work in this field:

(1) Determination of the influence of the metallurgical state of the pressure tube material on the defectoscopic signals. It is known the effect of the localized resistivity bands created by an enriched oxygen content [24]. Defect-like signals due to this effect was observed during the eddy current measurements for garter spring location at Cernavoda NPP/Unit 1. Also, others two topics are of interest here:

- determination of the effect of the hydride concentration on the defectoscopic signals, in order to evaluate the possibility to estimate the hydrogen (deuterium) concentration by eddy current techniques;
- determination of effect of the texture variations on the electrical resistivity of the pressure tube material and, therefore, on the eddy current defectoscopic signals.

Study of the influence of the metallurgical state is important, also, for a proper background of the eddy current NDE acceptance criteria.

(2) Development of methods, procedures and equipments for eddy current examination of the offcuts samples of the pressure tubes installed at Cernavoda NPP/Unit 1 and of the pressure tubes for Cernavoda NPP/Unit 2. The pressure tubes for this CANDU Units were not inspected by eddy current in the manufacturing stage [25]. Because of the limitations of the ultrasonic testing in detecting B2N06 lap-type flaws (long axial defects at internal tube surface, making a small angle with the surface), eddy current testing is a necessary complement of the ultrasonic manufacturing inspection.

(3) Improved eddy current techniques for the pressure tube-calandria tube gap measurement. The garter springs for Cernavoda NPP/Unit 1 are of the snug type (non welded girdle wire). It is known that this type of garter springs is, practically, not

detectable by the usual eddy current technique [18], because the surface of the girdle wire oxidize and prevent the electrical conduction around the wire. For this reason, the direct measurement, with high accuracy, of the pressure tube-calandria tube gap is compulsory in order to satisfy the requirements of the 1994 edition of CAN/CSA-N285.4 Standard.

In all our studies related on eddy current methods, numerical simulation is an important part of the experimental data evaluation process. For this, a number of phenomenological models, based on electrical equivalent circuits of the physical systems under study, were elaborated. Parametric analysis on this models are usually made with specialized electric network analysis software [15].

Detailed studies are now in progress concerning the effect of the pressure tube metallurgical state on the defectoscopic signals. In fig.8, it can be seen the horizontal component, the vertical component and the impedance plane representation of the eddy current signals corresponding to an artificial defect with h=0,2 mm depth, machined in a Zr-2.5%Nb pressure tube sample. The measurements, made before and after a slow rate hydriding process, show a significant influence of hydrogen, even at relatively low level concentrations ([14],[15]).

The parametric analysis performed on the appropriate phenomenological model have demonstrated that the most important contribution of the metallurgical state changes on the eddy current defectoscopic signals is due to the corresponding electrical resistivity variations. The amplitude variations of the horizontal component versus frequency for different values of resistivity variation are plotted in fig.9, in the case of an artificial flaw with h=0.2 mm depth.

5. CHARACTERIZATION OF THE PLASTIC DEFORMATION AND FRACTURE OF ZIRCONIUM ALLOYS BY ACOUSTIC EMISSION ([11],[12])

Zirconium alloys have a low solubility for hydrogen. For this reason, when solubility limits are exceeded, a brittle second phase (hydrides) appear which, even in small concentrations, can potentially have an dramatic effect on the structural integrity of zirconium alloys nuclear components.

In this conditions, complementary to NDE at periodic or as-request inspections, continuous monitoring of crack growth in pressure tubes is of a great interest. Acoustic emission (AE) is the most promising method for continuous structural integrity monitoring of the CANDU fuel channels.

The first step for a proper evaluation of the feasibility of the on-line structural integrity monitoring of the pressure tubes by this method, is to detect and analyze the specific acoustic emission signal generated by the hydride fracture in a zirconium alloy matrix.

For this, we have designed and constructed an experimental system (named CARD) for accurate reception of acoustic emission signals from the elastic energy release during the controlled mechanical deformation of specially designed samples. This system (see fig.10) has two channels and permits rejection of all acoustic emission events which are not localized in the deformed sample zone.

In this way, very accurate correlations was obtained between evolution of the deformation process and the corresponding acoustic emission activity, as it can be seen in fig.11, for a zircalloy-4 sample.

Also, both time domain and frequency domain of the acoustic emission signals can be analyzed by numerical processing. A very "quiet" mechanical system, set in motion by a stepper motor, permits a rigorous control of the deformation rate.

Figures 12 and 13 are time and frequency representation of a typical AE signal. The 3D plot in figure 14 illustrate the spectral evolution of the AE activity during the mechanical deformation and fracture of the zircalloy-4 sample.

6. CONCLUSIONS

Extensive efforts have been made to develop a complete experimental basis for the Research Program concerning NDE methods and techniques for characterization of the fuel channels structural integrity.

Now, our experimental basis consist of:

(1) ENDUS laboratory system for ultrasonic and eddy current measurements and testing on pressure tube samples

(2) MPUS-01 system for measurement of very small sound velocities changes and of ultrasonic attenuation variations under the influence of some controlled external parameters of the sample state (magnetic field, temperature, uniaxial stress)

(3) USG-MA Ultrasonic Goniometer for experimental determination of the Rayleigh-Lamb dispersion relations

(4) MICROSCAN-03 Acoustic Microscopy equipment

(5) MICROSCAN-01/CT Eddy Current Imaging System

(6) CARD system for characterization of plastic deformation and fracture behavior of metallic materials by acoustic emission

A series of useful and interesting results have been obtained in the framework of our Research Program:

- method for ultrasonic examination of pressure tubes with Rayleigh-Lamb waves
- method for phase analysis of ultrasonic signals by digital processing
- acousto-elastic characterization of Zr-2.5%Nb pressure tube anisotropy and hydrogen effects
- effect of the pressure tube metallurgical state on the eddy current defectoscopic signals
- analysis of acoustic emission signals generated during plastic deformation and fracture of zirconium alloys.

Many of this results will be applied, in the near future, to solve a number of NDE problems for Cernavoda NPP:

- examination of the offcuts samples of the pressure tubes from the Unit 1, by high frequency ultrasonic and eddy current imaging techniques;
- eddy current examination of the pressure tubes for the Unit 2.

Also, our experimental basis and the developed investigation techniques can be extremely useful for salving NDE problems for others CANDU Nuclear Power Plants. In respect to this, our objective is to integrate the research activity of our Laboratory in the framework of Research Programs of CANDU Community.

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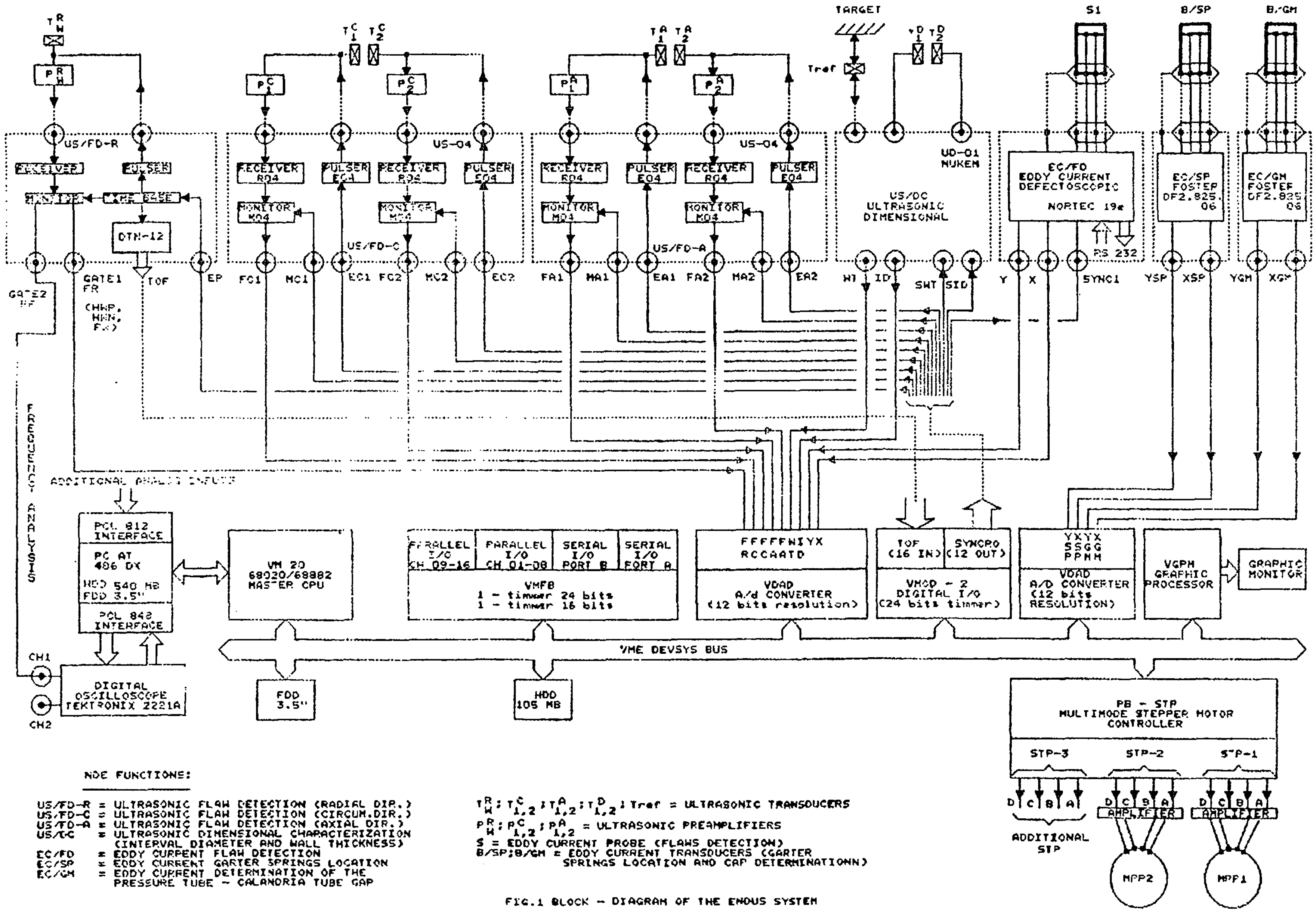


NDE FUNCTIONS:

US/FD-R = ULTRASONIC FLAW DETECTION (RADIAL DIR.)
US/FD-C = ULTRASONIC FLAW DETECTION (CIRCUM.DIR.)
US/FD-A = ULTRASONIC FLAW DETECTION (AXIAL DIR.)
US/DC = ULTRASONIC DIMENSIONAL CHARACTERIZATION (INTERVAL DIAMETER AND WALL THICKNESS)
EC/FD = EDDY CURRENT FLAW DETECTION
EC/SP = EDDY CURRENT GARTER SPRINGS LOCATION
EC/GM = EDDY CURRENT DETERMINATION OF THE PRESSURE TUBE ~ CALANDRIA TUBE GAP

T^R_W; $T^C_{1,2}$; $T^A_{1,2}$; $T^D_{1,2}$; Tref = ULTRASONIC TRANSDUCERS
P^R_W; $P^C_{1,2}$; $P^A_{1,2}$ = ULTRASONIC PREAMPLIFIERS
S = EDDY CURRENT PROBE (FLAWS DETECTION)
B/SP;B/GM = EDDY CURRENT TRANSDUCERS (GARTER SPRINGS LOCATION AND GAP DETERMINATIONN)

FIG.1 BLOCK - DIAGRAM OF THE ENDUS SYSTEM

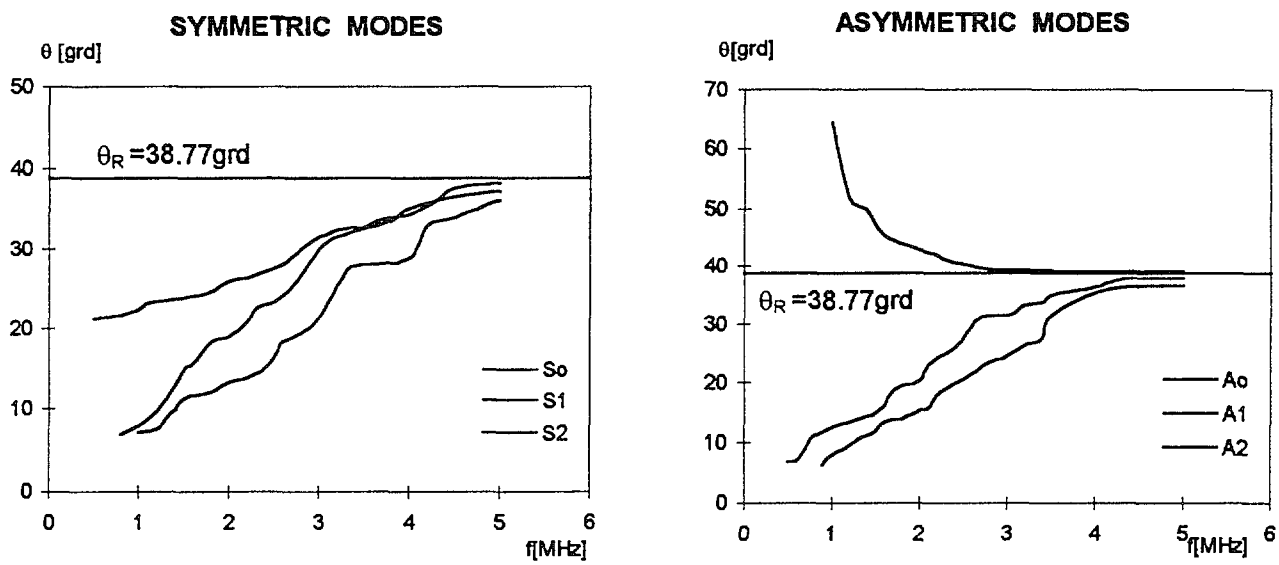


Fig.2. Rayleigh-Lamb dispersion relations for Zr-2.5%Nb pressure tubes expressed as incidence angles versus frequency (water/pressure tubes interface)

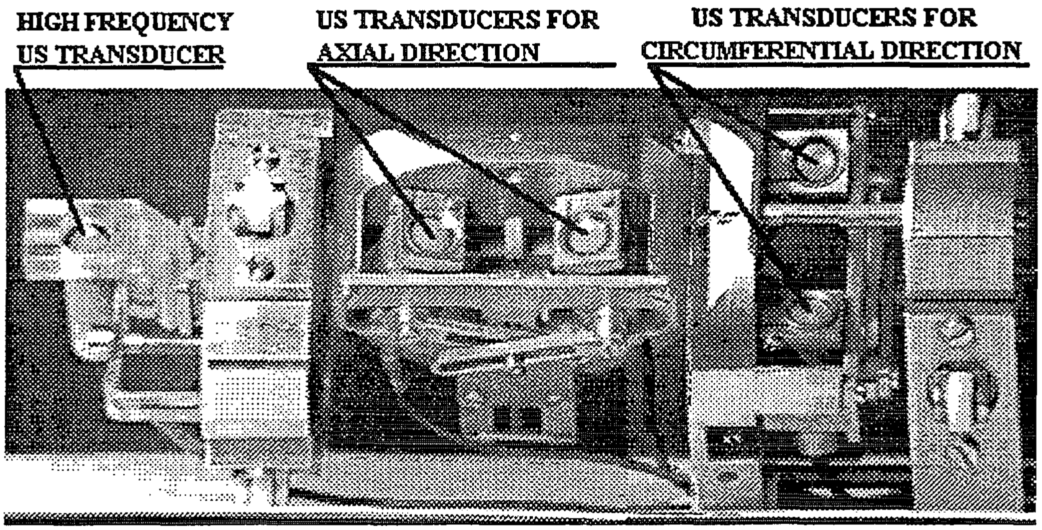


Fig. 3. Modular examination head for ultrasonic examination with Rayleigh-Lamb waves on the axial and circumferential directions and with high frequency longitudinal waves on the radial direction

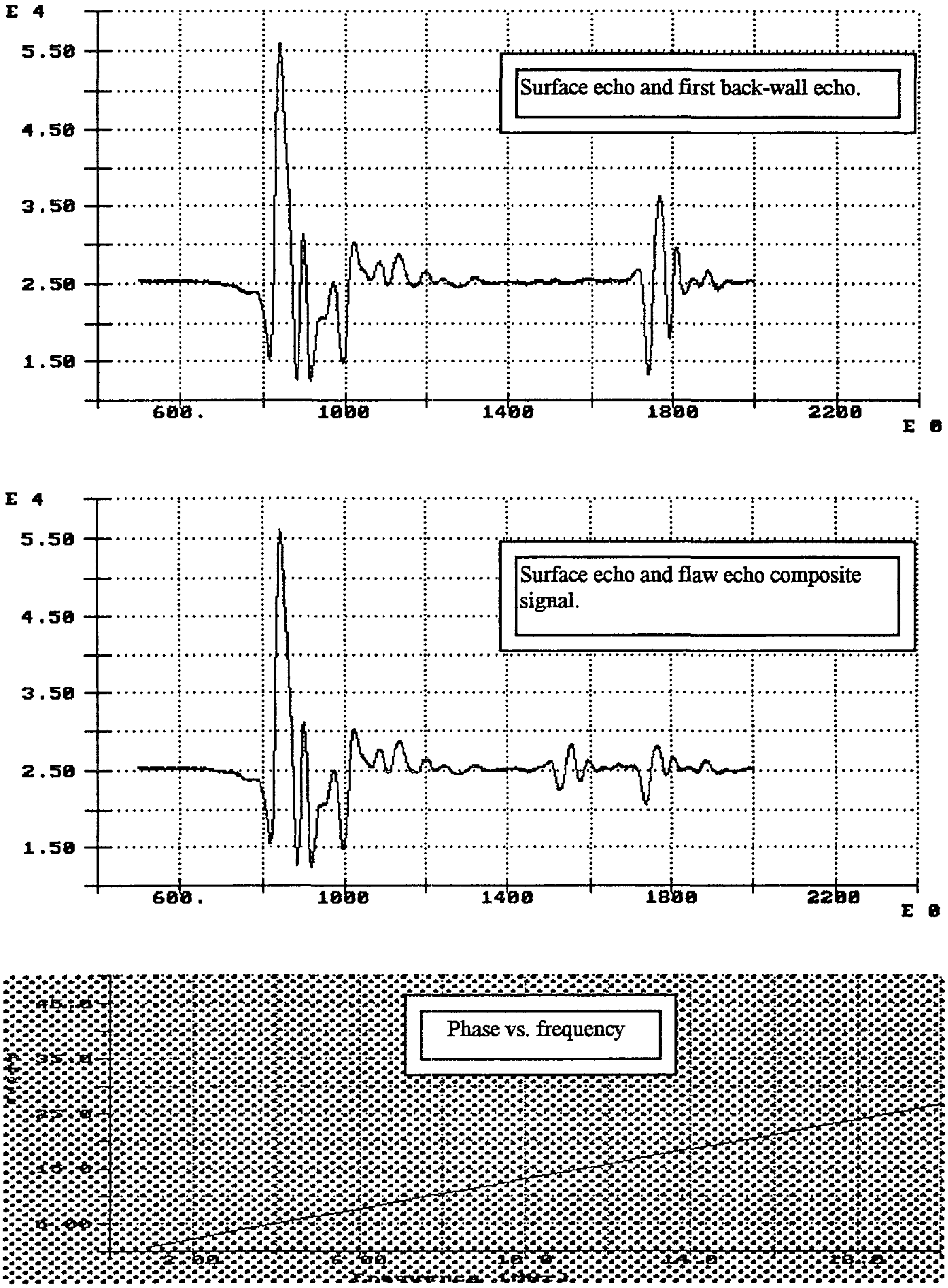


Fig. 4. Frequency dependence of the phase W(f) for a rectangular flaw, with h=1mm depth, in a pressure tube sample. Transducer used : PANAMETRICS A312R, 10 Mhz / 0.25".

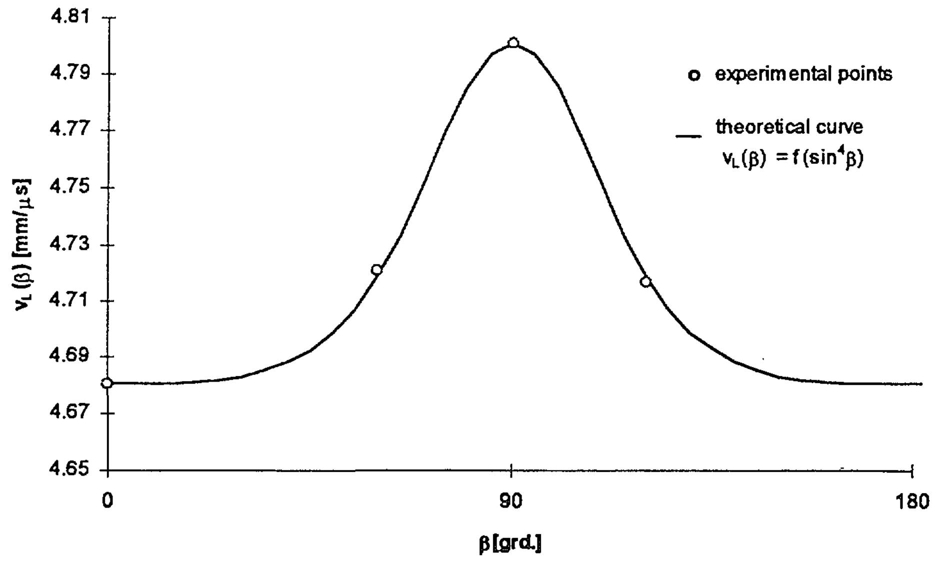


Fig. 5. Texture dependence of the ultrasonic longitudinal waves velocity in Zr-2.5%Nb pressure tube; β is the direction of propagation in the axial-circumferential plane (β = 0 is the axial direction)

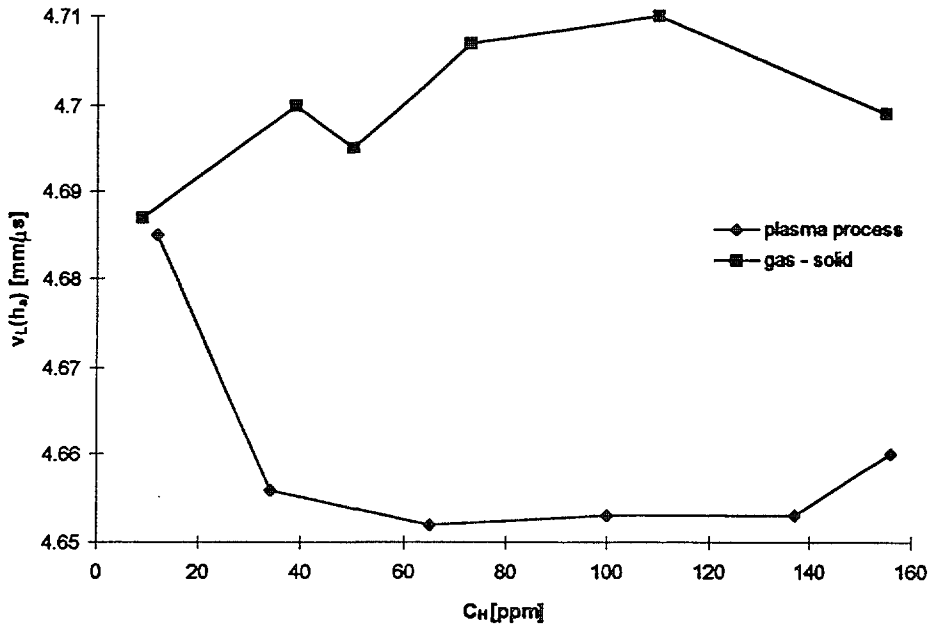


Fig. 6. Hydrogen effect of the longitudinal wave velocity (axial propagation direction) in Zr-2.5%Nb pressure tube samples, for:
- fast hydriding (non equilibrium plasma process);
- slow hydriding (gas-solid equilibrium reaction).

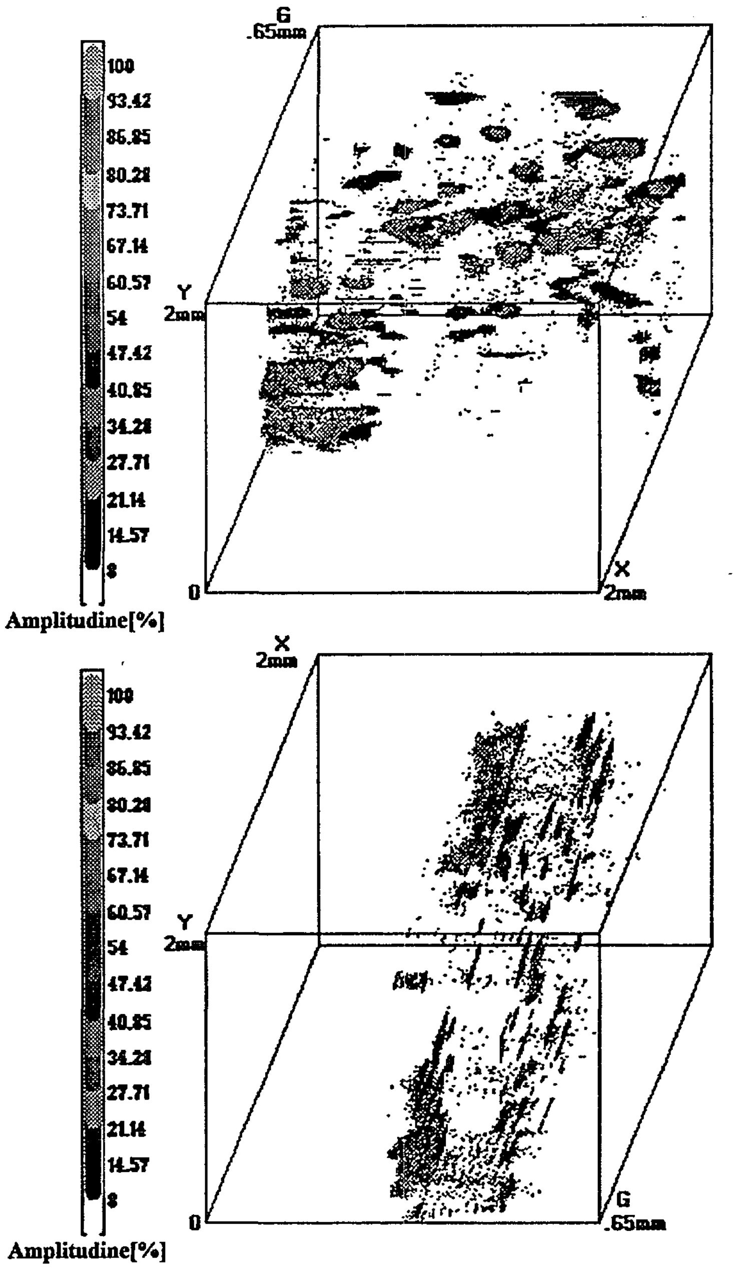
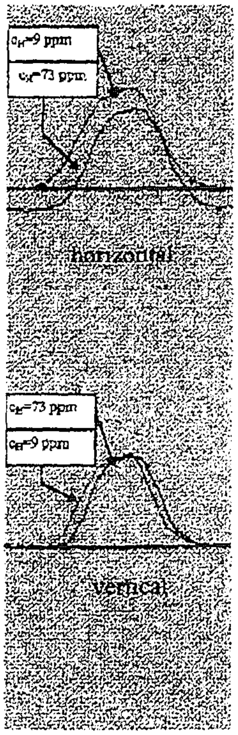
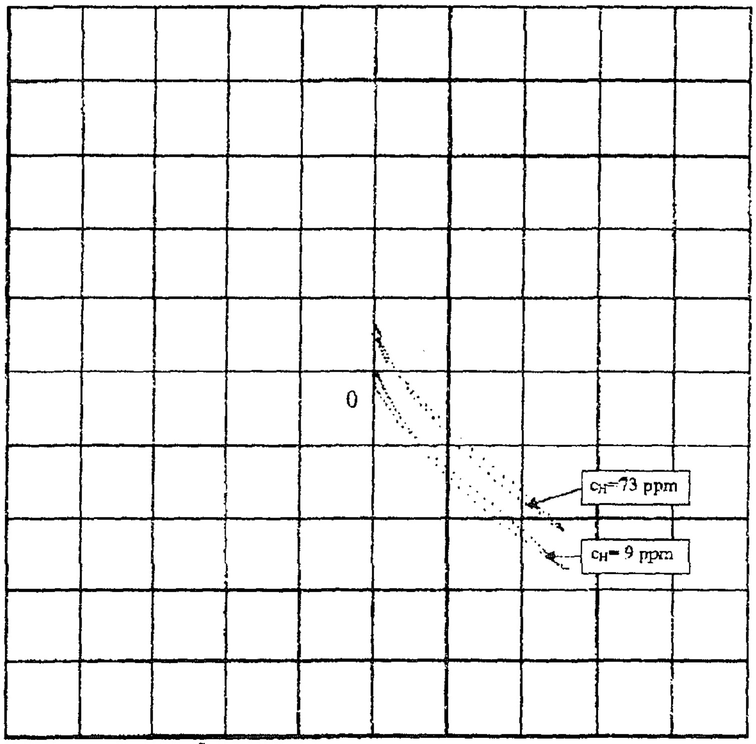


Fig.7. Ultrasonic 3-dimensional image of the acousto-elastic discontinuities in a Zr-2.5%Nb pressure tube sample with C_H = 110 ppm hydrogen content

MEASUREMENT PARAMETERS

Equipment	:	**MICROSCAN-03 (INR-Ultraacoustics R&D Lab)**
Flaw Detector	:	**USIP 12 / KRAUTKRAMER**
Transducer	:	**H10MP15 / KRAUTKRAMER**
Gain	:	**98 dB (25 MHz/BB)**
Threshold	:	**8% Full Scale**
Gate start	:	**2.3 mm on the radial direction G**
Resolution	:	**X x Y = 5 x 5 μm^2**





FREQUENCY=800 kHz IMPEDANCE PLANE

Fig. 8. Eddy current signals for an artificial flaw with h=0.2 mm depth, machined in a Zr-2.5%Nb pressure tube sample,before and after a slow rate hydriding process. The hydrogen content of C_H=9 ppm corespond to the "as recived" state.

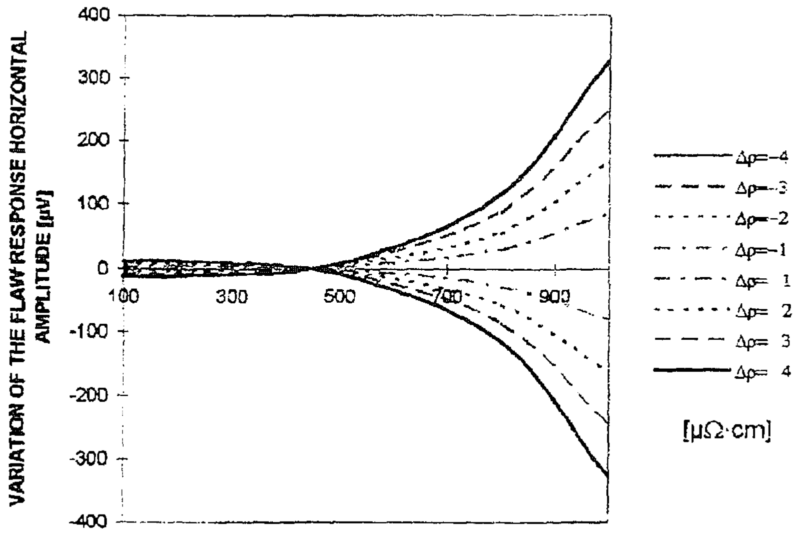
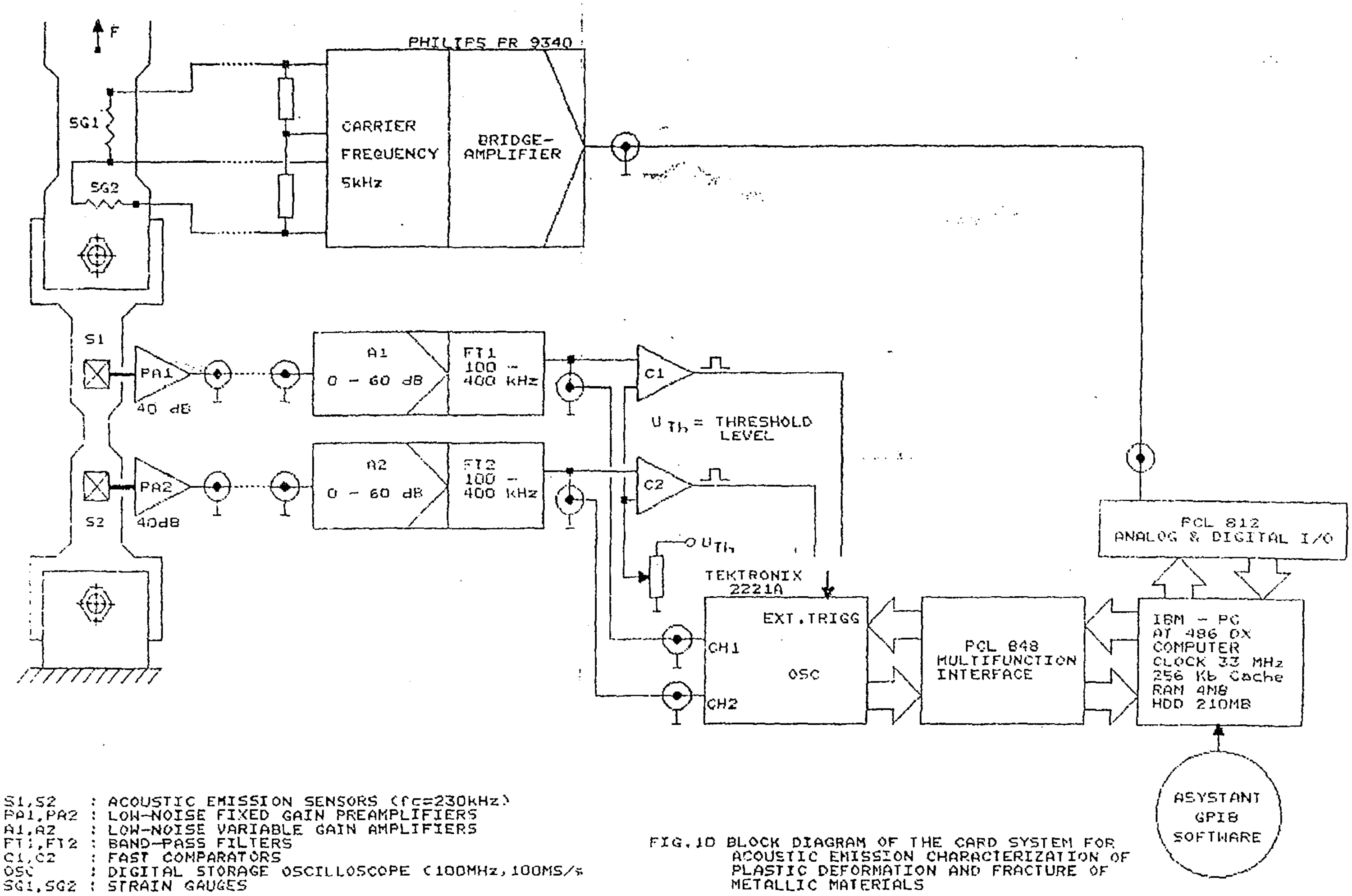


Fig. 9. Calculated influence of electrical resistivity variations Δρ on the eddy current amplitude for an artificial flaw with h= 0.2 mm depth in Zr-2.5%Nb pressure tube .



S1,S2 : ACOUSTIC EMISSION SENSORS (fc=230kHz)
PA1,PA2 : LOW-NOISE FIXED GAIN PREAMPLIFIERS
A1,A2 : LOW-NOISE VARIABLE GAIN AMPLIFIERS
FT1,FT2 : BAND-PASS FILTERS
C1,C2 : FAST COMPARATORS
OSC : DIGITAL STORAGE OSCILLOSCOPE (100MHz,100MS/s
SG1,SG2 : STRAIN GAUGES

FIG.1D BLOCK DIAGRAM OF THE CARD SYSTEM FOR ACOUSTIC EMISSION CHARACTERIZATION OF PLASTIC DEFORMATION AND FRACTURE OF METALLIC MATERIALS

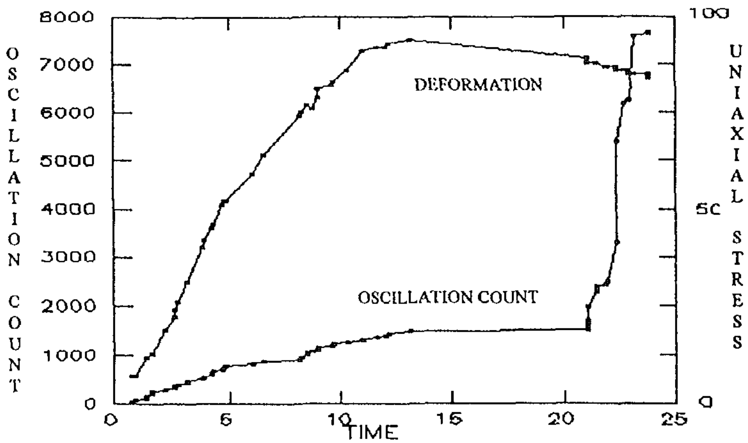


Fig.11. Uniaxial stress and total AE count versus time (constant deformation rate) during the mechanical deformation and fracture of a Zyrcaloy-4 sample.

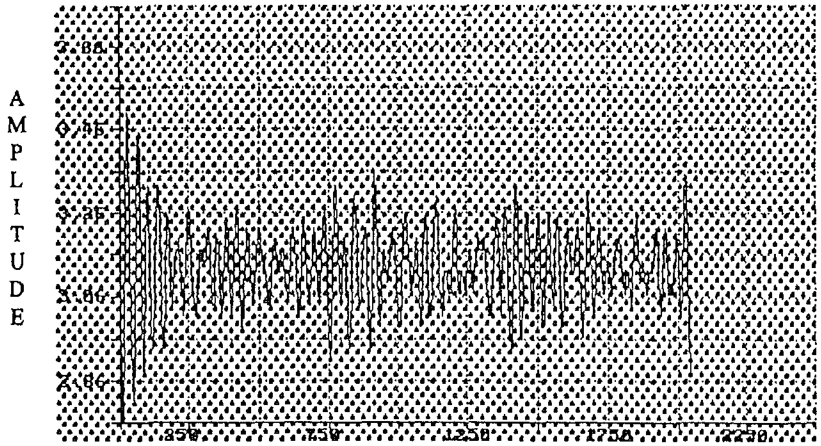


Fig.12.Tipical acoustic emission signal in time domain for the plastic deformation zone.

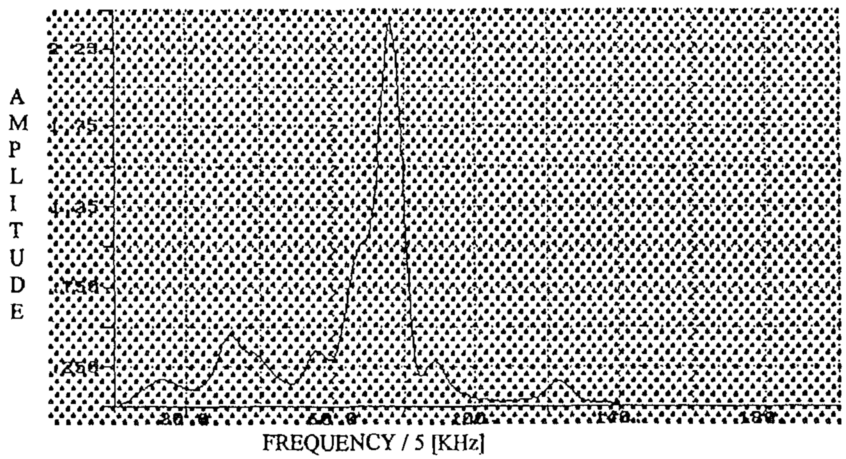


Fig. 13. Frequency spectrum of the AE signal from fig. 12, obtained by real-time Fast Fourier Transform.

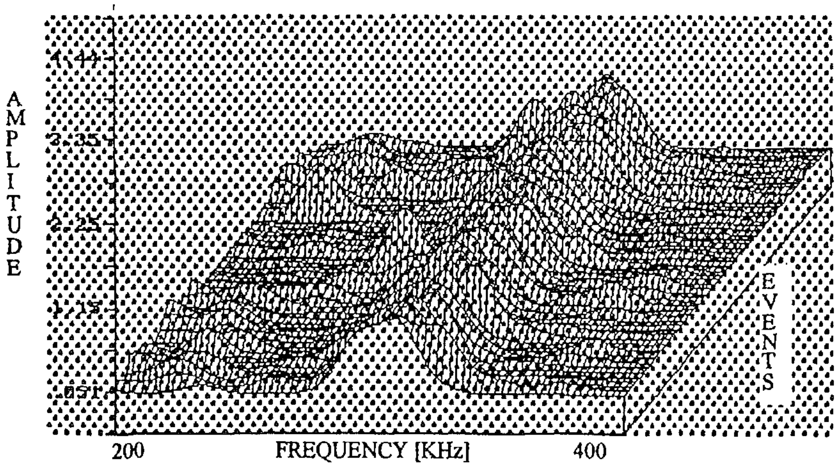


Fig. 14. Evolution of the frequency spectrum of the AE signals during the mechanical deformation and fracture of a Zircaloy-4 sample.

Table 2. CANDU-6 FUEL CHANNEL INSPECTION HISTORY (reference [8])

INSPECTION PURPOSE	TYPE OF INSPECTION	TECHNIQUE/ METHOD	LEPREAU	GENTILLY 2	WOLSONG 1	EMBALSE	CERNAVODA	WOLSONG 2
To verify absence of significant defects	Manufacturing	Full length UT	380	380	380	380	380	380
To detect defects that could be missed by UT	Manufacturing	Full length ET on OD & ID						380
To detect defects that could be missed by UT	Preservice	Full length ET on ID	380	380	380	380		
Reinspection of suspect regions identified by ET	Preservice	Selected area UT	2		1	2		
Verify presence and location all garter springs	GS Installation	ET					380	380
Verify presence of Lap-type Flaws	Post-Installation	Mettallography					28 [10] (top & bottom of ingots)	
Compliance with CAN/CSA-N285.4-M78 and provide baseline information for future inspections	Inaugural	rolled joint ET	14	14	14	14		
		full length ET	14			14		
		surface roughness	14	14	14	14		
		gauging(1)	14	14	14	14		
Compliance with CAN/CSA-N285.4-M83 to verify there is no generic degradation	First Periodic Inspection	CIGAR	5	5	5			
		"Dry Channel"				11		
In-service Inspection	1984							
	1985							
	1986	GS Location by ET	2					
	1987			6 (CIGAR)				
	1988	CIGAR	9					
	1989							
	1990	UT & ET	1	27 (CIGAR)	6 (CIGAR)			
	1991		3 (CIGAR)					
	1992				19 (CIGAR)			
	1993			4 (CIGAR)				
	1994				14 (CIGAR)			