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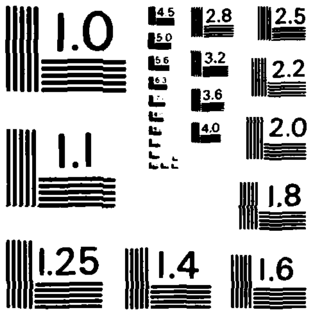

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DEFECTS AND MATERIALS CHARACTERIZATION BY ANALYSIS OF ULTRASONIC SIGNALS.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Recent techniques in defects and materials characterization are reviewed and some of them selected to be implemented at INTA's Ultrasonic Lab. Previous work includes design and manufacture of several items (ultrasonic test bed, facsimile recorder) as well as familiarization with instrumentation. Main effort in this first year has been devoted to prepare software and to test it via elementary experiments on materials characterization.

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PREFACE

The present work has been performed at the Ultrasonics Laboratory of the Department of Structures and Structural Materials of INTA as a first part of a two year program.

The first period is mainly devoted to setting up the instrumentation, technique and software to be used in the second year. It also includes the necessary period for all the research personnel involved to become familiar with new techniques and instrumentation.

This work has been funded in part by European Office of Aerospace Research and Development under grant number EOARD-82-0316.

The author wishes to achnowledge the effort of J. Miguel Alvarez in preparing the software as well as that of E. Gallego del Pozo in designing and making auxiliary equipment.

1 - General

The work reported here was programmed as a part of a wider research project of the Ultrasonic Laboratory of the Structures and Structural Materials Department of the INTA. An ultrasonic spectroscopy research program was formerly developed under the sponsorship of Spanish Government. Analog techniques used in this project soon proved to be unsuitable to perform adequate reflector characterization and, therefore, it was decided to implement the necessary instrumentation to digitize and computer process the signal.

In November 1981 a proposal was submitted to EOARD including several goals to be specified later. The proposal was approved and EOARD gave some useful recommendations for the best development of the work and in order to coordinate with other works already in progress in other Laboratories in the United States. With this aim, a trip was programmed to attend the Annual DARPA/AFML Review of Progress in Quantitative Nondestructive Evaluation to be held in La Jolla, California, and to visit Ames Laboratory of Iowa State University and Rockwell International Science Center (Thousand Oaks, California). A visit to NASA Lewis Research Center (Columbus, Ohio) was also suggested but, because of unknown reasons, it was not possible to arrange this visit. In any case, the information obtained during this trip, which took place in August 1982, as well as those from several "Proceedings of the DARPA/AFML Review of Progress in Quantitative NDE" supplied by London Office of the EOARD have been of major help in defining the objectives and selection test techniques.

One of the aims more clearly defined was the defect characterization subject that absorbs the largest portion of the scientific work carried out under DARPA/AFML

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sponsorship since 1973. Ultrasonic test quantification, in particular, is one of the main objectives of this project which tends to reduce the numerous sources of uncertainity found in conventional tests.

Therefore, it was decided to dedicate a part of the work to defect characterization and, after consulting available bibliography, two different techniques seemed to be the most adequate:

- Comparison of spectral amplitude as a function of the direction of incident beam. It is an empirical method first proposed by E. Domany (1).
- Unidimensional Born inversion. There are many papers available on this technique. We have taken as reference that of R.K. Elsley (2).

On the other hand the development of some technique suitable for materials characterization to determine elastic mechanical and fracture parameters was considered. The great interest of this objective is generally recognised, due to the high cost of the destructive mechanical tests necessary to make measurements of yield point, (σ_y) or fracture toughness (K_{Ic}, J_{Ic}). The Mechanical Test Laboratory of the Department of Structures and Structural Materials of INTA is developing a programme to study the fracture toughness as a function of heat treatment of several national low alloy steels. This gives additional interest to our nondestructive characterization objective and facilities to get suitable samples available.

Materials characterization by ultrasonics is based on the measurements of the acoustic velocity and attenuation as a function of frequency. When results are applied to suitable equations yield point and toughness can be evaluated. Even considering the limited validity of current

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equations, mainly because its empirical character, it seems undoubtfull the usefulness of the works of A. Vary and his group, NASA Lewis Research Center, (Columbus, Ohio) in view of the test systematization and searching a suitable model to explain interaction between elastic waves and inhomogeneities or dislocations present in solids.

Work to be carried out in our Laboratories will be mainly dedicated to check the validity of Vary's empirical equations (3) for materials other than those found in references (maraging steel and titanium alloy).

The definite structure of the works was stablished in the following way:

First year:

- Review of bibliography.
- Familiarization with computer and digital instrumentation.
- Design and fabrication of a precision automatic system for inmersion testing.
- Software for defect characterization.
- Software for materials characterization.
- Preliminary experimental work.
- Design and fabrication of auxiliary equipment.

Second year:

- Setting up the immersion test system and defect characterization tests.
- Tests for software functionability.
- Complete programme of experimental tests.
- Elaboration of results and conclusions.

It can be said that first year will be devoted to prepare equipment and software and the second year to carry out the greater part of the experiments.

Because of several administrative difficulties it has not been possible to complete all the objectives of the first year.

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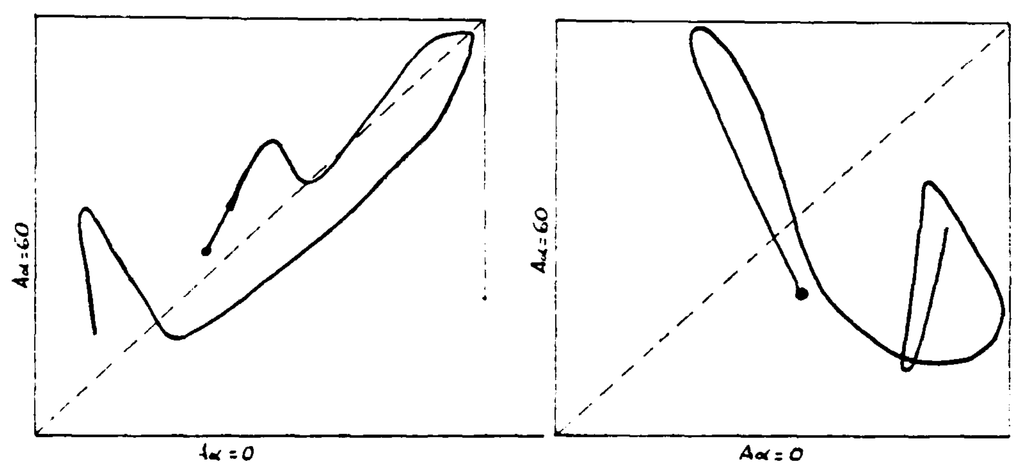
2 - Theoretical bases

2.1 - Defect characterization

The technique suggested by E. Domany (1) has a very simple principle. It consists in analyzing the frequency spectrum of two echos coming from different tests positions. If the reflector is a sphere it is evident that the response will be constant as the test angle varies. Then, if frequency amplitude from one angle is represented versus that obtained from the other angle, a diagonal of the first coordinate quadrant will be obtained unless some uncontrolled influences have gone into the work.

On the other hand, the curve will become deformed and apart from the diagonal as the reflector moves away from the spheric shape. In this way some information about reflector shape may be derived. Results of applying this technique to two spheroidal reflectors are shown. in fig. 1.



a) spheroid Semiaxes a:0.4mm b:0.2mm   b) spheroid semiaxes a:0.4mm b:0.1mm

Fig. 1. Spectral amplitude as a function of beam direction for two spheroidal reflectors. Parameter is frequency.

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Born approximation, in which the inversion algorithm is based, is a theory useful to explain the weak scattering that occurs when the difference of the acoustic impedance between the reflector and the host is low. It derives a relatively simple mathematical model which has proved to be useful in order to systematize experimental data. The inversion algorithm coming from this theory have shown to be adequate even when not strictly weak scattering occurs. Then, it is not surprising to find a large number of works related with either the theoretical exploration or experimental checking of this new tool.

In its direct formulation, Born's approximation makes easier the calculation of $\vec{R}$, which is the signal in the time domain and that will be received by the transducer after the interaction of the reflector with an infinitely short pulse (Dirac's step function). Firstly the respective incident pulse and observation direction must be defined.

$\vec{R}$ is also known as impulse response and it can be shown that it is proportional to the second derivative of the area function A(s) of the reflector's transversal section projected onto a plane perpendicular to the direction defined by addition of incidence and observation versors.

The inversion problem may be divided in two parts. The first one is to determine the characteristic function, $\gamma(\vec{r})$, of the reflector. That is to say its shape, because $\gamma(\vec{r})$ is defined as a function that is equal to 1 inside the reflector and zero outside. The second part of the problem is to find parameters of the material in particular Z (acoustic impedance) and ρ (density).

If a sufficient n mber of data are available for scatte-

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ring in several incident directions, $\hat{e}_i$, the characteristic function is given by the equation:

$$\gamma(\vec{r}) = const. \int d^2\hat{e}_i\, R\left(t = \frac{2\hat{e}_i \cdot \vec{r}}{v}; \hat{e}_i, -\hat{e}_i\right) \qquad (1)$$

where R is the impulse response which is in turn a function of the time. Equation (1) is formulated for backscattered energy and in consequence the observation direction $\hat{e}_o$ is equal to $-\hat{e}_i$. If the additional simplification introduced by the spherical symmetry of the reflector is taken into account, equation (1) becomes:

$$\gamma(\vec{r}) = const \frac{1}{2rv} \int_{-2r/v}^{2r/v} R(t; \hat{e}_i, -\hat{e}_i) \qquad (2)$$

where $\hat{e}_i$ is arbitrary due to spherical symmetry.

In the frequency domain the characteristic function takes the form:

[illegible] (3)

where A(ω) is the frequency spectrum or, that is the same, the Fourier's transform of the impulse response R (t).

If a single measurement of R(t) is taken, then unidirectional Born inversion can be obtained which gives the reflector radius in the test directi[illegible] as a distance [illegible]om its center (time origin) to th[illegible] [illegible]ne perpendicular [illegible] the incident direction and tange[illegible] the reflector [illegible]rface. In order that this technique may pr[illegible]uce accep[illegible]ble results it is necessary that some minimum conditions

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be fulfilled because, in certain cases, may become critical:

- Sufficient bandwith of the incident pulse.
- Adequate signal to noise ratio.

Born inversion gives good results in the medium range of frequencies such that:

$$0.5 < kr < 2$$

where $k=2\pi/\lambda$; λ:wave length; r: reflector radius

If sufficient information is not available in the low frequency range (k.r minimum too high), the estimate value of r is lower than actual value and if high frequency data are missing (kr maximum too low) then r is overestimated. A wide band transducer should have, to be useful for this technique, a range at k of 10:1.

It has been shown in experiments with spheroidal cavities that signal to noise ratio must be kept over 0dB level if estimate radius error is intended to maintain below 20% for a confidence level of 95% (2).

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2.2 - Materials characterization

Experiments whose theoretical basis is described in (3) and (4) have clearly shown that there are some relationship between acoustic characteristics of a material (acoustic velocity and attenuation) and its fracture toughness. This relation seems to be fairly intuitive because of the dynamic behavior of ultrasonic testing in which the material is forced to transmit elastic stresses through it.

Toughness is measured in classical destructive test by performing a tension (or similar) test in a precracked specimen. However recent studies have shown (5) that the pressure of a sharp crack is not essential in the determination of fracture toughness and is further suggested that the links between the strength properties and the ultrasonic factors are the material microstructural parameters, in particular, these are the size of the second-phase particles and the spacing between them.

It seems to be demonstrated that crack extension proceeds when the length of heavily deformed region surrounding the crack tip is comparable to the length between cracked particles (Fig. 2).

This condition may be expressed by:

$$\delta_c \simeq \ell \qquad (4)$$

where δ_c is the critical crack opening displacement and is related to the other fracture toughness parameters by the following equation:

$$G_{Ic} = J_{Ic} = \left[(1-\nu^2)/E\right] K_{Ic}^2 = 2(1-\nu^2)\,\delta_c\,\sigma_y \qquad (5)$$

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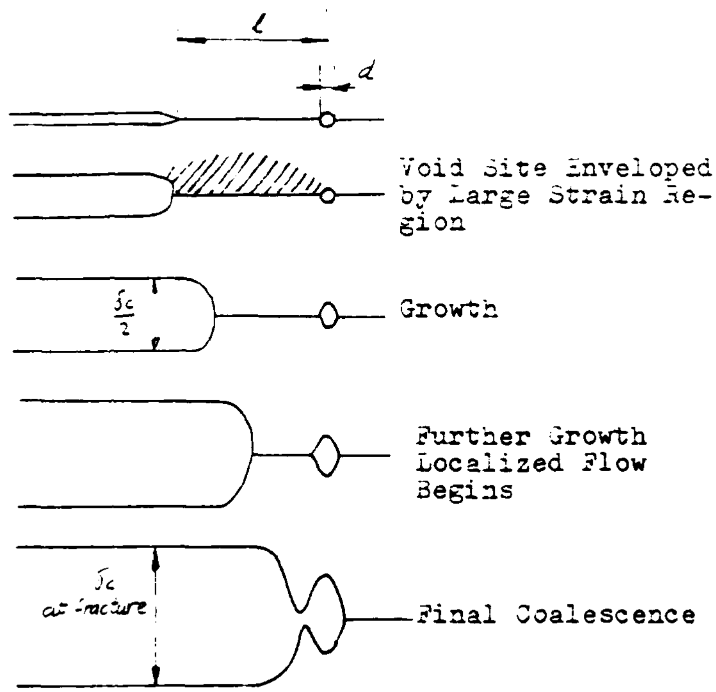

Fig. 2 Growth and coalescence of voids near crack tip (5).

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where E, ν and σ_y are Young's modulus, Poisson's ratio and yield stress, respectively.

It is, consequently, easy to show that, at least within the scope of linear elastic fracture mechanics, the following applies:

$$\frac{\sigma_y}{2E} \cdot \left(\frac{K_{Ic}}{\sigma_y}\right)^2 \simeq \ell \qquad (6)$$

which establishes a clear relationship between microstructural and fracture parameters.

The purpose of the paper in reference (5) is to attempt to provide a basis for a definite relationship between ultrasonic factors and the fracture toughness reasonally acceptable from the point of view of fracture mechanics.

A quantitie R is defined as:

$$R = \frac{\delta}{\ell + 2\delta} \ln \frac{|\sigma_{zz}^{a}|}{|\sigma_{zz}|} \qquad (7)$$

where σ_{zz}^{a} represents the stress intensity field associated with the incident wave and σ_{zz} the stress at any point of a medium containing two plate paralels inhomogeneities of thickness δ and distance ℓ between them.

Now, R must be plotted versus ℓ with δ as a parameter and is possible to show that R varies in a noticeably linear way for ℓ smaller than 10 μm and for a wave number $k\delta = 2\pi$. But, when $k\delta$ differs from 2π, the proporcionality of R is not observed. Then it is necessary to perform the experiments at a frequency such that wave length is equal to δ which is the condition expressed by the relation: $k\delta = 2\pi$.

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From the general equation of attenuation:

$$\alpha = c\,\omega^{m} \quad ; \quad (\omega = 2\pi f) \qquad (8)$$

it is a simple matter to show that:

$$\beta = \frac{d\alpha}{d\omega} = c\,m\,\omega^{m-1} = \frac{m\alpha}{\omega} = m\,\frac{\alpha}{2\pi f}$$

when the wave length is equal to δ :

$$\beta_\delta = \frac{1}{2\pi}\,\frac{m\cdot\alpha_\delta\cdot\delta}{v}$$

or:

$$\frac{v\cdot\beta_\delta}{m} = \frac{\alpha_\delta\cdot\delta}{2\pi}$$

which can be combined with the expression (6) to obtain:

$$\frac{2\pi}{\alpha_\delta}\cdot\frac{v\beta_\delta}{m} \simeq \frac{\sigma_Y}{2E}\left(\frac{K_{Ic}}{\sigma_Y}\right)^2 \qquad (9)$$

an expression which suggests the possibility of determining $\frac{K_{Ic}}{\sigma_Y}$ from attenuation measurements.

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2.2.1 - Measurements of acoustic velocity

In a first stage a measuring system conceptually similar to that described in the reference will be used.

The equipment will also permit the digital reading of the time interval in order to implement data acquisition by the computer. This technique gives a precision which is considered sufficient for the characterization of the elastic constants and of the fracture toughness.

At the time of writing this report we have not received the Tektronix 7D15 unit, in which the measurements are based, so that it is neither possible to include any experimental results nor to evaluate possible errors.

Fig. 3 shows the block diagram of equipment we will use in acoustic velocity measurements.

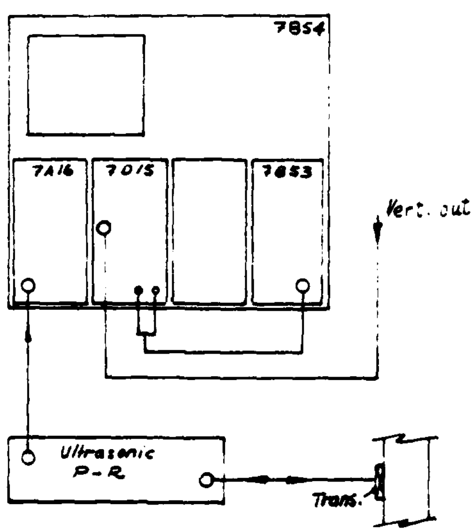

Fig. 3. Acoustic velocity measurements.

2.2.2 - Attenuation measurements

The technique proposed by E. Papadakis (7) using 5,10, 20 and 50 MHz commercial wideband transducers with water buffer for low and intermediate frequencies and quartz buffer for 50 MHz.

Echos of interest, usually first and second backwall echos, are FFT processed to calculate its power spectrum and a raw reflection coefficient is computed from handbook data for acoustic impedances. The amplitude relation curve is computed according the technique proposed by A. Vary (8) and given by the expression:

$$\alpha(f) = \frac{\ln(R/BB)}{2e} \tag{10}$$

where:

R: reflection coefficient of the interface buffer-sample.

BB: amplitude relation at a given frequency for two echos.

e: sample thickness.

By an adequate regression technique it is possible to calculate the values of c and m in the equation:

$$\alpha = c f^{m} \tag{11}$$

The diffraction correction is computed for low frequencies (usually below 15 MHz) and calculations for parameter β to be used in equation (9) are performed.

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3 - Equipment

The block diagram of the equipment to be used in our experiments is shown in fig. 4. Some are experimental units and others are in a workshop stage. Details are given in the following paragraphs.

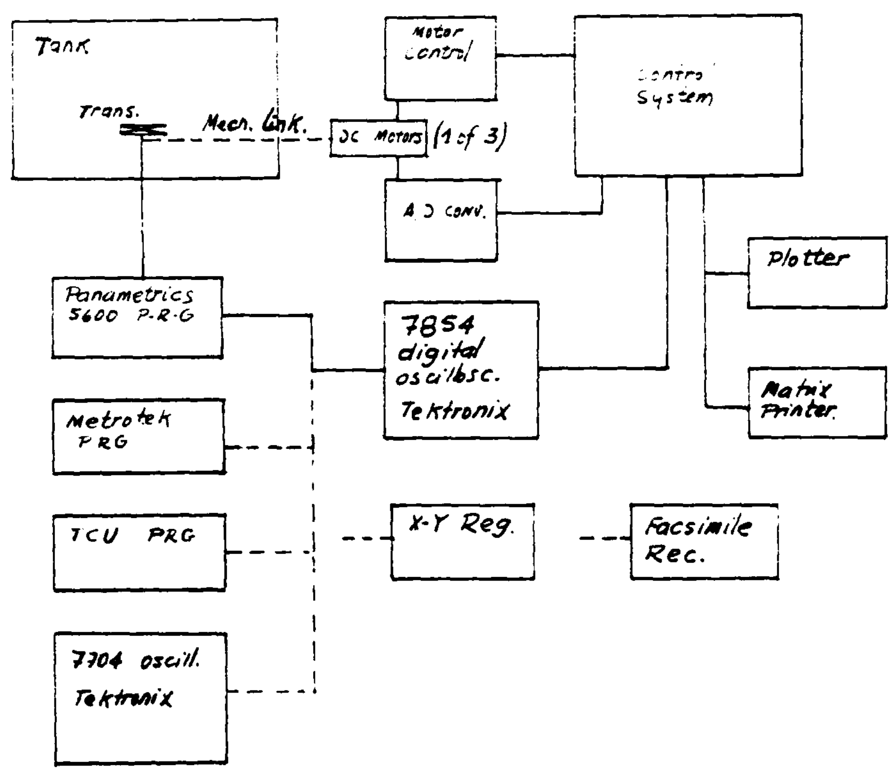

Fig. 4. Experimental equipment.

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3.1 - Automatically controlled ultrasonic inmersion test bed (SEICA).

SEICA are the Spanish initials for the system which was defined at the starting of the program as a major goal between equipment objectives because it is fundamental for high precission and reproductibility tests to be performed.

Its fabrication has been subcontracted to SUZPECAR, S.L. and design will be done by INTA's and SUZPECAR's engineering personnel. Design and fabrication will be under control and supervision of Ultrasonic Laboratory's personnel. To this time minor details of mechanical and control design are being defined and, if everything goes well, the system will be ready for setting up tests by the end of the year.

A summary description of the main characteristics of the system is followed.

Inmersion tank is 1000 x 800 x 600 mm of useful dimensions. Mechanic searching system is formed by three orthogonal axes driven by dc motors with servocontrolled speed and digital position control by means of Hewlett Packard discs of 500 div/turn. All three linear movements are driven by high precision ball screws being longitudinal clearance consequently about zero in any of the three directions. Sliding of movable parts is always through ball bush in one of the supports and a free ball bearing in the other. This assembly was already experimented in a system built some years ago and has shown to be quite satisfactory because its nearly null clearance and very low friction.

Z axis has, additionally, the possibility to perform

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a whole rotation around itself not being this rotation motorized in a first stage.

Fig. 5 shows a schematic draw of the mechanic parts.

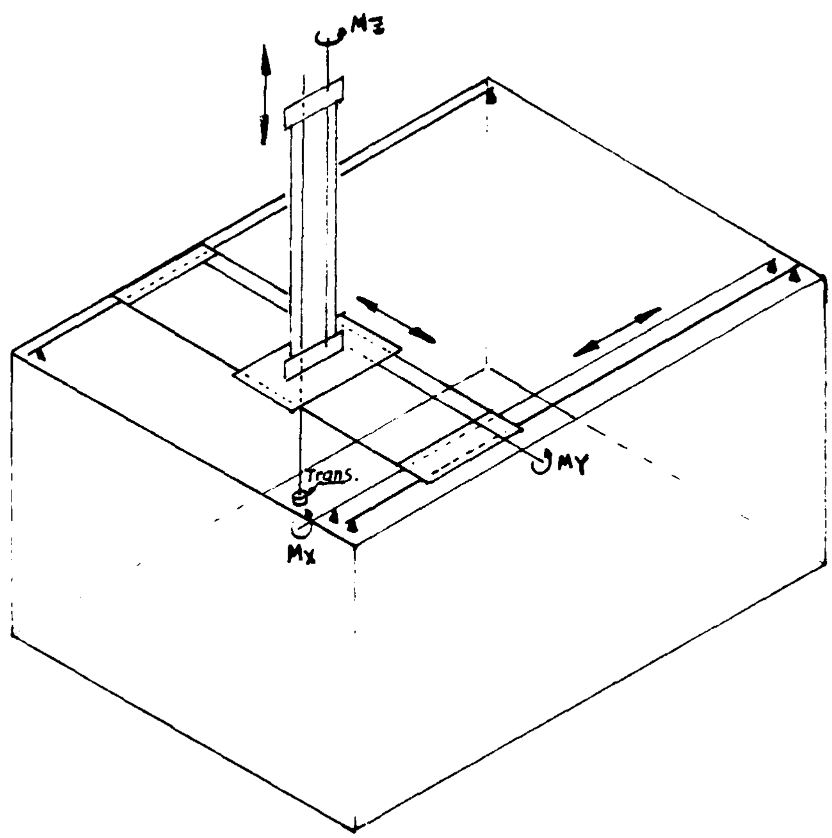

Fig. 5. Schematic draw of immersion tank.

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Position is to be read within 0.01mm and repeatability will be better than 0.1mm at any point of the tank.

All the three movements are servocontrolled by an DRAC-1 micro processor, based on Rockwell AIM65. It has 22 K RAM memory. An alphanumeric screen 60 x 22 characters, a disk unit and a thermal printer act as peripherals.

The structure of the control system is shown in fig. 6.

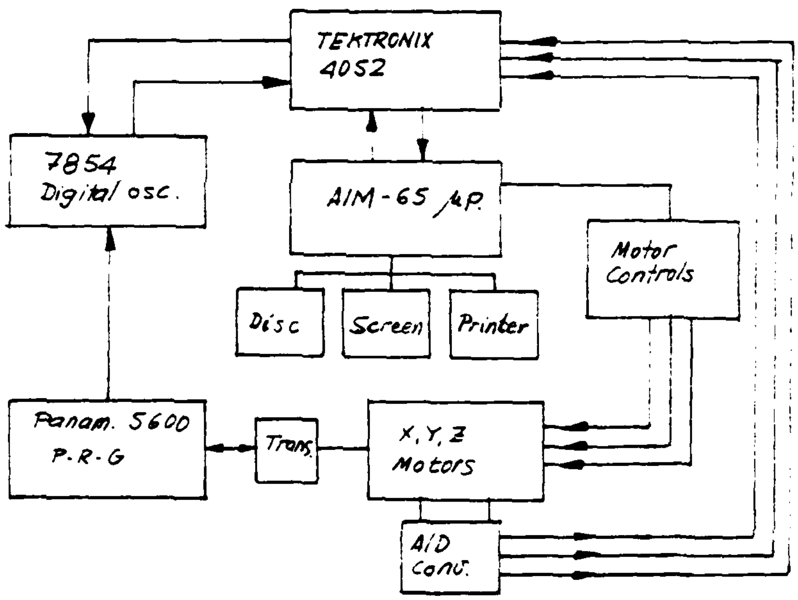

Fig. 6 Block diagram of control system.

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The software for controlling the motors will be resident in the EPROM memory of the microcomputer and will be written in assembly language to make it as compact as possible.

The master terminal is the 4052 computer and a multitasking program to control all the test bed operations will be written (9).

The program will allow:

1 - Send commands to the microcomputer AIM65. Examples of these commands would be request for current coordinates of the transducer, halt or continue commands.

2 - Allows the microcomputer AIM65 to send data to the master terminal, to the disc memory or to the screen (error messages, confirmation of data was received, transducer coordinates).

3 - Store the control blocks for specific scan profiles.

4 - Allows to 4052 to send commands to the 7854 digital oscilloscope to digitize the signal.

5 - Allows to the AIM-65 to accept digitized data and to store this data into the disk memory or into the tape memory.

6 - Stored data will be analyzed and if a threshold value is exceeded, coordinates of such point will be stored.

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3.2 - Ultrasonic pulser-receiver

There are a Panametric 5600 pulser-receiver-gate, (fig. 7a) up to 100 MHZ bandwith and a Metrotek system (fig. 7b) including MP 215 Pulser, MR101Receiver, MG701 stepless Gate and MP 702 Gated Peak Detector to be used up to 20 MHz. There is also a 20 MHz pulser-receiver and gate unit (fig.7c) built by J.P. Weight from the Department of Physics of the City University, London.

3.3 - Signal acquisition and display

To digitize signals we will use a Tektronix 7854 digital oscilloscope (fig. 7d) able to capture repetitive signals up to 400 MHz. The following plug-in units are available in our Laboratory.

7A15A Linear Amplifier (80MHz bandwidth)
7A16A " " (225MHz ")
7B53A Time base
7B50A " "
7L12 Analog spectrum analyzer (100 KHz to 1800 MHz)

In the next few weeks we hope to receive the digital counter timer 7D15 to be used mainly in the velocity measurement system.

For analog signals it is also available a Tektronix 7704 oscilloscope (fig. 7e).

There is a project to convert an analog X-Y recorder into a facsimile recorder to be able to display C-scan type signals. As shown in fig. 8, the output voltage of a peak detector (VI) is feed into the # 5 pin of IC6 (LM3914). The low level induced in some output is inverted and used to saturate the transistor which gives

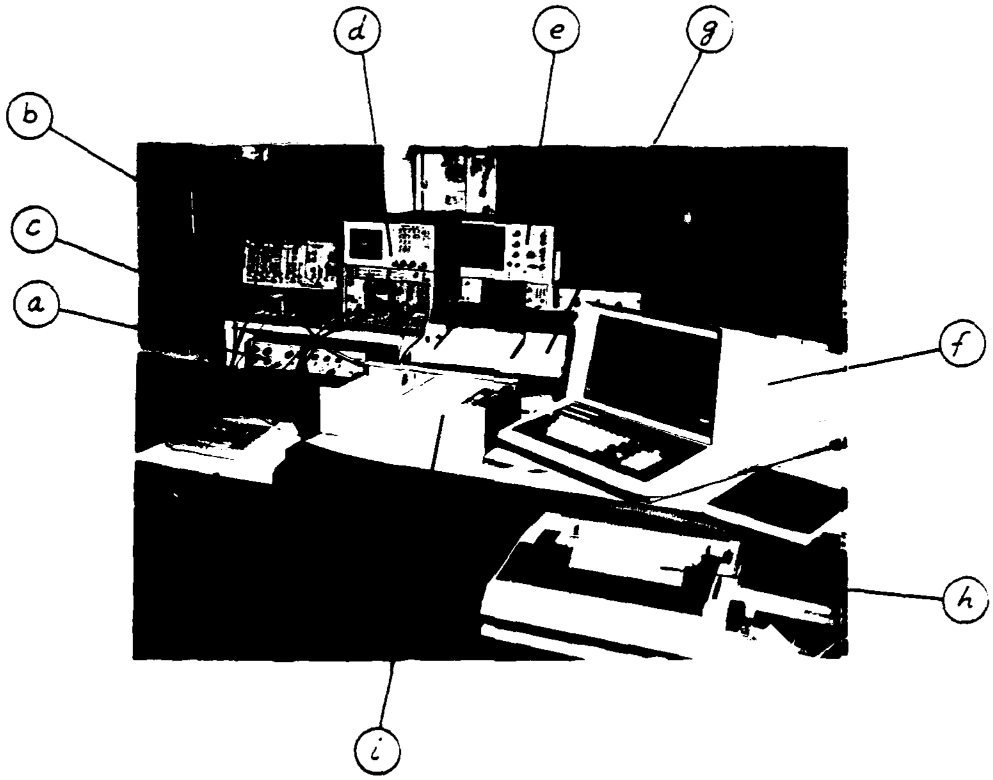


Fig. 7 Experimental equipment.

a fixed voltage (V3) at IC3. This voltage may be regulated with R1-R10 between 6 and 24 volts and is applied to the electrode placed instead of the pen of the analog X-Y register in which an electrosensitive paper sheet is used. Some LED's indicate the current output level and will be useful in calibrating stages.

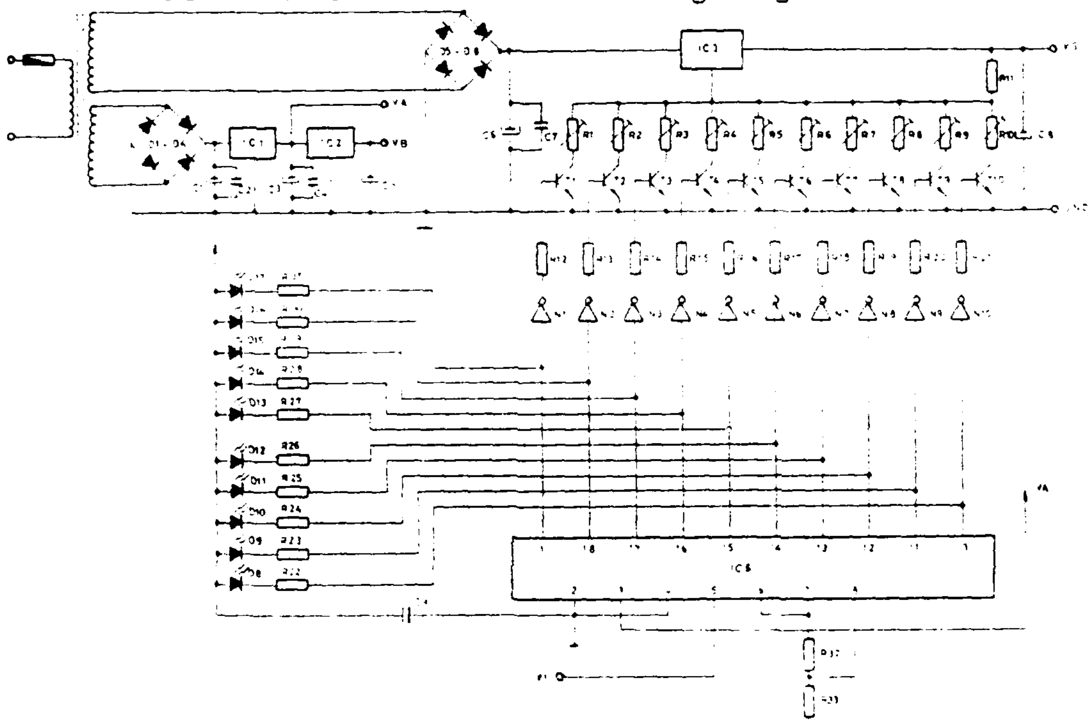


Fig. 8. Modification for X-Y register into a C-scan register.

3.4 - System control and signal analysis

It is based upon a Tektronix 4052 minicomputer (fig. 7f) with 64K RAM memory and two ROM packs R07, R08 to be used in signal analysis process.

As peripherals we have a digital plotter Hewlett-Packard 7470A (fig. 7g) and a matrix printer FACIT 4510 (fig.7h)

Major functions of control are given in paragraph 3.1.

4 - Software

In this first stage, software to acquire, analyze and display signals has been implemented in order to characterize materials.

Current program permits to perform any of the following operations:

- Select the number of points per waveform to be used in signal acquisition.
- Acquire signals.
- Store signals in tape file.
- Fourier transform to frequency domain. Amplitude and phase.
- Time and frequency domain signal conditioning.
- First and second derivatives to select frequency limits.
- Amplitude relation curve.
- Calculate the attenuation coefficient as a function of the frequency.
- Output to the plotter of any curve.

Two main difficulties have been found in making the software. One is related with the algorithm to perform FFT which, as is implemented in the ROM pack is quite useful for ultrasonic applications. That is because frequency window width is inverse to that of time window so that as greater the time definition of the signal, as lower is that of frequency. Three possible solutions are intended. First one is to utilize the oscilloscope to make a signal conditioning by means of the instruction HXPD (Horizontal expand) which, if a parameter less than one is used, a real compression is performed keeping almost every accident of the wave. This is useful for low and intermediate frequencies where signals are not too short in time domain, so compression is not too high. But this technique introduces heavy uncertainities when frequencies are of the order of 20 MHz or above being then unuseful for materials characterization.

Another possible way to solve this problem is to implement a routine for Discrete Fourier Transform which permits to select starting and ending frequencies as well as resolution results being fairly independent of the time domain signal. In this way the spectra calculated in the next paragraph have been made. The only difficulty with this algorithm is that the time to perform all the calculations is very long.

The third way is to implement a chirp Z-transform using the FFT algorithm. This solution will probably offer the best combination of resolution and time. We hope to have this algorithm implemented in our program in the next few weeks.

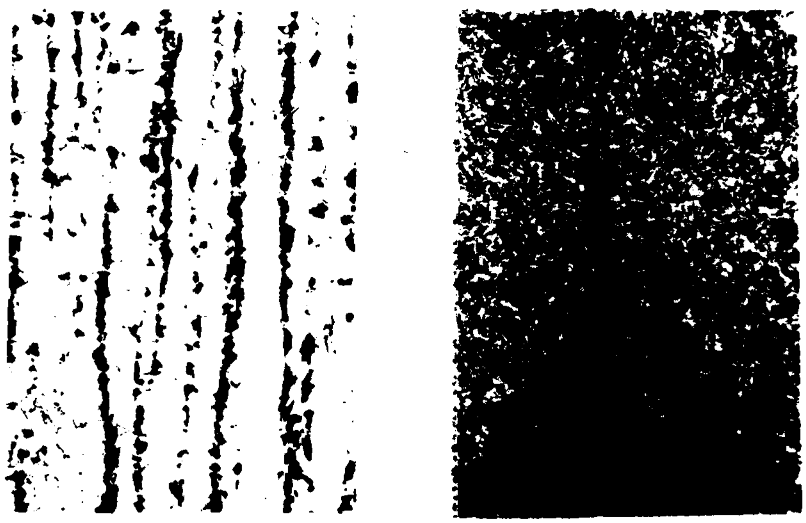
The other difficulty before mentioned is related with the software to drive the digital plotter. Hewlett-Packard 7470A is a very cheap instrument although its quality/price ratio is very high and was selected because of some budget limitations. Unfortunately, low cost hardware often comes together with high cost (time) software, and that is the major reason because complete software package for materials characterization, and even defect, has been impossible to be completed on time.

5 - Experimental results

Experiments have been carried out on steel samples of chemical composition:

C	Mn	Si	P	S
0.16%	1.45%	0.27%	0.02%	0.04%

Two different heat treatments have been considered and their respective microstructures are shown in fig. 9.



a) as rolled — Hardness : 28 HRC

b) quenched — Hardness : 46 HRC

Fig. 9. Microstructure of tested samples.

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Samples of 30 x 30 x 3mm thick were machined and ground finished.

A Panametrics 50MHz central frequency transducer with fused quartz buffer rod was used and medium motor car oil (SAE 30) as a coupling medium. To ensure uniform contact pressure and reproductible coupling conditions a simple device was built (fig. 10).

Fig. 11 shows a typical oscillogramme observed with A-scan when a rolled sample is tested.

To acquire signals sweep of time base must be much faster in order to improve resolution. Fig. 12 is the echo B1 in fig. 11 but which 10 nsec/div instead of 1 μs/div. This is a good image to be acquired but jitter is a little disturbing as shown oscillogramme in fig. 13, where three signals are averaged to improve sharpness of the digitized signal.

We have not still studied the influence of jitter on frequency spectrum but it seems not to be very strong as can be shown by comparing with spectrum such as that displayed in fig. 15a; fig. 15b is the calculated spectrum of the signal in fig. 13 and fig. 15c is the calculated spectrum for the smoothed signal of fig. 14.

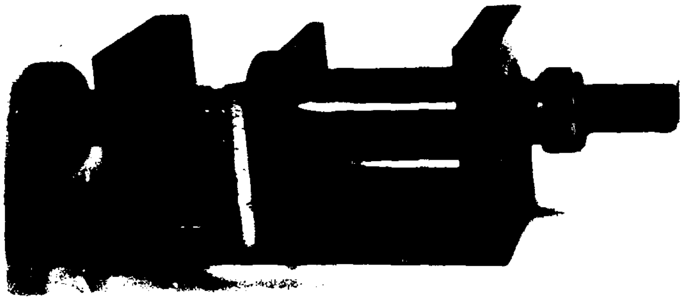
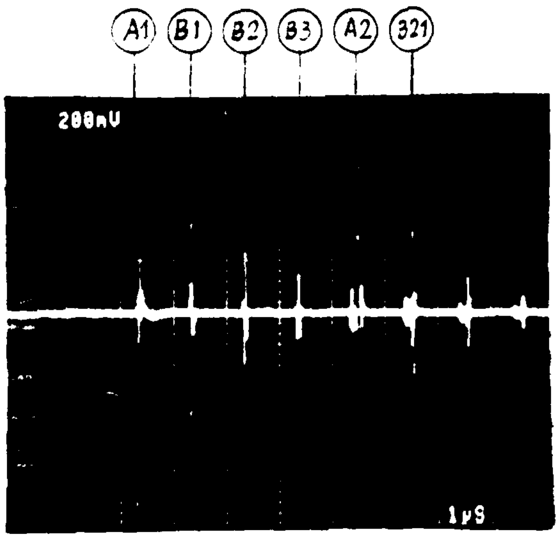


Fig. 10. Coupling transducer to sample device



A1: First interf. echo
B1: First backwall echo
B2: Second " "
B3: Third " "
A2: Second interf. echo
B21: First backwall echo from the 2nd sequence.

Fig. 11. Interface and backwall echos of as rolled sample.

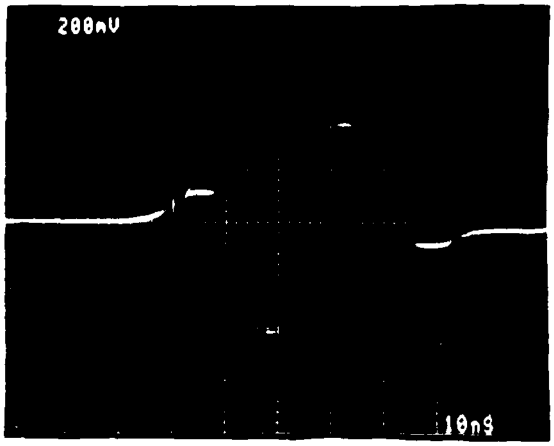


Fig. 12 Echo 31 in fig. 11.

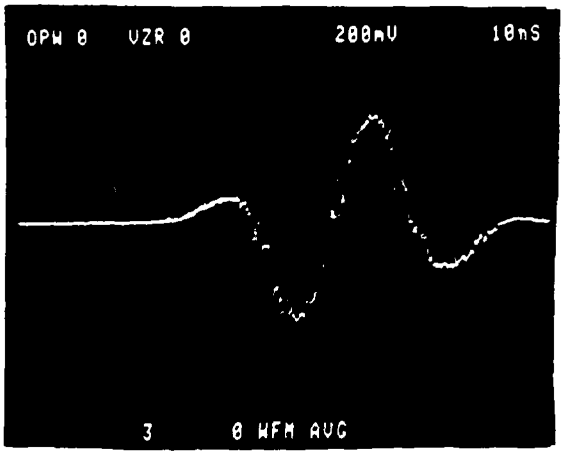


Fig. 13 Echo 31 acquired. Jitter of analog signal is the cause of poor sharpness.

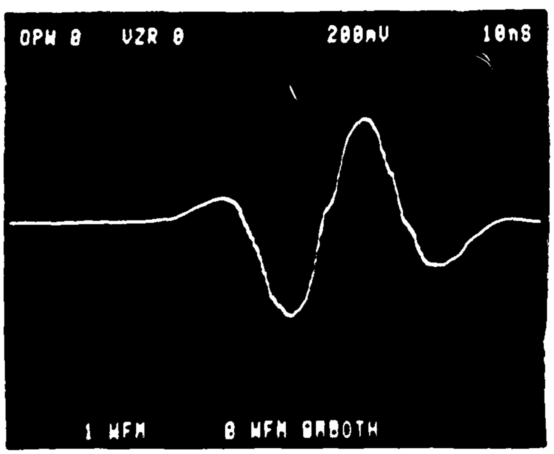


Fig. 14 Same as fig. 13 but .2 smoothed.

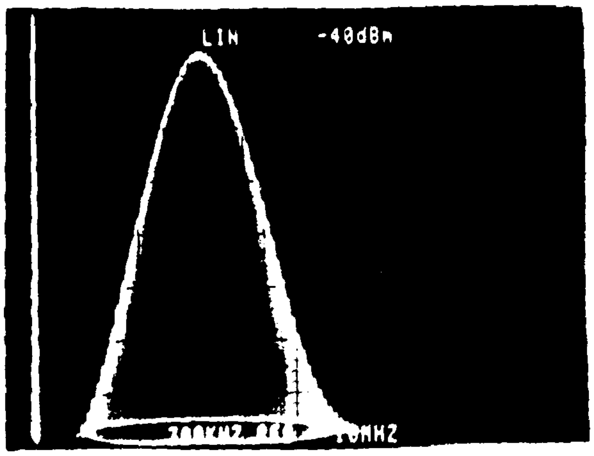


Fig. 15a Analog spectrum of signal in fig. 12.

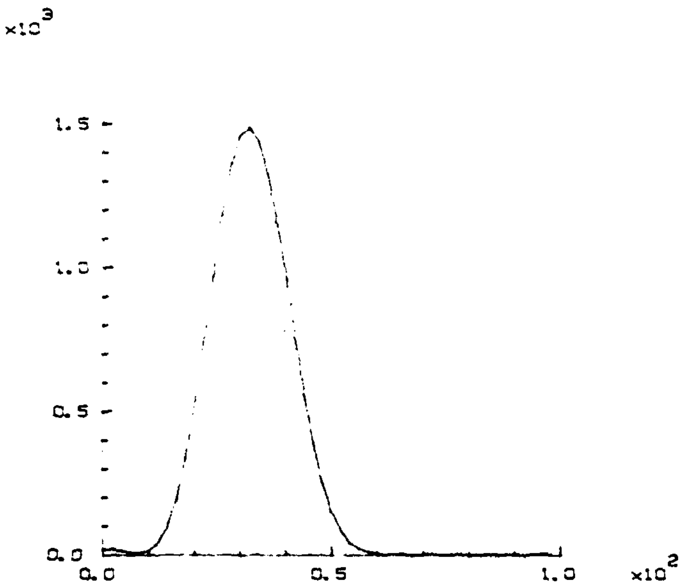


Fig. 15b Calculated spectrum for the signal in fig. 13.

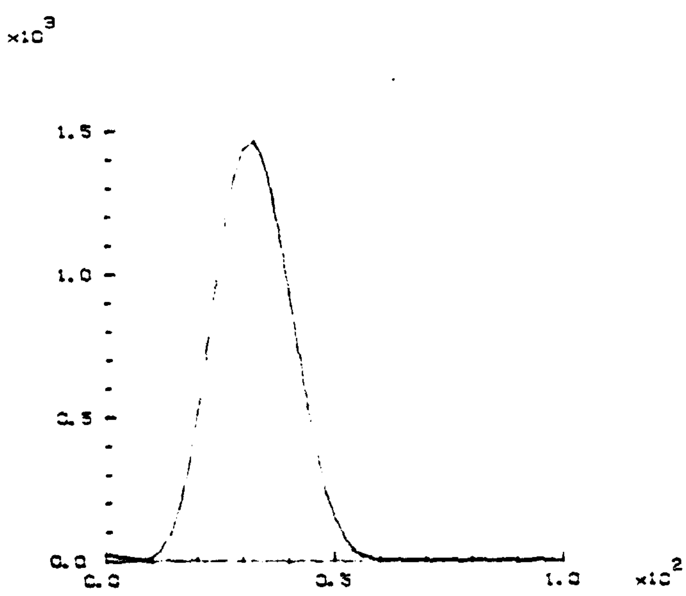


Fig. 15c Calculated spectrum for the signal in fig. 14.

The results described herein are derived from the analysis of echos B1 and B2 in both as rolled and quenched samples. Testing technique are intended to be similar to that of A. Vary in reference (8). The results are shown in fig. 16.

Time domain signals (fig. 16 a,d) are the result of averaging 10 waves samples in order to avoid jitter effects. B1 and B2 signals are overlaped only for easy to compare purposes.

Results of Discrete Fourier Transform (DFT) are shown in fig. 16 b,e). The difference between both samples is easy to see in a qualitative way by comparing the high frequency band of the spectra.

To make this difference quantitative first and second derivatives of the spectra are calculated and limits of validity are defined between the first maximum of first derivative and the second maximum of second derivative.

A new DFT is performed between the limits increasing the resolution relative to other spectra and the amplitude relation (B_2/B_1) curve is computed. Now upper and lower bounds for reflection coefficient are defined using handbook data for acoustic impedances (10):

Sample .... 45.10^6 $Kg/m^2.S$
(steel)

Coupling agent ...... $1.5\ 10^6$ "
(motor oil)

Buffer .... $14'5.10^6$ "
(fused silica)

Lower limit is R=0.51 and represents the pure buffer-sample interface. Upper limit is R=0.93 and comes from considering the pure oil-sample interface. The actual R coefficient must obviously be between these limits

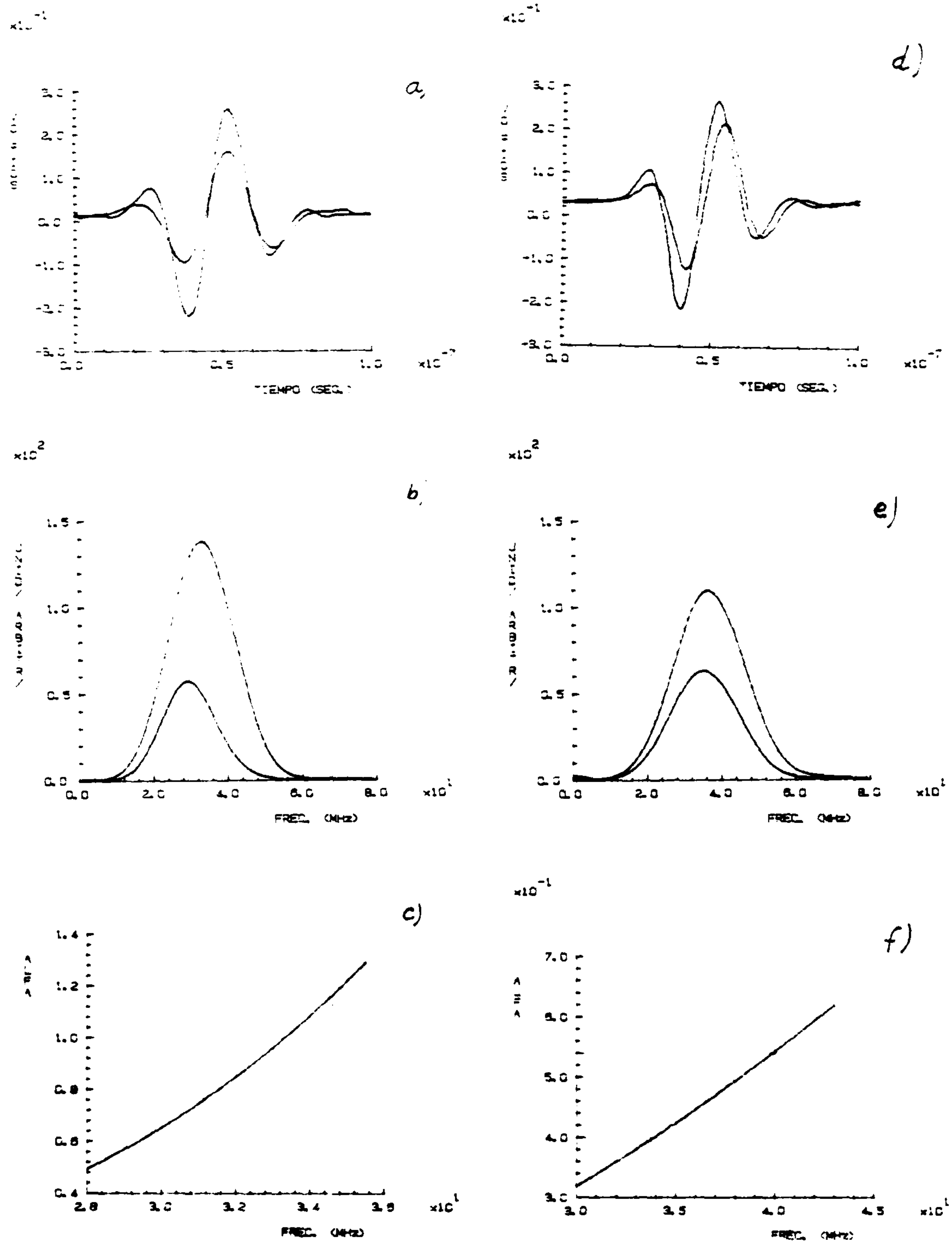


Fig. 1 Ultrasonic results for as rolled and quenched samples.

and there are some different ways to determine its value. To do that we have chosen the technique described by Vary which consist in select as actual value of R the one that gives the best fitting between real and calculated attenuation curve. Starting with R=0.9, the equation:

$$\alpha = \frac{\ln \left(\frac{[illegible]}{[illegible]} \right)}{2t} \qquad (12)$$

is solved for alpha at each frequency and from the curve obtained, values of c and m in the equation:

$$\alpha = c f^{m} \qquad (13)$$

are derived by a simple regression technique. Then fitting of curve from equation (13) with that of amplitude relation is calculated. A new value of R is then intended (i.e. R = 0.8) and all the process is repeated until a best value of fitting is obtained.

Results obtained by this technique are the following:

	As rolled		Quenched
R	0,6515	....	0,730
C	$6,59.10^{-7}$	....	$2,78.10^{-4}$
m	4,061	....	2,0529
fitting	0,99996	....	0,99990

The values of c are in good agreement with that reported in the literature (11), (12). Attenuation versus frequency curve is shown in fig. 16 c and f.

A different way to calculate the attenuation function is to solve for R and alpha the pair of equations:

$$B_1 = [illegible] R^2 \, e^{-2\alpha t}$$
$$B_2 = [illegible] R^2 \, e^{-4\alpha t}$$

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This technique is similar to that proposed by Papadakis (7) and is also reported by N. Grayeli etal. (11) and will be implemented in our computer in the next future as a part of second year effort.

Conclusions and recommendations

- Preliminary work to implement a computer based ultrasonic characterization program has been carried out and results for the exponent of the frequency agrees well with that of other authors.

- Nevertheless a great deal of work must be developed in order to:

  - Study repeatability.
  - Study sources of error.
  - Complete software to make it as versatile as possible.
  - Collect experimental data from fracture toughness samples.

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