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NON-DESTRUCTIVE ULTRASONIC MEASUREMENTS OF THE CASE OF HARDENING DEPTH

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16. Abstract

Two ultrasonic methods for nondestructive measurements of the depth of a case-hardened layer in steel are described. One method involves analysis of ultrasonic waves diffused back from the bulk of the workpiece. The other method involves finding the speed of propagation of ultrasonic waves launched on the surface of the work. Procedures followed in the two methods for measuring case depth are described separately at length.

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NON-DESTRUCTIVE ULTRASONIC MEASUREMENTS OF THE CASE OF HARDENING DEPTH /1*

Two ultrasonic methods for nondestructive measurement of the depth of a case-hardened layer in steel are described. One method involves analysis of the amplitude of ultrasonic waves diffused back from the bulk of the workpiece. The other method involves finding the speed of propagation of ultrasonic waves launched on the surface of the work. Procedures followed in the two methods for measuring case depth are described separately at length.

SUMMARY

Description of two ultrasonic tests allowing the measurement of depth of case-hardened steel surfaces. One of them is based on wave diffusion by the structure of the material, the other on measurement of Rayleigh waves speed.

I. INTRODUCTION

Verification of a heat treatment of steel (case hardening, or tempering after superficial heating) can only actually be done by destructive means on samples treated at the same time as the pieces or on pieces earlier removed from a production series.

The study undertaken by Center d'Etude Technique des Industries Metallurgiques has permitted the defining and putting to work two complementary methods capable of measuring the depth of the treatment without destroying the pieces.

The first method consists of analyzing the amplitude of ultrasonic waves reflected backwards from the workpiece material. Observation of the amplitude of this diffusion as a function of time permits making a

*Numbers in margin indicate pagination in foreign text.

count of the important effect of treated layers whose generally fine structure is only slightly diffusing. By an appropriate treatment of the Type B signal, the information is presented in the form of an image representative of a treated layer seen in section. This method permits the measurement of treated depths greater than about 3 mm.

The second method is based on the determination of the speed of propagation of ultrasonic bases incited on the surface of the material. The relationship between this magnitude and depth of the treatment is established by using the dependence between the speed of propagation of acoustical waves and the mechanical characteristics of the medium. The values of the medium are changed by the hardening operation in the treatment. This second technique is applicable in the case of treated depth less than 3 mm.

These studies have aimed to develop an instrument suitable for industrial measurements. It is presented in the form of a portable control instrument which integrates in modular fashion, two specific pieces of apparatus in the two methods described above.

The second method has permitted a further development at C. E. T. /2
I. M. independent of the commercial use cited above, in the form of research financed by the D. G. R. S. T. Here, measurements of the speed of propagation of surface waves is carried out as a function of the frequency of the waves. The researched purpose is to measure the gradient of the hardening on the surface of the pieces by a non-destructive method.

II. FIRST METHOD: MEASUREMENTS BY OBSERVATION OF DIFFUSION.

II.1 Diffusion of Ultrasonic Waves

Among the causes of the attenuation of ultrasonic waves propagating in a polycrystalline material, the most important is due to the phenomenon of diffusion by the small granules. This diffusion expresses itself by a dissipation of energy in the form of ultrasonic radiation in all directions of space. The extent of this depends on the frequency of the vibration, the average diameter of the small granules and the anisotropy of the granules.

The measurement of the depth of treatment is based on the fact, observed by different researchers [1 - 4] that, for the same thickness of basic austentite, the diffusion of ultrasonic waves is much weaker in the case of a martensite structure obtained by rapid cooling, than in the case of perlitic structure obtained by slow cooling. For structures such as bainite, troostite, the diffusion shows an intermediate value.

II.2 Principle of the Method

The observation of diffusion ultrasonic energy is made by using a classical ultrasonic control device. A sonde pulse in the material, and the waves reflected towards the sonde are strongly amplified by the receiver in order to visualize the diffusion echoes on the screen of the apparatus.

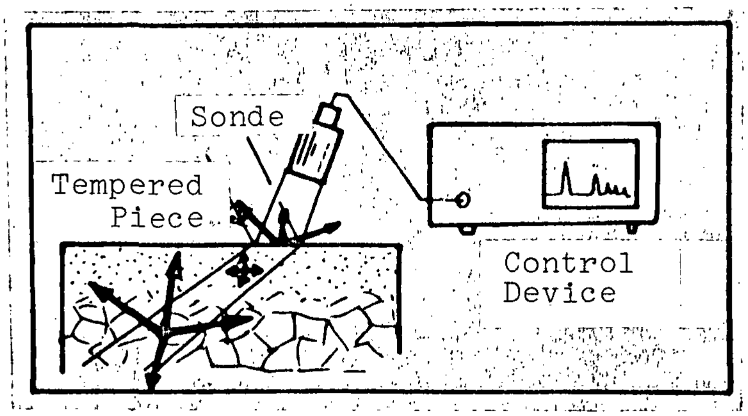

Figure 1: Principle of the method of treatment depth measurement

In practice, the sonde is placed in a connecting liquid and is inclined in respect to the surface of the piece to avoid the large echo, reflected specularly from the surface, from being received by the sonde.

On the screen of the apparatus, there is successively observed (Figures 2 - 3):

- An echo, due to a diffused reflection by the surface of the piece, the amplitude of which depends on the roughness of the same;

- A zone with no echo, representative of the absence of important diffusion in the heat-treated part;
- A zone having a large number of echoes, the position of which seems uncertain as a function of an unsteady displacement of the sonde; this zone is representative of the diffusion in the part of the piece which is not heat-treated.

Remark: These diffusion echoes, called "grass", are usually undesirable for the classical error control methods. /3

II.3 Implementation of the Method

The position of the diffusion echoes on the screen is random, and depends on the distribution of the grains in the material. Correct measurements are carried out by estimating an average observed value during one displacement of the sonde.

This problem was resolved by designing a representation called "Type B" of diffusion echoes. For this purpose, the amplitude of the signal modulates the luminosity of the spot of a cathode tube with a memory. At the same time, the time base is applied to the vertical deviation plates, and the position of the probe controls the horizontal displacement (Figure 4).

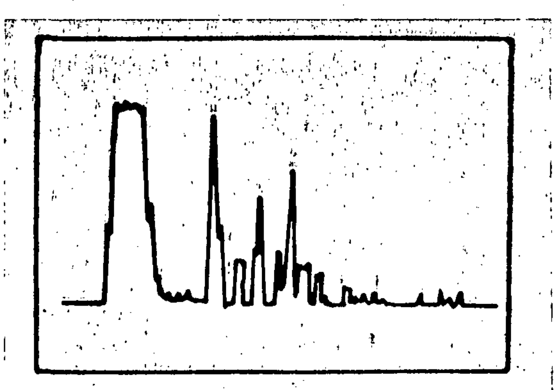

Figure 2: Oscillogram obtained for the case of a piece tempered to 5 mm depth.

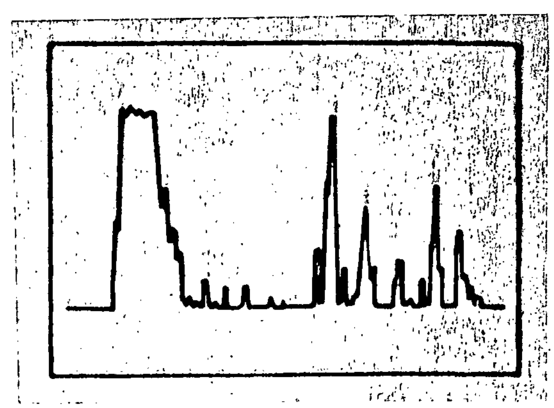

Figure 3: Oscillogram obtained for a piece tempered to a depth of 10 mm.

III. SECOND METHOD: MEASUREMENTS OF THE SURFACE WAVE SPEED OF SOUND

III.1 Principle of the method.

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The principle of the method is based on the determination of the propagation velocity of ultrasonic waves which are induced on the surface of the material. The relationship between this quantity and the treated depth is established by using the dependence between the propagation velocity of acoustic waves, and the characteristics of the medium (in particular, Young's modulus). These values are changed due to the hardening operation during tempering.

The technique consists of triggering a surface wave using an emitting sonde. Because it has variable inclination, the critical angle can be found beyond which there is total reflection. This angle corresponds to the limit of existence of longitudinal and transverse

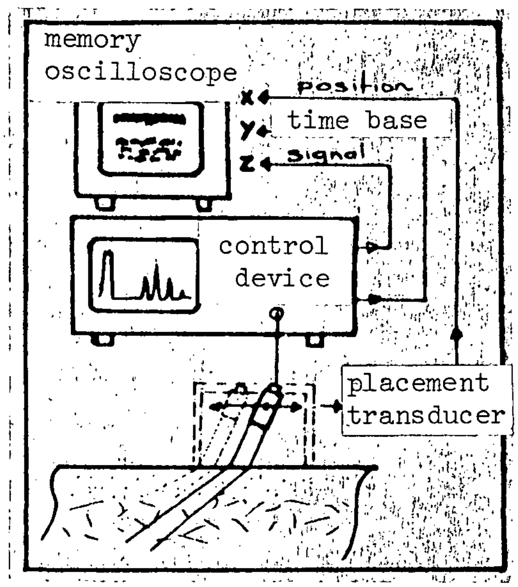

Figure 4: Implementation of the method.

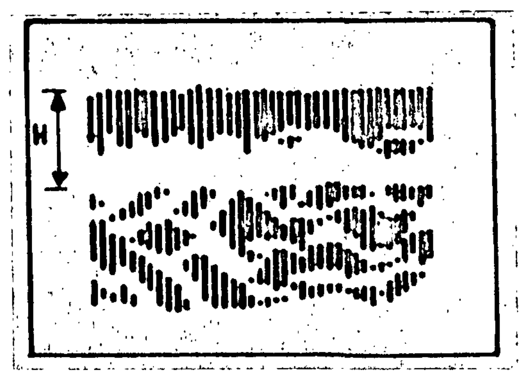

Figure 5: Representation of type "B", tempering depth 5 mm.

refracted waves and corresponds to the condition for the production of a complex surface wave which mechanically affects the medium over a depth which can be evaluated to be approximately one wavelength.

The measurement of the critical angle allows one to derive the propagation velocity using the relationship, $\sin \theta_R = V/V_R$, derived from the law of Descartes. From this, the variations over various parts of a sample can be evaluated, or the difference between various samples, compared with a non-treated sample. In this way one can determine the depth of zones which are affected by the treatment.

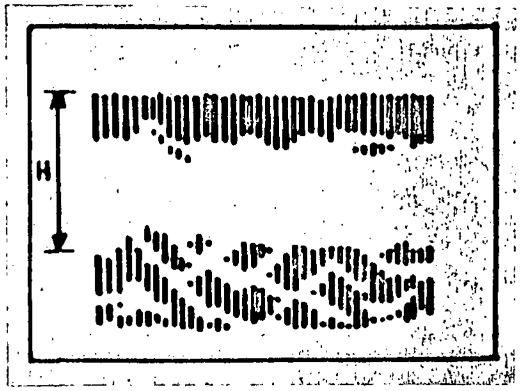

Figure 6: Representation of type "B", tempering depth 10 mm.

III.2 Principle of Measuring the Critical Angle.

In the technique we adopted, the critical angle is determined by observing the reflected bundle which is reflected by the surface which results in a lateral displacement when the critical angle is reached.

The analysis of the reflected bundle is carried out by installing a cylindrical mirror which returns the energy towards the emitting sonde in an inverse manner. The amplitude of the received echo passes through a minimum value for the critical angle, so that the value can be derived.

III.3 Implementation of the method

The measurement allows one to define an angle or a propagation velocity of a surface wave having a determined frequency. The determination of the treated depths requires a calibration which consists

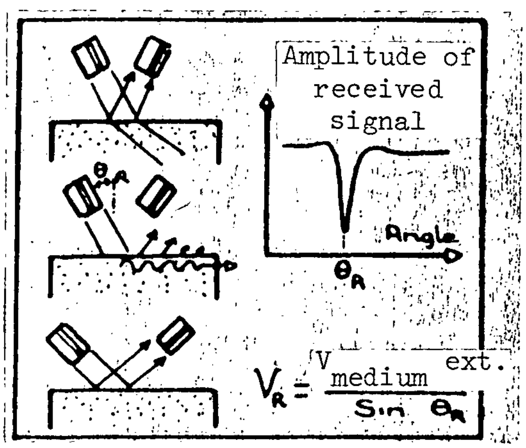

Figure 7: Principle of the Method

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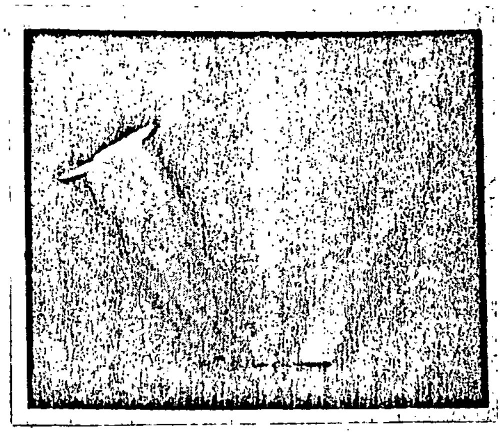

Figure 8: Visualization of the Reflected Bundle at the Critical Angle.

of performing a measurement of a non-treated sample, which has the following same characteristics as the treated sample:

- type of steel
- form and state of the surface
- strictly identical positioning in the control device.

The variation of the propagation velocity which was measured is plotted on the nomogram shown in Figure 9. From it, one can derive the average treated depth if one knows the frequency of the surface waves used and also the variation range of the velocities involved. (This range depends on the type of steel and the definition given to the treatment depth). /5

IV. DISCUSSION OF MEASUREMENT APPARATUS

The control device which was developed is in the form of a portable control complex which consists of the following:

- a standard part which includes the emission and receiving devices for ultrasonic waves, and the cathode tube part used for visualization of echoes.
- a modular part, a drawer which can contain either of the two devices specific to the two methods discussed above.

The photograph shows the apparatus installed in the frame for the

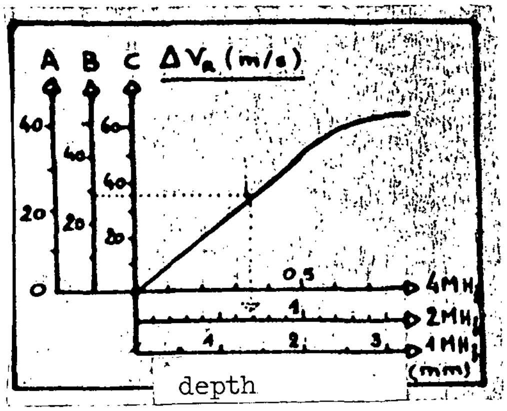

Figure 9: Calibration Curves

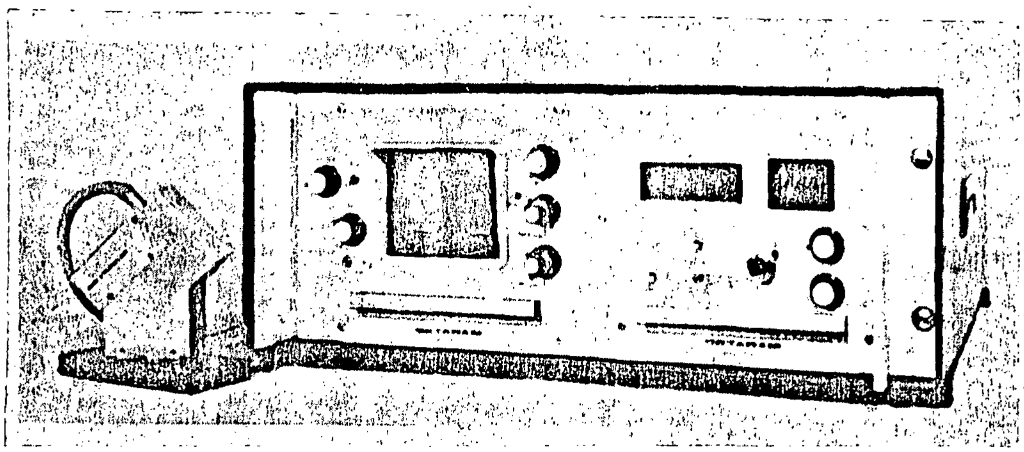

Figure 10

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method.

For each of these methods, a specific sonde carrier was developed for measurement.

IV.1 Drawer for large depths (measurements by observing diffusion)

This drawer essentially constitutes the interface which allows type B visualization. In order to avoid the use of a memory cathode tube, which is relatively fragile and which does not allow one to fix the trace of the image obtained, the signal is electronically treated so that the image "B" can be provided by a printer.

The scale of the image obtained can be selected among various simple scales (for example 0.5, 1, 2), so that the reading of the thickness is facilitated.

As an option, it would be possible to add an automatic sorting system for samples with respect to two previously pre-adjusted thresholds.

The standard control sonde allows one to carry out measurements /6 for samples with a simple geometric shape. In all other cases, it would be necessary to adapt this sonde to the control samples.

IV.2 Drawer for Small Depths (Measurement for the Speed of Surface Waves)

This drawer has several purposes

- command of angular motion of the sonde;
- automatic measurement of a quantity proportional to the critical angle which corresponds to the minimum energy received by the sonde on the return leg
- comparison of the measurement to the measurement carried out previously for a non-treated sample, and which is manually indexed by the operator.

The apparatus directly labels the sample with a quantity proportional to this angular difference, and this can be simply plotted on the calibration nomogram.

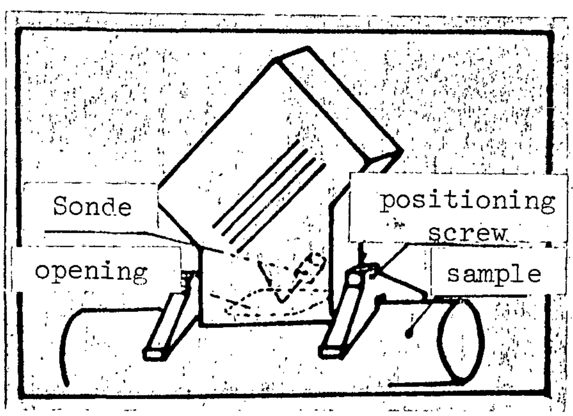

Figure 11.

The sonde holder consists of a sonde placed under local immersion conditions in a chamber, which on the sample side is limited by a semi-elastic membrane for control purposes.

The rotation motion of the sonde is controlled by a motor and the position is measured.

Various fixing methods for the sample (standard or specific ones) can be attached to the lower part (on the side of the sample to be checked).

V. DEVELOPMENTS OF THE METHOD USING THE SURFACE WAVES.

The method of determining the case hardening depths uses measurements of the speed of surface waves having a known frequency. This technique was supported by the C.E.T.I.M. and research financed by D.G.R.S.T. where the measurement is performed as a function of frequency.

One can evaluate the penetration depth of a surface wave into the material to be approximately equal to one wavelength. By varying the frequency, the investigated depth changes and one can evaluate the variations of the mechanical characteristics as a function of the depth using experimental values of the propagation velocity measured for each frequency. For this purpose, we performed a theoretical analysis. On a computer we can determine the propagation velocities as a function of frequency for a material model in which the mechanical characteristics Young's modulus, Poissant coefficient vary as a function of depth. The hardness to mechanical characteistic relationship is estimated experimentally in the case of tempering treatments.

Figure 12 shows an example of results obtained:

- the graph on the left shows the variation of hardness as a function of depth for a given sample;
- the graph on the right shows the variations of propagation velocity as a function of frequency over the wavelength.
- the results of the theoretical calculation obtained from the /7
hardness graph are given by the continuous curve. The points are representative of experimental measurements.

The tests carried out for 100 samples with various configurations showed a good correlation between experimental measurements and the theoretical calculations.

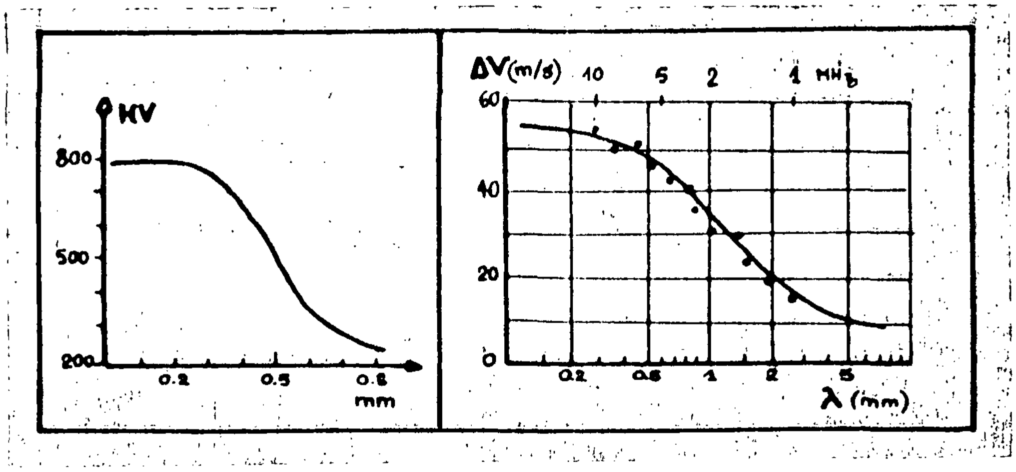

Figure 12.

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destructive testing. Z. Pawlowski (Polska Akademia Nauk, Instytut Podstawowych Problemow Techniki, Warsaw, Poland). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Plenary Conferences, Paper P3. 9 p.

Trends in the exploration, development, and extension of nondestructive test methods are discussed on the basis of certain common features shared by all existing methods. Attention is given to such aspects of the test methods as the interaction of physical fields with material flaws, extraction of information from an ultrasonic signal reflected by a flaw, characterization of material macrostructure, in-service testing of assemblies and components, and computer simulation. Recent trends noted include ultrasonic measurements, thermovision, various types of radiography, holography, image synthesis, and X-ray micrography. Mechanization of simple operations is suggested as a means of overcoming operator fatigue and making nondestructive testing more efficient, less laborious, and more reliable. F.G.M.

A77-30105 # **Weld defects and danger of failure (Défauts de soudure et danger de ruine).** J.-J. Chene (Gebr. Sulzer AG, Winterthur, Switzerland). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Formal Lectures, Paper M2. 8 p. In French.

The role of nondestructive testing of flaws in materials is discussed along with the organization of quality control in terms of user-supervision, design department, fabrication, technological development, quality control, and nondestructive testing. A critical discussion is presented of the situation pertaining to the selection and application of acceptance criteria for weld flaws. The role of the International Institute of Welding is highlighted. Future trends in the organization of nondestructive testing of weld flaws are noted. S.D.

A77-30108 # **Contribution to research on optimum techniques in steel radiography using cobalt 60 (Contribution à la recherche des techniques optimales en radiographie de l'acier avec le rayonnement du cobalt 60).** J. Cheret and A. Nouvet (Ministère de la Defense, Paris, France). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Section 3E, Paper 3E-3. 8 p. In French.

Films, filters, and screens are compared as to materials, thickness, and image quality in radiography of steel specimens ranging 80 to 140 mm thick with Co-60 radiation. Use of combinations of a forward screen of 'S'-alloy, 'S'-alloy plus Pb, or nickel, and a rear screen of Pb or a filter is assessed as to effect on image quality. Use of a forward Pb screen is judged counterproductive. The 'S'-alloy is a cobalt base superalloy. Use of a Pb backing filter (rear screen) is recommended. R.D.V.

A77-30115 # **High-energy televised industrial radioscopy, in inspection of solid-propellant engines (Radioscopie industrielle télévisée à haute energie appliquée aux moteurs à carburant solide).** V. Chalmeton, C. Patanchon, and C. Mesnage (Laboratoires d'Electronique et de Physique Appliquée, Limeil-Brévannes, Val-de-Marne; Société Nationale des Poudres et Explosifs, Saint-Medard-en-Jalles, Gironde, France). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Section 3E, Paper 3E-13. 8 p. In French.

A televised radioscopy system using 400 kV X-rays, for speeding up industrial radiographic inspection work and facilitating NDT of moving parts, is described. The system incorporates an image converter and image intensifier tube, and a closed-circuit television system with wide-angle optics. Missile solid-propellant propulsion engines are examined by the system for cracks, nonuniformities, presence of foreign bodies, cavities, changes in charge geometry. The system features good detection sensitivity with ease of identification and filing of plates, but requires long setup times for precision inspection (1 to 4 weeks) and consumes a large volume of imaging materials. R.D.V.

A77-30117 # **Ultrasonic nondestructive measurements of case depth (Mesure non destructive par ultrasons des profondeurs de cémentation-trempe).** C. Flambard and A. Lambert (Centre d'Etude Technique des Industries Métallurgiques, Senlis, Oise, France). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Section 1C, Paper 1C-1. 7 p. 6 refs. In French.

Two ultrasonic methods for nondestructive measurement of the depth of a case-hardened layer in steel are described. One method involves analysis of the amplitude of ultrasonic waves diffused back from the bulk of the workpiece. The other method involves finding the speed of propagation of ultrasonic waves launched on the surface of the work. Procedures followed in the two methods for measuring case depth are described separately at length. R.D.V.

A77-30118 # **Ultrasonic reverberation time measurement for detection of grain boundaries softening.** J. Deputat (Polska Akademia Nauk, Instytut Podstawowych Problemow Techniki, Warsaw, Poland) and J. Szczurek (Wytwornia Sprzetu Komunikacyjnego, Rzeszow, Poland). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Section 1C, Paper 1C-2. 5 p.

Reverberation time measurements and their use in the evaluation and selection of aerospace turbine blades containing dissolved grain boundaries in the surface layer are discussed. General advantages of using ultrasonic reverberation time as a tool are pointed out. The intricate shape of the turbine blade (tapered and twisted profile, cross section varying along the shank, surfaces of blade convex on one side and concave on the other) rule out reliance on the ultrasonic attenuation factor, and other NDT methods are also difficult to use to advantage in this application. The reverberation time measurements aid in detecting structural differences, measuring grain size, assessing grain boundary quality, and establishing the presence, size, and concentration of flaws. R.D.V.

A77-30119 # **Concerning the multi-parameter methods in the non-destructive material testing.** W. Stumm (Institut Dr. Förster, Reutlingen, West Germany). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Section 3C, Paper 3C-1. 5 p. 5 refs.

The discussion covers: NDT signal evaluation by general transformation methods, linear and nonlinear transformations important in multiparameter NDT work, generalized transformations with generalized frequency in the frequency domain, and some practical applications in NDT based on eddy currents and flux leakage. Two-channel and multifrequency eddy current systems are considered in the discussion of linear transformations. Application of a simple nonlinear transformation to compensation of centering errors in eddy current feedthrough coil tests is outlined. The generalized frequency approach is applied to inspection of cracks and inclusions in reactor holes and reactor rods. R.D.V.

A77-30121 # **Development of novel C-scan facsimile recording techniques for imaging discontinuities revealed by eddy current NDT in a variety of aerospace components.** F. R. A. Turner (Department of National Defence, Trenton, Ontario, Canada). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Section 3C, Paper 3C-3. 9 p. 10 refs.

A77-30124 # **Pulsed eddy-current response of point defects.** D. L. Waidelich (Missouri-Columbia, University, Columbia, Mo.). In: World Conference on Nondestructive Testing, 8th, Cannes, France, September 6-11, 1976, Proceedings. (A77-30101 13-38) Paris, Institut de Soudure, 1976, Section 3C, Paper 3C-6. 7 p.

The response of a pickup coil in air to a pulsed dipole current at a point below the surface of a metal, simulating a point defect in that location, is analyzed. Curves of the coil response voltage as a function of flaw-coil spacing are plotted. Changes in peak voltage caused by lift-off are plotted, and the amplitude and time of the peak response voltage are presented. The pickup coil is treated as an integral to be evaluated by computer. Results are applicable to precision pinpointing of point defects by pulsed eddy currents in inspection of nuclear power equipment. R.D.V.

A77-30125 # **Investigation of mobile conducting articles at complicated movements about the electromagnetic transducer.** D. N. Tsvetkov, P. Z. Kostadinov, B. L. Vasilev, and S. S. Staikov (Vissh Mashinno-Elektrotekhnicheski Institut, Sofia, Bulgaria). In: World Conference on Nondestructive Testing, 8th, Cannes, France,