NBSIR 80-2109

A Basis for Traceable NDE Measurements

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A Basis for Traceable NDE Measurements+

by

D. G. Eitzen, H. Berger and G. Birnbaum

ABSTRACT

The National Bureau of Standards is beginning to provide a mechanism for traceability for a number of NDE measurement procedures, an activity that is expected to have a significant, positive impact on the reproducibility and accuracy of NDE measurements. Much of the NDE standards activity has been in ultrasonics and acoustic emission, these efforts leading to calibration services for ultrasonic reference blocks and ultrasonic and acoustic emission transducers. Additional NDE standards are also available or are being developed in radiography, eddy currents, magnetic particles, liquid penetrants and visual testing.

INTRODUCTION

The National Bureau of Standards (NBS) has been involved in improving the reproducibility and quantitative aspects of nondestructive evaluation (NDE) measurements[1] in response to a growing need for improvements in this area. This report is an overview of NBS work which is concerned particularly with the development of NDE measurement procedures that provide a mechanism for traceability to National Reference Standards. There are several noninterchangeable concepts termed "traceability" which are carefully explored in ref. 2.

ULTRASONICS

Pulse/echo ultrasonic techniques offer great potential for detecting and evaluating material defects nondestructively. However, these methods are sensitive to measurement equipment characteristics and to the condition of the reference artifacts used. An effort to improve the reliability and diminish the uncertainty of these techniques has focused on the development of measurement services for transducers and reference blocks. The measurement services now available from NBS are described below.

+ This is based on a paper presented at the 1979 DARPA/AF Review of Quantitative NDE, La Jolla, California.

1. Ultrasonic Transducer Power Output versus Frequency. The absolute total power output of ultrasonic transducers versus frequency is measured over any part of a range from about 1-20 MHz using a modulated radiation pressure technique. The transducer undergoes swept continuous wave excitation and the radiation force of the ultrasonic beam acting on a conical metal target is detected. The uncertainty is frequency dependent but is nominally about ± 5 percent. In addition to the relative power versus frequency information, the measurement provides the value of the radiation conductance used to calculate absolute power output levels. The apparatus, procedure, error analysis and sample results are discussed in ref. 3.

2. Ultrasonic Transducer and System Power Output by Calorimetry. A twin, series flow, ultrasonic calorimetric comparator is used to measure the time-averaged total absolute power output of a transducer or ultrasonic system for any voltage input waveform, e.g. pulsed, in the range of 1-15 MHz. The ultrasonic energy is converted to heat by rubber absorbers and this energy raises the temperature of the working fluid. The uncertainty is approximately ± 7 percent. The system, procedures and uncertainties are described in ref. 4.

3. Aluminum and Steel Ultrasonic Reference Block Calibration. Sets of ASTM E-127 type aluminum ultrasonic reference blocks are compared with a block designated as the NBS Interim Reference Standard using an analytical model and a well-characterized measurement system. The service provides a mechanism for comparing sets of blocks with the NBS data base and with other reference blocks through the NBS ultrasonic system. The service has recently been expanded to include steel reference blocks. The system and detailed procedures are described in ref. 5.

4. Loaner Services for Transducers and Transfer Blocks. By arrangement, carefully characterized ultrasonic source transducers and aluminum block transfer standards can be made available for loan. By employing the accurately measured ultrasonic source transducers, a user's power or frequency measurement apparatus can be calibrated *in situ*. Some of the source transducers are currently being employed in an international intercomparison of ultrasonic power measurement methods. The transfer aluminum ultrasonic blocks, which have been carefully compared with the NBS Interim Reference Standard, see item 3, provide a means for users to compare their reference artifacts with those of NBS on their own ultrasonic system; i.e. they provide a basis for traceability to the NBS Interim Reference Standard. The transfer blocks can provide the basis for a measurement assurance program. Calibration of users' blocks can be accomplished by the user with an uncertainty of a few percent using a procedure developed at NBS.

Additional work on ultrasonic measurement systems is in progress. An expansion of the NBS measurement service for ultrasonic reference blocks to titanium is being developed. The feasibility of developing improved steel and titanium reference blocks was established in 1979.[6] Also under consideration are material independent reference blocks made of amorphous, low-attenuation material; these could replace much of the present multiplicity of reference artifacts.

The influence of changes in the components or adjustments of the instrument on the variations in the amplitude of response from reflectors has also been studied in some detail. For example, adjustments in the pulse length of an ultrasonic instrument resulted in differences in amplitude response from a reference block by over 13 percent, even after normalization with a ball reflector.[6] A study of the effects of different (but very similar) transducers was also conducted[7] which showed variations of over 26 percent in the response of a given block using different transducers. This study has raised some important questions, for example, what are the necessary tolerances on the instrumentation in order to obtain the required reliability and uniformity in ultrasonic NDE?

Another important activity is the development of methods for determining the directivity pattern of ultrasonic transducers.[8] A mathematically rigorous approach based on probing the amplitude and phase in a plane of the radiated field of a transducer is being developed as a laboratory method. It is capable of measuring the absolute value of all important point field parameters of transducers. Work is also proceeding on the development of techniques more appropriate for the user community. See, for example, ref. 9.

Additional work on standards for quantitative ultrasonic NDE is being planned. This planning process has been greatly enhanced by a study recently completed for the Defense Advanced Research Projects Agency (DARPA). The objective of this project was to examine the present system of standards for ultrasonic NDE measurements, to assess the standards needs of emerging and more quantitative systems and to present recommendations for the development of adequate standards for such NDE systems. In addition to an NBS report describing the results of this study,[10] outputs of this project include a separate summary of the open literature on ultrasonic NDE standards,[11] a detailed study of foreign and U.S. standards documents[12] and a chapter on ultrasonic transducers and their characterization.[13]

ACOUSTIC EMISSION

A calibration capability has been developed for acoustic emission (AE) transducers and is now offered as a measurement service.[14] This activity is part of an Electric Power Research Institute/NBS acoustic emission program and is also partially supported by the Office of Naval Research. The objective, to determine the sensitivity versus frequency of AE transducers over the approximate range of 100 to 1000 KHz, is accomplished by obtaining the voltage as a function of time from a transducer under test and the NBS standard transducer, both mounted on a large (2200 Kg) steel block. The input is a point force step function on the same surface of the block as the transducers. The simulated source and block produce a vertical surface displacement that is theoretically calculable (Fig. 1). The displacement measured by a capacitive transducer developed at NBS is shown to faithfully reproduce the actual displacement as shown in Fig. 2. The resulting time histories of the output voltage are digitized, Fourier transformed and processed to obtain the desired spectral response. A newly designed and constructed standard transducer which determines absolute dynamic displacement of the order of a nanometer with an uncertainty of about 3 percent (Fig. 3) has resulted in further measurement accuracy.

There is also a substantial theoretical effort associated with the ultrasonic and acoustic emission program. Theoretical developments describing the planar scanning of the radiated field of electroacoustic transducers have impacted work on determining directivity patterns of transducers. Also, a relationship between the total force on a transducer and its output voltage suggests future calibration techniques for users. Another development, which accurately models the behavior of transducers, is making possible more realistic standards procedures (NBS and ASTM). Theoretical advances in wave propagation in structures are leading to the development of primary and secondary acoustic emission calibration methods.

RADIOGRAPHY

A Standard Reference Material[++] (SRM) available from NBS[15] provides a mechanism for the traceability of radiographic film density measurements. This is SRM 1001, a radiographic film step tablet covering the H & D density unit range from 0 to 4.0. Density measurements are reproducible to about 0.02 H & D units.

Additional standards-related work in radiography at NBS includes a recommended practice for thermal neutron radiography (now under consideration by ASTM, Committee E-7) and work to determine important characteristics of x-ray film[6] (also being done in collaboration with ASTM E-7).

EDDY CURRENT TESTING

Facilities for dc and ac electrical conductivity measurements have been completed. The NBS is also establishing measurement procedures for conductivity standards over the range of 1-100 percent of the International Annealed Copper Standard and methods for the calibration of eddy-current test equipment.

[++] Standard Reference Materials are samples which have been characterized by NBS for some physical or chemical property and are issued with a Certificate that gives the results of the characterization.

Initial conductivity calibration services will be offered to accuracies of 0.5%. It is expected, as experience is gained in the measurements, that accuracy can be improved to 0.1%. In addition to the planned calibration facilities for electrical conductivity, the measurement of this quantity will also be traceable by means of SRM conductivity samples now under development.

Theoretical solutions[17,18] for the field and current distributions associated with defects in materials will also provide guidance for eddy current testing and development of artifact standards.

MAGNETIC PARTICLES

Work is under way to measure the brightness of fluorescent magnetic particles which is aimed at developing an SRM comparison standard for judging brightness and providing a calibration service. In addition, studies of magnetic flux leakage are in progress. A recent report[19] describes results of investigations of a test ring for judging the effectiveness of magnetic particles as used in a military specification. A theoretical model developed to describe the magnetic response of subsurface defects in the ring showed good correlation with experiment. This work is leading toward improvements in the testing procedure for general evaluation of magnetic particles. In addition, NBS is investigating the potentail of a fluorescent glass standard which would be used to compare brightness of both magnetic particle and liquid penetrant indications.

LIQUID PENETRANTS

Standards for brightness of fluorescent penetrants follow the same pattern as indicated above for magnetic particles. In addition, work is in progress to prepare a relatively inexpensive, well characterized, crack test plate for evaluating liquid penetrants and their consistency during operation as well as comparing one product or process against another. To fabricate these crack test plates, alternate layers of copper and nickel are plated. The nickel is merely a separator between thicknesses of copper (to values as small as 0.3 μm). When these copper layers are etched, they provide slots or cracks of known width which can be determined to within 0.15 μm or 50%, whichever is greater. The depths of the cracks, determined by etching, are somewhat more difficult to control. However, for shallow cracks, depth to width ratios of about 4, the minimum crack depth can be determined to an uncertainty of about 0.5 μm. This plated assembly can be etched, measured and cut into small specimens as indicated in Fig. 4. It is expected that this approach will result in a relatively inexpensive plate with cracks for determining penetrant sensitivity.

VISUAL TESTING

An important parameter in visual testing is the capability of the inspector to see details that may be small in size, of low contrast and unsharp. The visual acuity of inspectors is now measured with a Jaeger chart in which the inspector is asked to read small black letters on a white background. This high contrast situation does not always simulate what an NDE inspector may be called upon to observe.[20] He may be looking for a penetrant indication or a low contrast shading in a radiograph. Therefore, NBS is pursuing the development of a visual acuity measurement procedure that more closely duplicates the inspector's situation. The new procedure will involve varying the contrast as well as varying the sharpness and width of indications.

OTHER NDE MEASUREMENT AREAS

There are a number of SRM's available from NBS that impact NDE-related measurements in addition to those discussed previously. These well characterized materials provide assistance in several areas. One of these is the determination of wear through the availability of metallo-organic compounds that permit the blending of known concentrations of metal in lubricating oil. More than 20 of these SRM's are available (ref. 15, p. 46).

The measurement of coating thickness by eddy currents, magnetic techniques, beta (ray) backscatter and x-ray fluorescence methods can be improved by the use of one or more coating thickness SRM's. These are available with magnetic and nonmagnetic coatings on magnetic or nonmagnetic substrates and gold and tin coatings on various substrates for radiation measurements. More than 30 SRM's are available for coating thickness measurements (ref. 15, pp. 55-58).

One of the coating thickness SRM's (SRM 1370a) can also be used to evaluate the ferrite content of austenitic stainless steels. X-ray diffraction standards for powder diffraction measurements and for determination of iron carbide in steel are available (ref. 15, p. 71). Additional SRM's (ref. 15) include glass specimens for measurement of relative stress optical coefficient (p. 59), alumina for measurement of elastic wave resonances and calculation of elastic moduli (p. 59) and standards for the calibration of the Mössbauer isomer shift of iron compounds (p. 71).

Additional SRM's to improve NDE measurements are planned. Possibilities include calibrated leaks for leak testing in several ranges, reference samples for wear debris and SRM's for measurement of residual stress.

CONCLUSIONS

Several mechanisms for achieving traceable NDE measurements are now available from NBS. These, along with additional measurement services and improved procedures and techniques, will help industry achieve traceability and result in more reproducible and meaningful NDE measurements.

ACKNOWLEDGEMENTS

We are indebted to many NBS colleagues for sharing information with us and for their efforts in forming a basis for traceable NDE measurements.

FIGURE CAPTIONS

Figure 1. Theoretical waveform of displacement on the AE calibration transfer block. The vertical axis is dimensionless time P, S, and R designate features of the waveform which travel with speeds of longitudinal, shear and Rayleigh waves.

Figure 2. Displacement of transfer block measured with model 1 NBS transducer. New NBS transducer gives even better agreement (not shown) with theory.

Figure 3. Plot showing about 3 percent agreement in dynamic surface displacement between theory and measurement using new NBS standard transducer.

Figure 4. Crack sensitivity plate developed for liquid penetrants. The copper is etched to various depths to simulate surface cracks.

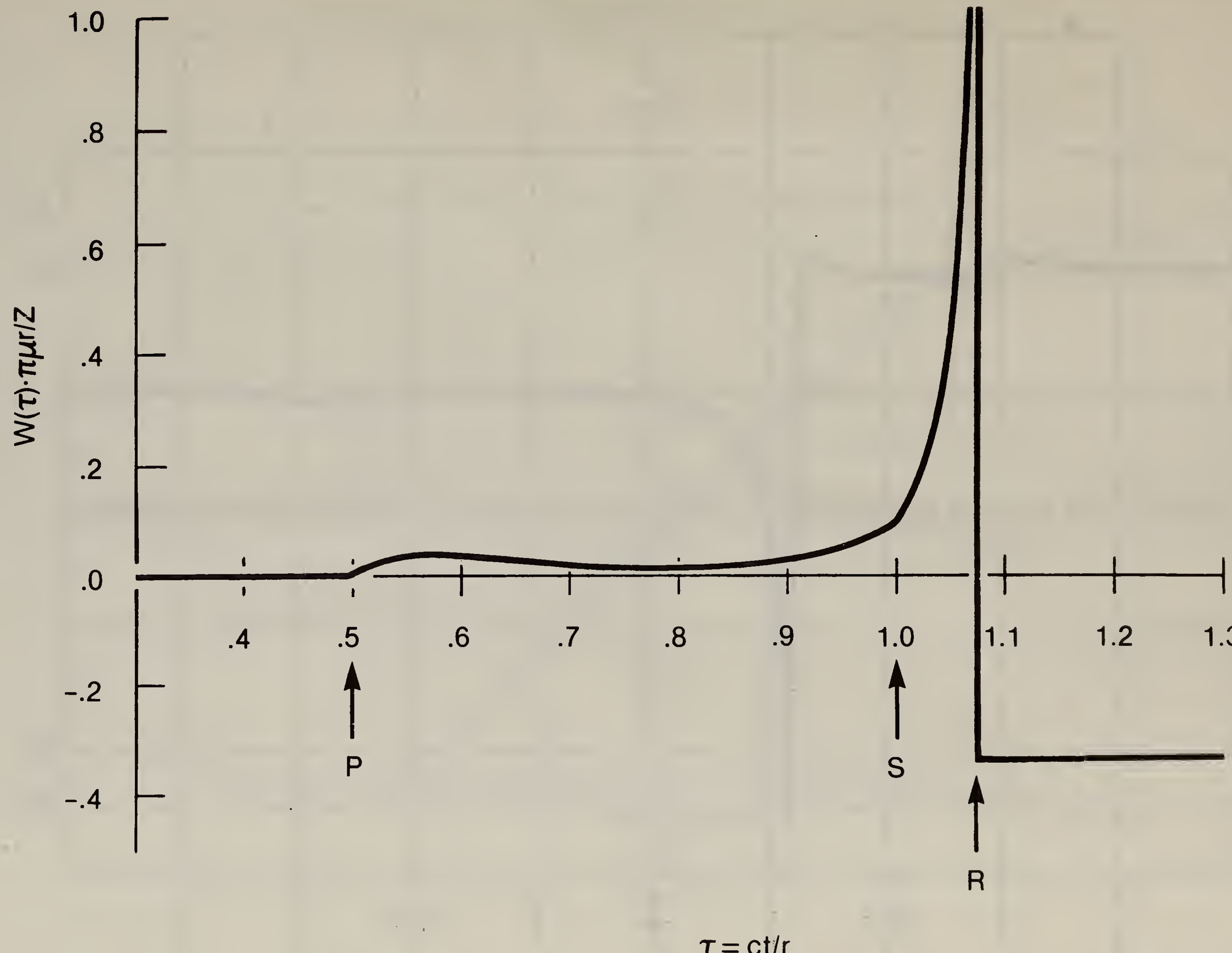

Figure 1

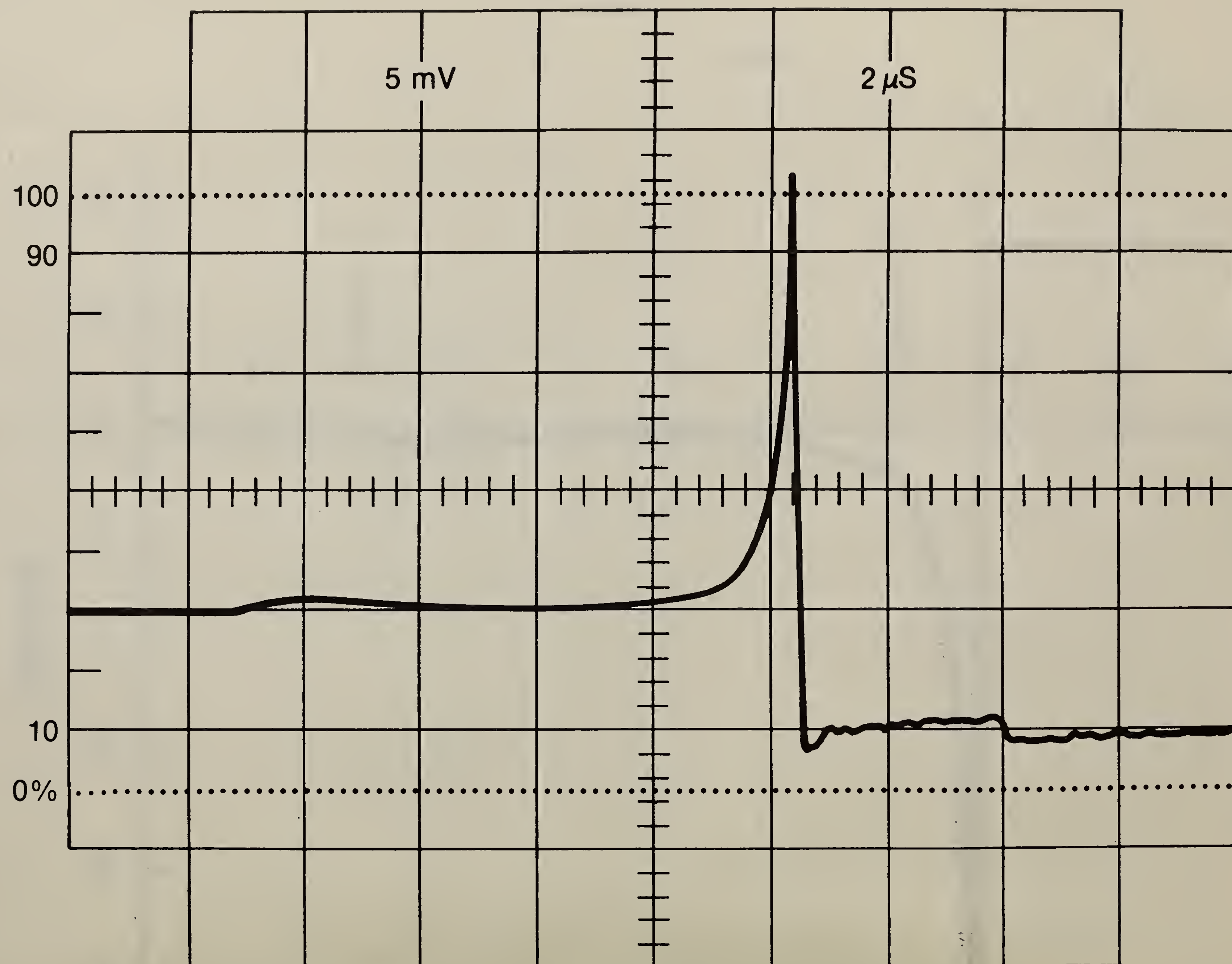

Figure 2

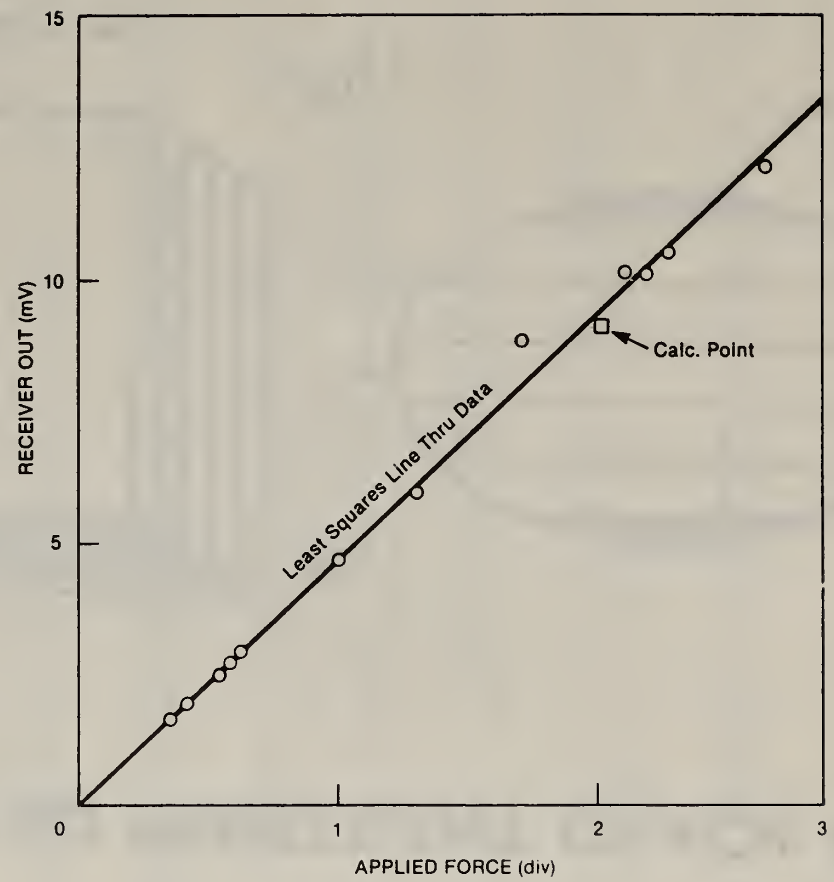
15
10
5
0
1
2
3
RECEIVER OUT (mV)
APPLIED FORCE (div)
Least Squares Line Thru Data
Calc. Point

Figure 3

PLATED PENETRANT CRACK PLATE

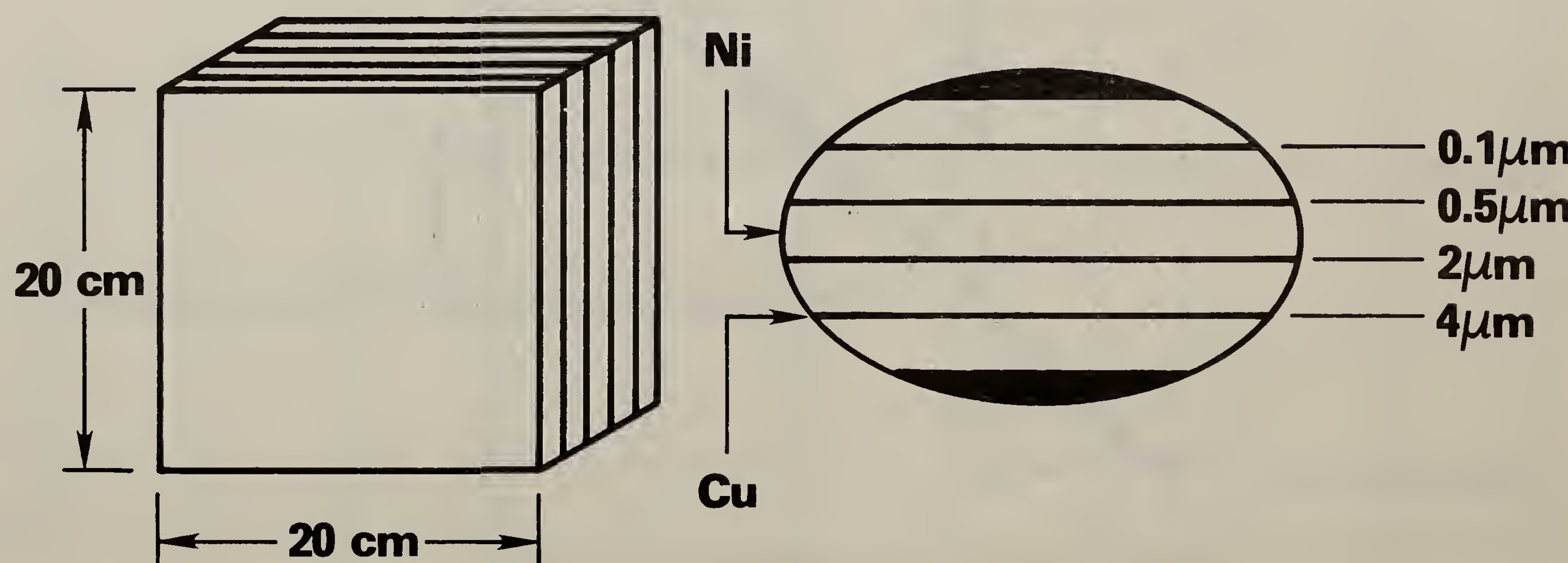

Figure 4

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The National Bureau of Standards is beginning to provide a mechanism for traceability for a number of NDE measurement procedures, an activity that is expected to have a significant, positive impact on the reproducibility and accuracy of NDE measurements. Much of the NDE standards activity has been in ultrasonics and acoustic emission, these efforts leading to calibration services for ultrasonic reference blocks and ultrasonic and acoustic emission transducers. Additional NDE standards are also available or are being developed in radiography, eddy currents, magnetic particles, liquid penetrants and visual testing.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Acoustic emission; calibration; eddy currents; magnetic particles; nondestructive evaluation; radiography; traceability; ultrasonics; and visual testing.

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