A BASIS FOR TRACEABLE NDE STANDARDS

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ABSTRACT

The National Bureau of Standards (NBS) 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, this effort 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 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 concerned particularly with the development of NDE measurement procedures that incorporate traceability†† to National Reference Standards. The work described is due to many NBS workers in addition to the authors. Points of contact for the various technical areas are listed at the end of this paper.

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:

1. Ultrasonic Transducer Power Output versus Frequency. By using a modulated radiation pressure technique, the absolute total power output of ultrasonic transducers versus frequency is measured over any part of a range from about 1-20 MHz. The transducer undergoes swept cw excitation. The uncertainty is frequency dependent but is nominally about $\pm$ 5 percent. In addition to this 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 reference 2.

2. Ultrasonic Transducer and System Power Output by Calorimetry. By using a twin, series flow ultrasonic calorimetric comparator, the time-averaged total absolute power output of a transducer system is measured for any voltage input waveform, e.g. pulsed, in the range of 1-15 MHz. The uncertainty is approximately $\pm$ 7 percent. The system, procedures, and uncertainties are described in reference 3.

3. Aluminum Ultrasonic Reference Block Calibration. Sets of ASTM E-127 type ultrasonic reference blocks are compared with a block designated as the NBS Interim Reference Standard and associated model by using 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 system and detailed procedures are described in reference 4.

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*. The transfer aluminum ultrasonic blocks, which have been carefully compared with the NBS Interim Reference Standard, 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. Some of the source transducers are currently being employed in an international intercomparison on ultrasonic power measurement methods. The transfer blocks can 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. Some of the source transducers are currently being employed in an international intercomparison on ultrasonic power measurement methods. 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 an NBS devel,oped procedure.

Additional work on ultrasonic measurement systems is in progress. An expansion of the NBS artifact system for ultrasonic reference blocks to steel and titanium reference blocks is being developed. The feasibility of developing improved steel and titanium reference blocks is to be established in 1979. Also under consideration are material-independent reference blocks made of

†This paper is to be published in a somewhat expanded version as an NBS report.

††There are several noninterchangeable concepts termed "traceability." The subject is carefully explored in "Traceability - an Evolving Concept" by B. C. Belanger to appear in Standardization News.

amorphous, low-attenuation material; these could replace much of the present multiplicity of reference artifacts.

The influence of changes or adjustments to instrumentation on the variations in the amplitude of response from reflectors has also been studied in some detail. For example, changes in the pulse length adjustment of a flaw detector result in amplitude response changes from a reference block by over 13 percent, even after normalization. A study of the effects of different (but very similar) transducers was also conducted.[5] The study showed variations of over 26 percent in response due to different transducers. This study has important implications; one of the key issues is: what are the necessary tolerances on the instrumentation in order to obtain the required reliability and uniformity in ultrasonic nondestructive evaluation (NDE)?

Another important area of study is the development of methods for determining the directivity pattern of ultrasonic transducers.[6] A mathematically vigorous method called planar scanning is being developed as a laboratory method. It is capable of measuring the absolute value of all of the important field point parameters of transducers. Work is also proceeding on the development of techniques more appropriate for the user community.

Additional work on standards for quantitative ultrasonic NDE are being planned. This planning process has been greatly enhanced by a study just completed for DARPA. The objective of the 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 an adequate system of standards for quantitative ultrasonic NDE systems. The results of the study have been reported to the sponsor and should soon be available to the public as an NBS report. Other outputs of this project include a separate summary of the open literature on ultrasonic NDE standards and a detailed study of foreign and U.S. standards documents both to be published as NBS reports and a chapter on ultrasonic transducers and their characterization in an upcoming volume of Physical Acoustics.

ACOUSTIC EMISSION

A calibration capability is being developed for acoustic emission (AE) transducers and will shortly be offered as a measurement service.[7] This activity is partially supported by a larger EPRI/NBS Acoustic Emission Program and by the Office of Naval Research. The objective is to determine the sensitivity versus frequency of AE transducers over the approximate range of 100 to 1000 KHz. This is accomplished by obtaining time histories from the transducer under test and the NBS standard transducer, both mounted on a large (2200 Kg) steel transfer block. The input is a simulated source on the same surface of the block as the transducers. The resulting time histories are digitized and processed in frequency space to obtain the desired measure of spectral response. The simulated source and transfer block produce a vertical surface displacement that is theoretically calculable (Fig. 1). The displacement measured by the first candidate standard transducer is shown to faithfully reproduce the actual displacement as shown in

Fig. 2. A newly designed and constructed standard transducer has resulted in further accuracy; it provides measurements of absolute dynamic displacement of the order of a nanometer with an uncertainty of about 3 percent (Fig. 3).

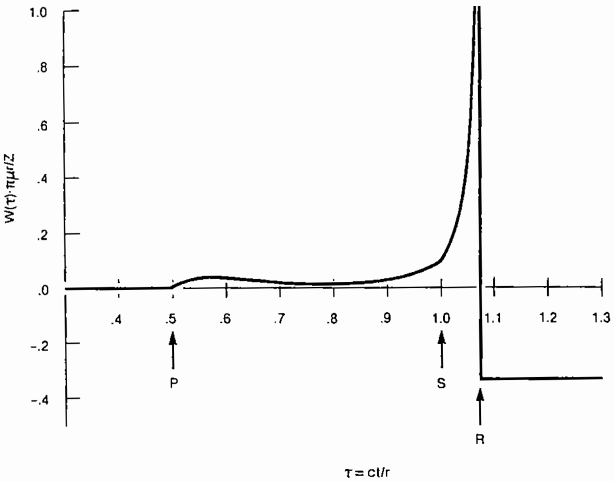

Fig. 1. Theoretical waveform of vertical displacement on the transfer block

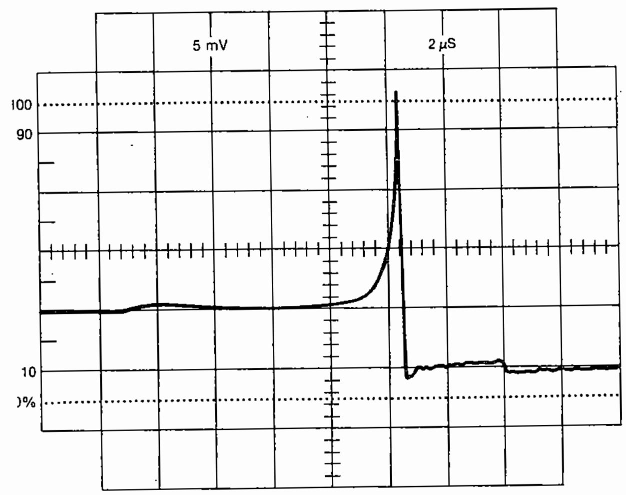

Fig. 2. Displacement of transfer block measured with model 1 NBS transducer. New NBS transducer gives even better agreement (not shown) with theory.

There is also a substantial theoretical effort associated with the ultrasonic and acoustic emission work. Theoretical developments using the scattering matrix description of electroacoustic transducers have impacted work on determining directivity patterns of transducers. Two recent theorems on the nature of the radiated field of generated acoustic sources suggest future calibration techniques for users. A recent theoretical description, which more accurately describes actual transducers, is making possible more realistic standards procedures (NBS and ASTM). Theoretical developments in dynamic elasticity are making possible the development of primary and secondary acoustic emission calibration methods.

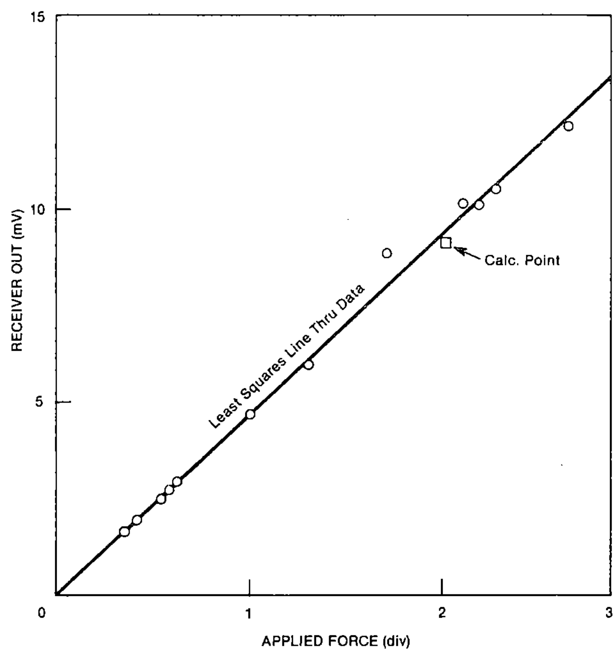

Fig. 3. Plot showing about 3 percent agreement in dynamic surface displacement between theory and measurement using new NBS standard transducer.

RADIOGRAPHY

A Standard Reference Material† available from NBS[8] provides a mechanism for 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[9] (also being done in collaboration with ASTM E-7).

EDDY CURRENT TESTING

Facilities for dc and ac electrical conductivity measurements have been completed. Future work will include 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. 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 characteristic will also be traceable by means of SRM conductivity samples, now under development.

†Standard Reference Materials are samples which have been characterized by the National Bureau of Standards for some physical or chemical property and are issued with a Certificate that gives the results of the characterization.

Theoretical solutions[10,11] for the fields 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. This could lead to a calibration service, or more likely, to an SRM comparison standard for judging brightness.

In addition, studies of magnetic flux leakage are in progress. A recent report[12] described results of investigations of a test ring for judging the effectiveness of magnetic particles (as used in military specification). A model was developed to describe the magnetic response of subsurface defects in the ring; the model showed good correlation with experiment. The work is leading toward suggestions for making the testing more useful for general evaluation of magnetic particles.

LIQUID PENETRANTS

Brightness of fluorescent penetrants would follow the same pattern as indicated above for magnetic particles. In addition, work is under way to prepare a relatively inexpensive, well characterized, crack test plate for evaluating materials and consistency during operation as well as comparing the one product or process against another.

In this approach, alternate layers of copper and nickel are plated. The nickel is merely a separator between well characterized thicknesses of copper (to values as small as 0.3 μm). When these copper layers are etched, they provide well characterized slots or cracks in terms of width. The width can be determined to within 0.15 μm or 10%, whichever is greater. The depths of the cracks, determined by etching, are somewhat more difficult to control. However, for 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 such as indicated in Fig. 4. It is expected that this approach would result in a relatively inexpensive crack sensitivity plate.

PLATED PENETRANT CRACK PLATE

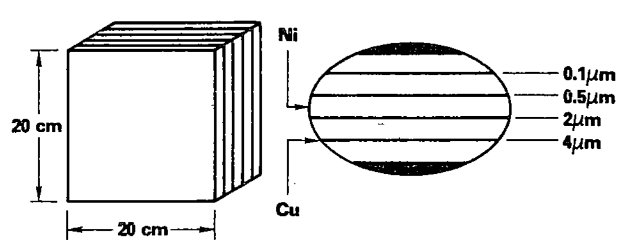

Figure 4. Crack sensitivity plate which is under development for liquid penetrants.

VISUAL TESTING

An important parameter in visual testing is the capability of the inspector to see detail 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.[13] 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 sharpness and width of indications. A report on this is planned for late 1979.

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.

Additional information on the various technical areas may be obtained from:

Ultrasonic Block Calibration and Transfer Blocks	D. Chwirut Sound A147 NBS Washington, D.C. 20234	(301)921-3646
Ultrasonic Transducer Calibration and Transfer Transducers	C. Tschiegg Sound A147 NBS	(301)921-3646
Acoustic Emission Transducer Calibration	F. Breckenridge Sound A147 NBS	921-3646
Radiography Standards, X-ray	R. Placious RADP C216 NBS	(301)921-2201
Radiography Standards, Neutron	D. Garrett Reactor A106 NBS	(301)921-3646
Eddy Current Conductivity Measurements	G. Free MET B146 NBS	(301)921-2715
Eddy Current Theoretical Solutions	A. Kahn MATLS A251 NBS	(301)921-2841
Magnetic Particle Brightness Measurements	K. Mielenz CHEM B222 NBS	(301)921-2143
Liquid Penetrants Crack Test Plate	F. Ogburn POLY B168 NBS	(301)921-2957
Visual Acuity Measurements	G. Yonemura BR A313 NBS	(301)921-2680

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

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