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Annual Report 1978 Office of Nondestructive Evaluation

Harold Berger and Leonard Mordfin, Editors

Office of Nondestructive Evaluation
National Measurement Laboratory
National Bureau of Standards
Washington, DC 20234

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Preface

This report summarizes the activities of the National Bureau of Standards (NBS) Nondestructive Evaluation (NDE) Program. It emphasizes activities over the Fiscal Year 1978. However, since this is the Program's first Annual Report, some material is included to summarize activities since the Program was formally instituted in June 1975.

Although the NDE Program was not established until 1975, this does not imply that no NBS attention was paid to NDE methods and problems prior to that time. Indeed, some significant developments include the recognition of the basic concepts of the magnetic particle test method by Major William Hoke (U.S. Army) while he was working at NBS in the 1920's, the invention of the highly sensitive ultrasonic transducer material PZT in the early 1950's by NBS scientists B. Jaffe, R. S. Roth and S. Marzullo and the development of the first ultrasonic velocimeter by M. Greenspan and C. Tschiegg in 1957.

More recently, interest in NDE was furthered by the efforts of many people who recognized the need for improved NDE measurements in terms of reproducibility and in terms of quantitative results. Their efforts led NBS to the establishment of the NDE Program.

Programs at NBS provide a focus for the activity both inside and outside NBS. The programs provide funds and directions for needed technical work that is done within NBS Centers. People remain attached to a Center but are funded for specific activities in a matrix management approach. A program provides a central organization for outside inquiries and for distribution of results. Often a program by its focus can provide improved assistance to outside agencies with measurement problems.

In the case of NDE, the Program has functioned in the above manner. Related activities were recognized and additional activities were funded to make a cohesive program.

Initial emphasis has been on short-range standards and measurement problems that will impact the major NDE methods. Thus, attention is given to such areas as ultrasonic reference blocks and transducers, radiographic film classification, magnetic field leakage and electrical conductivity standards. In the long-range plan for the Program, it is recognized that additional techniques or modifications of existing methods must also be developed in order to make NDE more quantitative and in order to measure important material parameters such as hardness, grain size and residual stress. Once all of these factors are in place, attention can be directed usefully to performance criteria for materials and structures.

It is hoped that this report will provide useful information to the technical community about the present directions of the NBS effort in nondestructive evaluation. We recognize that comments and suggestions from manufacturers and users of NDE equipment can provide guidance for the NBS program. We encourage readers to share with us their needs and interests in the field of nondestructive evaluation.

Harold Berger
Chief, Office of
Nondestructive Evaluation

Table of Contents

1. Introduction

Nondestructive evaluation (NDE) represents a class of industrial inspection techniques used for assessing the integrity of materials or assemblies without impairing their usefulness. NDE tests are designed to reveal the presence of harmful defects such as cracks, porosity, inclusions and similar inhomogeneities. In addition, NDE methods may detect more subtle inhomogeneities such as those associated with grain size or orientation, internal stress, compositional variations, cold work, and the like, since these variations also may seriously influence the useful life of the component. In each case, the goal of the NDE test must be to identify the inhomogeneity in terms of size and location. In this way, the influence of the defect on materials performance can be reliably assessed.

Nondestructive measurements yield information useful for:

- o eliminating defective materials prior to expensive machining or fabrication,
- o assessing the condition of parts or assemblies during and after fabrication,
- o determining the condition of materials or assemblies after a period of use,
- o monitoring to detect signs of failure during operation, and
- o aiding effective failure analysis to minimize future failure problems.

NDE has a strong impact on productivity, materials and energy conservation, as well as safety. Improved, more reliable NDE measurements will lead to improved confidence in trade as measurements on goods and materials are brought closer together. In the present climate of product recalls and large judgements in the area of product liability, improved NDE measurements and applications are of particular interest.

The NDE methods commonly used in industry include ultrasonics, radiography, visual-optical tests, eddy currents, penetrants and magnetic particles. The methods tend to be complementary. Therefore, it is not unusual to find more than one method used to inspect an object. Visual-optical and penetrant methods are useful for the inspection of surfaces and surface-connected defects. Magnetic particle and eddy current techniques can reveal surface and shallow defects in ferromagnetic and electrically conducting materials. Radiography and ultrasonic methods are capable of probing deeply into various materials and structures. Radiography offers advantages for confirming part placement in complex structures. Ultrasonic methods tend to be sensitive for the detection of cracks or any abrupt change in acoustic impedance. A comparison of the common NDE methods is given in Table I.

Table I. Comparison of Common Nondestructive Evaluation Methods

Method	Characteristics Detected	Advantages	Limitations
Ultrasonics	Changes in acoustic impedance caused by cracks, nonbonds, inclusions, or interfaces.	Can penetrate thick materials; excellent for crack detection; can be automated.	Requires coupling to material either by contact to surface or immersion in a fluid such as water.
Radiography	Changes in density from voids, inclusions, material variations; placement of internal parts.	Can be used to inspect wide range of materials and thicknesses; versatile; film provides record of inspection.	Radiation safety requires precautions; expensive; detection of cracks can be difficult.
Visual-Optical	Surface characteristics such as finish, scratches, cracks or color; strain in transparent materials.	Often convenient; can be automated.	Can be applied only to surfaces, through surface openings or to transparent material.
Eddy Currents	Changes in electrical conductivity caused by material variations, cracks, voids, or inclusions.	Readily automated; moderate cost.	Limited to electrically conducting materials; limited penetration depth.
Liquid Penetrant	Surface openings due to cracks, porosity, seams or folds.	Inexpensive, easy to use, readily portable, sensitive to small surface flaws.	Flaw must be open to surface. Not useful on porous materials.
Magnetic Particles	Leakage magnetic flux caused by surface or near-surface cracks, voids, inclusions, material or geometry changes.	Inexpensive, sensitive both to surface and near-surface flaws.	Limited to ferromagnetic material; surface preparation and post-inspection demagnetization may be required.

The Bureau's NDE Program was formally initiated in June, 1975. The program has grown in the intervening period by internal reprogramming, funds and personnel authorized by the Congress (following recommendations by the Department of Commerce and the Office of Management and Budget), and by funds transferred to NBS by other organizations to help solve measurement and testing problems.

The objective of the Nondestructive Evaluation (NDE) Program is to improve the reliability and durability of materials and structures through standardized NDE measurement procedures. NBS works to help industry develop methods for accurate and reproducible NDE measurements. This includes technical investigations of standards (both physical calibration standards and procedural documents such as recommended practices), characterization of instruments, development of improved techniques, and the assessment of the meaning of the NDE measurement relative to material performance.

The Program is organized to address those needs. First, attention is given to the measurement requirements of the presently used NDE methods. Secondly, new or modified NDE methods are emphasized to provide more quantitative measurements and to provide measurement capability for performance-related material characteristics. Thirdly, performance criteria will be emphasized in order to help provide better information about the actual influence of defects and material parameters on performance.

2. Personnel

The Office of Nondestructive Evaluation is a program office coordinated within the NBS National Measurement Laboratory (see Organization Chart in Appendix). NDE projects, however, are undertaken throughout the Bureau. Present NDE activities involve all five Centers in the National Measurement Laboratory and four centers in the Bureau's National Engineering Laboratory. Work is done at the Bureau laboratories in Gaithersburg, Maryland and in Boulder, Colorado.

NDE projects are started on the basis of need as determined by discussions with people from industry, technical societies and government agencies. Once a project is decided upon, the work is initiated following agreements on scope and schedule with NBS staff and Center or Division management. Occasionally, projects are conducted or supplemented by outside sources.

A diagram of the Office of Nondestructive Evaluation for FY 1978 is shown in Figure 1. During this past year, our efforts were supplemented by two visitors, Dr. W. Sachse of Cornell University and S. Golan of the Israel Institute of Metals, by a postdoctoral appointee, Dr. Stephen Norton, and by two guest workers, Dr. Sekyung Lee of Korea Standard Research and Mr. Yao-Feng Ho of the Institute of Nuclear Energy Research, Taiwan. M. Fahey and S. Norton have now been transferred to other NBS activities. Wolfgang Sachse has completed his NBS assignment and returned to Cornell. Yao-Feng Ho has returned to Taiwan.

Principal investigators in various NDE activities at NBS are listed in the summary in Table II. Investigators named are active in the areas indicated on the basis of NDE program or other related support.

Office of Nondestructive Evaluation

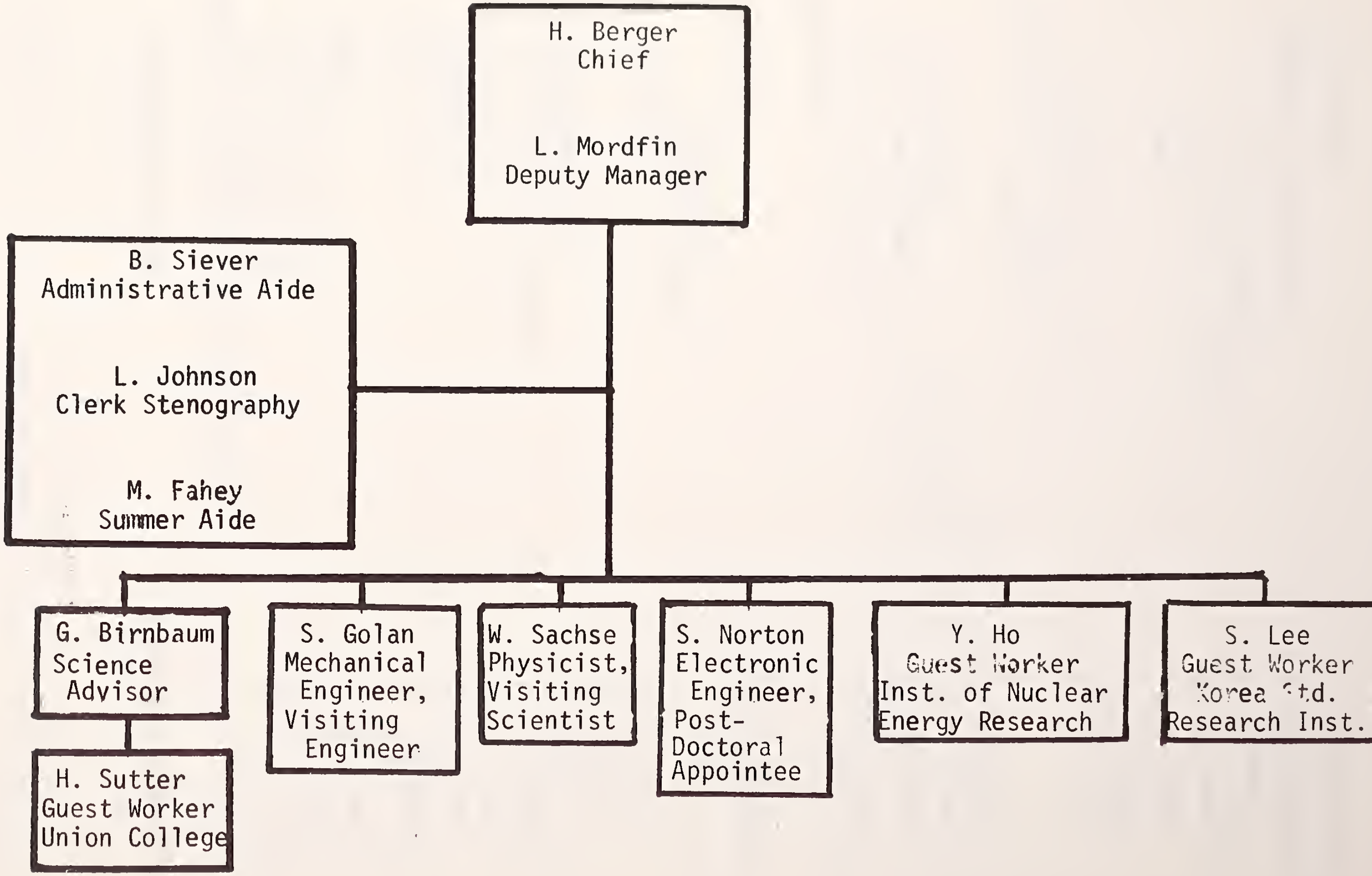


Figure 1. The Office of NDE; personnel participation during FY 1978.

Table II

Tabular Summary of

NBS - NDE Personnel

Technique or Area	Principal Investigators
A. Acoustic - Ultrasonic Application to:	
Building Materials	J. R. Clifton
Inorganic Materials	E. R. Fuller
Metals	J. A. Simmons, N. Hsu H. Ledbetter*
Polymers	R. W. Penn R. E. Green+
Crack Characterization	D. J. Chwirut
Instrumentation	M. Linzer S. Edelman
Standards Reference Blocks Transducers	D. G. Eitzen
Theory	J. A. Simmons R. B. Clough
B. Radiography	
Neutron Radiography	D. A. Garrett
Real-Time Systems	M. Kuriyama
X-Radiography	R. C. Placious J. W. Motz
C. Electromagnetic Methods	
Electrical, Eddy Current Methods	G. M. Free B. M. Field
Theory	A. H. Kahn
Conductivity Standards	L. H. Bennett
Visual Acuity Standards	F. Yonemura
Magnetic Measurements	L. Swartzendruber
Microwaves	D. Ellerbruch*

D.	Penetrants	
	Brightness, Fluid Properties	B. F. Howell K. D. Mielenz R. Velapoldi
	Crack Standard	F. Ogburn
	Flow Characteristics	S. Deutsch
E.	Wear Debris Analysis	L. K. Ives A. W. Ruff
F.	Thermal Tests	
	Microcalorimetry	E. J. Prosen
G.	Fracture	B. W. Christ M. B. Kasen* J. H. Smith
H.	Statistics	J. T. Fong
I.	Leak Testing	S. Ruthberg

+ WAE, Part-time

* NBS Boulder Laboratories

Telephone Numbers:

NBS, Gaithersburg, Maryland, (301)921-1000

NBS, Boulder, Colorado, (303)499-1000

Office of NDE, (301)921-3331

3. NDE Technical Program - An Overview

In this section of the report, the NBS technical program in NDE is described in general terms with specific information being given for the many NDE techniques now under investigation. Progress during the past year is discussed in some detail in selected areas under the heading, Some Examples of NDE Progress.

A. Acoustic-Ultrasonic Programs

Ultrasonic testing is widely used in industry. The potential for acoustic monitoring of structures is extremely attractive. The NBS acoustic-ultrasonic effort is heavily standards-oriented but also includes work to improve these NDE techniques and to provide improved understanding.

Work is in progress to develop methods for calibration of ultrasonic and acoustic emission transducers. Spectral characteristics, beam profile, and total sound power measurements are being studied. Transducer calibrations on a limited basis are now available for ultrasonic transducers in terms of total power (to values of about 15 watts; accuracy is estimated at about 5%) and radiation force as a function of frequency (range is from microwatts to 20 watts in terms of power and to about 30 MHz in terms of frequency). A full range of transducer calibration services is planned.

NBS researchers are studying ultrasonic test blocks in a project that had initial, partial funding from the Air Force, the Army and the National Aeronautics and Space Administration to determine the reasons for variability of these metal calibration blocks. A calibration service for aluminum ultrasonic reference blocks is now available. Calibration services for steel and titanium reference blocks are planned. Further directions for this effort include the development of material-independent test blocks and the development of well-characterized fatigue cracks that could serve as a calibration artifact for many NDE tests.

Instrumentation development work in both ultrasonics and acoustic emission is also in progress. This includes development of improved signal-to-noise ratio systems by methods such as signal averaging and pulse compression and the development of piezoelectric polymer sensors. A program to characterize the important variables in ultrasonic instrumentation is in progress. Imaging instrumentation, including tomographic systems, is also under development.

These NDE methods are being applied to metals, ceramics, plastics, building materials and electronic components. Specific application studies involving advanced ultrasonic instrumentation are also being conducted for the U.S. Nuclear Regulatory Commission (for steel reactor components) and the National Institutes of Health (ultrasonic diagnostic equipment for cancer detection). Ultrasonic inspection of pipeline welds is planned as part of a weld performance study supported by the Department of Transportation.

A project to develop a theoretical basis for acoustic emission spectral analysis to characterize moving cracks or defects is in progress, partially funded by the Electric Power Research Institute. This project includes work for improved transducer calibration. The calibration work for acoustic emission transducers is now well advanced; some initial calibrations have been accomplished.

B. Radiography

Current projects involve work in both neutron and x-radiography. The x-ray activity includes investigations of standards for the measurement of spatial resolution in radiographic systems, for the classification of industrial x-ray film and for the characterization of real-time fluoroscopic systems. Developments in progress include work on improved x-ray screens and grids and determination of scattered radiation content and its effect on radiographic detectors and systems. A study of the variables in field pipeline weld radiography and the influence of those variables on the interpretation of the radiographs and on the use of the radiographs to determine performance characteristics of the welds is part of the project now being pursued for the Department of Transportation.

The neutron radiographic studies are made primarily with a thermal neutron radiographic facility at the NBS reactor (a 10 MW, heavy water research reactor). However, work has also been carried out with a 3 MeV Van de Graaff accelerator and a 100 MeV linear accelerator; a Californium-252 source is also available. A recommended practice for thermal neutron radiography has been prepared in collaboration with the American Society for Testing and Materials, Committee E-7.05. Standards for characterizing neutron beams for radiography and gaging are under investigation. In a collaborative effort with Argonne National Laboratory, NBS scientists have investigated the use of three-dimensional thermal neutron radiography. This three-dimensional inspection, improved by image enhancement, is now being applied to the study of lithium-type, pacemaker batteries, in a project partially funded by the Food and Drug Administration. Recent work for the U.S. Navy concerns improved detection of corrosion in airframe structures by neutron radiography; part of this study involves development of new, improved scintillator screens for thermal neutron image detection.

C. Electromagnetic Methods

C.1 Visual-Optical

NBS scientists are examining methods for the measurement of visual acuity under typical NDE inspection conditions. This includes the effects of the subdued lighting common in radiographic reading rooms and of the dark booth situations typically used in fluorescent penetrant and magnetic particle inspections.

The project will characterize test methods used in NDE where the human eye is an integral part of the system. Visual parameters critical to the ability of people to detect and judge visual indications of defects will be identified. These accomplishments will lead to recommendations for improved visual acuity measurement methods.

Investigations of optical NDE methods are planned; these involve measurement of surface roughness and the need for standards in holographic NDE.

C.2 Electrical; Eddy-Currents

Facilities for dc and ac electrical conductivity measurements have been completed as the first stage of a new project in electrical and eddy-current methods. In the 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 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%.

Current work includes theoretical studies that are leading to improved understanding of the sensitivity of eddy current systems and new instrumentation development in which imaging techniques for eddy current systems are under investigation.

A Workshop on Eddy Current Nondestructive Testing was held in November 1977; a symposium on this topic is planned for September 1979.

C.3 Magnetic Methods

This project is particularly concerned with improving measurements for magnetic particle testing. The work includes efforts to determine the uniformity of magnetization within the inspected part and measurements of magnetic leakage flux.

C.4 Microwave Methods

Microwave measurements are being used to determine physical properties of materials. The NDE Program utilizes microwaves to measure moisture content of concrete. These measurements have been related to the strength of the material. This represents one area in which NDE methods are being explored for applications in the building industry. Future work to measure moisture content of other building materials is planned.

D. Penetrant Testing

NBS scientists are investigating the feasibility of preparing a master crack calibration plate for the evaluation of penetrant sensitivity. Electro-forming methods are being studied as an approach to the preparation of well-characterized, reproducible, inexpensive crack plates. Present methods offer the prospect for the preparation of cracks as small as 0.1 μm in width and depths in the 10 μm range. The fluids and particles used for penetrant testing are also of interest. Brightness measurements of fluorescent penetrants are planned along with work on measurements of key properties of the fluids. Surface tension, wettability, viscosity and corrosive tendencies will be examined in an effort to characterize penetrants and to identify meaningful measures of penetrant performance. The flow characteristics of penetrant systems are also under study.

E. Wear Debris Analysis

Detection of worn metal in lubricants in mechanical machinery is now used in both military and civilian programs to determine the proper time for engine, bearing and transmission overhaul. This method is now being expanded in a current NBS project in which the wear debris particles in the lubricant are detected, sized and examined in order to determine where and by what mechanism wear is occurring. Magnetic methods for obtaining size distributions of wear particles are used. X-ray microanalysis techniques have been developed for particles in the micrometer range. The techniques offer increased sensitivity compared to conventional SOAP methods for engine condition monitoring.

F. Thermal

This project is aimed at developing a method for the nondestructive evaluation of batteries used in critical assemblies such as cardiac pacemakers. A microcalorimeter capable of measurements in the 0.2 to 1000 microwatt range is used to measure heat generated in batteries and, in some cases, fully assembled pacemakers, under a variety of conditions. Heat generation by new and partially discharged batteries is measured under no-load conditions as a measure of self-discharge. The work will be done in combination with other nondestructive and destructive tests and will result in a nondestructive method to determine power cell quality.

G. Fracture - NDE

Fracture mechanics analysis of pipeline girth welds to determine what types and sizes of defects may lead to failure is under investigation as part of a project funded in part by the Department of Transportation. Fracture mechanics models are being examined and future plans include work to provide experimental verification of the model or models that offer promise. Destructive tests of pipe weld samples containing real defects are under way. One of the aims of these tests is to determine whether or not fracture mechanics analysis is necessary to evaluate all types of weld defects, particularly round, unsharp defects such as porosity or slag. The accuracy of NDE procedures to identify defects and to provide size and location information is also being examined; emphasis is on radiography and ultrasonics.

Another effort in this area is directed at providing a rational basis for selecting safety factors in structural systems.

H. Material Property Studies

It is recognized that variations in material parameters, such as texture and grain size can perturb NDE signals. Work to study effects of material variables on acoustic signals is in the early stages. In addition, it is recognized that nondestructive measurements can be very useful in detecting variations such as those mentioned above as well as characteristics such as hardness or residual stress. NBS plans call for a substantial upgrading of nondestructive methods for measuring residual stress through the development of improved measurement techniques and reference standards. This activity will address existing x-ray diffraction and ultrasonic approaches as well as some new nondestructive measurement concepts.

4. Some Examples of Recent NDE Progress

A. Ultrasonic Annular-Array Imaging

D. Dietz, S.I. Parks and M. Linzer
Signal Processing and Imaging Group
Center for Materials Science

A dynamically-focused ultrasonic array system has been developed. The design is based on a constant F-number approach (Figure 2) whereby, at short focal lengths, the aperture is increased in proportion to the focal length. The approach allows the use of larger area array elements, thus increasing the sensitivity of the system. Other major advantages include a substantial reduction in the delays and refocusing rates required for the lens synthesis with a corresponding reduction in the electronic complexity of the system. The initial design employs an array operating at 2.25 MHz with four annuli active at the near focal length of 1.5 cm. As the focal length increases, the array expands to a maximum of twelve rings with 4.0 cm outer diameter for focal lengths greater than 12 cm. A single, tapped delay line with 1 μs total duration provides the time delays for focusing on receive. A variable point or line focus is provided on transmit. Preliminary results of water-bath scans of stainless-steel components show that the system is capable of providing high-resolution imaging of flaws in practical NDE applications.

A combined theoretical and experimental study of the effect of bandwidth on the focal plane response of a circular lens and annular array was also undertaken. The wideband response of a lens and single annulus was calculated by convolving the impulse response of these imaging devices with the driving function. For a circular lens, the beam width in the focal plane, as well as the position and height of the sidelobes, was analyzed as a function of bandwidth and aperture weighing. The wide bandwidth model of an annulus was used to calculate the response of an annular array. Excellent agreement was obtained between this model and the experimentally measured response of the array operating at 2.25 MHz with 40% bandwidth.

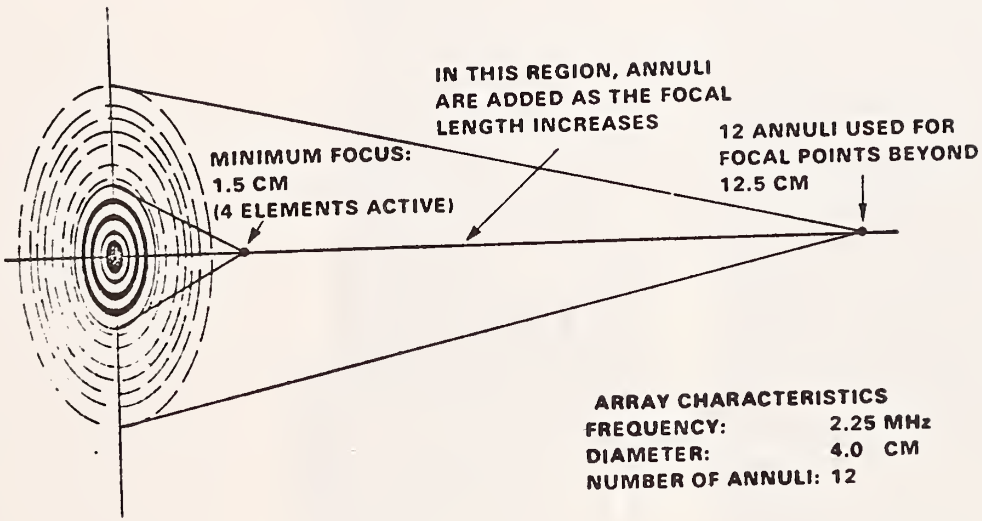


Figure 2. Principles and schematic diagram of expanding aperture annular array used for dynamic focusing on receive.

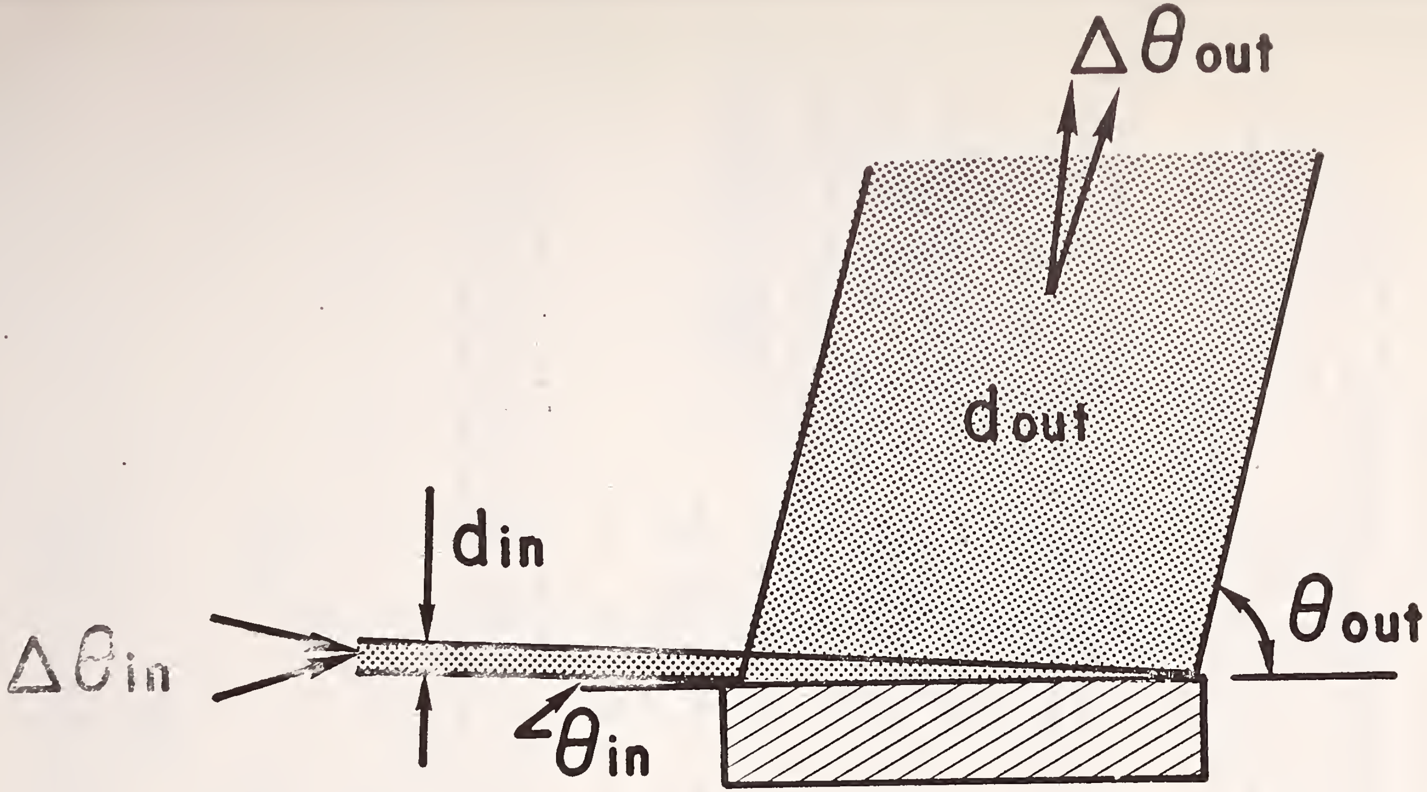
B. X-Ray Image Magnification

Masao Kuriyama, W. J. Boettinger and H. E. Burdette
Metal Science and Standards Division

Industrial applications of radiography presently demand the early real-time detection of small flaws such as tight cracks in materials. The live images of flaws or structure are recorded (or viewed) usually on a detector (an electro-optical imaging system) with similar size as the image itself. In order to detect small objects, an improvement in the resolution of real-time imaging systems is required, hopefully without loss of image brightness. However, attempts to improve the resolution usually result in a significant loss of intensity. Thus, the detectability (or intensity sensitivity) of small signal changes caused by flaws will be lost due to a lack of brightness. Any approach in the improvement of resolution for real-time imaging always encounters two opposing problems; if one improves the resolution, then the brightness generally decreases, and vice versa. Present commercial image intensifiers have resolution limits determined by the multistage configuration and the fiber diameter in fiber optic plates. They may be about 50 μm, down to 10 μm at best.

We have developed a technique which enables us to magnify an x-ray beam containing structure information (radiography or topographic images) before it reaches a detector. This magnification capability can be used either to improve the overall resolution of existing x-ray radiographic techniques which are limited by the detector or to permit the use of less complex (and high gain) imaging systems to attain resolutions already possible. In our demonstration an x-ray magnifier displayed a detailed image of 1000 mesh gold grid (25 μm spacings) with good contrast on a real-time basis on an ordinary image intensifier of 100 μm resolution. In order to magnify an x-ray beam which contains structure information (such as one containing radiographic images), the beam is successively diffracted from two silicon crystals. The first diffraction magnifies the beam horizontally and the second in a perpendicular direction.

This magnification technique makes use of Bragg diffraction from a nearly perfect silicon crystal free from dislocations. This type of Bragg diffraction, often called <u>dynamical diffraction</u>, has unique features which are essential for making x-ray image magnification possible. When an x-ray beam diffracts from the surface of a crystal and the diffracting planes are not parallel to the crystal surface, the diffraction is termed asymmetric. There are three aspects of asymmetric dynamical diffraction which are important for the x-ray magnifier; beam magnification, reflectivity and the acceptance angle for the diffraction. Figure 3 shows schematically the asymmetric diffraction geometry. An incident parallel monochromatic beam of x-rays is magnified in one dimension by a factor m as shown in Figure 3, where θ_{in} and θ_{out} are the angles between the crystal surface and the incoming and outgoing beams respectively. Obviously, high magnifications are obtained when θ_{in} is very small. The "quantum" efficiency of an x-ray magnifier is determined by reflectivity under Bragg conditions. The ratio of the diffracted total flux (photon/sec) to the incident total flux is called the reflectivity and is a function of the deviation from the Bragg condition. For a thick perfect crystal with negligible absorption, this ratio is unity for a range of angles centered about the Bragg condition and falls to zero rapidly for larger deviations from the Bragg condition. Because the reflectivity is unity regardless of the diffracting plane, the intensity (photons/sec cm^2) of a parallel beam magnified in one dimension by asymmetric diffraction from a perfect crystal is decreased by a factor (1/m) only because of the magnification of the beam area. Since refractive indices for any materials cannot be larger than one for the ordinary x-ray energy range, the unity reflectivity is the highest efficiency, that is no loss, which one can expect in x-ray optics. As shown in Figure 3, the maximum divergence of the outgoing beam, $\Delta\theta_{out}$, is related to the quantity ω_s, which is determined by the crystal property of silicon, and is of the order of 6 arc second. This small value of θ_{out} guarantees the one to one correspondence of the details between the unmagnified images and the magnified images.



$$d_{out} = m\,d_{in} \quad ; \quad m = \frac{\sin\theta_{out}}{\sin\theta_{in}}$$

$$\Delta\theta_{out} = \frac{\omega_s}{\sqrt{m}} \qquad \Delta\theta_{in} = \sqrt{m}\;\omega_s$$

Figure 3. Asymmetric Bragg diffraction showing one-dimensional magnification of an x-ray beam. The cross-section of the incoming beam, d_{in}, is magnified by a factor, m, to produce the outgoing beam d_{out}. The extremely narrow divergence of the outgoing diffracted beam created by dynamical diffraction guarantees the faithful magnification of x-ray images present in the incoming beam.

C. Theory of Eddy Current Crack Detection

Arnold Kahn
Ceramic, Glass and Solid State Science Division

Eddy current inspection methods at frequencies of the order of 5 to 200 kHz are very commonly used for the detection of cracks and flaws. However, there has been relatively little attention given to the fundamental analysis of the sensitivity of the method. To contribute to what we consider to be an important element in this field, we have performed rigorous calculations on the eddy current distribution in a model problem. The results are now being prepared for publication.

The case studied is that of a cylinder with a longitudinal, radial surface crack. A detecting solenoid surrounds the cylinder. The effect of the crack is to modify the impedance of the surrounding coil. This modification is shown in Figure 4, where the arrows indicate the shift of the complex impedance due to the crack. The figure shown is for a depth of one half the radius, a large value selected for demonstration purposes. The change of impedance is largest in the vicinity of a/δ (radius/skin depth) equal to 2, and the change is mostly in the reactance component. The calculations have been executed for varying crack depth at selected values of a/δ. We obtain the results that for small crack depth, the relative reactance change is proportional to (crack depth/radius)^2 with a constant of proportionality that depends on the ratio a/δ. The results are shown in Figure 5. In the region of greatest sensitivity, $a/\delta \simeq 2.0$, we find that in the limit of small crack depth the optimum detectability is given by

$$\Delta \, \mathrm{Im}Z = 0.70 \, \mathrm{Im}Z_0 \, (d/a)^2,$$

where Δ indicates the change due to the presence of the crack and Z_0 is the impedance in the absence of the crack. Application to laboratory measurement capability will be carried out in the near future.

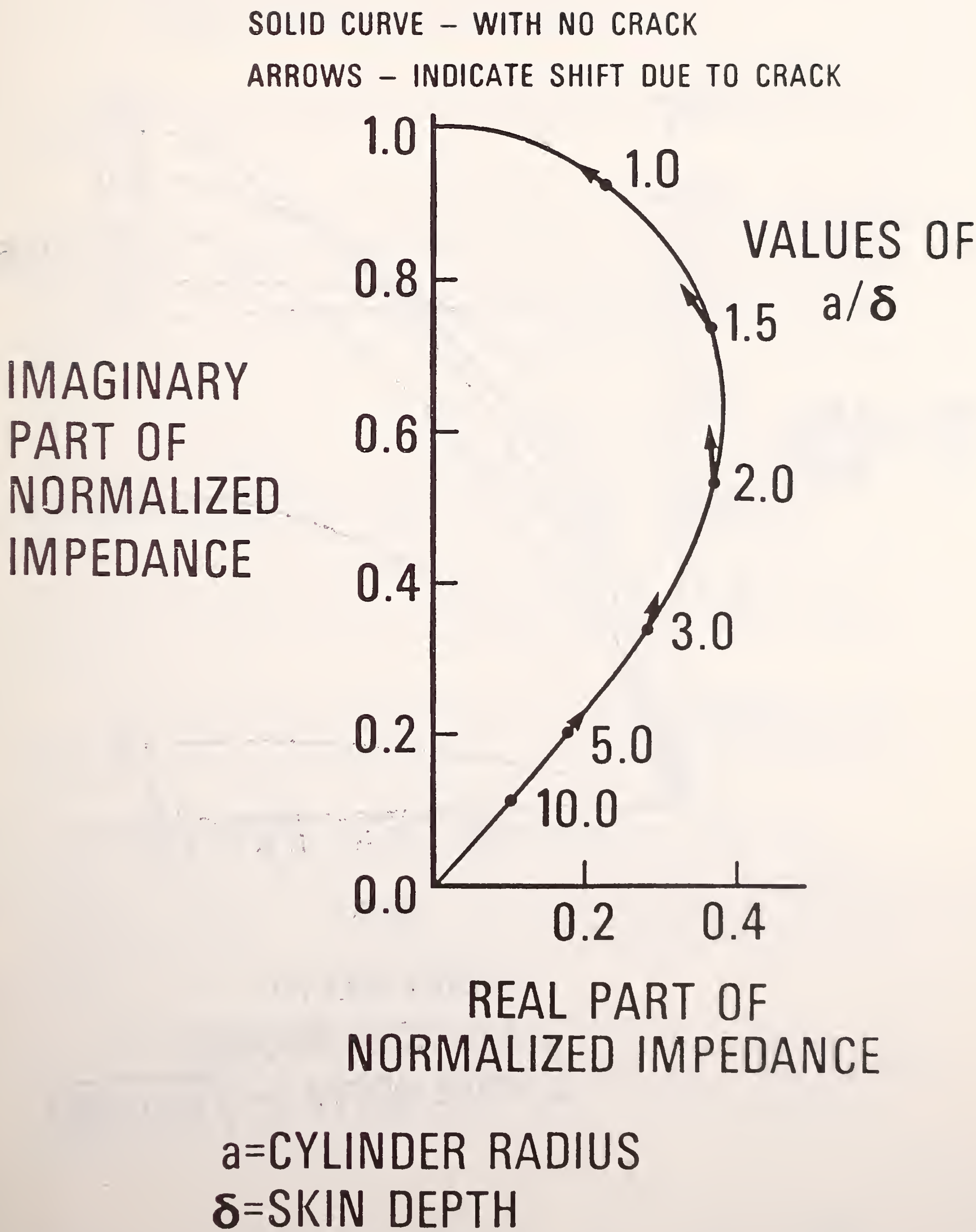


Figure 4. Impedance Diagram for a cylinder with crack depth equal to 0.5 x radius.

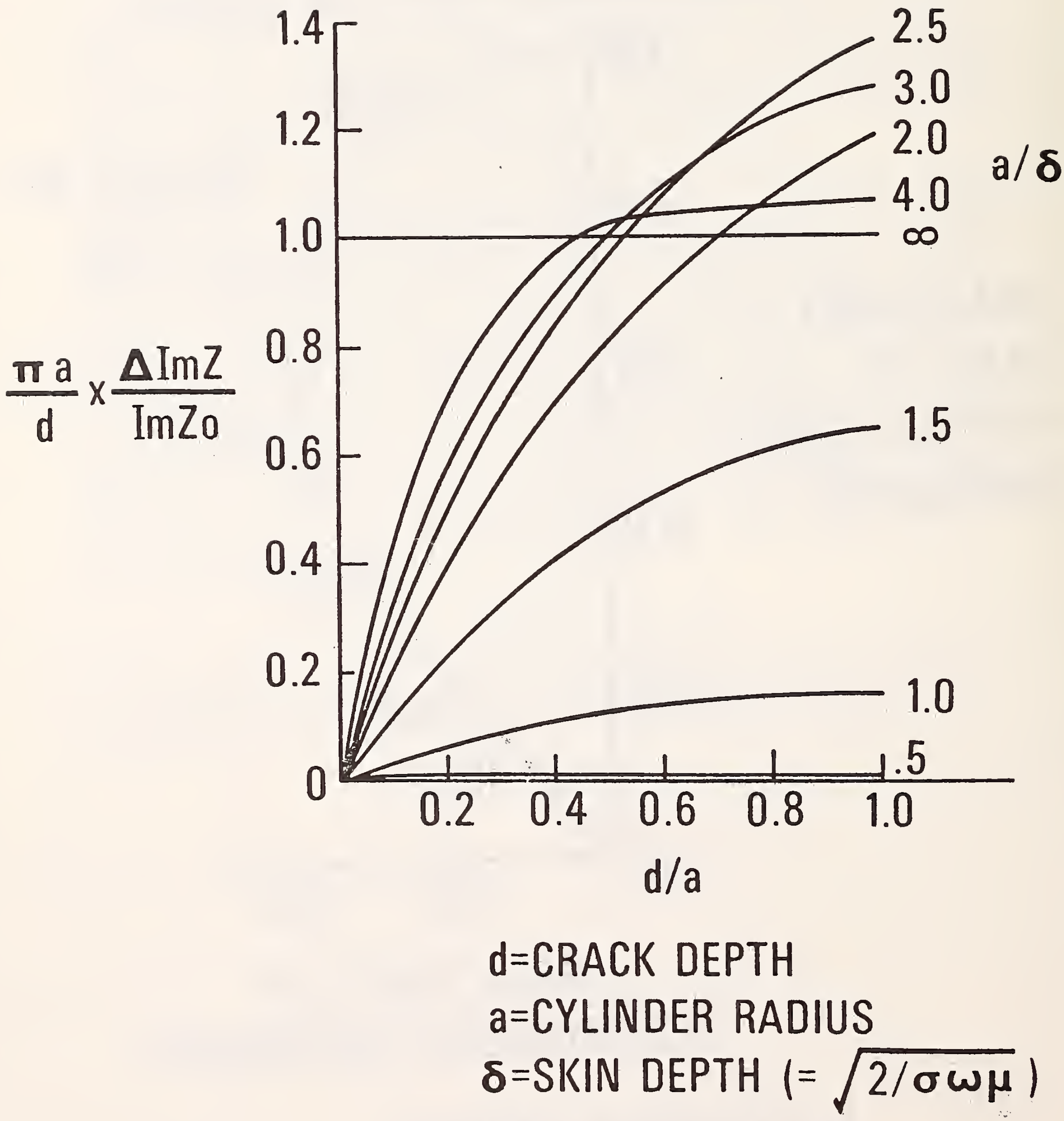


Figure 5. Plot of $\pi a/d$ x relative change of reactance vs. crack depth for varying ratio of cylinder radius (a) to skin depth (δ).

D. Use of Vibrational Spectroscopy for NDE

Darrell Reneker
Polymer Science and Standards Division

The structural soundness of an object can be evaluated if its vibrational spectrum can be compared with that of a like object of known mechanical integrity.

We have developed a method for making such observations that combine the use of a piezoelectric polymer transducer, a synchronized method for mechanically exciting the test sample, and a small computer capable of making digital Fourier transforms. We initially applied this technique to a bar of poly-methylmethacrylate, exciting vibrations by dropping a steel ball or striking the end-surface with a glass bob pendulum. Impact points were varied, and an electromagnet was used to release the ball so that time and point of contact were reproducible.

The electrical signal from the transducer was complicated, oscillatory, and decaying. It was amplified and applied to a digitizer. The digitizer was triggered by an electrical signal from the electromagnet for the vertical drops or by the positive slope of the signal for the pendulum hits. The analog signal was filtered by a 20 kHz 4-pole Butterworth filter and then digitized at a rate corresponding to a spectral width of 20 kHz. Digital resolution was 10 Hz per point. The power spectrum of the signal in the frequency range 0 to 20 kHz was obtained using a fast Fourier transform algorithm in a computer with an 8k memory. A series of such spectra were obtained for varying modes of excitation.

These spectra were compared with those obtained from corresponding experiments conducted after the bar was altered, first to simulate mass defects and then cracks, and again after temperature-induced changes in modulus were produced. See Figures 6 and 7.

The data indicate that there are defects to which the modes observed in a particular experiment are insensitive, but in principle there exist modes of vibration sensitive to every aspect of the mechanical integrity of the sample. This method requires that the sample support, excitation, and transducer position be chosen so that the observed spectrum is in fact sensitive to the important aspects of the mechanical integrity of the part tested.

Although we have demonstrated this NDE technique on plastics, it is also applicable to metal or ceramic objects and even to assemblies of the same or different materials involving several parts in good mechanical contact. The spectra are sensitive to changes in modulus or density, both of which may vary significantly in plastics due to differences in cooling rates or additives.

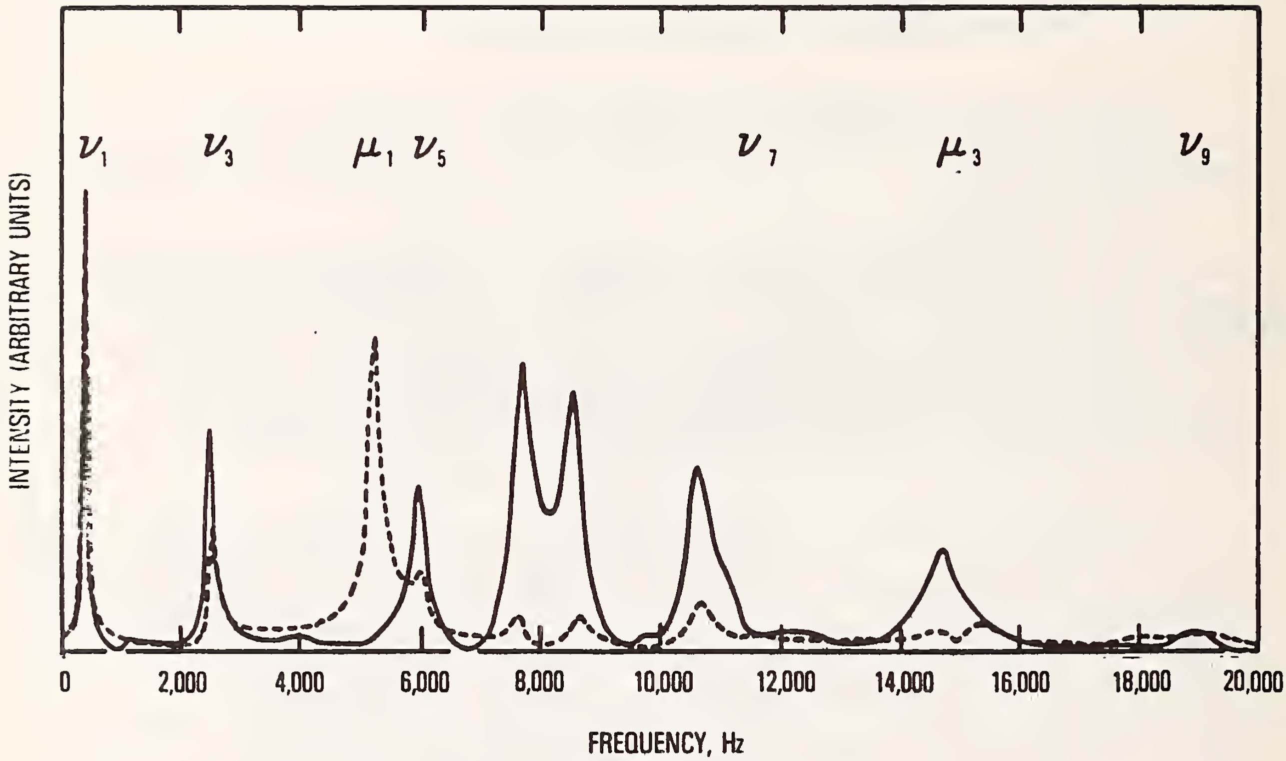


Figure 6. A typical spectrum for a ball drop excitation (solid line) and for a pendulum impact at the center of the end face (dotted line). The peaks labeled ν_n are due to modes that bend the long axis and those labeled μ_n are due to longitudinal modes along the long axis. The amplitude of the ν_1 peak was reduced by 1/4 with respect to the others so it could be plotted conveniently. The ν_1 peak of the dotted curve lies almost exactly beneath the ν_1 peak of the solid curve.

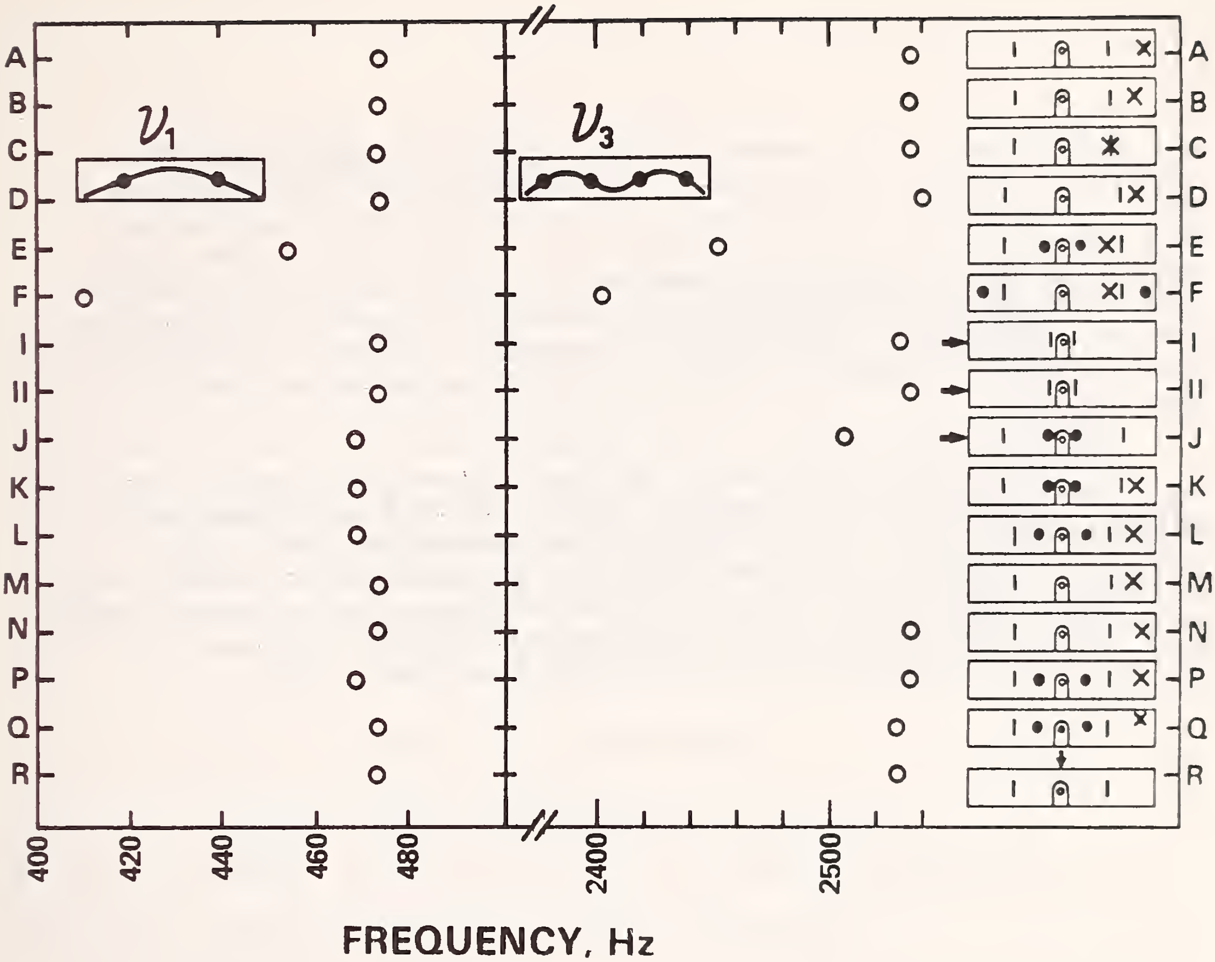


Figure 7. The positions of the peaks assigned to the n=1 and n=3 bending modes shown on an enlarged scale. The displacements and nodes associated with each mode are indicated schematically in the insets. The demonstrated sensitivity to optimally placed mass defects was about 2% of the mass of the bar. On the diagrams at the right the impact point of the ball is indicated by an x, the impact point of the pendulum by an arrow, the position of the supports by a small vertical bar, and the points at which pieces of wax were added to increase the mass by black dots. In all cases the active area of the transducer was at the center of the broad face of the bar as indicated by the small open circle inside the schematic outline of the transducer. The mass was added in two equal and symmetrically placed pieces. The total mass added was 8.2 grams for E, 12.7 grams for F, and 2 grams for J, K, L, P, and Q. The peak positions χ_n were strong peaks observed in most experiments but were not assigned to normal modes.

Defects may cause frequency shifts, changes in amplitude of modes, or the introduction of new modes. Some defects have little effect on a particular mode, and observation of a single mode can be regarded as a test for only certain kinds of defects at certain points in the sample. Since a number of modes can be observed by varying the point of excitation (and even more by attaching additional transducers), a reasonably complete examination of the sample can be made. Higher order modes are expected to be particularly useful for detecting periodically distributed defects.

The method described here can be used to survey and then to observe those modes of greatest interest in detail. Related vibrational NDE methods, specialized to particular objects, do not have such broad capability for survey. The fact that data are processed in digital form facilitates comparison of spectra from a test object and an object known to be good. This reduces, or in many cases eliminates, the need to identify the displacements associated with a particular peak.

E. Safety Factors and Mathematical Modeling
Jeffrey T. Fong
Mathematical Analysis Division

The objective of this project is to propose a mathematical framework (model) to integrate all available quantitative and qualitative information about an engineering system such that the uncertainties in the so-called engineering data could be transformed into "rational" factors of safety for design and regulatory decision-making. The framework should be flexible enough to allow experienced engineers and NDE scientists to fine-tune their judgment as more information becomes available. Typically, a sizable amount of NDE data and engineering test data are generated with varying degrees of uncertainties, and the problem is to integrate all available information for a "rational" decision involving the safe operation of a specific system. Mathematical modeling becomes the natural vehicle to accomplish this task.

This project will consist of three phases:

Phase I — Conceptual Modeling and Design of Data Structure,

Phase II — Modeling of Data Uncertainties and Their Integration,

Phase III — Testing of Models on Specific Applications.

In carrying out Phase I, care must be taken on the quality and the legal implication of a large body of engineering data currently available on mechanical components. This requires the collaboration of many knowledgeable engineers and managers in both the industry and the government where data are generated and evaluated. Phase II requires the expert collaboration of material scientists, statisticians, NDE specialists, and computer scientists to formulate a workable model. To test the validity of a class of models, we intend to apply them selectively to critical systems for which the engineering data are sufficiently well-documented.

During FY78, the first year of this project, we undertook several small steps on the Phase I aspect of this work; progress was achieved in two major areas as described below:

1. Safety factors for fatigue life prediction - a proposed definition based on test data uncertainties and sampling theory.

In an invited paper soon to appear in Nuclear Engineering and Design, the concept of safety factors for fatigue life prediction is discussed using both the well-known Gaussian and the not-so-well-known

Weibull statistics on a typical set of data as available in the literature. Attention was given to the inherent uncertainties of any set of test data as well as the interpretation of the data based on elementary results of a sampling theory. The importance of using engineering judgement to interpret failure data is illustrated by ranking the uncertainties of some engineering data on U.S. pipelines. A new definition of safety factors for design under uncertainties is proposed.

2. NBS to co-sponsor an International Symposium on Inservice Data

During the Winter Annual Meeting of the American Society of Mechanical Engineers, San Francisco, December 10-15, 1978, a two-session symposium on Inservice Data Reporting and Analysis for Pressure Vessels, Piping, Pumps and Valves will be held to discuss both the current status and some new approaches to the collection of engineering data on critical components. This symposium is co-sponsored by four ASME divisions (Pressure Vessel & Piping, Design Engineering, Materials, and Nuclear Engineering), two ANSI committees, two research institutes (EPRI and SwRI), and two government agencies (NRC and NBS). A total of 13 written contributions from U.S. and abroad have been received for presentation and discussion at the conference. A special publication containing the full text of all those contributions will be available to symposium participants and the public prior to the December meeting. To promote more incisive discussion during the one-day symposium, the organizing committee has initiated the preparation of a preview containing the abstracts of all papers as well as one or more official discussions of each paper by invited experts in the field of data collection and reliability analysis. The symposium organizing committee is chaired by this author, who also serves as the editor of the ASME Special Publication on the Symposium.

F. Standards for Ultrasonic NDE

Donald G. Eitzen
Mechanical Processes Division
Center for Mechanical Engineering and Process Technology

The detection and evaluation of defects using acoustic emission and pulse/echo ultrasonics relies heavily on comparative measurements. While these techniques have great potential, they are sensitive to measurement system characterisitics and to the condition of the reference artifacts used. An effort to improve the reliability and uncertainty of these techniques is underway. Part of this effort has focused on the development of measurement services for transducers and reference blocks. The measurement services now available are indicated below:

1. Ultrasonic Transducer Power Output Versus Frequency

   Using a modulated radiation pressure technique, the absolute total power output of ultrasonic transducers is measured versus frequency over any part of a range from about 0.1 - 20 MHz. The uncertainty is frequency dependent but is nominally about ± 5%. In addition to this frequency information the measurement provides the value of the radiation conductance used to calculate absolute power output levels. The apparatus, procedure, error analysis and results are discussed in "Ultrasonic Transducer Power Output by Modulated Radiation Pressure" by Greenspan, Breckenridge and Tschiegg, J. Acoust. Soc. Am., 63(4) (Apr. 1978).

2. Ultrasonic Transducer and System Power Output by Calorimetry

   Using a twin, series flow ultrasonic calorimetric comparator, the time-averaged total absolute power output of a transducer or system is measured for any voltage input waveform in the range of 1-15 MHz. The uncertainty is approximately ± 7%. The system, procedures and uncertainties are described by "Ultrasonic Calorimeter for Beam Power Measurements" by Zapf, Harvey, Larsen and Stoltenberg, NBS TN 686 (1976).

3. Aluminum Ultrasonic Reference Block Calibration

   Sets of ASTM E-127 type ultrasonic reference blocks are compared with an interim reference block and associated model 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 "Procedures for the Calibration of ASTM E 127-Type Ultrasonic Reference Blocks" by Chwirut, Sushinsky and Eitzen, NBS TN 924 (1976).

4. Loaner Services for Transducers and Reference Blocks

By arrangement, carefully characterized ultrasonic source transducers and aluminum reference blocks can be made available for loan. These can provide on-site calibration with the user's system. Using the accurately measured calibration ultrasonic source transducers, a user's power or frequency measurement system can be calibrated in-situ. The loaner aluminum ultrasonic reference blocks, which have been carefully compared with the NBS interim reference standards, provide a means for users to compare their reference artifacts with those of NBS on their own ultrasonic system.

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 by mid FY 1979. 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 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%, even after normalization. A study of the effects of different (but very similar) transducers was also conducted ("The Evaluation of Search Units Used for Ultrasonic Reference Block Calibrations" by Chwirut and Boswell, NBSIR 78-1454). The study showed variations of over 26% 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 NDE?

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

A calibration capability is being developed for acoustic emission (AE) transducers and will shortly be offered as a measurement service. This activity is partially supported by the larger EPRI/NBS Acoustic Emission Program described in section 4.I and by ONR. The objective is to determine the sensitivity versus frequency of AE transducers over the approximate range of 100 KHz to 1 MHz. This is accomplished by obtaining time histories from the transducer under test and the NBS standard transducer both mounted on a large (4800 lb) 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 (Figure 8). The displacement measured by the first candidate standard transducer is shown to faithfully reproduce the actual displacement as shown in Figure 9. A newly designed and constructed standard tranducer has resulted in further accuracy; it provides measurements of dynamic absolute displacement of the order of angstroms with an uncertainty of about 3% (Figure 10).

There is also a substantial, associated theoretical effort. Theoretical developments using the scattering matrix description of electroacoustic transducers has impacted work on determining directivity patterns of transducers. Two recent theorems on the nature of the radiated field of generalized 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.

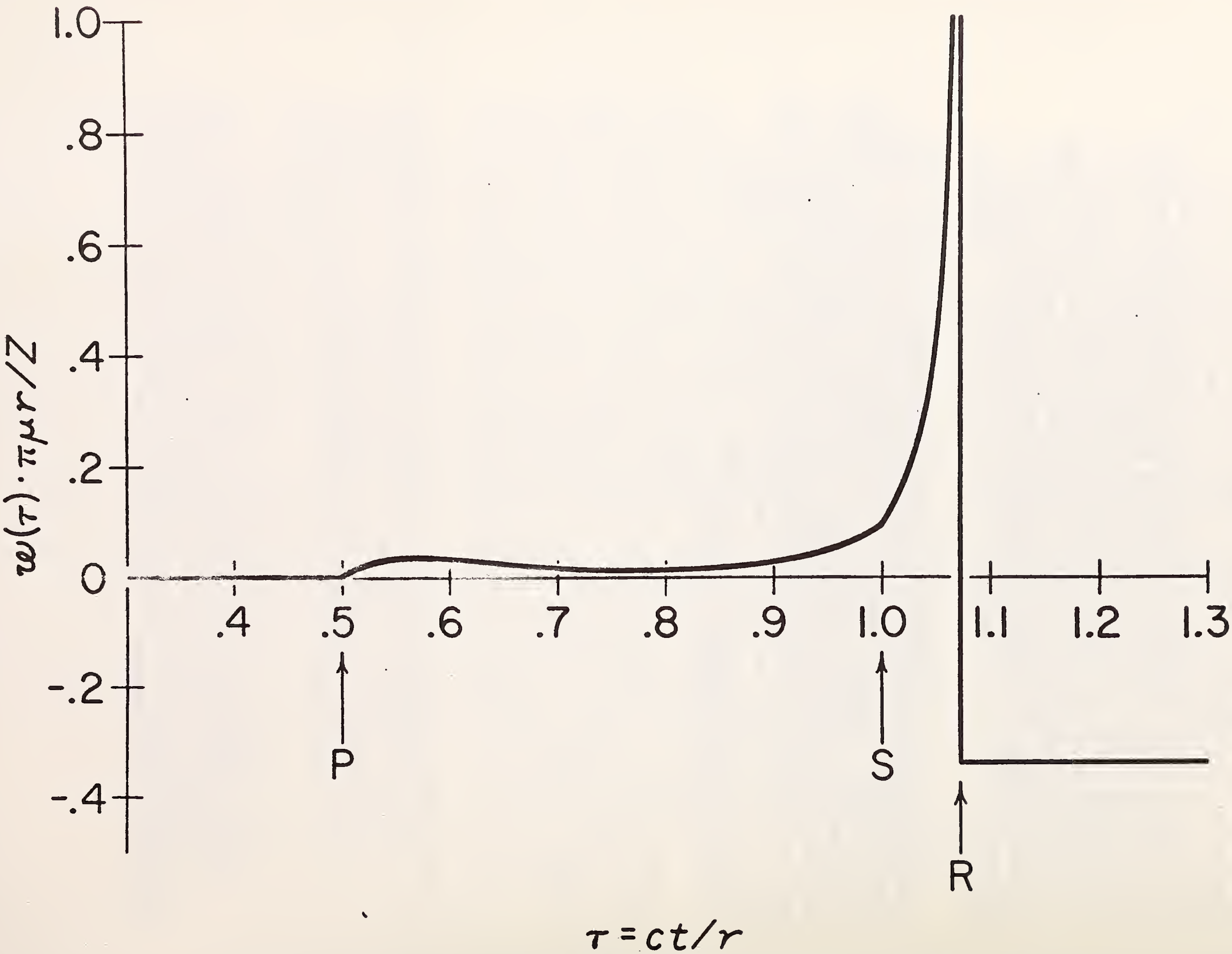


Figure 8. Theoretical waveform of vertical displacement on the transfer block.

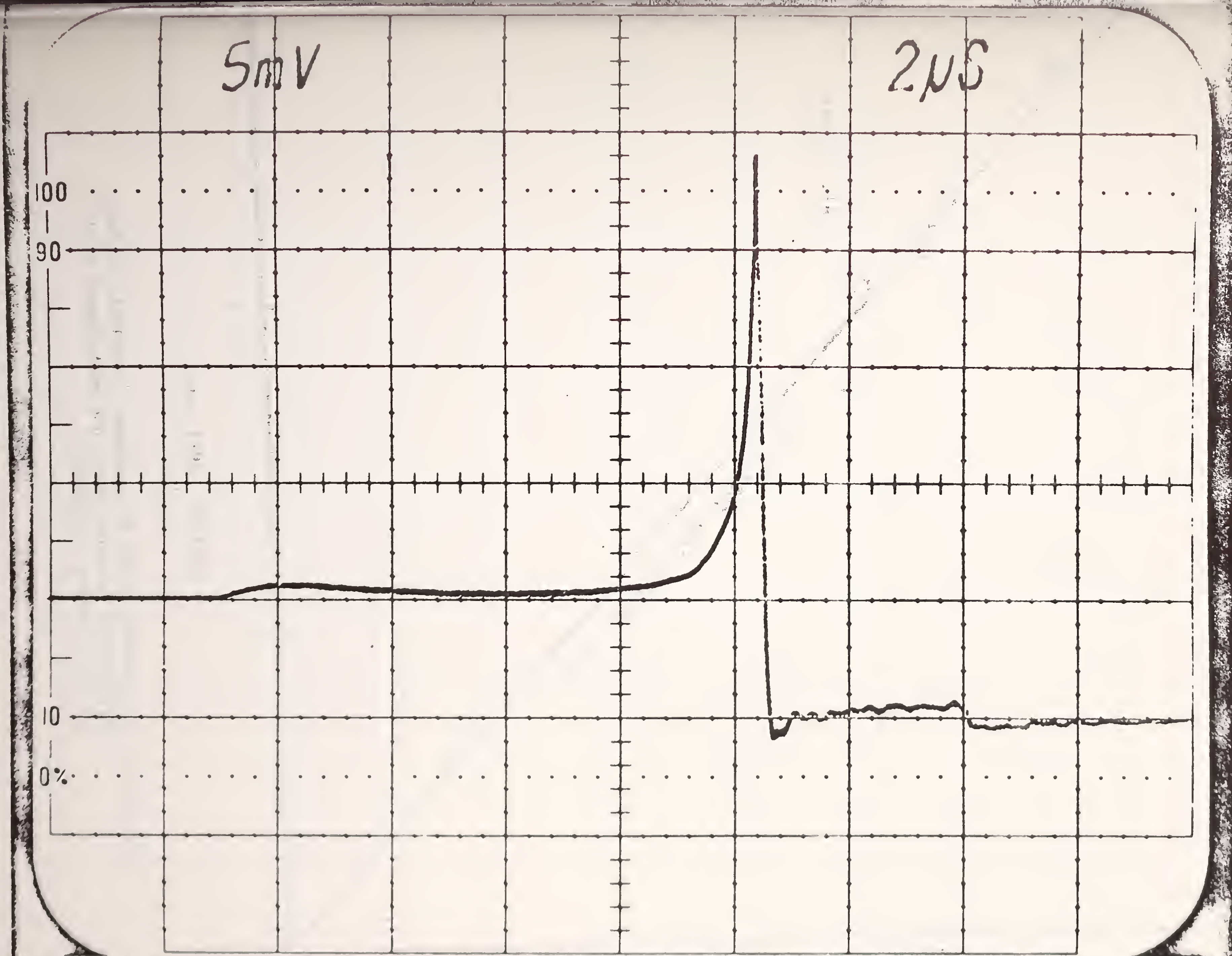


Figure 9. Displacement of transfer block measured with model 1 NBS transducer. New NBS transducer gives even better agreement (not shown) with theory.

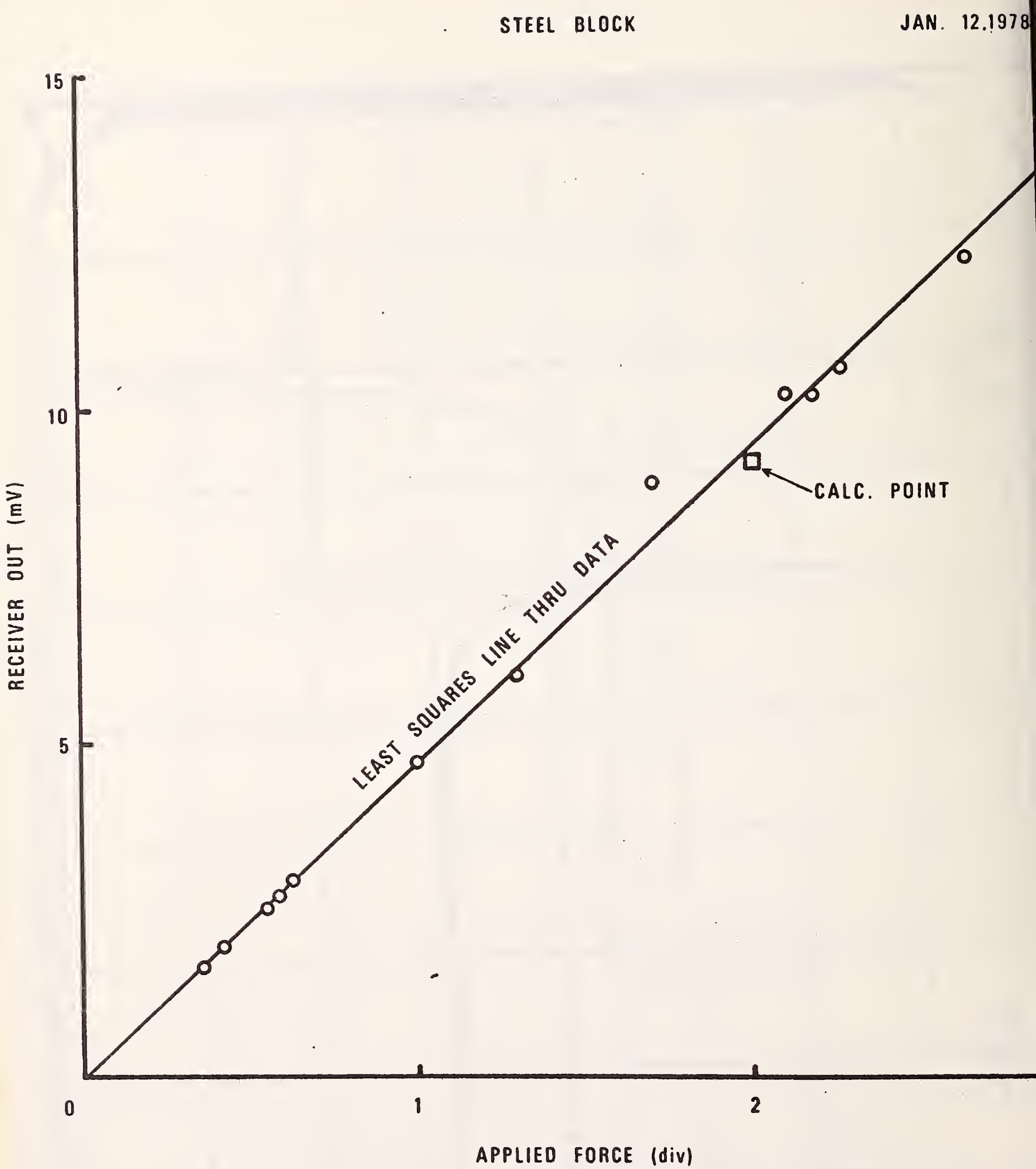


Figure 10. Plot showing about 3% agreement in dynamic surface displacement between theory and measurement using new NBS standard transducer.

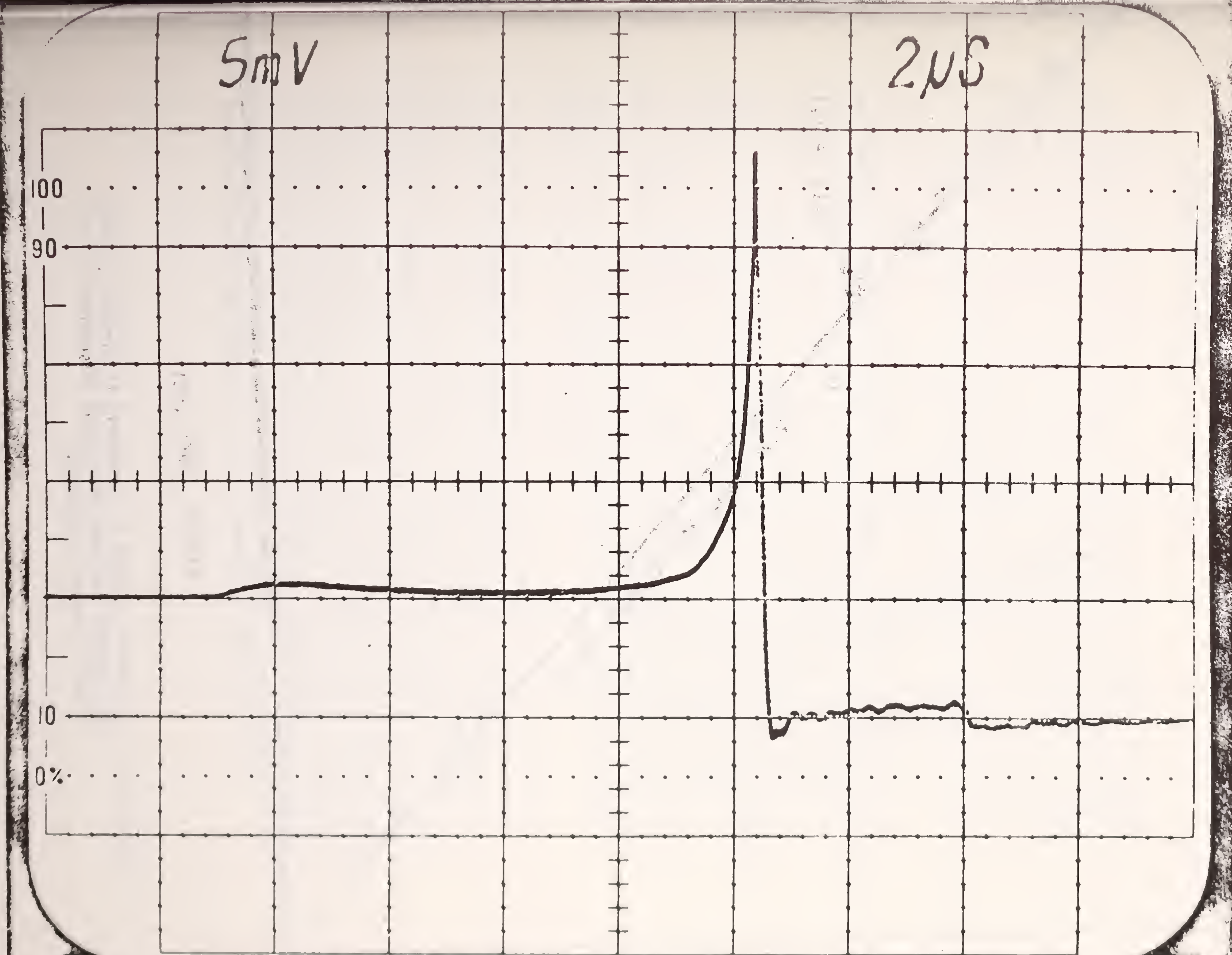


Figure 9. Displacement of transfer block measured with model 1 NBS transducer. New NBS transducer gives even better agreement (not shown) with theory.

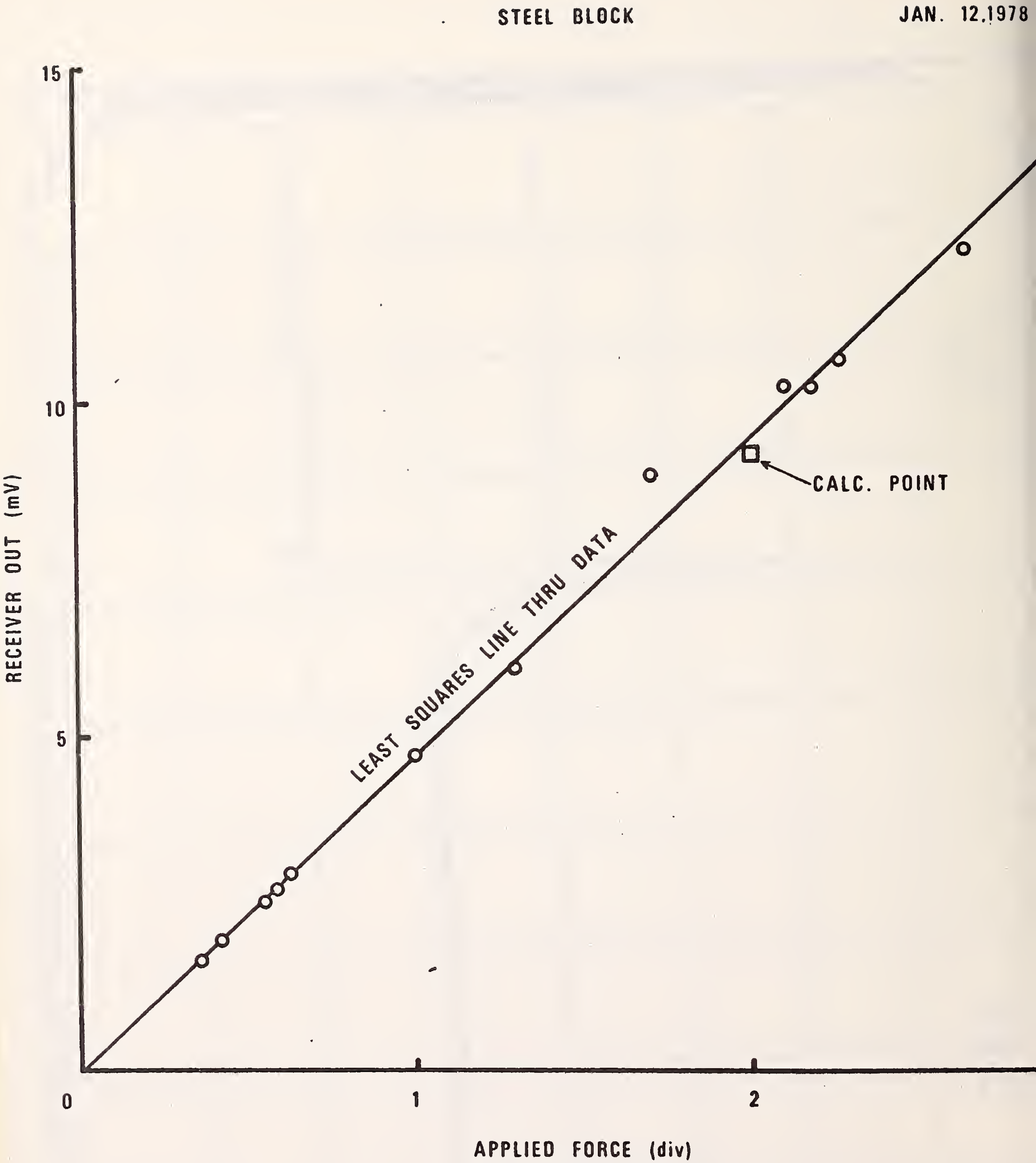


Figure 10. Plot showing about 3% agreement in dynamic surface displacement between theory and measurement using new NBS standard transducer.

G. A Systematic Approach to Ultrasonic NDE Standards

George Birnbaum
Office of Nondestructive Evaluation

NBS has undertaken a study, supported in part by DARPA, to assess the current status of NDE ultrasonic standards and calibrations and to determine current and future needs in this area. The source material for this study includes surveys of the literature and patents, a study of foreign practice, surveys of NBS and consensus standards (e.g. ASTM) programs, discussions, visits and letters, and a Workshop on Ultrasonic NDE Standards: "Current Needs and Future Directions," held October 17-18, 1977 for the purpose of implementing the objectives of this study. This resource material is being critically analyzed to determine: I. what needs to be done to improve existing standards or standards for existing systems; II. to select for further evaluation proposed standards and calibration methods; and III. to assess the requirements for standards and calibration for developing ultrasonic systems. Following this analysis, we will make recommendations for work in parts I to III which should provide the basis for an approach to a system of ultrasonic NDE standards. In part I, we recognize that improvement of accepted standards, e.g. those proposed by ASTM, traceable to NBS, or those widely used in practice, will have an immediate and cost effective impact on improving the reliability and more quantiative use of current methods. It is also clear that improvements in these standards and in the underlying theory, and in their relation to practice will have significant, direct impact on future systems. Part II deals with proposed methods which are new, rather than improvements to those considered in Part I. The emphasis here is not on unexplored ideas but rather on the examination and possible implementation of the concepts for specific standards needs. Part III deals with standards and calibration needs for evolving and future NDE methods.

Recommendations for improvement in existing standards will impact primarily on conventional pulse echo systems and include work on transducers, the electronic system and reference blocks. The fields produced by transducers are complex and the variability is high. Thus an important aspect of the transducer characterization problem is the need for a better understanding of the experimental and theoretical nature of transducers to develop minimum specifications to obtain reproducible results in flaw evaluation. Similar considerations apply in the electronics characterization. What are the right things to be measured and how should they be measured? The electronics and transducer calibration problem is not so much how to do it but what. In the areas of blocks, the development of quartz blocks free of the material problems of metal blocks is a promising future direction. However, a new problem, that of transferring the calibration to metal components, must be solved.

Many methods of standardization and calibration have been proposed which seem to offer logical or practical advantages over currently accepted features but are not widely used or used at all. These methods should be completely analyzed with a proper set of criteria and promoted if they indeed prove to be significantly advantageous. As an example of this process we have examined the possibility of using theoretically characterized scatterers such as spheres where the theoretical knowledge of the scattering cross section is to play a crucial role in the calibration process. Although this feature would appear to be attractive, we find that some of the advantages claimed for the method are really not important in practice and that further work is necessary. On the other hand, this study indicates that theory may play a significant role in aiding the transfer of a calibration to different conditions, for example, frequency and bandwidth.

We finally consider the standards needs for developing techniques. Two of the major needs which motivate these developments are quantitative measurements of flaw geometry, orientation and size and a decrease in the dependence on operator interpretation. The coupling of minicomputers to NDE equipment, and the use of adaptive and imaging systems, appear to make such hopes real. What are the standards requirements of such systems? Do such systems need standards? Our analysis of the problem leads us to suggest that more complex systems will require more careful characterization and more complex reference standards. Exactly what these will be is the subject of further research. However, it appears even at this stage that some of the necessary standards might not be too different from many that are in current use.

H. Evaluation of Pipeline Girth Welds

Leonard Mordfin
Office of Nondestructive Evaluation

The Department of Transportation (DOT) is sponsoring work at NBS on the inspection and evaluation of girth welds of the kind used in cross-country pipelines for oil and gas.

Recent advancements in NDE and fracture mechanics have led to a widely held contention that the existing quality standards for pipeline welds are too stringent. In particular, the contractor for the now-completed Trans-Alaska Oil Pipeline asked DOT to waive these standards for a substantial number of defective welds on the grounds that a fracture-mechanics analysis showed that they would not diminish the performance of the pipeline. Acting in a consulting capacity to the Department's Office of Pipeline Safety Operations, NBS evaluated the technical merits of that waiver request. This proved to be a difficult task because the contractor's application provided insufficient data for a rigorous assessment.

In order to provide a more efficient procedure for future evaluations of this type, the present NBS effort is designed to furnish DOT with some of the technical information it would need to establish guidelines governing the content of such waiver requests.

The NBS effort has both fracture-mechanics and NDE components. In the former, experimentally verified fracture-mechanics models and other predictive approaches for pipeline girth welds are being developed in order to identify the kinds of data needed to properly assess the performance of flawed welds. The NDE part of the work seeks to identify the kinds of radiographic information which are needed to properly assess defect dimensions, and will also develop improved inspection procedures (radiographic and ultrasonic) that will enhance the characterization of weld defects.

This three-year project was initiated quite recently (February 1978), but substantial progress has already been achieved. Literature surveys and test method evalutions are under way. The most visible results involve the fabrication of girth welds, containing intentional defects of various kinds, in full-scale pipe of a commonly used type. These welds have been inspected radiographically and ultrasonically and will be cut into laboratory-sized samples for mechanical testing evaluations.

I. Electric Power Research Institute/National Bureau of Standards Acoustic Emission Program

Donald G. Eitzen
Mechanical Processes Division
Center for Mechanical Engineering and Process Technology

Acoustic emission (AE) is a new nondestructive evaluation technique for monitoring structural integrity. It is a passive ultrasonic technique for detecting and locating active structural defects. When a defect in a structure is stimulated, for example by loading in a pre-service test or by the actual operating conditions, the defect may emit high frequency stress waves. The detected signals from the stress waves are processed in an attempt to locate and evaluate the significance of a flaw. Applications of AE include its use in determining the structural integrity of aerospace and petrochemical structures, bridges and power plant components; detection of leaks and loose parts and the monitoring and control of on-line welding. AE techniques have already proved a valuable tool in materials research studies.

AE techniques are relatively new and significant problems remain in their application. One problem is in the reliability of detection of defects. There is a significant potential for false calls since noise sources other than structural defects often exist. Methods for source discrimination and identification are needed to minimize this problem. Another problem is one of extracting the necessary information from the signals in order to determine the character and severity of the source. Techniques such as threshold counting, energy measures, peak detection and straight-forward spectral analysis often fail to yield the critical information. A third problem area is in interpretation, intercomparison and repeatability of AE test results. Methods of determining system or subsystem (e.g. transducer) characteristics have not been adequately developed and agreed upon. Methods of calibration and standardization of AE systems and tests are needed.

The need for the development of basic calibration capabilities, theories of AE and experimental verification was jointly recognized by the Electric Power Research Institute and the National Bureau of Standards. A jointly supported project was developed to answer some of the basic questions regarding the use of AE techniques. The stated objective of this joint project is

> To develop and demonstrate the theoretical basis, measurement techniques and calibration procedures required to evaluate the technical feasibility of using acoustic emission spectrum analysis for characterizing moving cracks or defects. To provide the electric power industry with an acoustic emission transducer calibration

capability referred to national standards, and evaluated spectral analysis methods for retrieving acoustic emission source signals, and for demonstrations of the feasibility of the spectral method for predicting defect velocity in structural materials representative of power plant structures through controlled experiments.

While the objective is stated in terms of the electric power industry, the impact of this effort is clearly much broader than a single industry or agency.

The project elements, progress and plans are briefly described below.

Task 1 - Develop calibration capability for AE transducers

The calibration capability for the ultrasonic sensors used for AE measurements is to be referred to national standards and offered as a service. The capability is also to be used to characterize the transducers for the experimental phases of the project.

A theoretical base for the calibration is provided by the exact dynamic elasticity solution to the halfspace with a point force step function. Some initial results of this calibration effort are described in this report, Section 4.F.

Task 2 - Develop theoretical basis for moving defects

This work will result in a theoretical base for methods of retrieving acoustic emission source signals and for distinguishing between defect motion and spurious signals. The generalized transfer function approach for describing a theoretical basis for AE analysis developed and disseminated in the project has received further acceptance in the technical community and forms standard language. Significant refinements have been theoretically developed which permit quantitative separation of the source characteristics from the signal coloration due to the propagation medium and transducer. Their numerical implementation is being pursued.

The theoretical solution for elastic wave propagation in a plate has been carried out, based on a new Fourier Inversion technique. This development, equivalent to determining a new Green's Function, has created significant interest in the theoretical community. The results have been reported to the Acoustic Emission Working Group and are being prepared for formal publication.

Significant theoretical direction for the other tasks has been accomplished and groundwork for new signal processing techniques and for specialized theories of AE signals from defect mechanisms have been developed.

Task 3 - Correlation of theory and experiment using transparent materials

The objective is to correlate experimental AE results from defects in transparent materials with the theoretical analysis of moving defects. These controlled experiments will demonstrate the feasibility of the AE analysis methods for predicting defect characteristics.

The computer data handling analysis, transform and plotting routines were developed and have found considerable use. Several experimental configurations for obtaining AE from glass have been developed. These include a ball impact, indentor, wedge opening of a surface crack and pressurized cracked (rehealing) plate configuration. A library of AE signals and associated Fourier spectrums has been developed for cracks in glass using these configurations. The data indicate that crack velocities in glass are exceedingly fast. Time and frequency data can be used to discriminate between fracture and no fracture in the ball impact configurations. Most recently a decomposition of the surface traction (which defines the source) has been postulated. Experimental verification will lead to characterization of the defect using AE measurements, the plate theory and the decomposition.

Task 4 - AE measurements in structural steels

The objective is to perform exploratory tests for measuring crack characteristics in structural steels, particularly those important to the electric power industry. The experiments should determine the feasibility of AE analysis for determining defect characteristics in structural steels.

Significant effort has been spent developing, recording and processing systems for AE from structural steels. Recording systems and transducers have been characterized. Signal processing programs such as time domain deconvolution, spectral analysis, digital filtering, and signal averaging and enhancement have been written and checked. Explicit force-time functions of simulated signal sources such as breaking glass capillaries and pencil leads, ball impact, electric arc and pulsed ultrasonic transducers have been determined. These results, very important for Task 1, also ready the AE testing laboratory for experiments on defects in structural steels.

Several experimental configurations and concepts for controlled defects in the steel specimens are being investigated. The sensitivity of the analysis to specimen configuration and to specimen structure and internal "geometry" e.g., weld zone, is being determined.

5. Appendix

A. Publications-September 1977 to Present

(1) "The Nondestructive Evaluation Program at the National Bureau of Standards," H. Berger, NDT International, Vol. 10, pp. 277-279 (Oct. 1977).

(2) "Neutron Radiographs Using the Ionographic Process," P. B. Scott, S. E. Johnson, G. W. Watson, Xonics, Inc., and H. Berger, NBS, J. Appl. Phys., Vol. 49, 5078-5080 (Oct., 1978).

(3) "Nondestructive Testing Standards - The Role of NBS," H. Berger, Trans. ANS, Vol. 28, pp. 124-125 (1978).

(4) "Innovative and Advanced NDT," H. Berger, NDT International, Vol. 10, No. 6, pp. 337-340 (Dec. 1977).

(5) "Californium-252 Source Technology, H. Berger, Scientific and Industrial Applications," Dept. of Energy Report CONF-760436, Vol. II, PP. V-1 to V-14 (1978).

(6) "Calibrations and Standards for Nondestructive Testing," H. Berger and L. Mordfin, Materials Evaluation, Vol. 36, No. 11, pp. 36-39 (Oct. 1978).

(7) "NDE," H. Berger and L. Mordfin, National Bureau of Standards LC 1080 (April 1978).

(8) "Report on the Symposium on Nondestructive Testing Standards," G. Birnbaum, Proceedings of the ARPA/AFML Review of Progress in Quantitative NDE, Sept. 76, P. 158 (Sept. 77).

(9) "The Evaluation of Search Units Used for Ultrasonic Reference Block Calibrations," D. J. Chwirut and G. D. Boswell, NBSIR 78-1454 (Feb. 1978).

(10) "Acoustic Emission in the Nuclear Industry--The State of the Art," Roger Clough, ASM Proceedings of 2nd International Conference on NDE, Feb. 1978, Salt Lake City, Utah.

(11) "Ultrasonic Transducer Output by Modulated Radiation Pressure," M. G. Greenspan, F. Breckenridge and C. Tschiegg, JASA, Vol. 3, No. 4, (April 1978).

(12) "Ultrasonic Resolution," E. Miller, Letter to the Editor, Physics Today (June 1978).

(13) "Eddy Current Losses Due to a Surface Crack In Conducting Material," A. H. Kahn, R. Spal and A. Feldman, J. Appl. Phys. 48, 4445 (Nov. 1977).

(14) "Development of High-Sensitivity Ultrasonic Techniques for In-Service Inspection of Nuclear Reactors," M. Linzer, D. R. Dietz and S. I. Parks, NRC Annual Report, October 1976 - September 1977, Contract No. B-5680.

(15) "An Ultrasensitive Ultrasonic System with Applications to Nondestructive Evaluation and Medical Diagnosis," M. Linzer, Ultrasonics International 1977, IPC Science and Technology Press, London, U.K., pp. 28-29 (1977).

(16) "Acoustic Emission in Brittle Materials," A. G. Evans and M. Linzer, Ann. Rev. Matls. Sci. 7, 179 (1977).

(17) "New Method for the Experimental Evaluation of X-Ray Grids," C. E. Dick and J. W. Motz, Medical Physics, Vol. 5 , No. 2 (Mar/April 1978).

(18) "Image Information Content and Patient Exposure," J. W. Motz and M. Danos, Medical Physics, Vol. 5, No. 1 (Jan/Feb 1978).

(19) "X-ray Scatter Data for Diagnostic Radiology," C. E. Dick, C. G. Soares and J. W. Motz, Phys. Med. Biol., Vol. 23, No. 2, pp. 235-244 (March 1978).

(20) "A Standard Method for Determining the Efficiency of Fluorescent X-ray Intensifying Screen: A Status Report," R. C. Placious, E. S. Moser, R. S. Holland and F. Masi, SPIE Vol. 127, Optical Instrumentation in Medicine VI (1977).

(21) "Characterization of Debris Particles Recovered from Wearing Systems," A. W. Ruff, WEAR 42, pp. 49-62 (1977).

(22) "Quantitative Methods of Wear Debris Analysis," A. W. Ruff, WEAR 46, No. 1, pp. 263-272 (1978).

(23) "Debris Analysis of Erosive and Abrasive Wear," A. W. Ruff, Proceedings of the International Conference on Fundamentals of Tribology, MIT (June 1978).

(24) "Materials Failure Analysis," J. H. Smith, Proceedings of 9th Synthetic Pipeline Gas Symposium," October 31, 1977, American Gas Association.

(25) "An Approach to Acoustic Emission Signal Analysis - Theory and Experiment," N. N. Hsu, J. A. Simmons, S. C. Hardy, Materials Evaluation, 35, No. 10, pp. 100-106 (Oct. 1977).

(26) "The Macroscopic Detection of Corrosion in Aluminum Aircraft Structures With Thermal Neutron Beams and Film Imaging Methods," Donald Garrett, NBSIR 78-1434 (Dec. 7, 1977).

(27) "Elastic Properties of Zinc: A Compilation and a Review," H. M. Ledbetter, J. Phys. Chem. Ref. Data 6, pp. 1181-1203 (1977).

(28) "Recent Low-temperature Elastic-constant Measurements On Technological Materials at NBS," H. M. Ledbetter, Advances in Cryogenic Engineering, Vol. 24, Plenum, New York, pp. 103-119 (1978).

(29) "Temperature Dependence of the Elastic Constants of an NbTi/Cu Superconducting Composite," D. T. Read and H. M. Ledbetter, Composites 9, pp. 100-104 (1978).

B. Publications in Press or Preparation

(1) "Improving the Reliability of Ultrasonic Measurement: Recent NBS Progress," D. J. Chwirut and D. G. Eitzen, ASNT Proceedings.

(2) "Toward the Development of Improved Reference Fatigue Cracks for Use in Ultrasonic Nondestructive Evaluation," D. J. Chwirut and D. G. Eitzen, International Advances in Nondestructive Testing, Vol. 6.

(3) "Sizing of Cracks With Scattered Ultrasonic Waves," S. Golan, Proceedings First International Symposium on Ultrasonic Materials Characterization, June 1978, ASNT.

(4) "The Characterization and Calibration of Ultrasonic Transducers Used in NDT and Materials Testing," W. Sachse, Proceedings First International Symposium Ultrasonic Materials Characterization, June 1978, ASNT.

(5) "Ultrasonics Transducers for Materials Testing and Their Characterization," W. Sachse and N. N. Hsu, Physical Acoustics 14, (W. P. Mason and R. Thurston, eds.) 1978.

(6) "Eddy Current Workshop Proceedings," G. Free, National Bureau of Standards, Gaithersburg, Maryland, November 3-4, 1977.

(7) "Review of Ultrasonic Techniques for Measuring Residual Stress," N. Hsu and W. Sachse, 39th National ASNT Fall Conference - Residual Stress Measurement, Denver, CO, October 2-6, 1978.

(8) "Visualization of Transducer - Produced Sound Fields in Solids," W. Sachse, N. Hsu and D. Eitzen, 1978 IEEE Ultrasonics Symposium, Cherry Hill, NJ.

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(13) "'New' Candidates for Ultrasonic NDE Standards and Calibrations," G. Birnbaum, ARPA/Rockwell Cornell Conference Proceedings.

(14) "Internal Friction and Sodium Transport in Beta Alumina," J. H. Simmons, A. D. Franklin, K. F. Young, and M. Linzer, J. Am. Ceram. Soc.

(15) "Electromagnetic Theory and Its Relationship to Standards," A. H. Kahn and R. D. Spal, Proceedings of the Eddy Current Workshop, NBS, Nov. 3-4, 1977.

(16) "Ultrasonic Transducer Characterization at NBS," E. Miller and D. G. Eitzen.

(17) "A Method for Calibrating Electroacoustic Transducers by Measuring the Total Near-Field Force," E. Miller and A. D. Yaghjian.

(18) "An Ultrafast Signal Averager," R. S. Shideler and M. Linzer, To be submitted to Review of Scientific Instruments.

(19) "Expanding-Aperture Annular Array," D. R. Dietz, S. I. Parks and M. Linzer. To be submitted to Ultrasonic Imaging.

(20) "Tomographic Reconstruction of Reflectivity Images," S. J. Norton and M. Linzer. To be submitted to Ultrasonic Imaging.

(21) "Wideband Annular Array Response," D. R. Dietz, S. J. Norton and M. Linzer. To be submitted to Proceedings of 1978 Ultrasonic Symposium, and in a more elaborate version to the Journal of Acoustical Society of America.

(22) "Attenuation and Velocity Dependence of Chirped Ultrasound Signals," A. C. Kak, M. Fatemi and M. Linzer. To be submitted to IEEE Trans. on Sonics and Ultrasonics.

(23) "Basic Limits in Real-Time Industrial Radiographic Systems," by Masao Kuriyama, W. J. Boettinger and H. E. Burdette, to be published in an ASTM special publication.

(24) "X-ray Magnifier," by W. J. Boettinger, H. E. Burdette and M. Kuriyama, to be published in Review of Scientific Instruments.

(25) "Amplitude-Matching Dynamic Focusing for Imaging in Inhomogeneous Media," T. Sato and M. Linzer. To be submitted to Ultrasound in Medicine and Biology.

(26) "Ultrasensitive Ultrasonic Techniques" (Invited review article), M. Linzer. To appear in Research Techniques in Nondestructive Testing, Vol. 4, R. S. Sharpe, ed., (Academic Press, Inc., London, 1979).

(27) "Ultrasonic Materials Characterization," H. Berger and M. Linzer, eds. American Society for Nondestructive Testing.

(28) "Bispectral Analysis of Random Signals and Its Applications," T. Sato, M. Linzer and K. Sasaki.

(29) "Reconstruction and Optical Interferometric Visualization of Ultrasonic Fields," F. P. Higgins, S. J. Norton and M. Linzer.

(30) "Ultrafast Signal Averaging and Pulse Compression Techniques for Sensitivity Enhancement," M. Linzer, R. S. Shideler and S. I. Parks.

(31) "Three-Dimensional Radiographic Imaging," W. A. Ellingson and H. Berger, to appear in Research Techniques in Nondestructive Testing, Vol. 4, R.S. Sharpe, ed., (Academic Press, Inc., London, 1979).

C. Talks by NDE Office Personnel

(1) Nondestructive Methods of Corrosion Testing and Monitoring.
Air Force Workshop, School of Engineering, University of Florida, St. Augustine, FL.
Harold Berger, September 1977.

(2) A Review of the NBS Program in Nondestructive Evaluation.
Aerospace Industries Association, Subcommittee #4, Cincinnati, OH.
George Birnbaum, September 1977.

(3) Some Novel Methods for Neutron Image Detection.
37th National ASNT Fall Conference, Detroit, MI.
Harold Berger, October 1977.

(4) Calibrations and Standards for Nondestructive Testing.
37th National ASNT Fall Conference, Detroit, MI.
Leonard Mordfin, October 1977.

(5) Radiographic Measurements for the Trans-Alaska Pipeline Girthwelds.
Long Island Sections of American Society for Nondestructive Testing and American Welding Society, Westbury, NY.
Harold Berger, February 1978.

(6) Scattering of Ultrasonic Pulses by Obstacles in Elastic Solids.
Physics Department, Catholic University, Washington, DC.
Wolfgang Sachse, February 1978.

(7) The Disposition of Elastic Waves and the NDT of Composite Materials.
5th Conference on Composite Materials Testing and Design, ASTM, New Orleans, LA.
Wolfgang Sachse, April 1978.

(8) Techniques in Quantitative Ultrasonic NDE.
Mohawk-Hudson Section of ASNT, Bunthill, NY.
Wolfgang Sachse, April 1978.

(9) Sizing of Cracks with Scattered Ultrasonic Waves.
National Bureau of Standards NDE Seminar Series, Gaithersburg, MD.
Shmaryahu Golan, April 1978.

(10) Sizing of Cracks with Scattered Ultrasonic Waves.
Department of Materials Science and Engineering, Northwestern University, Evanston, IL.
Shmaryahu Golan, April 1978.

(11) Sizing of Cracks with Scattered Ultrasonic Waves.
Department of Metallurgy and Mining, University of Illinois, Urbana, IL.
Shmaryahu Golan, April 1978.

(12) Ultrasonic NDE of Materials.
Conference of What is New in Materials, Engineering College, Cornell University, Ithaca, NY.
Wolfgang Sachse, May 1978.

(13) Welcoming Remarks
First International Symposium on Ultrasonic Materials Characterizations, National Bureau of Standards, Gaithersburg, MD.
Harold Berger, June 1978.

(14) The Characterization and Calibration of Ultrasonic Transducers Used in NDT and Materials Testing.
First International Symposium on Ultrasonic Materials Characterization, National Bureau of Standards, Gaithersburg, MD.
Wolfgang Sachse, June 1978.

(15) Sizing of Cracks with Scattered Ultrasonic Waves.
First International Symposium of Ultrasonic Materials Characterization, National Bureau of Standards, Gaithersburg, MD.
Shmaryahu Golan, June 1978.

(16) Nondestructive Testing Standards - The Role of NBS.
American Nuclear Society Annual Meeting, San Diego, CA.
Harold Berger, June 1978.

(17) Determination of the Size of Flat Defects with Diffracted Ultrasonic Beams.
Air Force Materials Laboratory, Wright-Patterson AFB, OH.
Shmaryahu Golan, June 1978.

(18) Visualization of Transducer Produced Sound in Solids.
ARPA/AFML Review of Progress Meeting in Quantitative NDE, La Jolla, CA.
Wolfgang Sachse, July 1978.

(19) Crack Size Measurements with Ultrasound.
Dept. of Physics, University of Tennessee, Knoxville, TN.
Shmaryahu Golan, August 1978.

(20) The NBS Program in NDE - Opportunities in NDE. Engineering Foundation Conference, The Role of Education in NDE.
Franklin Pierce College, Rindge, NH
Harold Berger, August 1978.

(21) Ultrasonic Characterization Sizing.
Naval Research Laboratory, Washington, D.C.
Shmaryahu Golan, September 1978.

D. NDE Meetings At NBS

The NDE program has been active in sponsoring NDE meetings, both symposia and workshops. A list of these meetings is given in Table III.

The purposes behind this significant meeting activity include (1) drawing attention of the industrial community to NDE, (2) providing a good record of the state-of-the-art, (3) providing a forum for information exchange, (4) helping our NBS staff meet individuals active in NDE and learning the status of current work in the field, and (5) providing a mechanism for NDE people to discuss their NDE standards needs.

E. NBS Seminars On Nondestructive Evaluation

A series of seminars at NBS on the subject of NDE started in 1973-1974. Approximately one seminar has been arranged each month during the period September to May. The series has served to bring many recognized authorities to NBS to describe their work and to discuss with the staff the NDE activities under way or planned at NBS. The seminars are open and advertised locally; visitors usually attend.

A complete listing of the past two seasons' seminars is given in Tables IV and V. The speakers come from both academic and industrial backgrounds and the topics have ranged from very advanced research to practical testing.

Speakers and topics in previous seminar seasons followed a similar trend. Among the speakers in the 1975-1976 series were Gerald Gardner (Southwest Research Institute), Donald Kettering (Grumman), H. C. Kim (University of London), Shmuel Mardix (University of Rhode Island), Paul Packman (Vanderbilt University) and Amos Holt (Babcock and Wilcox). Previous series included William Baxter (General Motors Technical Center), Bill Yee (General Dynamics), William Ellingson (Iowa State University) and Roy S. Sharpe (NDT Centre, Harwell).

There are, of course, many closely related seminars at NBS. Recent examples include a Fracture and Deformation Division seminar on, "Current Status of Pressure Vessels and Their Steels in Japan," by Michio Inagki, National Research Institute for Metals, a Metal Science and Standards Division seminar on "Ultrasonic Investigation of Radiation Damage in Al-Mn and Al-Fe Random Dilute Alloys," by Gordon Setser, University of Illinois; and the NBS Colloquium, "A Review of the NDE Program at Stanford University," by Gordon Kino of Stanford.

Table III

NDE Meetings at NBS

Title	Dates	Comments
Review of Government Sponsored NDE Activities	June 13-14, 1973	This review, organized by R. Thomson, was held as part of the activities of the Ad Hoc Working Group for NDE, Interagency Council For Materials.
Review of NBS Ultrasonics Standards Program	Dec. 16-17, 1974	This meeting constituted a review of the AFML-AMMRC-NASA sponsored program at NBS on ultrasonic reference blocks.
Practical Applications of Neutron Radiography and Gauging	Feb. 10-11, 1975	The primary sponsors for this open symposium were ASTM and NBS; proceedings are published as ASTM STP 586.
Nondestructive Testing Standards	May 19-21, 1976	ASTM and ASNT were the primary cosponsors with NBS; proceedings are published as ASTM STP 624.
Workshop on Ultrasonic NDE Standards	Oct. 17-18, 1977	A by-invitation meeting to review the status of ultrasonic standards. This meeting was held as part of an NBS- ARPA sponsored study of ultrasonic standards.
Workshop on Eddy Current NDT	Nov. 3-4, 1977	A by-invitation meeting to review the status of eddy current techniques and standards. Proceedings are planned for publication as an NBS Special Publication.
Second Workshop on Government Sponsored R & D in Nondestructive Evaluation	Mar. 14-15, 1978	Second in a series of meetings for government NDE managers to compare programs.
Nondestructive Evaluation of Buildings	Apr. 18, 1978	A one-day meeting arranged by the NBS Center for Building Technology.

NDE Meetings at NBS

Title	Dates	Comments
Real-Time Radiologic Imaging: Medical and Industrial Applications	May 8-10, 1978	ASTM, ASNT, BRH and NBS were the primary sponsors of this meeting. Good interactions between medical and industrial scientists were obtained. Proceedings are planned for publication as an ASTM STP.
First International Symposium on Ultrasonic Materials Characterization	June 7-9, 1978	This meeting, cosponsored by ASNT and NBS, brought medical and industrial scientists together for discussions of ultrasonic techniques and instrumentation. Proceedings are planned for publication in book form by ASNT.
Eddy Current Characterization of Materials and Structures	Sept. 5-7, 1979	A planned symposium to review eddy current techniques. Planned cosponsors are ASTM, ASNT and IEEE.

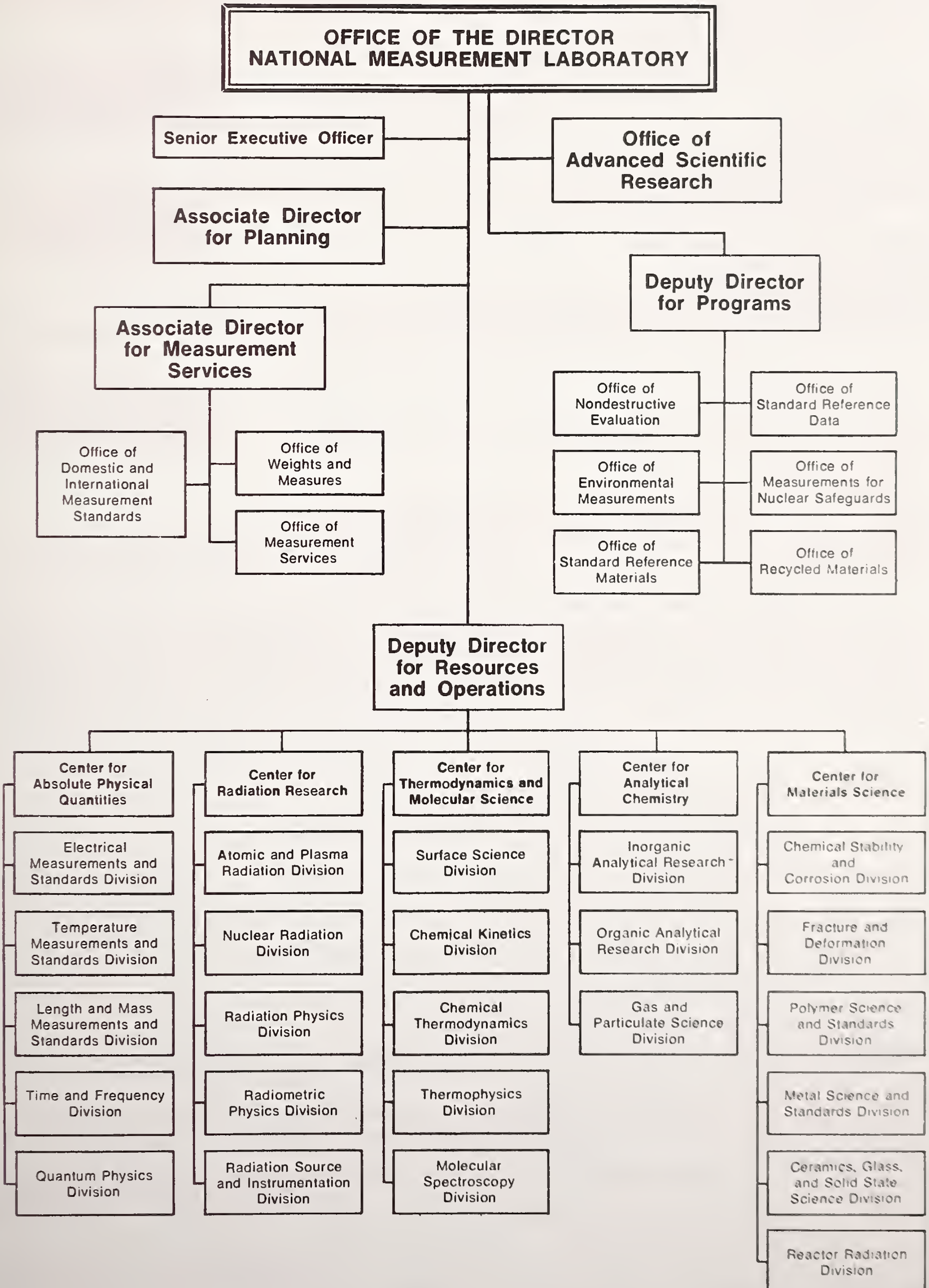
Table IV
1976-1977 NBS-NDE Seminars

Speaker	Date	Topic
Daniel Polansky, Naval Surface Weapons Center	Sept. 30, 1976	ASTM Activities in Nondestructive Testing Standards
Matthew J. Golis, Battelle Memorial Institute	Oct. 8, 1976	NDE Research at an Independent Research Laboratory
Lester Feinstein, Stanford Research Institute	Nov. 18, 1976	Application of Microwave Technology to NDT of Materials
S. Weissmann, Rutgers University	Nov. 22, 1976	Elucidation of the Strain Distribution in Defect Structures of Silicon
Wolfgang Sachse, Cornell University	Jan. 13, 1977	Elastic Waves and the NDT of Materials
William Parker, Reed College	Jan. 19, 1977	Xeroradiography
Donald Janney, Los Alamos Scientific Lab.	Feb. 10, 1977	Digital Image Enhancement in Radiography
Robert E. Green and Harvey Palmer Johns-Hopkins University	Feb. 24, 1977	Optical Detection of Ultrasound and Acoustic Emission Signals
Robert C. McMaster, The Ohio State University	Mar. 24, 1977	New Developments in NDT
A. J. Julicher, A. J. Julicher and Associates	Apr. 14, 1977	NDE of Structural Welding
H. J. Fulbright Los Alamos Scientific Lab.	Apr. 28, 1977	Analysis of Archeological Materials at LASL
E. Richard Cohen Rockwell Int'l Science Center	May 19, 1977	Scattering of Elastic Waves

Table V
1977-1978 NBS-NDE Seminars

Speaker	Date	Topic
Don Hagemaier, McDonnell Douglas Corp.	Sept. 12, 1977	NDE at McDonnell-Douglas
Udo Schlengerman, Krautkramer, Cologne, West Germany	Oct. 13, 1977	Sound Field Theory and Practice
Y. H. Pao Cornell University	Nov. 1, 1977	Scattering of Elastic Waves and Nondestructive Testing of Materials
Robert E. Green, Johns-Hopkins University	Jan. 26, 1978	Dynamic X-Ray Diffraction Investigation of Materials
Charles Hellier, The Hartford Steam Boiler Inspection and Insurance Co.	Feb. 10, 1978	The Role of ASNT in the Advancement of the Technology in NDT
Joseph S. Heyman, NASA Langley Research Center	Mar. 16, 1978	Recent Applications of Ultrasonics to Materials Measurements
Francis Tang, University of Missouri	Mar. 23, 1978 (Joint NDE - Safeguards Seminar)	Neutron Filtered Beam Techniques-Doppler Effect Measurements-Neutron Tomography-Neutron Radiography
S. Golan NBS and Israel Institute of Metals	Apr. 27, 1978	Sizing of Cracks With Scattered Ultrasonic Waves
Anton Zeilinger, MIT and Atominstitut der Osterreichischen Universitaten, Vienna	May 1, 1978	Coherent and Incoherent Neutron Transmission Methods: Neutron Interferometry and Neutron Radiography
Gary Hawkins, Wayne State University	May 25, 1978	Photoacoustic Spectroscopy Applied to NDE

F. NML Organizational Chart



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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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.)*

This reprot summarizes the activities of the National Bureau of Standards (NBS) Nondestructive Evaluation (NDE) Program. It emphasizes activities over the Fiscal Year, 1978. However, since this is the Program's first Annual Report, some material is included to summarize activities since the Program was formally instituted in June 1975.

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)*

Annual report; nondestructive evaluation; ultrasonics, radiography; visual-optical tests; eddy currents; penetrants; magnetic particles; inspection; acoustic;and statistics.

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