Report Summary

Acoustic Techniques for Measuring Stress Regions in Materials

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

A large part of EPRI's efforts in nondestructive evaluation (NDE) are oriented toward improving the conventional in-service inspection techniques. These efforts are aimed at ensuring that well qualified technology is available to meet the mandatory in-service inspection requirements of nuclear power plants. However, considerable savings are possible if surveillance techniques can be developed to replace some of the periodic inspection requirements. Thus, some long term research projects, including this one, were initiated to establish the technical base necessary to develop surveillance methods.

PROJECT OBJECTIVES

The primary objective of this project is to develop methods for the precise measurement of residual stress, to use these methods to make measurements on specific metallic samples and to compare the results with calculated values. The successful achievement of this objective will establish the potential uses and limitations of ultrasonic measurements of material properties that can be indicative of conditions leading to service failure. A by-product of this work was to involve key faculty at Stanford University experienced in ultrasonic technology and signal processing in NDE technology.

PROJECT RESULTS

The first phase of this project developed and demonstrated a system with the ability of making accurate measurements of stress profiles over the full cross section of a metal sample. The stress profiles are in excellent agreement with the analytical predictions using traditional stress analysis techniques. These results show that the acousto-elastic material constants obtainable from simple uniaxial tension experiments are also applicable for determination of multi-axial stress states in samples with complex geometry and loading. The multi-disciplinary collaboration on these efforts lead to discovery of an approach for using ultrasonic measurements to evaluate the J-Integral or M-integral used in assessing structural integrity of a component. The significance of this development appears to be of fundamental importance with potential of greatly extending the predictive value and reliability of some types of in service inspection.

Considerable progress is being made in simplifying this laboratory method aimed at eventual use under field conditions in power plants.

This project, because it has required a substantial interdisciplinary effort, has been the nucleus of a larger NDE effort at Stanford. It has contributed to the training of several graduate level students and has stimulated wider faculty interest in NDE. Because of it and other related projects, Stanford now has the largest university interdisciplinary research program on NDE in the country, with approximately ten faculty and 25 students involved in various aspects of NDE research. The project has been extended to produce a fieldable system.

Gary J. Dau, Program Manager
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SUMMARY

A new and sophisticated computer-controlled system which produces quantitative two-dimensional images of stress contours in metal samples has been developed. The system makes use of the principle that the velocity of an acoustic wave in a metal sample is changed by the presence of stress. The theory for this effect has been worked out based on the original third order elastic constant theory of Murnaghan.

In operation, a small acoustic transducer in a water bath is mechanically scanned over the face of a stressed metal sample approximately one half inch thick. The transducer emits and receives a longitudinal wave. The phase difference between the waves reflected from the front surface and the back surface of the sample is measured to a relative accuracy of 2-5 parts in 10^6. By this means, stresses as small as 5 MPa can be determined.

In order to carry out the measurements, a special purpose MTS machine has been constructed for use in the acoustics laboratory. It has been fully instrumented with strain gauges and a thrust relieving spring, so that we can perform measurements of the applied force well into the yield range. Electronics and the mechanical scanning of the transducer are controlled from a PDP 11/T34 minicomputer. The measured data is stored in the computer, so that further calculations and/or stress profile plots can be made at a later time. In addition, plots of theoretical results can be made along with the experimental data.

The facility is now in reliable operation and is being used mainly on the EPRI program at present, but is also beginning to be used in cooperation with other Stanford NDE studies. In our experiment we determine the third elastic constant and thus calibrate the measurement by measuring the stress in a uniformly-stressed sample of a particular

metal; then we scan the inhomogeneous stress fields in the same type of material. As far as we are aware, this is the first time that the resulting quantitative maps of inhomogeneous stress fields have been obtained by acoustic techniques. In addition to the development of theory and experimental methods that we have undertaken, many points must be obtained for one plot, so that it has been vitally necessary to computer-control the system. At the present time, we can record a complete scan of about 500 points in approximately twenty minutes.

In our early work, we plotted the stress field around a hole in a stressed sample and compared the results with theory. The experiments and theory were in excellent agreement, showing compressed regions as well as regions where the stress is much larger than the applied uniform stress field. Experiments have also been undertaken to demonstrate the presence of plastic yield. Although there is no detailed theory available at the present time for a measurement technique in this range, the results appear to be in very reasonable agreement with numerical elastic-plastic yield plots.

At a later stage we made measurements of highly inhomogeneous stress profiles of single-edge and double-edge cracks. In all cases, the results were in excellent agreement with the theoretical expectations, and showed the power of this new measurement technique. More recently, we have carried out measurements of residual stress in aluminum, steel, and copper; in particular, the results obtained on extruded aluminum and copper samples appear to be in good agreement with theoretical calculations. They indicate very clearly when the stress profile is non-symmetrical.

A further set of measurements shows that this kind of technique is extremely sensitive to differences in microstructure, so that by measuring the changes in velocity as a function of stress, it is possible to observe large differences in the third order elastic constants between two samples of ostensibly the same type of material, but which have been processed in different ways and thus have a different microstructure.

The results obtained are the first of this type and are in excellent agreement with theory, where the theory is available. This new technique opens up rich areas of further applications of the acousto-elastic effect in the near future to measurements of stress and plasticity in metals. These measuring techniques are now being extended to provide shear-wave scans of stress fields and also to measure scattering from stress gradients along the direction of the ultrasonic beam.

New ultrasonic systems have also been developed to obtain high speed, electronically-scanned images of stressed regions in metals, particularly regions around crack tips and welds. A linear array of transducer elements, 128 at present, is operated in a phase contrast acoustic imaging system. The latest machine, which uses digital technology with a dedicated microprocessor, was designed on the basis of experience with an earlier system which had provided images of internal stress fields in aluminum samples. The new machine has just been made operational and is undergoing initial imaging evaluations.

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