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USE OF COMPUTERIZED DATA ACQUISITION SYSTEM TO AURALIZE NDE DATA FOR IMPROVED INSPECTION CAPABILITY

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ABSTRACT

Southwest Research Institute has developed computer-aided technology for converting electronic signals generated by conventional nondestructive evaluation (NDE) equipment (i.e., ultrasonic, eddy current, and acoustic emission) into audible information so that the inspector can make use of both the conventional NDE signals (which are often confusing) and the audible information to make a flaw/nonflaw decision. One objective of this work was to develop a computerized data acquisition system that could collect ultrasonic data, perform time dilation of the ultrasonic data, and help develop algorithms. The aural technology has been applied to composite impact damage, composite delamination detection, and corrosion detection. In addition, the aural technology was used to detect and discriminate intergranular stress corrosion cracking. Examples of application of aural NDE technology are described.

I. INTRODUCTION

Nondestructive evaluation (NDE) and inspection technologies as used today rely primarily on some form of visual presentation of the inspection information for human interpretation. The signals and images for some classes of inspection are easily interpreted (e.g., thickness measurement). However, a number of classes of inspection can provide signals that are difficult to correctly interpret and often result in what is called a "false call" or a "missed defect call." A false call can result in expensive removal of a good part, and a missed defect call could result in a catastrophic failure. Both of these results are not acceptable. Therefore, some way is needed to aid the inspector in correctly perceiving the presence or absence of flaws with a greater reliability than is now available with only the interpretation of the visual signals presented on the NDE instrument or computer-generated image.

One method for improving the accuracy of data interpretation would be to utilize multiple human senses simultaneously to characterize the material (e.g., use both eyes and ears for data evaluation). In the past, cursory attempts have been made at using this concept. For example, the electronic signals received by an NDE instrument have been used to generate alarms if their amplitude exceeded a certain threshold. This was done to alert the inspector with an aural as well as a visual signal. The technology, however, was only an "off/on" process and did not make use of any information inherently contained in the NDE signal except amplitude (UT/ET) or phase (ET).

If it is assumed that the NDE signal contains complete information about the condition of the material under inspection or the process being monitored and that the information could be converted into aural signals (while keeping the content of the NDE signal intact), then both the ear and eye can be used to enhance the accuracy of data interpretation.

II. AURALIZATION AND AURAL CONVERSION OF NDE SIGNALS

Since 1985, Southwest Research Institute (SwRI) has been conducting internally funded research to develop the capability to convert NDE signals from conventional NDE instrumentation into aural signals. The intent has been to improve the quality and accuracy of NDE inspections and material characterization.

Auditory studies show that principles used in listening perception are analogous to visual perception principles. These, in turn, are parallel to classic Gestalt perception concepts used in psychology.[1-4] The Gestalt concepts (1) interpret the perception processes by the relationships among all human senses and (2) allow each of the human senses its own unique way of interacting with the surrounding environment.

These and other concepts were used to determine how to best use sound to represent NDE signal information from different inspection methods. A more thorough discussion of the Gestalt concepts and how they have been applied to auralization of NDE data is given by K. D. Polk, et al.[5]

A. Conversion of NDE Signals

Developing algorithms to convert high-frequency electronic signals from NDE instruments into meaningful aural signals is the most difficult challenge. The task requires, first, an appropriate data acquisition and analysis system (DAAS). The prototype DAAS designed for this work uses a conventional UT instrument appropriately interfaced to the computer decision system, as illustrated in Figure 1.

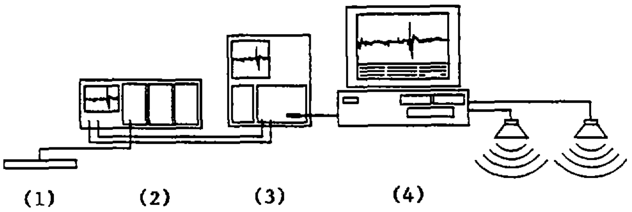


Figure 1 – Aural NDE System Configuration of (1) Sample/Transducer, (2) Conventional UT Equipment, (3) Signal Digitizer, and (4) Amiga 2500 Computer.

The selected computer is a realtime, icon-driven, modular DAAS decision tool (software/hardware package). Its modular construction provides graphical selection and control of individual processing modules including gating, filtering, scaling, data source, and audio playback, depending on the specific design of the NDE process under study. Current programming modules offer selection of up to 16 channels of waveform data with the capability of changing the number of channels and some channel content dynamically. The inspector also can use one or two audio output channels for either mono or stereo (binaural) presentation of the aural information.

Several different ultrasonic instruments have been used including the MetroTek modular system that allows multiple receivers and pulsers to be operated simultaneously in a controlled fashion. The heart of the system is the signal digitizer. The signal digitizer system can digitize ultrasonic waveforms at rates from 10 Hz to 200 MHz.

B. Auralization of Ultrasonic Signals

One basic form of aural conversion involves time dilation. This process increases the time interval between the digitized samples of UT information, and a new waveform with frequencies in the audible range is formed. For example, if a waveform is digitized at a 10-MHz sampling rate, then it is sampled every 0.1 microsecond. By taking each of these sample points and increasing the time between them from 0.1 microsecond to 0.1 millisecond, the waveform appears to have a frequency 1000 times lower than the actual waveform before time dilation. Using the user-interface display, the operator can hear this time-dilated signal information through the two audio channels in mono or in stereo. When presented in two separate channels, the operator can take advantage of binaural hearing capabilities.

To develop the aural UT system, a trained UT operator is asked to position a transducer on a test sample and locate a region with a signal of interest. The waveform (A-scan, amplitude-time) is acquired and digitized. The actual digitized waveform is displayed on the computer screen (which is set up to look like an oscilloscope). The time-dilated signal derived from the ultrasonic signal is sent through an audio receiver and can be played in mono or stereo. To form an initial set of data to begin algorithm development, signals from other areas, both good and defective, are then acquired and digitized.

The modular elements of the system software are key to the developing technology because they permit the operator to produce a variety of waveform processing techniques. Using realtime interactive computer feedback, the operator can experiment with different features to enhance aural perception of the aural signal information. The acquired UT signal information is played back audibly in several different analysis forms. The operator then can begin to discern differences aurally in the data obtained from good and defective regions.

The procedure used to develop the aural signals is very important to the final aural output. The signal of interest is usually gated and digitized at a rate that faithfully reproduces the waveform. The aural output is a combination of the time-dilated signal and the window.

III. DISCUSSION OF RESULTS

The following discussion concerns the use of aural NDE technology to detect corrosion on metallic plates, debonds and impact damage in composite panels, and intergranular stress corrosion cracking (IGSCC) in stainless steel piping. The preliminary results obtained for each experiment are discussed in this section.

A. Hidden Corrosion

Detection of hidden corrosion in aircraft structures is difficult using conventional techniques. By using multiple reflections from the internal surface of the material and converting that signal into aural signals by time dilation, the operator can easily hear the difference between good and corroded material. When both the A-scan and aural UT data are used simultaneously, the presence of the hidden corrosion is easily detected.

B. Characterization of Composite Material

In the aerospace industry, aircraft aluminum structure is often replaced by composite material because of the latter's stiffness and light weight. The composite material, adhesively attached to the aluminum parts, must be well bonded for aircraft safety. The quality of the bond, therefore, has to be verified throughout service life. Composite material also can lose much of its strength if its layers delaminate or the matrix cracks. These two problems often are caused by an impact of the aircraft with objects such as runway debris, hail, or birds.

To inspect composites, data from conventional UT using pulse-echo contact techniques can be difficult to interpret. When the UT signal was time dilated to audible signals, the difference between good and defective material was easily heard. Again, by using both the UT and aural data, the quality of the inspection was increased.

C. Detection and Discrimination of IGSCC

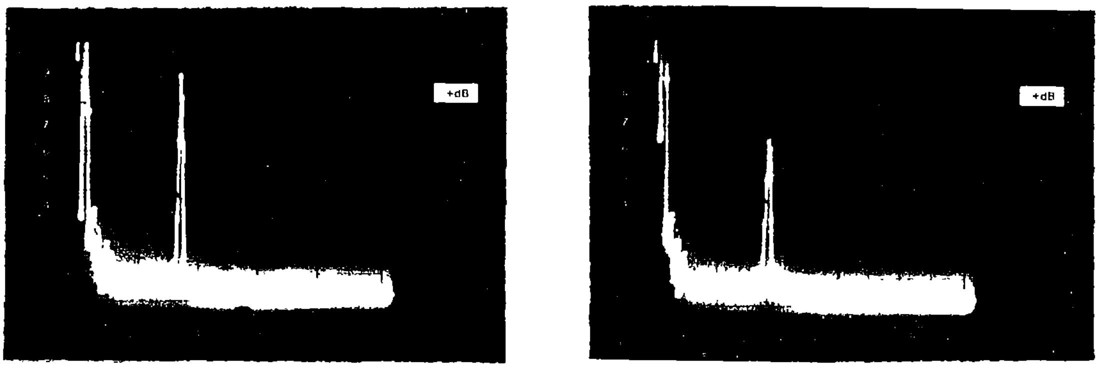
Detection and discrimination of intergranular stress corrosion cracks (IGSCC) in stainless steel recirculation piping in boiling water reactors are of major importance to the nuclear power-plant industry. IGSCC is particularly difficult to discriminate correctly from root geometry because IGSCC develops in the heat-affected zone of the weld at the root region. Examples of root geometry and IGSCC signals obtained using a 1.5-MHz, 45-degree, shear-wave transducer are shown in Figure 2.

The Electric Power Research Institute NDE Center has been working with ultrasonic inspectors that have had many years' experience in training and testing their abilities to detect and discriminate IGSCC successfully. The first-time failure rate on this test by these highly trained inspectors is as high as 60 percent.[6] This attests to how difficult evaluating stainless steel material for IGSCC is.

One goal of the SwRI aural NDE development is to improve detection and discrimination of IGSCC. Only preliminary work has been conducted so far, but results seem promising. By properly setting up the auralization system, both mono and stereo data can be obtained. Two channels of the four-channel aural system have been used to present the data to the inspector, with one channel sent to each ear, respectively. To test this concept for IGSCC, a special transducer fixture was developed that contained three transducers. One transducer provided for 1.5-MHz, 45-degree, shear-wave pulse-echo data to be obtained normal to the weld. The other two provided for 1.5-MHz, 45-degree, shear-wave received-only data to be obtained at angles between approximately 20 and 45 degrees of normal to the weld. These data were time dilated and separated into right and left channels on the audio output presented to the inspector. Using this approach, the inspector could discern the IGSCC. Figure 3 shows the aural frequency content of a geometrical reflector compared to an IGSCC.

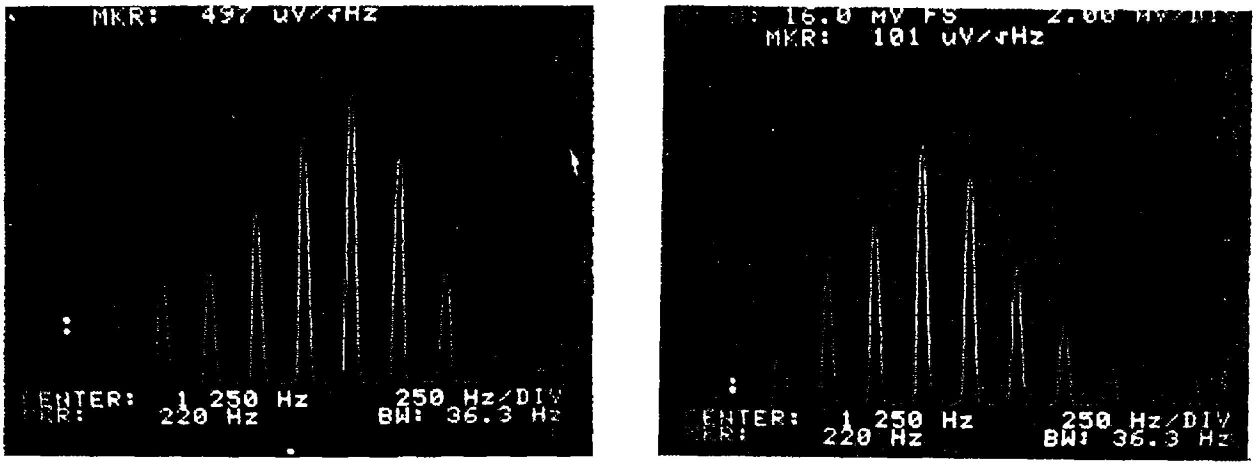
IV. CONCLUSIONS AND FUTURE WORK

SwRI has developed an inspection method to provide simultaneously to the eyes and ears of an inspector material-characterization information obtained through UT techniques. This method converts the actual ultrasonic signal into an aural signal so that it can be presented to the ear of the inspector in conjunction with the visual signal. The method, called Aural NDE, has been successfully demonstrated for ultrasonics, eddy current, and acoustic emission.[7] This paper illustrated uses of the computer-aided aural NDE method for ultrasonic detection and discrimination of hidden corrosion in aerospace material, delaminations and impact damage in composites, and IGSCC in stainless steel piping.



(1) (2)

Figure 2 – Ultrasonic A-Scan Data from (1) Root Geometry and (2) IGSCC Obtained Using a 1.5-MHz, 45-Degree, Shear-Wave Transducer.



(1) (2)

Figure 3 – Aural Frequency Content of (1) Geometry and (2) Actual IGSCC.

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