OVERVIEW OF PLANNED ULTRASONIC IMAGING SYSTEM
WITH AUTOMATIC ALN DATA INTERPRETATION

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ABSTRACT

This presentation discusses a new program designed to investigate the effectiveness with which adaptive learning network (ALN) analysis can be combined with linear array, phase steered, ultrasonic imaging techniques to provide an enhanced means for automatic data interpretations. The DARPA-sponsored program is being performed as a team effort between Adaptronics, Inc. and Battelle-Northwest. Battelle, under a subcontract from Adaptronics, is adapting the linear array imaging system being developed for the Electric Power Research Institute of Palo Alto, California, for use on this project. A special ultrasonic array will be developed to operate with the high-speed imaging system to acquire and record both specular and nonspecular signal information in both the time and frequency domains. Signal information from a multitude of simple and complex reflectors and defects will be recorded on the PDP 11 disk pack incorporated into the ultrasonic imaging system.

Adaptronics will utilize the time domain and frequency spectral data recorded from several thousand data points to develop algorithms and train networks which may describe uniquely the pattern of the reflections. The objective of the program is to provide a high-speed and automatic means for detecting, locating, sizing and displaying flaws in solid materials.

INTRODUCTION

It is generally recognized that the ultrasonic energy pattern or signature reflected from a given target contains substantially greater information than is being utilized by present ultrasonic non-destructive testing techniques. When an ultrasonic sound beam illuminates a given target, the pattern generated by the target contains reflected, diffracted and redirected energies which include time, amplitude and frequency spectral information that uniquely describes the reflector. Linear arrays afford the opportunity of capturing the pattern reflected from a flaw or target. The concept is shown in Fig. 1.

The figure describes an illuminating sound beam striking a target. In this instance, the target is not normal to the illuminating sound beam and little energy is reflected back to the elements which generated the sound beam. In a normal pulse-echo inspection, the target would not be seen as most of the energy reflected from the target falls outside the field of view. However, when an array is used, the length of the array extends the field of view to include capture of the reflected energy, the diffracted energy and any mode-converted redirected energy from the flaw. Reconstituting these energies into a pattern recognition "signature" which uniquely describes the defect as the source of the energy pattern requires computer interpretation of the acoustic "signature".

Battelle's effort on this research program is to develop the experimental procedure and acquire the ultrasonic "signatures". Adaptronics, using adaptive learning network analysis, is responsible for the characterization of the "signatures" for automatic interpretation and identification of the type, shape and nature of defect identified by the data.

The principal objective of the experimental effort is to develop new technology, demonstrating that ultrasonic arrays can provide the additional information available from the pattern of energy reflected from the flaw required to achieve automatic ALN interpretation.

1Contract DSA MDA 903-78-C-0223
The Electric Power Research Institute, under Contract RP 606-1, has funded Battelle-Northwest to develop an ultrasonic imaging system for the rapid and accurate characterization of flaws in heavy section steel structures. This ultrasonic system utilized two linear arrays: (1) a 120-element phase-steerable array for pulse-echo operation, and (2) a single illuminating transducer coupled to a 120-element linear array receiver for acquisition of the phase information. The computer-based ultrasonic system represents an advanced means for displaying subsurface defects in solid materials and can operate in either the pulse-echo or holographic modes. When complete, the system will provide an advanced means for visualization and interpretation of the size, shape and position of subsurface defects.

The major advantage of array technology, as used in the EPRI ultrasonic imaging system, is speed. The time required to perform an inspection in either the pulse-echo or the holographic mode is much less than that required to perform a similar inspection with conventional single transducer technology.

In the pulse-echo mode, the phase-steered ultrasonic sound field is nearly identical to the sound field that can be achieved with a monolithic single-element transducer. The electronic steering provides for high-speed zero and angle-beam inspections. Data from these inspections can be superimposed on the display to provide a full perspective of the volume.

In the holographic mode of operation, the array network provides the means for high-speed acquisition of phase information from a large aperture (e.g., 6-inch x 6-inch - 150mm x 150mm). Operational details and performance results are given in other reports (1,2,3). The significance of this work is that the ultrasonic imaging system being developed is capable of providing "images" for enhancing the interpretation of the amplitude or phase information reflected from a given flaw. The theories involved in either the pulse-echo or holographic systems are within the state of known art.

The Electric Power Research Institute has agreed to make available the ultrasonic imaging system being developed on RP 606-1 for use on this program. The computer, display and mechanical scanning bridge components of the system will be utilized as the core for its technical effort. The imaging system, in its present configuration, is not directly adaptable to the investigations. Data acquisition rates for automatic interpretation research programs are much slower than those required for imaging. As an example, the illuminated sound field will remain in one position for the period of time required to switch through the various receiver locations and data from each appropriate position will be recorded. To achieve the desired protocol, a separate electronic network will be fabricated. A block diagram of the functional requirements is shown in Fig. 2.

Eight elements of the 120-element array will be used to generate a sound field. The receiver switching network will sample through 64 separate locations; amplitude, time, phase and RF waveform data will be recorded from specific locations. The RF waveforms will be recorded on a Bionetics 8100 transient analyzer which interfaces with the EPRI computer system. This system is compatible with the Adaptronics computer networks.

The arrays used in the present EPRI imaging system are not directly adaptable. The EPRI pulse-echo array is a 120-element linear array which is 3.6 inches (91mm) long by 1-inch (25mm) wide and is designed to operate in a narrow-band mode at a center frequency of 2.3 MHz. The DARPA program requires a broad-band array that is somewhat longer and somewhat narrower. Consequently, a new array will be designed and fabricated that has the performance features desired to obtain both amplitude

![Fig. 2. Block diagram of electronic network](image-url)
ALN interpretation is an essential learning step.

Table 1. Machined defects in steel blocks

<table>
<thead>
<tr>
<th>Flat Bottom Holes</th>
<th>Round Bottom Holes</th>
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<tbody>
<tr>
<td>0° 30°</td>
<td>0° 30°</td>
</tr>
<tr>
<td>1/64 1/64</td>
<td>1/64 1/64</td>
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<tr>
<td>16 16</td>
<td>16 16</td>
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<tr>
<td>EDM Notches</td>
<td>EDM Notches</td>
</tr>
<tr>
<td>0° 30°</td>
<td>0° 30°</td>
</tr>
<tr>
<td>&quot;3-1&quot; &quot;5-1&quot;</td>
<td>&quot;3-1&quot; &quot;5-1&quot;</td>
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<tr>
<td>0.010 0.010 0.001 0.01</td>
<td>0.020 0.020 0.02 0.02</td>
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<td>0.030 0.030 0.03 0.03</td>
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<td>0.070 0.070 0.07 0.07</td>
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<tr>
<td>8 8 8 8</td>
<td>8 8 8 8</td>
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<td>Total Number: 96</td>
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</table>

The shape of the machined defects (FBH, RBH, EDM) was chosen to represent laminations, spherical voids and crack-like defects. Theoretical work being performed under other DARPA/AFML programs may be directly cor-related to the experimental results achieved on this program. During the course of the program, other, more typical, "natural" defects will also be evaluated. The signature patterns reflected from the machined defects will establish the basis for future work.

DATA ACQUISITION AND IMAGE DISPLAY

Figure 1 shows the basic concept in which the flaw is illuminated by the transmitted beam and the reflected pattern is received at various locations along the length of the array. The engineering experiment is designed to acquire the data, identify its parameters and present these data so that the significant parameters can be selected for further analysis. Between 10 and 25 data points will be recorded for each of the 96 flaws in the test blocks. Figure 3 shows an RF waveform typical of the pattern recorded on the Biomation 8100 transient recorder. A printout of the 2048 sampling points from the Biomation, as well as a hard-copy RF waveform of the signals at each of the selected positions, will be recorded.

AUTOMATIC ARRAY OPERATION

To demonstrate the display capability of current technology, photographs and recordings of images of flaws within the test blocks will be taken. Commercially available pulse-echo C-scan techniques will be used as one of the display presentations. In addition, the ultrasonic array imaging system developed for EPRI to provide B-scan, C-scan and isometric (combined B-C-scan) images and to generate phase or holographic images of the various flaws will be employed.

Array positioning and transmitting and receiving logic will be under the microcomputer's control, and will initially follow an optimum sequence for defect detection. Analysis of the returned signals in this mode will be made by the ALN 4000 and will result in a detection log, giving the locations of suspicious regions in the test specimen.

Once these regions of interest have been identified, the microcomputer will position the transducer array over each of them in turn. For each defect, a series of measurements will be made, again under computer control, which will result in a decision regarding the type of defect under examination and its orientation. After this classification step is completed, the system will proceed to defect sizing.

The sequence or operations involved in sizing defects will depend on the results of the classification step described above. The processor will position the array in the correct orientation (or orientations) and generate the required ultrasonic beams. Analysis of the returns at selected elements will yield an estimate of the defect size.
The EPRI imaging system will be compatible with the ALN 4000, so a visual image of the defect will be available at the same time. Figure 4 shows the shared system of control. Instructions for gathering the information required by the imaging system, as well as that for the classification and sizing procedure, can be stored in the ALN 4000. Consequently, the image formation can be automated as well, and a simultaneous comparison of these methods of ultrasonic inspection made.

**Fig. 4.** Shared system of control between the EPRI imaging system and the ALN 4000 micro-computer interpretative system.

**ALN CLASSIFICATION AND SIZING**

An adaptive learning network will be developed to process the ultrasonic data in a mode parallel to that which provides the images of the previous section. Figure 5 shows the streams of data flow. The sequential processes must be performed by the processing system: classification and sizing. They are sequential because the particular measurements and their interpretation for sizing depend, to some extent, on the nature or the target under examination.

**Fig. 5.** Information flow for systems shown in Fig. 4.

**Classification:** It is anticipated that classification of the defects into planar or spherical voids or cracks can take place using time-domain parameters only. Advantage will be taken of the fact that the angular distribution of the scattered and diffracted power is determined by the shape and orientation, as well as the size of the defect. Thus, ratios of total power scattered in various directions, for a few directions or the incident energy, should be sufficient to distinguish between some of the types and orientations of defects to be encountered during this study. These ratios can be formed from powers measured from the time waveform, simplifying the data processing requirements.

Further information as to detect type will come from the location of the returned signal in the time-domain waveform. This information, combined with the velocity and path length or ultrasound in the test block, will give the defect's spatial location, assisting in discriminating between cracks growing from the back surface and voids within the metal.

Since, in general, mode conversion occurs when ultrasonic energy in solids strikes a defect, more than one type or returned wave may be detected by the receive array. Again, power ratios among these arrivals are expected to give information useful for classification.

**Sizing:** Once the nature and orientation of the defect have been determined, the appropriate RF waveforms will be acquired to proceed with sizing. Some of these waveforms may already have been taken during the classification process; if so, they will not be remeasured. Now, Fourier spectra of the data will be taken and additional parameters extracted. It is expected that the ratio of mode-converted energy determined in the classification step may also be used in the sizing step. These spectral and time-domain parameters will be input to an ALN trained to estimate the size of the particular defect type and orientation under inspection. Then the outputs of the classification ALN and the sizing ALN will be presented simultaneously to give the best available estimate of the defect type, orientation, and dimension.

**REFERENCES**


DISCUSSION

Don Forney, Chairman (AFML): Thank you, Tony. The bell went off while the applause was going on, so the timing was perfect. We're running behind time, and as a result, I would like to press on without questions at this time. I know that the talks deserve an opportunity for questions and answers, but we're just running out of time and perhaps you can attack either Tony or Jerry during the poster session this afternoon and get some more details. Thank you.

Robert Green (Johns Hopkins): Don, could they just comment on when they'll get some results on this?

Don Forney, Chairman: Bob asked the question, "When do you expect some results from this that they can look at?"

Anthony N. Mucciardi (Adaptronics, Inc.): Preliminarily, within six months, and more specifically, by about this time next year.

Don Forney, Chairman: So you do have time to wait until this afternoon.