This report describes an effort to develop a portable ultrasonic imaging system for NDE use. Results of a short applications study undertaken to identify important NDE problems which would benefit from such a system are presented. The overall system design goals and methods to accomplish them are described.

INTRODUCTION

In late 1977 the Systems & Techniques Laboratory within the Corporate Research Division of Varian contacted Mike Buckley regarding development of an ultrasound imaging system for use in nondestructive evaluation based on previous work in medical ultrasound imaging. A contract was subsequently awarded in late 1978 which has two parts: an applications study and a development program. The applications study was intended to identify important NDE problems whose solution might be assisted by high-speed ultrasonic imaging. Also, an appropriate instrument configuration was to be described. The instrument development phase called for development of a portable ultrasonic imaging system for nondestructive evaluation.

Applications were to include phased-array steering techniques with transducer frequencies between 5 and 10 MHz, real-time contact scanning, and a display and simple operator interface. Development of appropriate multi-element transducers whose beams could be steered were also specified in the work statement.

A list of the Varian professional staff involved in this project is shown in Fig. 1.

Robert Alvarez
Weston Anderson
Doug Clark
Ron Dalgle
Ted Davids
Steve Gehlbach
George Jahn
Wendell Lehr
William Painter
Joseph Sharp
Peter Stonestrom
Dennis Wanzellius
Alice Wehlau

Fig. 1
Participants in Varian NDE Development Project

APPLICATIONS STUDY

Earlier this year Wendell Lehr and I went to a number of military and commercial facilities to learn about NDE problems. The list includes United Airlines in South San Francisco, Mare Island Naval Station in Vallejo, California, Kelly Air Force Base, Tinker AFB, Mcllelan AFB, Wright Patterson AFB, Naval Research Laboratories, and AMRC in Watertown, Massachusetts. We asked the NDE users to describe the kinds of problems they had, the types of flaws, the size, the material, the seriousness of the problem, and current methods of detecting and characterizing the flaw, and how the detection and evaluation process could be improved, hopefully with an imaging system. In the course of the study we had hoped to learn the economic severity of various NDE problems. Unfortunately this information was not discernible in the interviews.

Figure 2 shows a table of the kinds of defects about which we learned. Figure 2 was reorganized into Fig. 3 according to types of flaws including cracks, disbands, honeycomb core damage, voids, and corrosion damage. The minimum critical dimensions are shown along with the different types of material involved. In looking over Fig. 3 we attempted to determine which problems could be helped by high-speed imaging. We came to the conclusion that examining high-quality bearing-grade steel billets to provide a cleanliness index would be a good first application. Among other things, the geometry is simple to understand and there is a good opportunity to make good acoustic contact with the specimen. Imaging of welds also seems to be an extremely important NDE problem. While examination of fastener holes for cracks is an important subject, techniques for detecting the flaws already seem to exist. Also, the detection of flaws in the second and third layers is difficult, if not possible, using ultrasound. Core damage due to corrosion appears to be important; however, there also seem to be suitable techniques for determining the core damage and disbands. We felt that the problems with contact and geometry of engine discs would not be appropriate for our contact scanner. The conclusion of the study is that we would design our instrument to inspect high-quality steel billets and welds using an imaging technique.

INSTRUMENT DESIGN

Figure 4 shows a block diagram of the proposed instrument. The transducer is a multi-element piezoelectric design; the initial prototypes have been built by Pierre Khuri-Yakub of Stanford University. The transmitter shock excites a single element of the transducer. The ultrasonic echoes resulting from a single transmit pulse are received by the transducer array and preamplified by each channel prior to frequency conversion. All elements of the transducer except the transmitter element are connected to wide band rf amplifiers which are low noise and have a dynamic range of approximately 70 dB. The output from each
receiver channel is frequency converted to base band. The down converted signals are processed using nonlinear square root circuits to compress the 70 dB dynamic range into approximately 35 dB. The multiple channel outputs are A/D converted using high-speed TRW 6-bit converters clocked at approximately 10 MHz. The multiple outputs are written into high speed static memory. Approximately 100 microseconds worth of data are captured for each transmit pulse. Each point in the field of view of the transducer corresponds to a point on the display. Signals at various memory locations are summed to reconstruct a specific point within the field of view. The reconstructor generates a picture 30 times per second. Control hardware, keyboard, and display are included in the instrument.

Figure 5 shows a block diagram of the frequency conversion process. We decided to down convert because the A/D converters can sample the bandwidth adequately but not the carrier. The data storage memory is also reduced. The frequency translation operation is performed in quadrature by using multipliers and local oscillators with 90° phase difference. The difference frequency is selected by the low pass filter and then the signal is A/D converted and stored in the random access memory. The data rate for the A/D converter is consistent with the Nyquist rate for the half bandwidth of the bandpass signal since two channels are used. All of the information contained in the input signal is retained by this method so that signal reconstruction and beam forming can be performed.

Figure 6 shows some of the specifications of the instrument. Our initial transducers will have 16 elements but we may go to a wider aperture 32-element design. The digital approach allows

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**Fig. 2**

Flaw Data

<table>
<thead>
<tr>
<th>Type of Flaw and Location</th>
<th>Dimensions, Inches</th>
<th>Material</th>
<th>Contact Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRACKS</td>
<td>Unknown</td>
<td>Aluminum</td>
<td>1, 3, 5, 7, 9, 12, 21</td>
</tr>
<tr>
<td>Flat Holes (Airfoils, etc.)</td>
<td>1/4 x 1/2</td>
<td>Poly Metal</td>
<td>4</td>
</tr>
<tr>
<td>Holes (Tank, Nuts)</td>
<td>1/4</td>
<td>Unknown</td>
<td>Rubber on steel</td>
</tr>
<tr>
<td>Voids</td>
<td>1/8</td>
<td>Aluminum Honeycomb</td>
<td>8</td>
</tr>
<tr>
<td><strong>SUMMARY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 3**

Summary of Flaw Data

- The multiple channel outputs are A/D converted using high-speed TRW 6-bit converters clocked at approximately 10 MHz. The multiple outputs are written into high-speed static memory.
- Approximately 100 microseconds worth of data are captured for each transmit pulse. Each point in the field of view of the transducer corresponds to a point on the display.
- Signals at various memory locations are summed to reconstruct a specific point in the field of view. The reconstructor generates a picture 30 times per second. Control hardware, keyboard, and display are included in the instrument.

**Fig. 4**

Block Diagram of Proposed Instrument

- The multiple channel outputs are A/D converted using high-speed TRW 6-bit converters clocked at approximately 10 MHz. The multiple outputs are written into high-speed static memory. Approximately 100 microseconds worth of data are captured for each transmit pulse. Each point in the field of view of the transducer corresponds to a point on the display. Signals at various memory locations are summed to reconstruct a specific point in the field of view. The reconstructor generates a picture 30 times per second. Control hardware, keyboard, and display are included in the instrument.

**Fig. 5**

Block Diagram of Frequency Conversion Process

- The multiple channel outputs are A/D converted using high-speed TRW 6-bit converters clocked at approximately 10 MHz. The multiple outputs are written into high-speed static memory. Approximately 100 microseconds worth of data are captured for each transmit pulse. Each point in the field of view of the transducer corresponds to a point on the display. Signals at various memory locations are summed to reconstruct a specific point in the field of view. The reconstructor generates a picture 30 times per second. Control hardware, keyboard, and display are included in the instrument.
Specifications

expanding the size of the array easily. A receiving time period of 100 microseconds after the transmit pulse corresponds to a depth of approximately 30 cm in steel. One of the components which makes this digital delay approach now possible is the TRW LSI A/D converter. We have found that the circuits work well and are relatively easy to use. It was a pleasant surprise recently to learn that they have been reduced in price by 50% so now they are less than $100 each in quantity.

A simple mock-up of the system has been constructed. The mock-up multiplexes the outputs from 16 channels into one A/D converter channel, then into a minicomputer system. Computer reconstruction of the images will provide information on the exact reconstruction algorithms to be implemented and hardware. Preliminary pictures are not yet available. The design work on the project should be finished by the end of August at which time the construction will begin.

ACKNOWLEDGEMENTS

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