# A COMPUTERIZED ULTRASONIC SCANNING BRIDGE FOR DEFECT IMAGING: COMPOSITE MATERIALS

Donald Boyd, William McDonald and Andrew Simmons

Lawrence Livermore National Laboratory

Livermore, CA 94550

## ABSTRACT

A computerized ultrasonic scanning bridge has been developed for the scanning and imaging of defects in structures. The raster scaning pattern can be implemented with any pair of the six available axes. The digitized ultrasonic signal can be imaged using a Peritek Graphic system. Details of the ultrasonic scanning bridge and imaging system will be reviewed.

Examples of the evaluation of a graphite epoxy component will be reviewed. The scanning of the composite part requires the use of the two angulation axis for the raster scanning. The correlation of the ultrasonic inspection with failure pressure of the graphite epoxy component will be presented.

## INTRODUCTION

The use of a computerized ultrasonic scanning bridge for the evaluation of structures has improved the reliability and repeatability of the inspection of many parts. As an example, the inspection of a graphite epoxy dome when inspected by hand took approximately two hours and provided limited, operator dependent results. With the scanning bridge a much more complete and repeatable inspection can be done in thirty minutes and provides a C-scan image. The first part of this paper will review the design of the ultrasonic scanning bridge

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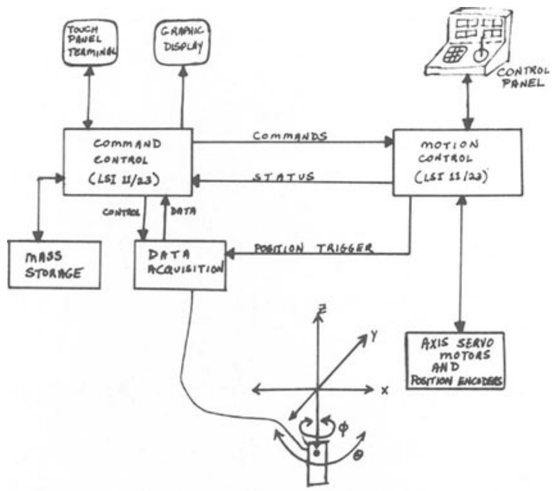


Fig. 1. Schematic diagram of hardware.

system. Following that general discussion, an application of the scanning bridge to a graphite epoxy dome will be described. The fabrication and inspection of a standard part will be reviewed. The paper will be concluded with the development of an accept/reject criteria for the inspection of the graphite dome.

## COMPUTERIZED ULTRASONIC SCANNING BRIDGE SYSTEM

The ultrasonic scanning bridge is capable of positioning and orienting a transducer in an arbitrary manner using the 5 axes shown in Fig. 1. A sixth degree of freedom is provided by a rotary stage. Two Digital Equipment Corporation LSI 11/23 microcomputers are used to control the system. One of these computers controls the mechanical motion and the second computer coordinates all other system functions. The hardware configuration is shown in Fig. 1.

The scanning bridge can currently be programmed to perform a raster scan pattern using any two of the six degrees of freedom. Future control of the motion will involve up to 5 axes for more general contour following.

For operator convenience two modes of interaction are available: a standard keyboard terminal, and/or a cathode-ray tube terminal with a touch panel. Figure 2 shows an example of a typical touch screen menu used for I/O to the computer. The desired option is selected by physically touching the area where it appears on the screen. Certain parameters such as comments and file names must be entered through the keyboard.

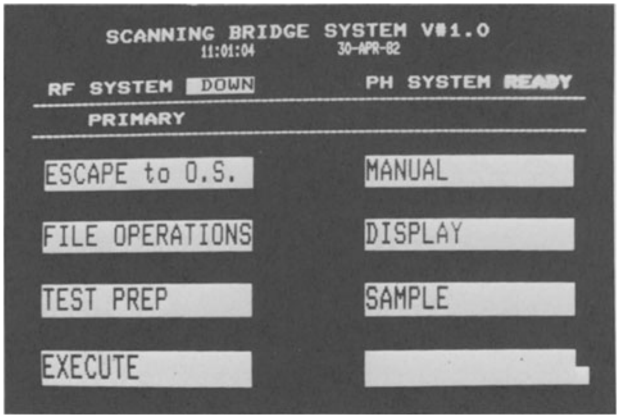


Fig. 2. Touch screen menu for scanning bridge control.

The ultrasonic equipment used for performing C-scan inspections includes an ultrasonic pulser/amplifier with a 4 channel peak height detector. The digitized peak amplitude signals for each of the four gates are stored either in a 30 megabyte disk drive or a floppy disk drive. Further details on the ultrasonic equipment will be described later.

Once the ultrasonic data are recorded, the graphics subsystem can then provide imaging and analysis capabilities. The graphics hardware is a Peritek VCG-512Q graphics display with a medium resolution (512 x 512 x 4) frame buffer. Sixteen levels of grayscale or sixteen colors (out of a palette of 4096) can be displayed.

Software has been developed to allow the display and manipulation of ultrasonic data gathered by the Ultrasonic Scanning Bridge. The main piece of software allows the user to display C-scans of data taken by several different raster scanning methods, as well as allowing the emphasis of particular data, selection of grayscale or pseudo-color output, and thresholding of data.

Since the Ultrasonic Scanning Bridge is capable of scanning a part in three dimensions, it is necessary to be able to display data to the operator in a form that lends itself to simple analysis. Currently, raster scans are made using any two of the six axes. Hence, for data scanned in the X-Y axes, displaying data is simply a matter of scaling and plotting, as shown in Fig. 3. If a raster scan is done in the Phi-Theta axes, however, just displaying the data as an X-Y array of points makes for difficult data interpretation. This difficulty is overcome by mapping the data points which look inherently like an X-Y scan, to a polar coordinate system and then plotting. The resulting image gives a much clearer correlation between

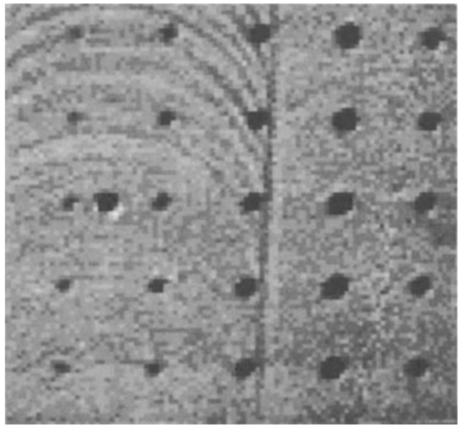

Fig. 3. C-scan image of steel plate with flat bottom holes.

the actual data and the part being tested. The graphite dome to be described in the next section is an example of a part for which a polar image of the data is desirable. Although being able to display in either cartesian or polar format takes care of cases where only two axes are used to scan, new display formats will be designed to handle data from more complex scans.

Because the range of the data on the scanning bridge is much greater than the number of displayable intensities, it is necessary for the software to map the data points into the available range of display values. Unfortunately, the data are not usually uniformly distributed over the entire effective data range, but are often bunched over some subrange. If this distribution of data is then normalized for the graphics display and output, the data appear to cover a very narrow range of intensities which does not provide much useful information. Our solution to this problem is to allow the operator to specify the range of data that would map to the display values. Thus, the operator can enhance features in the output that are of interest. We accomplish this by having the computer normalize the data to the minimum and maximum values. With the above scaling, data that fall below the lower bound are displayed at the lowest intensity and data that fall above the upper bound are displayed at the highest intensity. All other data are displayed at intermediate intensity levels.

Another facility that exists to assist in the interpretation of data is the ability to select the color format of the display: either grayscale or pseudo-color. Selecting the grayscale display format shows the lowest data levels as black and the highest as white, with other levels falling in between. In the case where features are not so easily contrasted, the pseudo-color display format tends to bring out the features. The pseudo-color format does this by using unique colors for each of the various data levels.

A second software package that has been developed allows the operator to perform simple image processing. Manipulations available include such things as addition, subtraction, multiplication, division, and inversion of images. Also available are simple filtering operations such as averaging, high and low pass filtering, and edge enhancement. With this package an operator can emphasize data features such as flaws. Correlation operations may also be performed between different images.

These software packages currently present adequate displays of the ultrasonic data. The software will be added to and modified as new applications for the scanning bridge are found.

## GRAPHITE EPOXY DOME

### Design

The graphite epoxy dome is fabricated from twenty-four plies of Thornel T300/Fiberite 934 tape laminate. Figure 4 shows a cross section of the design. This part requires ultrasonic inspection for locating internal voids and delaminations.

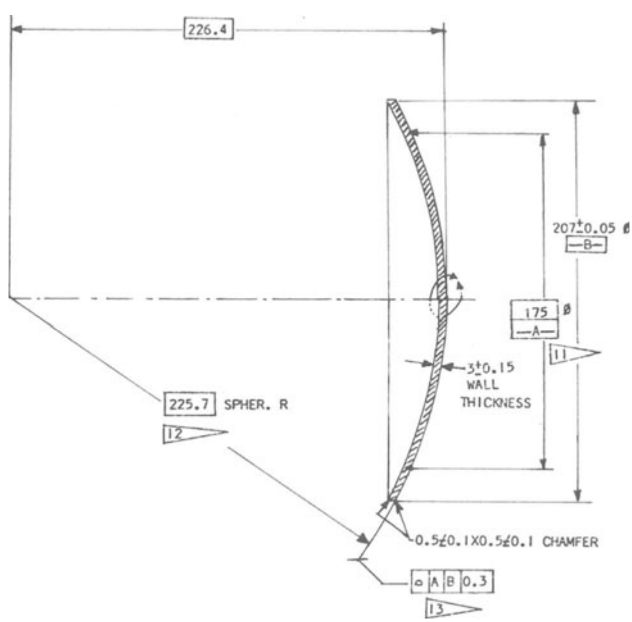


Fig. 4. Cross-sectional view of graphite epoxy dome.

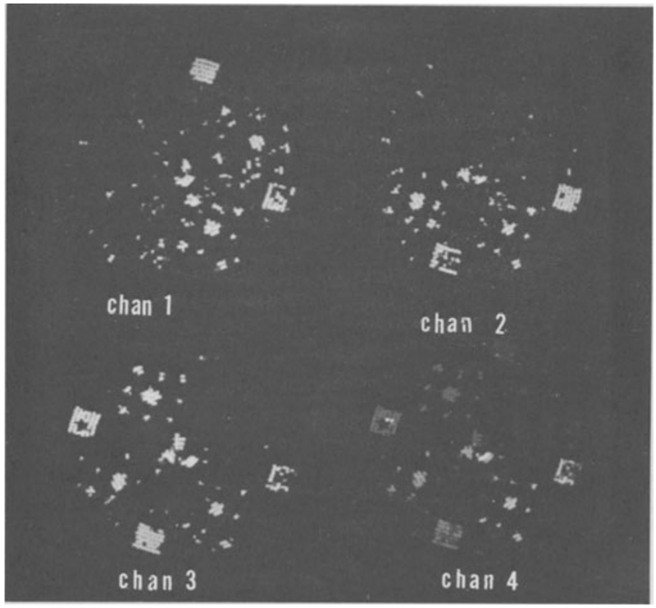


Fig. 5. C-scan image of graphite dome with teflon tape inserts.

Ultrasonic Inspection

For this particular part the two angulation axes of the ultrasonic scanning bridge were used to perform a raster scan. The 5 MHz 4 inch focal length transducer was mounted on an extension arm so that the face was maintained normal to the concave side of the dome. The four channel peak height data acquisition system was used for this inspection. Three internal gates were set at successive depths of the part. The fourth gate was set on the back surface reflection.

A standard was fabricated with teflon squares arranged in a pattern at four different depths. Figure 5 shows the C-scan image of the standard. The largest to smallest squares are 400, 100, 25 and 4 $mm^2$, respectively. The various depths were recorded by the location of the three internal gates. The fourth channel was obtained using the image processing software and is the sum of the three internal gates.

An example of a graphite dome with a large epoxy-rich region is shown in Fig. 6. During the fabrication of the dome a ridge in one of the plies occurred, causing a buildup of epoxy approximately .127 mm (.005 in.) thick. This provided an excellent ultrasonic interface and was easily imaged.

In order to verify that a detected ultrasonic signal was a void or a delamination a sample was sectioned. Figure 7 shows the four

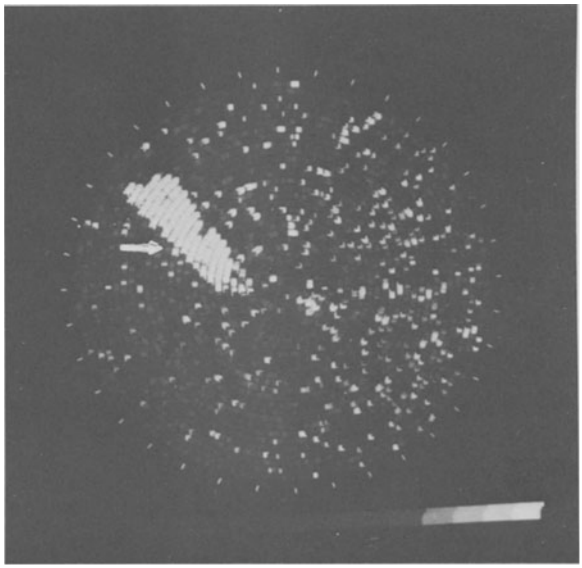

Fig. 6. Epoxy-rich region detected in graphite dome.

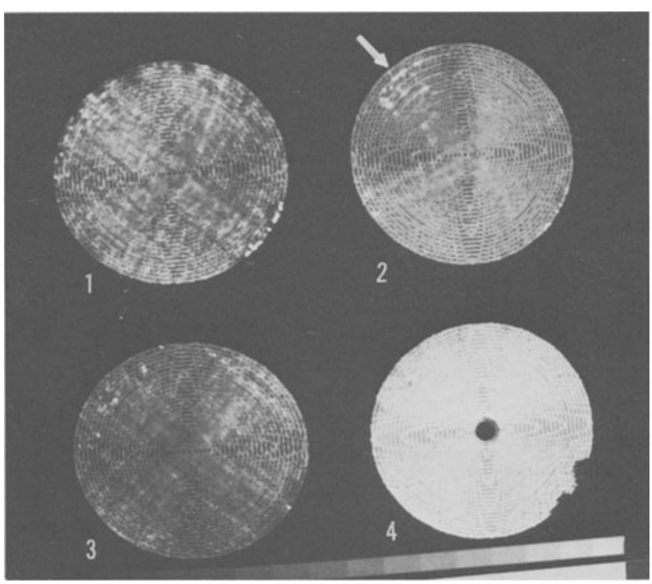


Fig. 7. C-scan image of graphite dome. Upper left quadrant shows internal reflection sites.

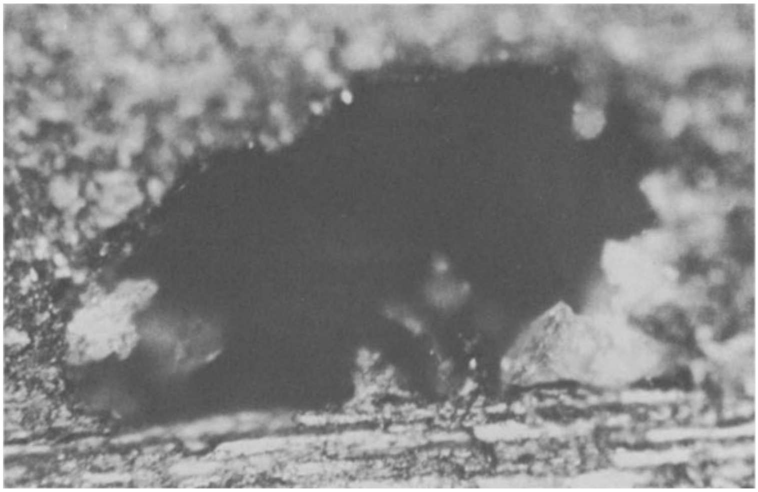

Fig. 8. Photomicrograph of sectioned dome shown in Fig. 7. The diameter is approximately .13 mm.

four ultrasonic images obtained during the inspection of a graphite dome. It can be seen from the three internal gates that several internal reflections were detected in the upper left quadrant. Several of the locations were marked and the dome was sectioned. Figure 8 shows a typical void, .13 mm in diameter, found at the ultrasonically detected sites.

## Accept-Reject Criteria

An accept/reject criteria was required for the inspection of this part. After the ultrasonic inspection, the part was subjected to a hydrostatic proof test. The dome was mounted in a fixture and a hydrostatic pressure was applied to the convex side. Several domes were destructively tested. By comparing the failure pressure to the area of the ultrasonically detected internal reflections, a correlation was found. Table 1 shows those data for nine parts.

Table 1. Accept/Reject Criteria

| Part | Area of Ultrasonic Reflection ($mm^2$) | | Failure Pressure (psi) |
|---|---|---|---|
| 109 | 200 | | 970 |
| 112 | 125 | | 1065 |
| 113 | 150 | REJECT | 1125 |
| 116 | 50 | ACCEPT | 1145 |
| 107 | 50 | | 1155 |
| 108 | 50 | | 1155 |
| 115 | 50 | | 1160 |
| 100 | 50 | | 1250 |
| 110 | 50 | | 1275 |

Based upon these data, an accept/reject criteria was determined. Internal reflections with a total area greater than 100 mm$^2$ will be cause for the rejection of the part. Figures 9 and 10 show typical acceptable and rejected parts, respectively.

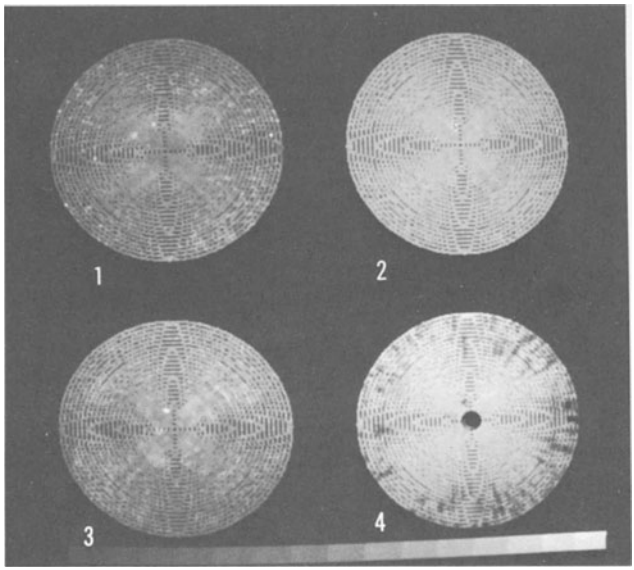

Fig. 9. C-scan images of acceptable graphite dome.

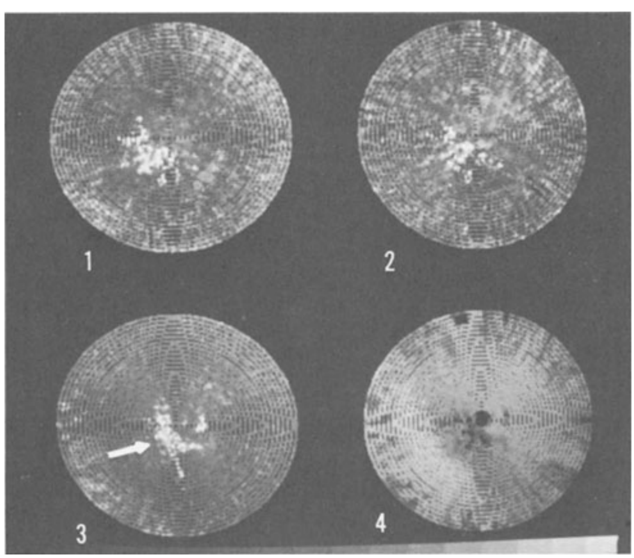

Fig. 10. C-scan images of rejectable graphite dome.

## CONCLUSION

A computerized ultrasonic scanning bridge system is currently being used as a tool for the inspection of parts. Five axes are available for the positioning and orienting of the transducer. A sixth axis can be added through the use of a rotary table for scanning of axisymmetric parts. A four channel peak height data acquisition system records the amplitudes of the ultrasonic signals. C-scan images of the data are made using a Peritek graphics subsystem.

The general purpose inspection system has been successfully used on the inspection of a graphite epoxy dome. The graphite dome was inspected using the two angulation axes in a raster scanning pattern. A standard was fabricated to evaluate the resolution of the inspection procedure. Polar C-scan images were used for evaluating the parts. The inspection of several graphite domes showed that epoxy-rich regions, voids, and delaminations were easily detected. An accept/reject criteria was developed from a correlation of the ultrasonic inspection data with the destructive failure pressure.

Future development of the computerized ultrasonic scanning bridge will include contour following and waveform analysis. Additional work on the inspection of the graphite epoxy dome will include refinement of the accept/reject criteria and signal analysis for discriminating between voids and epoxy-rich regions.

## ACKNOWLEDGEMENTS

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