

## COLOR GRAPHICS: AN AID TO DATA INTERPRETATION

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### ABSTRACT

Color displays, because of their high information content, have inherent advantages over monochromatic display terminals. The extra dimensions that color adds to traditional CRT displays can be utilized to provide faster and more accurate pattern recognition for the human eye, as well as a corresponding increase in quantitative and qualitative information. These advantages have been realized in a newly-developed color graphics system for nondestructive evaluation.

### INTRODUCTION

The field of color display has gained enormous interest due to recent growth in available graphics hardware and software. The coupling of this new technology with increasingly sophisticated user requirements makes a color graphics system a useful tool for visualizing complex, multidimensional data structures and for displaying results of abstract algorithms. This paper reports selected details of a newly-developed color graphics system (CGS), and its applications, primarily in the field of nondestructive evaluation. The particular hardware will be described as well as the graphics and application software package.

Of necessity, all images reproduced in this publication are in monochrome, and the original information available through the medium of color is therefore compromised. Actual color prints are available on request, although a nominal fee will be charged for requests involving more than one figure.

### HARDWARE

The color graphics system (CGS) comprises three separate entities: data sources, a host minicomputer, and a display system. Data sources may be external to the entire system, or may consist of instrumentation attached to the host; in this report the Science Center Test Bed<sup>1</sup> has been primarily used to acquire the data. The host minicomputer utilized is a Data General S/200 Eclipse with tape and disk storage; there is a DMA link between the S/200 and the color display processor. A schematic of this equipment arrangement is shown in Fig. 1.

The display processor, a GENISCO GCT-3000, is linked with a CONRAC 19 in. red-green-blue (RGB) video monitor, a trackball for cursor control, and a keyboard. The processor controls storage of data in 8 parallel internal planes of  $512 \times 512$  RAM memory, which provides the user with 256 ( $2^8$ ) different integer values that may be assigned to each location in RAM. Each location in RAM corresponds to one spatial location in x and y on the video monitor, called a pixel (picture element). The integer value in the RAM location is interpreted for color intensity level assignment

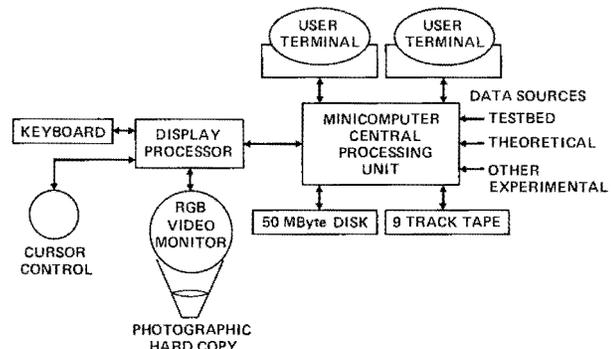


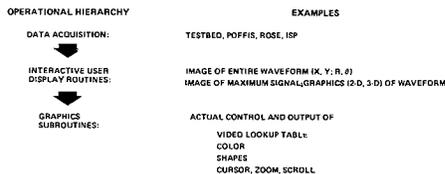
Fig. 1 Schematic diagram of hardware.

by a video look-up table (VLT), described in more detail later, which can be displayed for reference on the monitor. The refresh frame rate is 30 Hz interleaved. A hardware character-vector generator allows enhanced speed for graphics manipulation, and the hardware ZOOM/SCROLL feature provides high speed display enlargements of 1, 2, 4 or 8 times, and horizontal and vertical scrolling of the image. Both of these functions are performed without altering the contents of the RAM memory. A 4 in.  $\times$  5 in. view camera is currently being used to generate hardcopy. To avoid flicker, the cathode ray tube in the monitor is of the long persistence phosphor type.

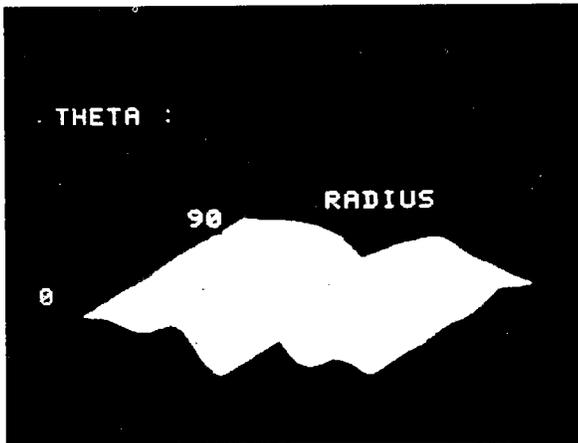
### SOFTWARE

Introduction - The goal in the development of this software was to provide highly interactive graphics and image display capabilities in a research environment. To promote simplicity in creating programs to meet new applications, the software was modularized and structured. This was accomplished by the generation of a set of FORTRAN callable subroutines for use by application routines in the host. These subroutines function independently, each having a separate display function, and are merged together to form a comprehensive graphics library in the host, which interfaces with the display processor via an

assembly language driver. The routines in the library generate macro instructions which, when received by the display processor, are executed under the processor's own operating system on the monitor. Several features of the library are noteworthy: it is an independent set of exclusive functions which can be easily accessed in virtually any combination by a user (application) program; the functions allow user control over character and shape generation; the user can easily define new sets of colors (VLT's) to be utilized for a particular application; and the user can interactively control cursor, zoom, and scroll features. Figure 2 indicates the flow of software control, as well as examples of line graphics and imaging. Figure 2a indicates the logical use of the software, including data input from various sources, the development of user interactive routines, and the actual interfacing to the color processor through the set of library functions. Figure 2b exhibits the vector graphics capabilities. Figures 2c and d are examples of images generated from C-scans of an 800  $\mu$  flaw; both utilize the hardware zoom capabilities, with 2c set at a zoom factor of 2, and 2d at 8.

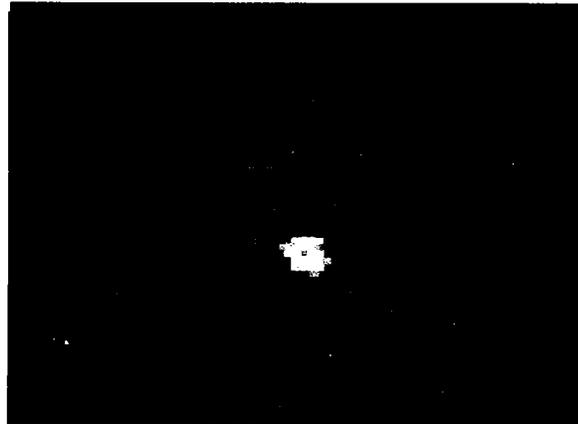


a. Logical use of software.

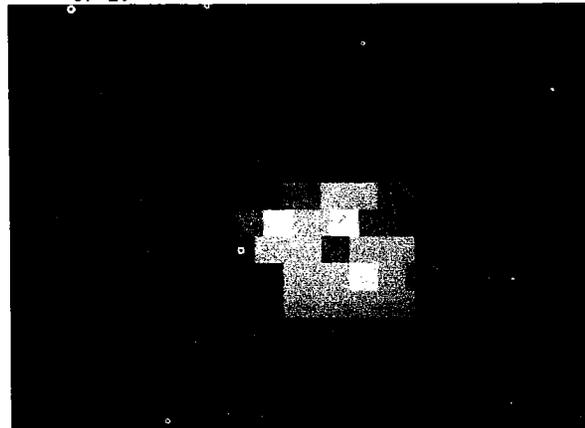


b. Line graphics.

Library Functions -Shape and character generation is provided by routines which construct, in user defined sizes, vectors, filled or unfilled rectangles, three-dimensional boxes, circles generated by separate vectors, and alphanumeric strings in vertical or horizontal directions. Examples of shapes, labels and color control are shown in Fig. 3. Color output can be controlled both by assigning a particular color from the video look-up table (VLT) for succeeding shapes and labels, and by redefining the VLT itself. The VLT is a 256 element array, which is referenced by host programs to assign a particular color to each



c. Imaging of 800  $\mu$  flaw, with zoom factor of 2.



d. Imaging of 800  $\mu$  flaw, with zoom factor of 8.

Fig. 2 Logical flow of software plus examples of software to generate line drawings or images.

data value. A simple example of this is the renormalization of a parameter such as signal amplitude which may range from 0 to 5 volts into the integer range 1 to 256. The exact value resulting from this mapping of volts to the range 1-256 is then the exact index for the VLT array. If the VLT is a simple linear 16-level gray scale, the resulting image is very easy to interpret: bright areas represent large signal amplitude and dark areas represent small signal amplitude.

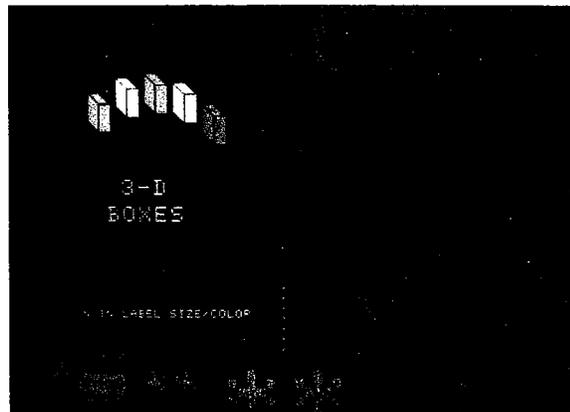
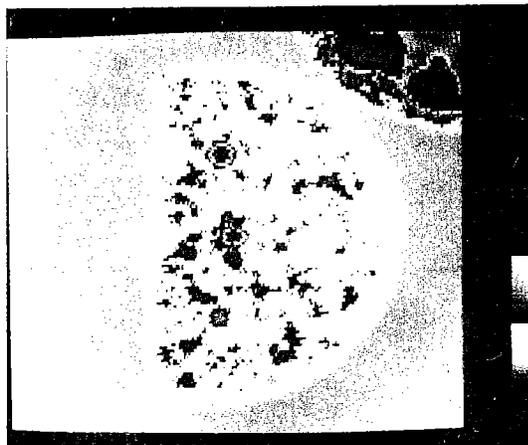
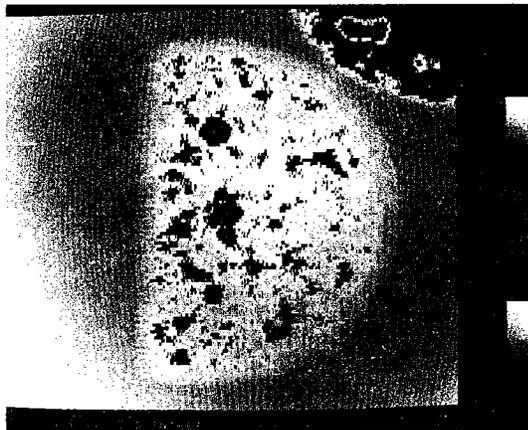
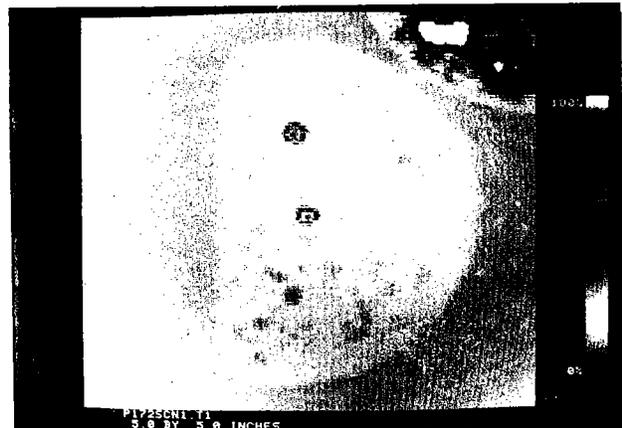


Fig. 3 Shape, label, and color control capabilities.

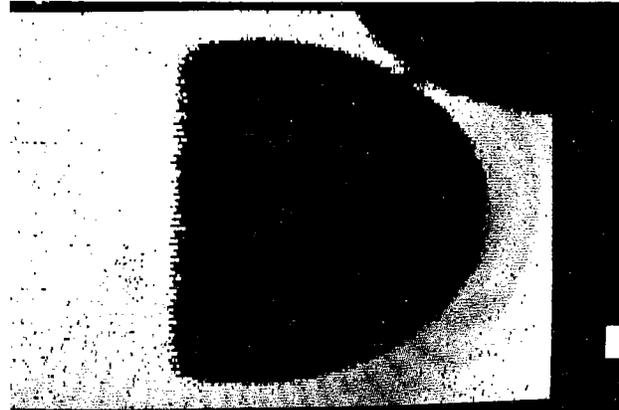
To obtain color images, the VLT values must be tailored to yield a desired pattern. Each element of the VLT consists of 12 bits, 4 each defining red, blue, and green; this allows each of the 256 elements to be defined as one of 4096 ( $2^{12}$ ) colors, i.e., combinations of various intensities of red, green and blue. It should be noted that changing a VLT, i.e., changing the bit pattern assigned to each of the 256 elements of a VLT, automatically changes the color assignment of the image currently represented on the monitor; therefore, a single image may be displayed with several different VLT's in succession, in an attempt to find the best representation for that image. Figure 4 shows 6 color assignments for a C-scan of a D-shaped titanium sample with 3 flaws. The irregular shape in the upper right hand corner should be ignored. Although reproduced here in monochrome, it is still possible to see that different VLT's can produce quite different results. Unique to this work is the use of graded-intensity four color scales; examples are shown in Figs 4a and 4b. This color structure yields easily quantified contours as well as a large dynamic range. A fifth color is added to indicate signal saturation. Figure 4c shows a more conventional continuous spectrum scale. Figures 4d, 4e and 4f are examples of color scales that identify specific signal ranges by different solid colors; this technique could be valuable for field inspection and recording.



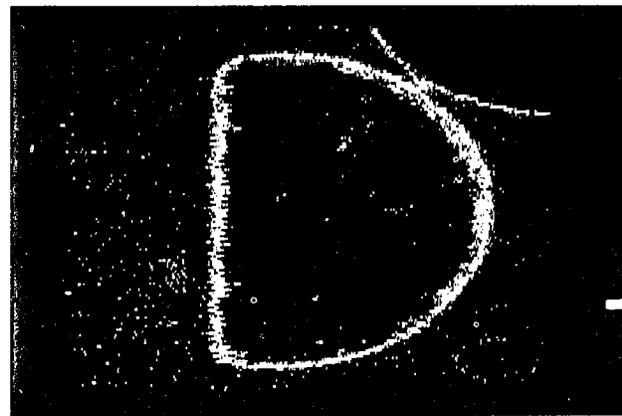
a, b. Two arrangements of the four-color scale: (white, red, green blue) and (red, green, blue, white).



c. Continuous spectrum - rainbow.



d. Two defined ranges.



e. Two other defined ranges.

Fig. 4 Six examples of different VLT's

#### APPLICATIONS

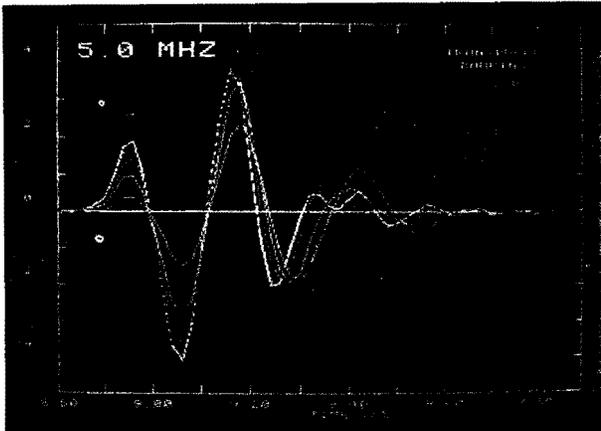
There exists a constant need for improving productivity and reliability, both in general industry and in NDE. To this end, the high content of information and easy interpretation of color displays yields distinct advantages over monochromatic displays. We will briefly describe here various applications of our color graphics system (CGS). Techniques for the acquisition of data vary, but all acquired data require some form of display to be interpreted. In general, there are two basic methods for displaying information: line graphics and imaging. Line graphics include drawing vectors, characters, and points to form



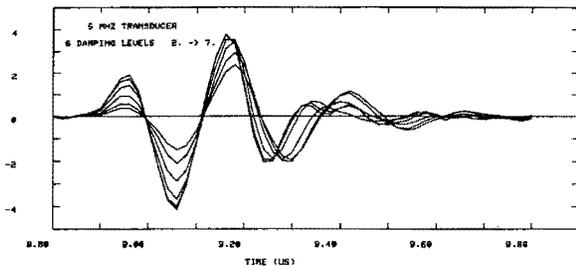
f. Five defined ranges.

Fig. 4 Color assignment by changing VLT's.

ordinary graphs in two dimensions. It also includes perspective drawings of multiple two-dimensional graphs to form three-dimensional graphs. Two and three dimensional graphics are often formed on monochromatic black and white systems; on a CGS, the added dimension of color allows the user to enhance information which may have been obscured in a black and white system. An example of this is shown in Fig. 5 where transducer waveforms for several different settings of the damping parameter have been plotted on the same coordinate axes. Although the various colors reproduce only as various shades of gray in this publication, in the original the color coding allowed easy comparison of all six settings at once.



a. Color coded.



b. Monochromatic.

Fig. 5 Transducer response.

For the purposes of this discussion, the term "imaging" will mean the display of a two dimensional pattern of many tiny rectangles (pixels), each of which displays the value of a parameter by a shade of gray or color value at the relative spatial position it is placed. To interpret any image, a video look-up table or legend must be provided which shows the relationship between the set of color values and the parameter values. Ultrasonic imaging is often done on monochromatic systems that normally yield a reasonable reproduction of the object values; with the use of color, further dynamic range can be gained and specific details of the object enhanced. Figure 6 illustrates both a graphics drawing and an image of the theoretical data describing a 2:1 oblate spherical void.<sup>2</sup> Note the correspondence of the two areas of low level of signal on the image with the valleys shown in the 3-D graphics image. Each representation has certain advantages. The perspective drawing in this case is more immediately recognizable to the untrained eye, but "hides" data values which lie behind large peaks, and is difficult to quantify without painstaking use of a straight-edge. The image pattern is more difficult to recognize until the eye is accustomed to the VLT, but it has other advantages:

- (a) there is no hidden data;
- (b) there is a built-in dynamic range of 1 to 256; and
- (c) by using four colors, each shaded from dark to bright, the image is automatically quantified and contoured.

The use of shading in (c) above is, to the knowledge of the authors, unique to the CGS used with the Testbed,<sup>2</sup> but promises to be generally useful in NDE and other imaging applications because of its large dynamic range and natural contouring capability.

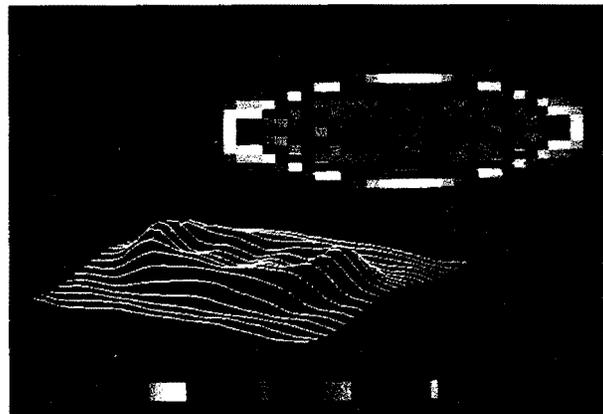


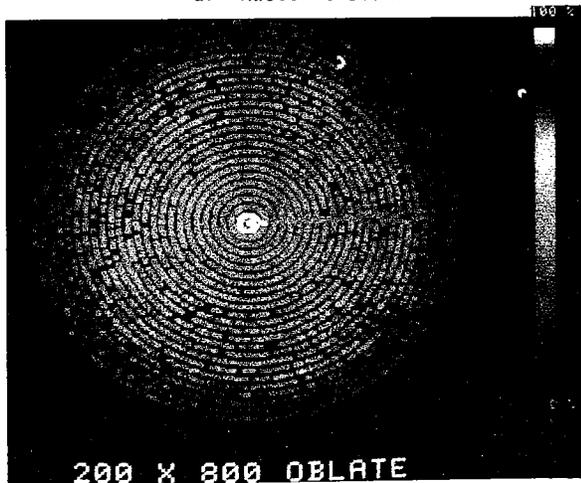
Fig. 6 Line graphics and image of oblate spherical void 2:1.

Most programs developed on this imaging system are for displaying data taken on the Testbed, indicated in Fig. 1 and described in more detail in Reference 1. Data is acquired through an A/D by the S/200 and stored on disk for later analysis and display. The microprocessor is capable of either raster or circular scans, and

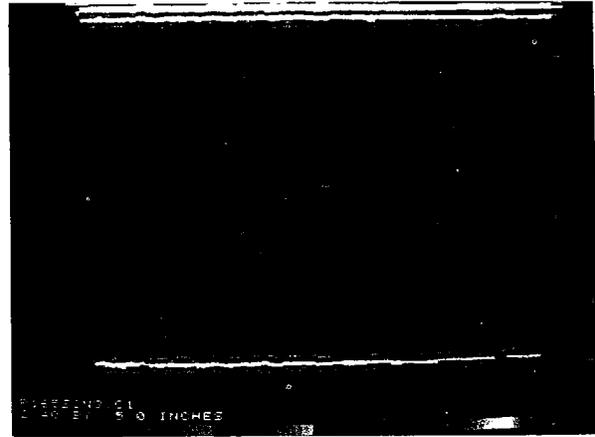
the S/200 can acquire either the peak amplitude of a waveform within a time gate, or the full waveform, yielding C- or B-scans. The four resulting combinations are illustrated in Fig. 7. Figure 7a shows a raster C-scan of a 1 in. thick disk of titanium, where the transducer moved back and forth in the x dimension, alternating with small indexing motions in the y dimension. The area scanned is 0.5 by 0.5 in., and the flaw is a seeded 800 micron spherical void. Figure 7b shows a circular C-scan of a similar sample with an oblate void. In this example, the sample was rotated in a full 360° under the transducer before each small index move along the radial dimension. Figure 7c shows a circular B-scan of the same sample used in 7a. The void shows clearly in the center, halfway between the front face echoes and back face echoes. In this display program, one may choose what band of rotation angle will be displayed. In Fig. 7c, the entire 0° to 180° rotation is shown at once. Figure 7d shows a raster B-scan. Nine successive B-scans are shown, one for each of 9 sequential values of the y dimension. Each is a plot of x vs time for a titanium sample with a weld bead on the lower surface. The irregularity in the back face echo at the end of the weld bead shows clearly in the right most image of the middle row.



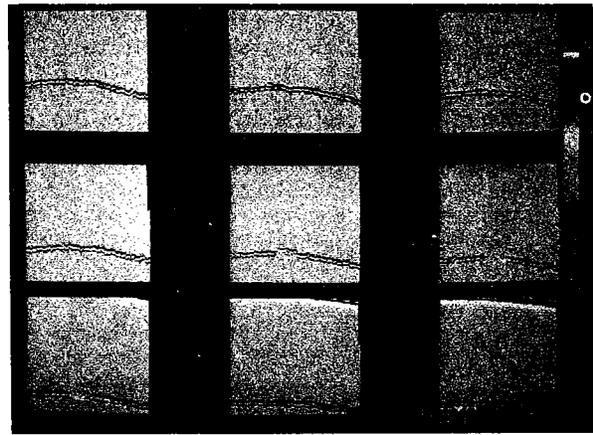
a. Raster C-scan.



b. Spiral C-scan.



c. Spiral B-scan.



d. Raster B-scan.

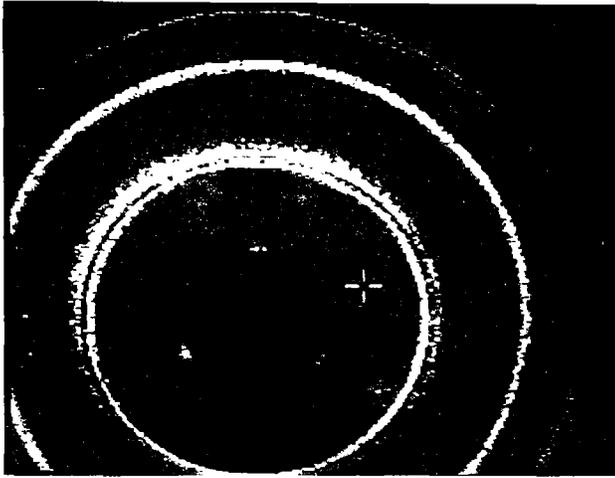
Fig. 7 The basic four scan modes.

read a disk file and show the control data blocks to be sent from the S/200 to the test-bed micro-processor. It also plots the paths the transducer and pivot point will follow with respect to the part itself. This allows rapid checking of a Testbed control block file to make sure the transducer won't hit the part during the scan.

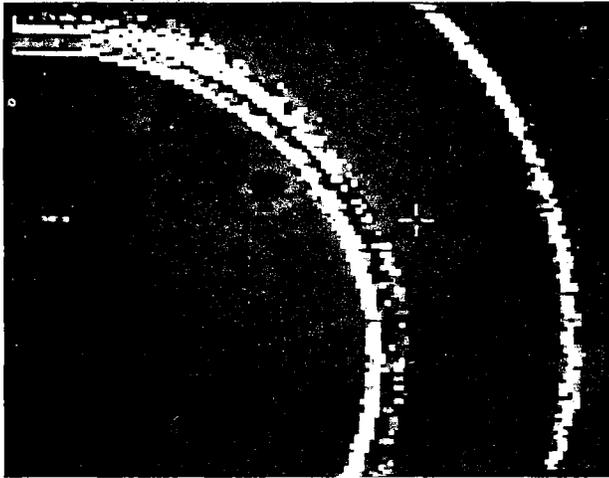


a. Entire image

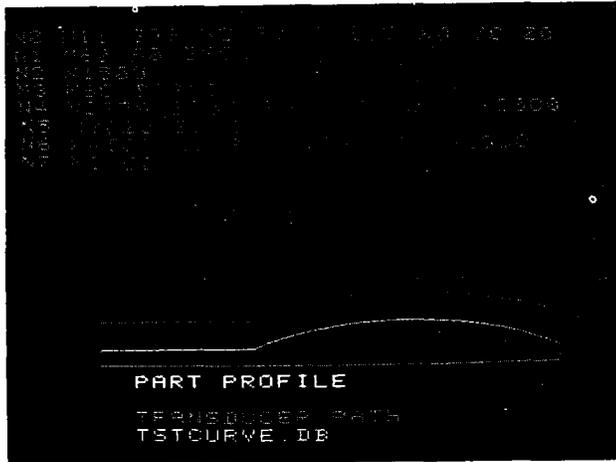
Figure 8 shows a circular C-scan of a 13 in. radius turbine disk. Figures 8b and 8c show two different zooms of that image. Figure 8d shows the output of a diagnostic program designed to



b. Portion of image, with zoom factor set to 8.



c. Portion of image with zoom factor set to 8.

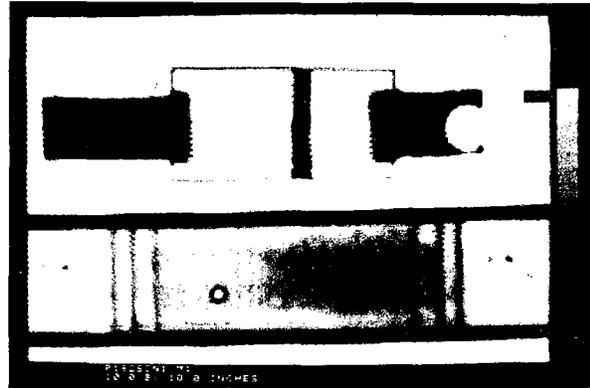


d. Displays of data blocks and the resulting path of transducer and holder with respect to part.

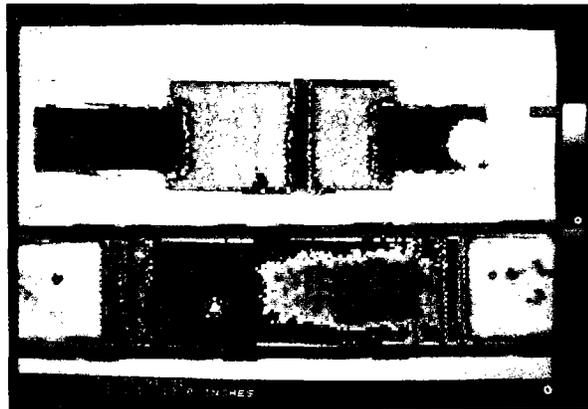
Fig. 8 Displays used for circular C-scans of a 13 in. radius turbine disk.

Figure 9a shows ultrasonic transmission attenuation C-scans of two pieces of graphite/epoxy composite about 0.100 inches (2.5 mm) thick,

imaged in 16-level gray scale. The top piece is held by two pieces of scrap metal and is free of natural defects. It is a calibration piece with an artificial slot and a 0.025 inch (0.64 mm) hole, parallel to the scan plane, which are clearly visible in the otherwise rather uniform pattern. The lower piece is the test piece and has only 5 artificial defects, consisting of drilled through holes: 4 small, 1 larger. The rest of the pattern is caused by poor transmission of ultrasound, probably due to porosity. Figure 9b is the same image with a color VLT. Even in the monochrome rendition of the color image which is presented here, far more detail can be seen and quantified in Fig. 9b than in Fig. 9a.



a. Initial grey-scale image



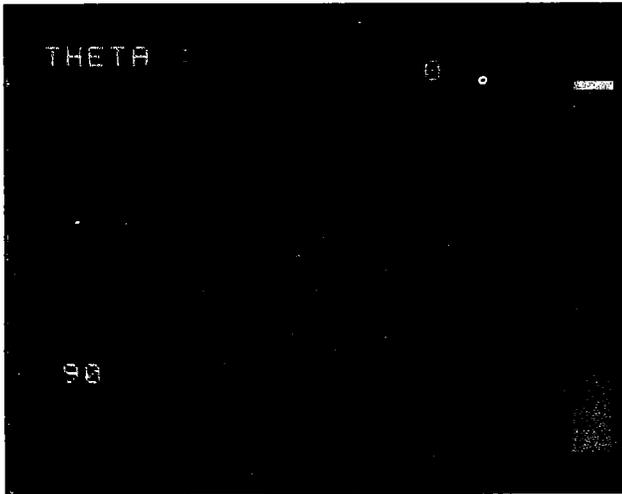
b. Same image with further detail enhanced through color representation.

Fig. 9 C-scans of graphite-epoxy composites.

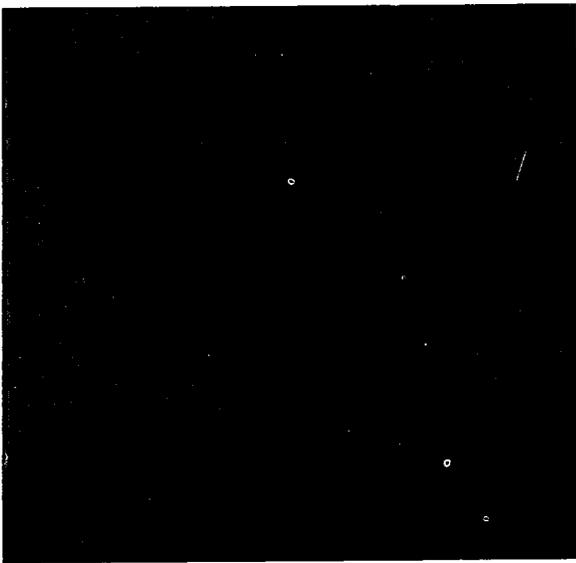
Other applications have been developed as needs emerged. Figure 10a is an image of 91 POFFIS "waveforms" which resulted from inverting theoretical scattering data representing a quadrant of an 800 micron void.<sup>3</sup> Each waveform is displayed at a different angle, corresponding to the direction in which data was generated.

Figure 10b is a display of data taken with an infrared imaging system of a human face. The data was transferred to the CGS by magnetic tape and translated into a common format.

In summary, the ability of a CGS to display and manipulate a large amount of information, with capabilities not available on monochromatic systems, has been illustrated for a variety of NDE



a. Image of POFIS-generated inversion data



b. Infrared imaging of human face

Fig. 10 Additional applications.

oriented data. It can be expected that more applications will follow. Further software development is now in progress on real time display during scans, and on displaying B-scans obtained from parts with curvilinear profiles. Additional processing of the acquired data, beyond the simple peak amplitude detection shown in this paper, is planned.

#### ACKNOWLEDGMENTS

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