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Various methods of imaging defects were used on a titanium casting 4 in. (100 mm) thick. The techniques, all involving acoustic waves, were C-scan, isometric projection, scanned holography, and a new method called stereo-acoustic imaging. The results are compared, and the latter method is shown to provide a true three-dimensional image of the material volume.

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CONTENTS

ACOUSTIC IMAGING OF A TITANIUM CASTING

BACKGROUND

Titanium is a candidate material for naval pressure vessels, especially for applications requiring high strength/weight ratios. The high cost and increased reliability requirements dictate thorough nondestructive evaluation (NDE) at various stages of the fabrication process. Unfortunately, from an NDE point of view, titanium exhibits several undesirable properties, including high grain boundary scattering and moderate attenuation loss, that make ultrasonic inspection difficult. This report presents a case history of the acoustic inspection procedures used on a thick titanium casting considered typical of the cast material. The casting of Ti-621-0.8Mo shown in Fig. 1 is 8 in. (200 mm) in diameter and 4 in. (100 mm) thick. The piece was supplied by a sister naval laboratory as part of a titanium rework development program and contains manufacturing defects which are to be excised in the most efficient manner and weld repaired. Therefore, it was of prime importance in this study to locate accurately the relative positions of the defects within the casting.

INITIAL EXAMINATION

Upon receipt, the casting was first inspected with conventional ultrasonic hand scanning techniques to gain some insight into the relative locations of the defects and the quality of the return echo signals. As can be seen in Fig. 1, the as-cast surface was too rough for the performance of a continuous hand scan. For this reason, the surface was marked with 3/4-in. (19-mm) grids, and each area was spot tested with an ultrasonic transducer. Because of the roughness problem the specimen was then placed in a water-filled tank and investigated with a scanning inspection system.* All subsequent inspections were performed using this system in various operating modes. The first mode used was the conventional C-scan pulse-echo (plan view) mode with the scan plane parallel to the midplane of the circular section. For this inspection a 5-MHz, 1/4 by 1/4-in. (6 by 6-mm) plane wave transducer was used. A comparison of the C-scan result with the radiograph supplied by the vendor is shown in Fig. 2. The C-scan shown was selected from a series of such scans taken at various levels of RF gain and is the one which most closely matched the radiograph. This choice was necessary in the absence of a standard reference block for this material. Several B-scan (profile views) not shown were also recorded to gain depth information on the defects.

VISUALIZATION STUDIES

While the C-scan and B-scan data taken together provide sufficient information for

*Model 200, Holosonics, Inc., Richland, Washington.
Note: Manuscript submitted June 15, 1976.

Fig. 1 — Two photographs of the titanium casting. The reference grid is 3/4 × 3/4 in. (19 × 19 mm).

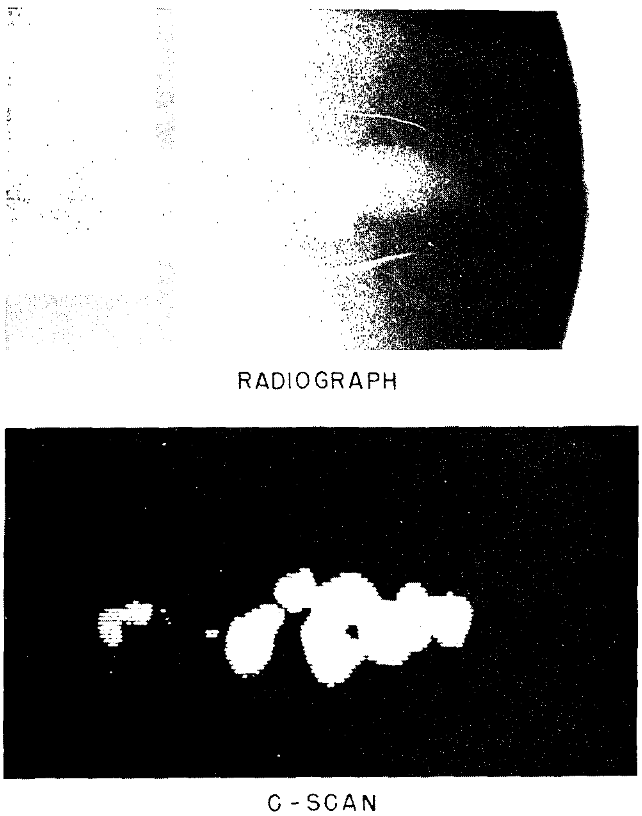


Fig. 2 — Comparison of the vendor supplied radiograph and the C-scan (3-MHz) recording

locating each of the defects, the spatial relationships among the defects are not easily visualized by these methods. The model 200 has the capability of combining the C-scan and B-scan information electronically and displaying isometric representations of the inspected volume [1]. By means of this mode a series of scans was made. In each case the mechanical scan plane was parallel to the midplane of the circular section. In addition, various amounts of rotation and tilt were electronically injected into the display to provide an isometric projection. Two representative projections are shown in Fig. 3. There is a rotation of approximately 60° between the two views, and each has a tilt of nearly 10° (from the normal of the scan plane). In most cases the clearest presentation is obtained with only a slight tilt, which accentuates the appearance of depth but does not obscure one flaw by another. The elevated square shown in the figure is a reference marker obtained by placing a 3/4-in. (19-mm) lucite cube over the area bounded by the reference lines 3 to 4 and C to D (see Fig. 1) and including in the image the top surface of the specimen. Clearly the representations shown in Fig. 3 have more "image-like" characteristics than the planar view provided by the C-scan. However, care must be exercised in interpreting these representations so as not to mistake them for true images of the defects. For example, since only the return echoes from the top surface of the defects contribute to the isometric projection, the defect indications lack thickness. Also, the size and frequency of the transducer, the gain of the system, and the defect curvature

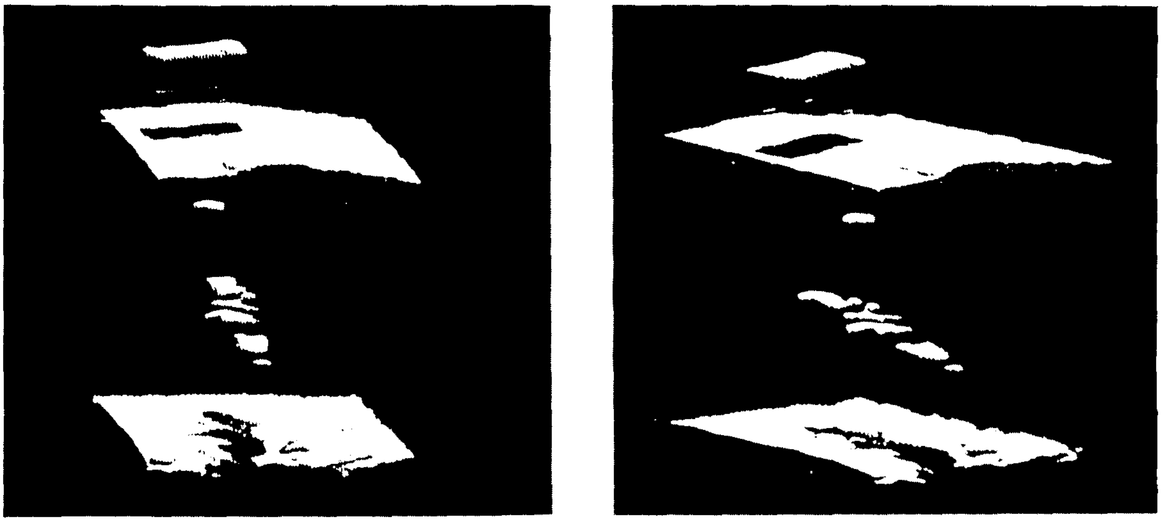


Fig. 3 — Two representative isometric views of the defects. Elevated square corresponds to grid 3-4, C-D (see Fig. 1)

all contribute to change the appearance of the image—compared to what one might expect to see if the material were optically transparent.

A further improvement toward producing an "image-like" presentation was developed in the course of this investigation. This technique, called stereo-acoustic imaging, provides the visual depth perception information missing from the isometric presentation. The stereo views were obtained by recording two separate isometric views of the same scanned volume with a small change in rotation between them. When the two separate images are viewed simultaneously in a stereo viewer, a truly three-dimensional image appears. Stereo pairs of images of the defects in the titanium casting are shown in Figs. 4, 5, and 6. These images can be viewed without a stereo viewer by placing a card vertically between the two pictures and viewing them from a distance of approximately 9 in. (230 mm). With concentration the two pictures can be made to merge into a single stereo image. The views shown in Figs. 4 and 5 correspond to the isometric views shown in Fig. 3. The stereo pair shown in Fig. 6 corresponds to the same defect volume. However, in this view the specimen was insonified from the underside (i.e., the specimen was turned over). Attempts were made to combine top and bottom views together to produce a "total" image of defect, i.e., top and bottom features on the same image so as to gain an impression of defect volume. However, the problems of registration of the images could not be overcome, and the resulting images were not satisfactory. More research on this method needs to be done. Note that the faces of the casting were machined flat prior to recording the images shown in Fig. 6. This machining had no significant effect on the isometric or stereo views but had an influence on the holographic results to be described later. A further discussion of the stereo imaging method is given in Appendix A.

The scanned acoustic holographic mode available in the Mode 200 was also used to examine the casting. For these studies a 3-MHz, 1-in.-diameter, (25-mm) 4-in. focal-length (102-mm) transducer was used. The transducer was focused on the surface and scanned over an aperture 4.5 in. (114 mm) by 6 in. (152 mm); conventional holographic detection

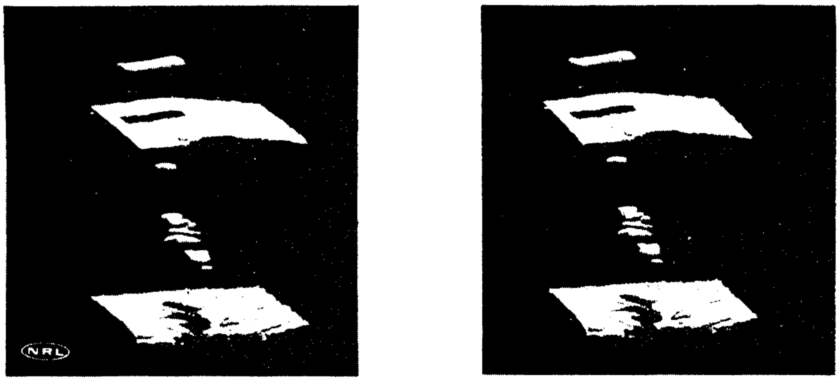


Fig. 4 — Stereo pair of acoustic images, same view as Fig. 3 (left)

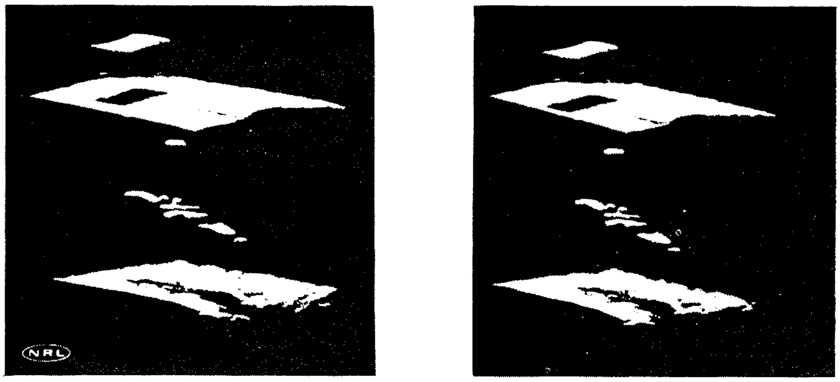


Fig. 5 — Stereo pair of acoustic images, same view as Fig. 3 (right)

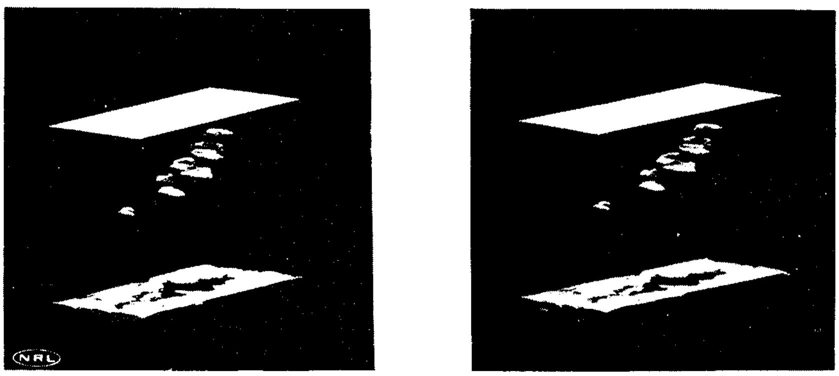
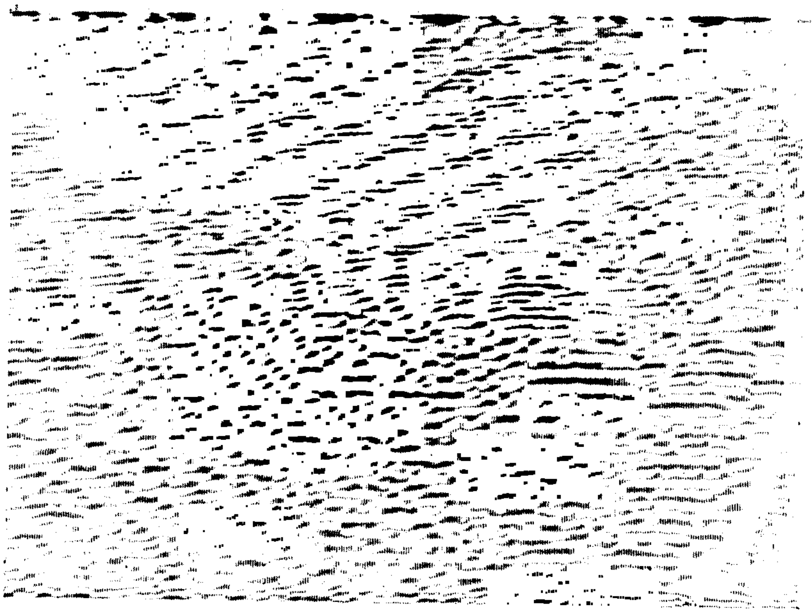


Fig. 6 — Stereo pair of acoustic images, specimen inverted



(a) before machining

(b) after machining

Fig. 7 — Scanned acoustic holograms

procedures were used [2]. The casting was first examined just as received. The side view shown in Fig. 1 shows the surface is shaped like a roof and is rough. A typical hologram recorded with these surface characteristics is shown in Fig. 7a. Notice in particular that the hologram appears to have three distinct regions which correspond roughly to the three facets of the surface and has none of the systemic features characteristic of acoustic holograms. When this hologram was reconstructed in the optical processor, no images were formed. The faces of the casting were then machined flat, and the holographic recording was repeated. A typical hologram made after this surface preparation is shown in Fig. 7b. In this case the hologram has some of the features of an off-axis zone plate. Reconstruction of this hologram produced an image. The image was characteristic of specular reflections from spherical objects but contained considerable background noise. This noise was attributed to grain boundary reflections. It is clear from these studies that the surface condition has an influence on the ability to record a hologram.

CONCLUSION

Clearly it would not be possible to inspect every titanium part with the detail used on this test piece; however, if a choice of one approach must be made, the stereo imaging technique provides the most image-like features. With suitable instrumentation the stereo images can be recorded with a single scan over the inspection area, i.e., with no greater effort than used to record a conventional C-scan. It should also be noted that techniques are available for determining the coordinates of points from the stereo pair [3]. These techniques are used frequently in stereo electron microscopy. The stereo imaging method has the same disadvantage as other amplitude-dependent acoustic methods, in that size calibration depends on comparison with a standard.

One advantage of the isometric presentation is that spurious signals, common in titanium, are located randomly in the three-dimensional space and are less objectionable than in the two-dimensional (C-scan) view. Defects can still be located even in the presence of high background noise.

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Appendix A

STEREO IMAGING METHOD

The perception of depth is based upon the proper assessment of numerous inputs to the brain. The separation of the two eyes of a viewer produces binocular vision. Each eye sees objects at a slightly different angle, and the brain is able to resolve the two similar but not identical images that it receives into a single image in which the objects have depth. Note that as the distance from the eyes increases, the difference between the images from each eye approaches zero and the sense of depth approaches zero. The principles of binary vision have been used for some time in a variety of ways to produce stereo images.

Experience has shown that an acceptable stereo presentation can be produced with an angular rotation of between 5° and 10° between the two images of the subject. This amount of rotation produces the stereo effect without undue eyestrain. By means of such rotation a stereo pair of images can be generated by the Holosonics 200 unit operated in the isoscan mode. First, the tilt and rotation planes are adjusted to show the desired details, if possible with some separation between the defects. After one image is made, a 5° to 10° rotation is introduced (electronically), and a second image is produced at the same tilt. Viewing the two images in a stereoscope then produces the desired three-dimensional effect.

Figure A-1 clearly demonstrates the benefits of the extra dimension. The figure shows nine flat-bottom holes that are grouped in three diagonal rows inside an aluminum test block. When each half of the stereo pair is observed independently, the middle trio of holes appears to be descending between two sets of stepping stones that are ascending. Viewing the holes in stereo will reveal that in reality all three sets slant in the same direction.

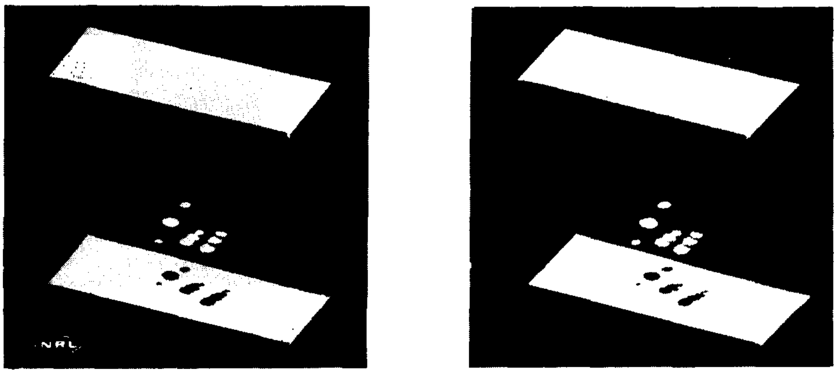

Fig. A-1 — Stereo pair of acoustic images from an aluminum test block

The two images can be generated in several ways. The results shown here were obtained by making two separate scans over the same area with a change in the rotation control of the Holoscan 200 of approximately 7°. The same results could be achieved in a single scan by storing the image points on a scan converter tube and changing the rotation in successive displays of the prerecorded image. Alternately, two isometric display units could be used simultaneously with a fixed difference in rotation angle between them. This latter method would result in stereo displays in real time.

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