ULTRASONIC IMAGING ANALYSIS OF COMPONENT INTEGRITY

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INTRODUCTION

For every component in use there are at least three major processes for its creation. The first stage is the conceptual stage when a component is designed to be made of a certain material with a specific tolerance dimension, to undertake certain loads or stresses, and to serve for a designated number of years in a high temperature or a corrosive environment. The second stage is the manufacturing stage in which the component is fabricated. The process can be brazing, casting, forging, machining, molding, shrink fit, welding or any other methods. The last stage is the application of the component in service. Natural wear is expected, but cracks or other defects may grow unexpectedly fast due to severe environmental effects.

The integrity of each component requires individual analysis. For example, a metallic structure is in general homogeneous and isotropic. Flaws in a metal appear as discontinuities from which incoming sound waves are reflected. On the other hand, for a fiber composite material, the microstructure is inhomogeneous and causes sound propagating through it to attenuate drastically with increasing material thickness. Flaws in a composite material can be either discontinuities such as delaminations and separation of bonds, or microcracks between tiny individual fibers and local epoxy with no major gross structure fracture. The technique for inspecting different materials varies in different cases. Various ultrasonic image techniques and principles are given in Ref (1).

DESCRIPTION OF EQUIPMENT & TEST METHODS

The equipment used in the present investigation is the ULTRA IMAGE III system Ref(2), developed by General Dynamics/ Electric Boat Division, a portable, microprocessor-controlled ultrasonic imaging and analysis system shown in Figure 1. It consists of four packages: the microprocessor, the ultrasonic pulser/receiver and gate package, the dual diskette drive and a display package of a 5" black & white 2-D monitor and a 3-1/2" CRT. Each package weighs less than 30 lbs and the system can be set up for operation in less than 15 minutes.

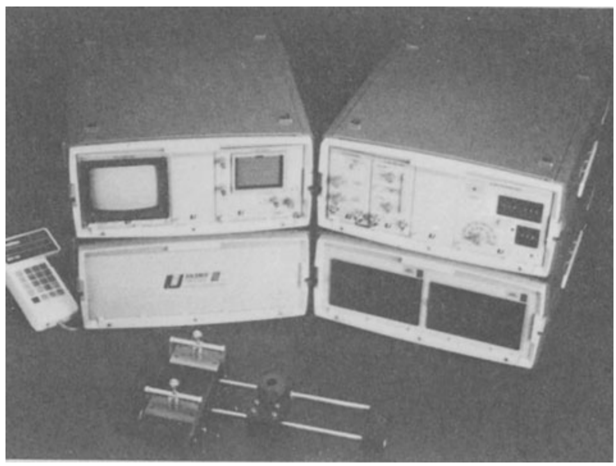

Figure 1. ULTRA IMAGE III system.

A transducer, mounted on a scanner arm, can scan an area of 2" x 4" with a pixel size of 0.02" x 0.02" expandable to 20" x 40" with a pixel size of 0.2" x 0.2". Depending on the geometry of the structure to be inspected, the scanner can be operated manually or automatically. Information of the transducer location, the ultrasonic signal amplitude and its time-of-flight are recorded for each pixel. Various software algorithms are programmed in the microprocessor permit analyses of the top view, front and side view of the discontinuities inside the structure tested. The system, originally designed for inspecting metallic structures, has been used for characterizing the integrity of composite structures as well. Both metals and composites have been examined as follow.

RESULTS

Figure 2(a) shows a photo of the inside surface of a corroded pipe. Water was used as a compression medium in a hydrostatic test for testing the strength of the pipe. With water inside the pipe for two weeks, the pipe was opened for inspection

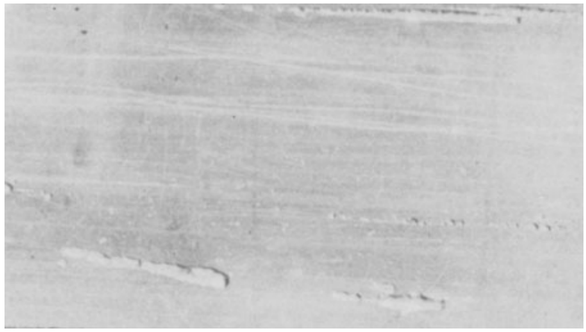

Figure 2(a).- Photo of the inside surface of a pipe

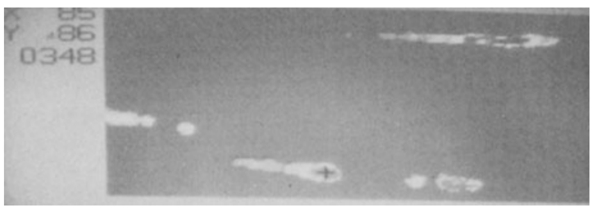

Figure 2(b).- Ultrasonic image of the pipe

and corrosion was witnessed. Figure 2(b) shows the image obtained, using the ULTRA IMAGE III system, from the outside of the pipe. By moving the cursor to any location (x,y) on the screen designated area, the local depth of the pipe wall can be read accurately. As in this case, the depth at pixel point (85,86) is 0.348". Another study of corrosion of an aircraft aluminum alloy gas tank tested with this equipment is reported in Ref (3).

Figure 3(a) shows the photo of a steel specimen machined from a heavy water processing tank taken out of service. With hydrogen sulfide and water flowing inside the processing tank, hydrogen migration from the inside surface of the tank through the steel tank wall has been suggested to have caused the stair-stepped cracking shown in Figure 3(b). The cracks actually have propagated over a wide area with different depths in different color patterns as shown on the top picture of Figure 3(c). With slicing at the cursor position along the X-direction, a cross sectional view of the crack,corresponding to the shape of Figure 3(b), is shown on the lower picture of Figure 3(c).

Even when the structure components do not contain distinctive discontinuities, the structure may still be defective in some cases such as shown in the following example. In such cases, the amplitudes of the returning ultrasonic signals may provide a valuable means of analysis of material quality. By displaying the distributions of the signal amplitudes, the pattern of the color images can be correlated with the integrity of the component. Figure 4(a) shows the photo of three composite flywheels designed to store excessive kinetic energy for automotive vehicles during braking. The flywheel has three parts: the disk, the retaining ring and an aluminum hub glued at the

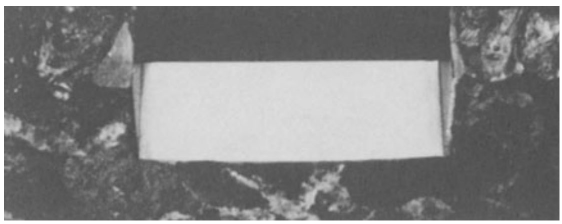

Figure 3(a).- Photo of a steel plate with a crack

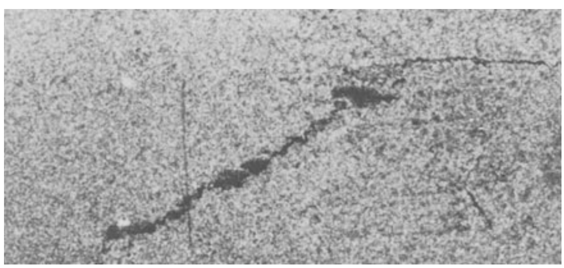

Figure 3(b).- Stair-stepped crack

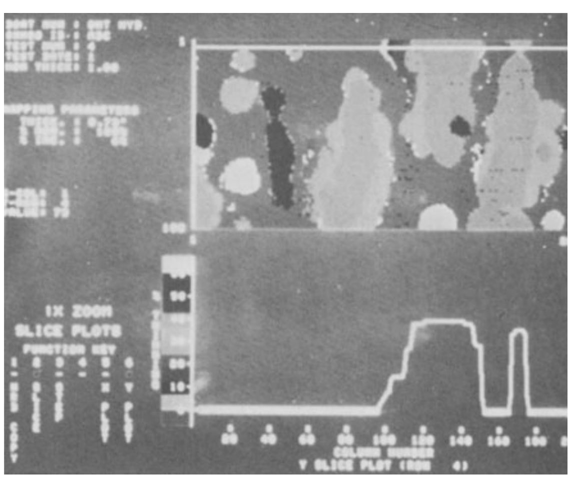

Figure 3(c).- 2-D ultrasonic image of the crack center of one side of the disk. The disk is made of multiple layers of fiber plys mixed with epoxy resins. The disk is then shrink-fit with a retaining ring made of wound plys of graphite fibers mixed with epoxy resins. Figure 4(b) shows the ultrasonic image of the interior structure pattern of the flywheel. The blue and green colors represent the high amplitudes of the ultrasonic signals echoed from the bottom surface of the flywheel, and in turn, they represent the good bonding characteristics of the structure. Around the ring-edge and ring-disk interface areas, only a small portion of the transducer is encountered over the tested area, and hence on these areas,the signal amplitudes are small. Small signal amplitudes are represented by red and pink colors. Aside from the ring-edge and ring-disk interface areas, the red and pink colors represent areas where microvoids are concentrated through the disk thickness such that the ultrasonic signals are attenuated by the clustered microvoids. The flywheel was then spin tested up to 35000 RPM to evaluate the structure integrity at these speeds. In one case, as shown in Figure 4(c), the aluminum hub was separated from the disk and a band of fiber ply was torn from the disk top surface. Figure 4(d) shows the

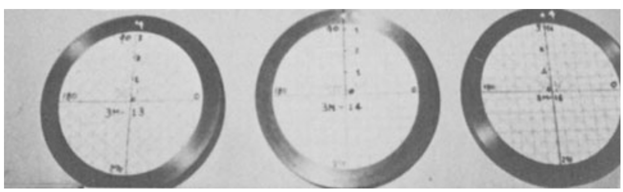

Figure 4(a).- Photo of composite flywheels

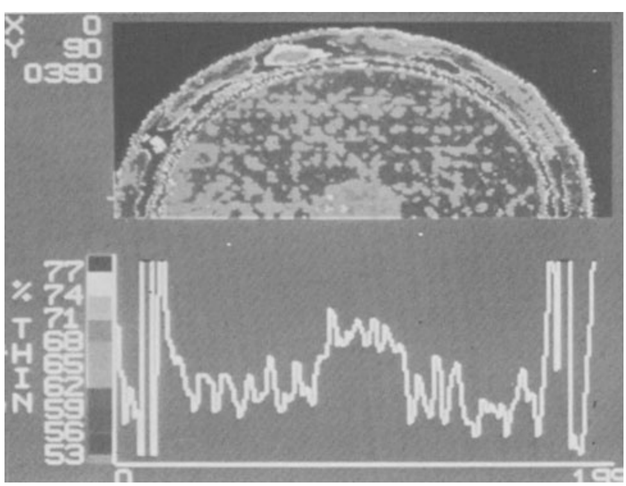

Figure 4(b).- Ultrasonic image of the flywheel results of the ultrasonic image inspection of the flywheel after spin tested. The pink and red colors suggested the detection of microvoids inside the composite flywheel subjected to high stesss due to the spin test. More details of the ultrasonic testing results of the composite flywheel can be found in Ref (4).

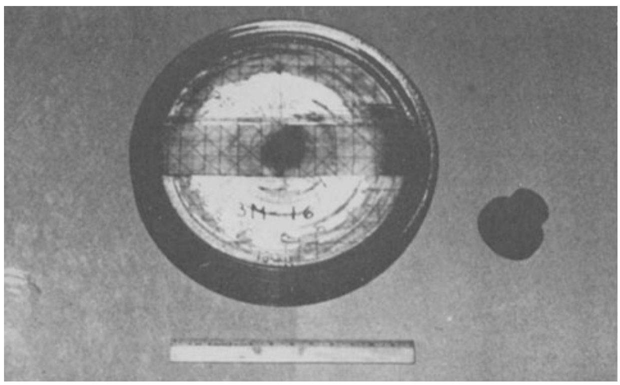

Figure 4(c).- Photo of the flywheel after spin test at 35000 RPM

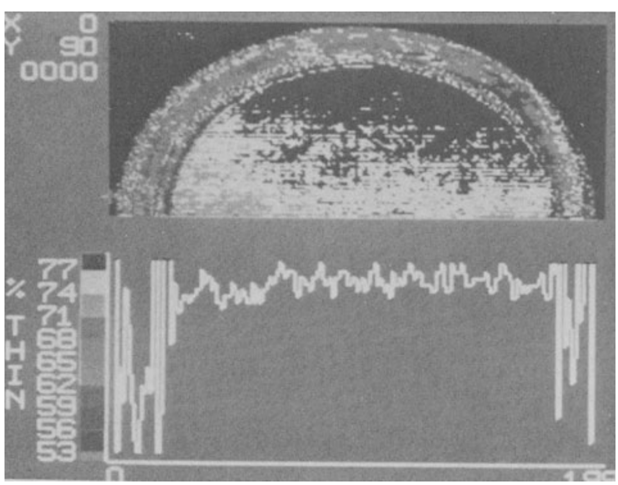

Figure 4(d).- Ultrasonic image of the flywheel after spin test at 35000 RPM

SUMMARY

The safe operation of a mechanical system depends on the integrity of all its structural members. Defects in a structure can occur due to the material property, during the component manufacturing process, or due to fatigue through the service period and/or due to corrosive environmental effects. Hence,the serviceability of the structure must be ensured during all stages of operations. Due to the high cost of down time and destructive testing and the inconvenience of dismantling parts, many structures are not inspected as often as they should be. Furthermore, many inspection methods do not contain complete information and the decision to replace a structure of unknown degree of defects is a difficult task. In this paper, the uses of ultrasonic imaging techniques in inspecting corrosion, cracking in metals and in composite materials by contact tests and immersion tests are discussed. The top view of the corrosion or other defect pattern is recorded in such detail that when combined with the software data analysis package, a precise front view (y-slice) or side view (x-slice) is available at any location in the tested area. The ultrasonic image results have been compared in detail with those obtained by destructive testing after the ultrasonic test. In all cases, there is a consistent close dimensional correlation between the actual defect geometry and its ultrasonic image. Consequently, it can be concluded that ULTRA IMAGE III system has performed with detail precision and can be used, with high degrees of reliability, for the inspection and qualification of structure integrity.

References

(1) M. C. Tsao, "Industrial Ultrasonic Tomography: Principle, Practice and Limitation," Materials Evaluation, Oct, 1983, p.1248-1254.

(2) "New Images Born to the Electronic Age," Materials Evaluation, Jan. 1982, p.36-38.

(3) R. H. Grills, D. E. Kitchel, P. Hearne and N. Harper, "Ultrasonic Imaging Inspection on Aircraft Components," Air Transport Association Conference, Kansas City, Mo. Sept 1, 1983.

(4) M. C. Tsao R. H. Grills, G. A. Andrew and A. P. Coppa, "Characterization of Fiber Composite Flywheels by Ultrasonic Imaging Techniques," 14th Symposium on Nondestructive Evaluation, San Antonio, Texas, April 19-21,1983.

DISCUSSION

M. Horn (Grumman Aerospace): I'd like to know: how many axes of orientation does this simulator have?

M.C. Tsao: How many axes? Right now it is an X axis and a Y axis.

M. Horn: X and Y?

M.C. Tsao: Yes, just the plane, but we can do it at each cross axis, if you wanted to.

M. Horn: So I notice that thing slides this way and this way?

M.C. Tsao: That's right.

M. Horn: But you're working on a curved surface. Don't you need at least a Z axis?

M.C. Tsao: You don't need the Z axis at this point If it is a curved surface, a pipe for example, you can scan circumferentially, or you can scan longitudinally this way.

M. Horn: I have one more question. You say it has no screws or chains. What is the mechanism that's used to measure the motion?

M.C. Tsao: There is a precise edge cutting inside the scanner, so as you rotate, you turn it, the edge will cut at the precise angle, and it travels 20 inches without missing one 10th of an inch. It is a coupler. It is very specifically designed so we don't use the lubricant, we don't have the chain breakage problem, and we don't have the oil, which can cause many, many problems.

The capacity of this system was designed to measure an area of two inches by four inches, so you have a pixel size of 100 in Y reaction and 200 in X reaction. Each pixel size is 20 mill, and the largest area that we can scan at this point is 20 inches by 40 inches.