1 of 1

✓
Conf-930722--14

UCRL- JC-112604
PREPRINT

Three Dimensional Ultrasonic Imaging:
An Aging Aircraft Nondestructive Inspection Tool

Graham H. Thomas, Steven Benson
and Susan Crawford

This paper was prepared for submittal to
SPIE International Symposium on Optics,
Imaging and Instrumentation, San Diego, CA
July 11-16, 1993

RECEIVED
AUG 02 1993

OSTI

July 1993

Lawrence
Livermore
National
Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER

30

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

Three dimensional ultrasonic imaging: an aging aircraft nondestructive inspection tool*

Graham H. Thomas, Steve Benson, and Susan Crawford
Lawrence Livermore National Laboratory
PO Box 808, L-333
Livermore California, 94550

ABSTRACT

Ultrasonic nondestructive evaluation is a valuable technique for finding defects in aircraft structures. It can detect unbonds, corrosion damage and cracks in various aircraft components. Ultrasonic nondestructive evaluation techniques interrogate materials with high frequency acoustic energy. A piezoelectric transducer generates acoustic energy and converts returned acoustic energy into electrical signals which can be processed to identify the reflector. The acoustic energy propagates through the component and is reflected by abrupt changes in modulus and/or density that can be caused by a defect. Ultrasonic nondestructive evaluation typically provides a two dimensional image of internal defects. These images are either a planar view (C-scan) or a cross-sectional view (B-scan) of the component. The planar view is generated by raster scanning an ultrasonic transducer over the area of interest and capturing the peak amplitude of internal reflections. Depth information is generally ignored. The cross-sectional view is generated by scanning the transducer along a line and capturing the amplitude and time of flight for each internal reflection. The amplitude and time of flight information is converted into an image of the cross section of the component. By fusing the C-scan information with the B-scan information a three dimension image of the internal structure of the component can be produced. The three dimensional image can be manipulated by rotating and slicing to produce the optimal view of the internal structure. Visualizing defects in three dimensions aids the interpretation of the severity of defects and helps confirm the need to repair or replace components.

2. INTRODUCTION

Ultrasonic nondestructive evaluation is a powerful tool for finding defects and measuring material properties. In ultrasonics, high frequency acoustic energy is propagated into the component by a piezoelectric transducer and any abrupt acoustic impedance change will reflect part of the sonic energy. This reflected sound energy is sensed by a transducer and converted into an electrical pulse. The amplitude of the electrical signals are related to the defect size and the time of flight of the signal provides depth information. Raster scanning a focused ultrasonic transducer over the part generates a high resolution image of the reflector which provides information such as shape, depth and density of the reflector. Traditional ultrasonic imaging is based on either X and Y scanning, or X scanning with Z information provided by time of flight measurements. The reflector can be further accentuated by color coding the amplitude of the acoustic reflection from the defect. The X and Y scanning generates a plan view, and X or Y with depth scanning produces a cross sectional view. These two methods can be combined by capturing all the available information in the acoustic signal and processing the data into a three dimensional image of the reflector. Three dimensional images are much easier to interpret since they display size, shape, location, and orientation in a single picture. Additional image processing can provide slices, rotation, transparent surfaces, and enlargement to further aid defect characterization.

*Work performed under auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

3. BACKGROUND

Aircraft inspectors must make decisions based on the results of ultrasonic nondestructive evaluations. Displaying the ultrasonic results in a form that is complete and easily interpreted is important. Ultrasonic results are routinely displayed as planar (C-scans) and/or cross-sectional (B-scan) views. Planar views display size, shape, and location of the reflector in the x and y plane. For example, an ultrasonic surface wave scanning technique to image small cracks perpendicular to the surface has been developed. This technique will sense cracks that are within one acoustic wave length beneath the surface. Cracks propagating in any direction will be imaged with a single ultrasonic C-scan. Figure 1 displays an enhanced image of a crack extending from a rivet in an aircraft skin specimen. Another example of ultrasonic imaging is shown in Figure 2 which displays adhesive bond quality in an aircraft type lap joint. The cross-sectional view displays size, shape, and location of the reflector in the x or y and the z plane. Combining the two views and implementing special processing algorithms allows the ultrasonic data to be displayed in three dimensions. Once the results of the ultrasonic evaluation are in a three dimensional digital format, extensive software can be implemented which will rotate and slice the 3-D image to visualize the defect in any orientation. Thus the inspector can quickly and easily see the defect and decisions regarding remediation of the component can be based on complete information about the flaw.

4. DATA ACQUISITION SYSTEM

Three dimensional images of ultrasonic evaluations depend on computer based scanning and digitized data acquisition. Each volume element in the three dimensional array represents an X, Y, and Z coordinate and an amplitude measurement of the reflector. X and Y information is determined by scanner location. Z information is calculated from the time of flight and the velocity of sound in the material. Amplitude or reflector strength is extracted from the digitized wave forms and stored as byte information. All of these calculations and measurements are performed by the computer.

An acoustic microscope (see Figure 3) was modified to capture full radio frequency (R-F) wave forms. Most ultrasonic imaging is based on the peak amplitude of the reflector. The acoustic microscope accurately scans the ultrasonic transducer over the component storing digital location information. A digitizing oscilloscope or an analog to digital converter then captures the full radio frequency wave form (see Figure 4) and stores it along with the location information. Time of flights and amplitudes are calculated from the stored R-F wave forms and combined with location data to generate a four dimensional matrix (X, Y, Z, and amplitude). The time of flight determines the depth of the reflector and the amplitude is related to the strength of the reflector. From the information in the matrix, a three dimensional image is constructed on a workstation.

Fast computers and large storage devices are necessary to generate and manipulate three dimensional ultrasonic images. For example there may be 1000 X coordinates, 1000 Y coordinates and 1000 Z coordinates for a total of 10^9 elements in the position matrix. This represents one gigabyte of information to be stored and processed. Data compression routines are desirable to efficiently handle the large amount of information and for archiving the data.

5. RESULTS

Three dimensional ultrasonic imaging was demonstrated by scanning a test sample which was made by trapping porosity in an epoxy resin which might represent an adhesive bond, see Figure 5. The air bubbles serve as excellent ultrasonic reflectors and are distribute randomly through out the epoxy volume. Full ultrasonic wave forms were captured at each location in the raster scan, therefore x, y, and depth information was retained, as illustrated in Figure 6. This data was processed by a computer algorithm developed at Lawrence Livermore National Laboratory to construct a three dimensional image of the gas bubbles in the resin.

Traditional images were generated on the test sample to demonstrate the advantages of three dimensional ultrasonic imaging. First the standard planar view called an ultrasonic C-scan, was generated as shown in Figure 7a. The planar view is a two dimensional picture of the bubbles with no depth information. Figure 7b is an ultrasonic B-scan which displays a cross-sectional view along a single x or y line. The B-scan is also a two dimensional display. Displayed in Figure 8 is a series of views which illustrate the power of visualizing the data in three dimensions. A video tape was made showing the three dimensional cube of ultrasonic data rotating. The motion aids the interpretation by displaying the defect revolving inside the component.

6. CONCLUSIONS

Three dimensional visualization of ultrasonic results is a method for representing large volumes of information in an easily interpreted manner. Unlike planar and cross sectional views, three dimensional images clearly display defect size, shape, location, and orientation in a single picture. This picture can be processed and manipulated to enhance the visualization of embedded defects. For example the object can be rotated and/or sliced to see the defect at any angle.

To produce three dimensional images, large amounts of ultrasonic data must be captured and processed. Fortunately computer systems are improving rapidly. They are continually shrinking in physical size and cost. Recently designed CPUs can process data at astounding speeds and the storage devices can hold extremely large amounts of data. For example a 1000 by 1000 raster scan with a 1000 point R-F wave form capture will generate a one gigabyte data set. The large amount of data to be stored and processed in three dimension ultrasonic imaging will benefit from advances in parallel processing and data compression.

Fig. 1. Ultrasonic C-scan image of a crack radiating from a rivet hole

Fig. 2. Ultrasonic C-scan image of adhesive bond quality in an aluminum lap joint.

Fig. 3. Photograph of an acoustic microscope.

Fig. 4. Diagram of transducer-specimen configuration (a). Example of amplitude-time data (b)

Fig. 5. Diagram of air bubbles trapped in epoxy resin specimen.

Fig. 6. Schematic of ultrasonic data acquisition protocol for gathering three dimensional information.

Fig. 7a. Ultrasonic C-scan (planar view) of air bubbles entrapped in epoxy.
No depth information is presented

Fig. 7b. Ultrasonic B-scan (cross sectional view) of air bubbles entrapped in epoxy.

Figure 8a 0 degree view

Figure 8b 90 degree view

Fig. 8c. 180 degree view

Fig. 8d. 270 degree view

Fig. 8. Three dimensional ultrasonic images of air bubbles trapped in an epoxy cube which was 2 mm on a side

**DATE
FILMED**

10 / 15 / 93

END