Quantitative Ultrasonic Tomographic Imaging

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Quantitative Ultrasonic Tomographic Imaging

Abstract
An ultrasonic transmission technique is described which images the velocity variation within metal parts. The arrival time of the first ultrasonic pulse to traverse the object is detected and displayed as a gray scale on a cathode ray tube while the part is being scanned horizontally and vertically. The velocity variation imaged within several cast turbine parts will be shown. The system can detect voids as small as 0.020 inch. With a more complex computer program and knowing the dimensions of the part, tomographic reconstruction of the velocity variation within parts with curved surfaces should be possible.

Keywords
Nondestructive Evaluation

Disciplines
Materials Science and Engineering
An ultrasonic transmission technique is described which images the velocity variation within metal parts. The arrival time of the first ultrasonic pulse to traverse the object is detected and displayed as a gray scale on a cathode ray tube while the part is being scanned horizontally and vertically. The velocity variation imaged within several cast turbine parts will be shown. The system can detect voids as small as 0.020 inch. With a more complex computer program and knowing the dimensions of the part, tomographic reconstruction of the velocity variation within parts with curved surfaces should be possible.

**Results**

Figure 2 is a composite ultrasonic gray scale velocity image of a HIP Rene 95 sample. The sample is 6" in diameter and 2 1/4" thick with parallel ground faces. The part was too large to scan and image in one picture so that it was scanned in four sections and put together as a composite picture. The irregular imaging of the edge is caused by acoustic refraction which makes the ultrasonic image larger than the true dimension of the part and backlash in the scanning lead screw. This sample was known to have low average density and our results show that there is a large low velocity area in the center of the sample and a low velocity striation in the
lower right hand section. The entire lower right hand section has low average velocity. The black area has 16.4% lower velocity than the white area which is enough to account for the low density of the sample. A similar sample which was pressed to theoretical density had no detectable velocity variations. Clearly this imaging technique can show the location of low velocity (density) areas inside HIP parts and perhaps lead to improved process control during the design phase of the part's manufacture.

This imaging technique also has good spatial resolution as shown by Fig. 3 for a cast stainless steel turbine blade section. Fig. 3a is a full size front surface photograph of the turbine blade section. The area shown is the same as that imaged in Fig. 3b being 1.5" wide by 2.3" high. Note the two 0.02" diameter holes spaced about 1.1" apart on the center line of the sample. The ultrasonic gray scale velocity image is shown in Fig. 3b. The acoustic edge refraction has been masked to indicate the true dimensions of the sample. Black is low velocity and the black/white ratio in this case is 4%. The one pixel high and two pixel wide black strips spaced 1.1" apart on the center line are the images of the two 0.02" diameter holes. The hole image is horizontally elongated due to diffraction from the small diameter hole projected on the back face which is 0.67" behind the holes and also due to the horizontal scan speed which is too fast for the A/D converter used in this system. The larger black low velocity areas are internal defects. Figure 3c is the side view ultrasonic image of the same sample. Using Fig. 3b and 3c the position of the defect areas can be located. Thus, the lower black areas of Fig. 3b are mostly located near the back of the part, the middle black areas of Fig. 3b extend through the entire depth, while the upper black areas of Fig. 3b are very near the front surface.

Figure 4 is a different set of TOF data showing an expanded front view of the defects in the cast turbine blade section. This data was taken without scanning over the edges of the front surface, thus, enhancing the internal structure. The top hole is imaged in the center of the view. Note the tensile structure emanating from the large low velocity areas. The defects imaged by ultrasonic TOF in this cast turbine blade section have not been identified. They do not show up with standard x-ray examination. The sample is now being sectioned for detailed metallurgical examination and some microporosity has been discovered but the examination is not complete.

Tomographic Imaging

The ultrasonic TOF imaging discussed above required samples with parallel faces. To image the internal structure of samples with complex surfaces, tomographic imaging must be used.

By using ray-tracing techniques, the time-of-flight method can be extended to include corrections for refraction in metals. This can be important in two ways. Firstly, correcting for refraction at the water-metal interfaces can be used to account for curved surfaces for imaging of odd-shaped specimens. Secondly, images can be enhanced by correcting for refraction of sound at boundaries of different acoustic velocity within the specimen.

In order to accomplish ray-tracing in odd-shaped metallic specimens, it is necessary either to have prior knowledge of the shape of the part (usually known) or to use a hardware scanning device which can follow surface contours (such as a state-of-the-art eddy current probe). Then the angles of the specimen boundaries can be determined. Finally, a small microprocessor and a simple algorithm can account for the odd shape of the specimen by reconstructing the path of the sound wave, and the velocity profile can be displayed with suitable gray scale. (See Fig. 5.)

Production of accurate time-of-flight profiles is the first step towards a full tomographic reconstruction. Tomography requires that many profiles or "projections" of the ultrasonic velocity be measured at different viewing angles. Then the ensemble of data is used by a minicomputer to reconstruct the image. The acoustic absorption can also be reconstructed using this technique without any major additions to the scanning hardware.

It is considerably more difficult to reconstruct quantitative images from ultrasound data measured in the reflective mode. However, this mode is desirable, because it has the advantage of one-port viewing. Only one transducer may be necessary, and it is possible to image specimens with obstructions that prevent imaging in the transmissive mode (large very large specimens). The quantity to be imaged is generally either the acoustic impedance or the attenuation. For smaller specimens, reflective and transmissive techniques may be combined to provide more complete information about the material.

In the reflective mode, it is necessary to collect and analyze complete echo traces. Then these traces are converted into projections of the acoustic impedance or attenuation for input to the tomographic reconstruction programs. The advantage of such an approach is that it provides the opportunity to obtain quantitative images of specimens where specular reflections are important. This can be accomplished in some specimens by using a deconvolutional procedure and a mapping algorithm.

Conclusion

A transmissive ultrasonic TOF quantitative velocity measuring system has been shown to image the internal structure of parallel face metal samples with good velocity and spatial resolution. The internal defects are probably density variations (microporosity) but their positive identification is not complete. Using a more complex computer program and the known dimensions of the sample, it should be possible to correct for variation in sample thickness and the effects of edge refraction to image the internal structure of samples with complex surfaces, tomographic reconstruction techniques must be used possibly with a contour following mechanism and wide angle receiving transducers or arrays. Tomographic reconstruction techniques open the possibility of imaging the sample using the measured values of velocity, impedance or attenuation in both the transmissive or reflective mode.
References


Figure 1. Block diagram of TOF velocity measuring system.

Figure 2. Composite ultrasonic gray scale velocity image of HIP Rene 95 sample. Black/white velocity ratio is 16.4%.

Figure 3. Cast turbine blade section. (a) Front surface photograph. Note the two 0.02" dia. holes on the center line. (b) Ultrasonic gray scale velocity image. Black is low velocity, white high velocity, B/W ratio 4%. The 0.02" dia. holes are clearly imaged. (c) Side view velocity image of same part.

Figure 4. Expanded front view of defects in cast turbine blade section. The top hole is imaged in the center of the view. Note the tensile structure emanating from the large low velocity areas.

Figure 5. Block diagram of apparatus used for producing quantitative tomographic imaging in specimens of arbitrary shape.