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THE USE OF SCANNING ACOUSTIC MICROSCOPE FOR FLAW DETECTION IN METALLIC MATERIALS

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ABSTRACT

The main objective of this paper is to understand the principles and theories behind the operation of the equipment, and its architecture. The advantages and limitations of the scanning acoustic microscope are also investigated by imaging a set of samples. The principle of operation of a scanning acoustic microscope is producing magnified acoustic images of the surface or interior of a solid by passing high-frequency focused acoustic pulses through the material and displaying the received signal in the image form as shades of grey. The significant advantage to be gained in using scanning acoustic microscope for producing images are the ability of acoustic waves to penetrate opaque material and the distinctive origin of contrast in the mechanical properties of the specimen. Three sets of samples are observed under the scanning acoustic microscope and they are Vickers hardness indention samples, quenched samples and porosity samples. It is found that the results obtained for the samples are subjected to the overall ability of the equipment used. The operating frequency was one of the most significant limiting factors in this work, as the resolution obtained was not as high as would be favourable. However, satisfactory images with distinctive contrast *were still achieved. One of the advantages of using scanning acoustic microscope, which is the sub-surface imaging ability, is also revealed. Finally, the operating software of the equipment is also an important aspect that should be given proper consideration.*

1.0 INTRODUCTION

Scanning acoustic microscopy is where an object to be imaged is mechanically across the waist of a tightly focused acoustic beam [1]. The instrument has advanced to a point where the resolution of the image produced is now comparable to that of a high quality optical instrument. However, the significance of the scanning acoustic microscope does not lie in its resolution alone. Comparable sub-micron resolution can be obtained by an optical microscope with a great deal less trouble and expense, whereas electron microscopes can easily surpass this resolution. The two main advantages that stand to be gain in using acoustic waves for producing images are:

1) The ability of the acoustic waves to penetrate materials that are opaque to other kinds of radiation, most notably light.
2) The distinctive origin of the contrast in the mechanical properties of the specimen [2].

In scanning acoustic microscopy, both the source and the detector are scanned relative to the specimen, or alternatively they are fixed and the specimen is scanned relative to them.

2.0 OPERATION PRINCIPLE

The principle operation of a scanning acoustic microscope is producing magnified acoustic images of the elastic structure from the surface interior of a solid by passing high-frequency focused acoustic pulses through the material and displaying the received signal in the image form as shades of gray. The acoustic pulses are focused directly, or the energy used to produce the pulses is focused into a small region. This small area is then scanned with a series of focused pulses and the transmitted or reflected signals are viewed on an imaging system.

In this study the reflection mode scanning acoustic microscope is examined. A common configuration of the reflection mode scanning acoustic microscope is shown in Figure 1. The transducer, which is normally a piezoelectric material, is attached to the flat end of the buffer rod. It excites a plane-wave ultrasonic beam into the rod. The other end of the buffer rod has a spherical or cylindrical lens. The lens primary function is to focus the sound beam, which is transmitted in the fluid. When the microscope starts operating, an electrical tone burst excites the transducer, thus transmitting a packet of ultrasonic energy, which is focused by the lens to a diffraction-limited spot. A portion of the ultrasonic signal is reflected by the sample and propagates back through the lens and back onto the transducer. The transducer will generate an electrical signal that is collected by the receiving electronics.

The amplitude and the phase of the return signal is collected and used to modulate the intensity of the display on the monitor at a location corresponding to the location to the focal spot over the sample. By scanning either the transducer or the object, an acoustic image of the sample is formed on the display monitor. Variations in the local mechanical properties of the sample or changes in the location of the surface with respect to the focus of the lens cause changes in the amplitude and phase of the reflected signal and appear as contrasted features in the image. The local variations can be induced by changes in orientation of a material, by the presence of a different material, or by defects at or below the surface of the sample.

As imaging using scanning acoustic microscope depends on the physical interactions that occur between the ultrasonic field and the sample, the images show new images and do not blur as the lens is brought closer to the sample, unlike optical microscopes. When the lens is brought closer to the sample or defocused, other modes of acoustic waves propagation leak energy back into the transducer, thus giving a new image of the sample [3].

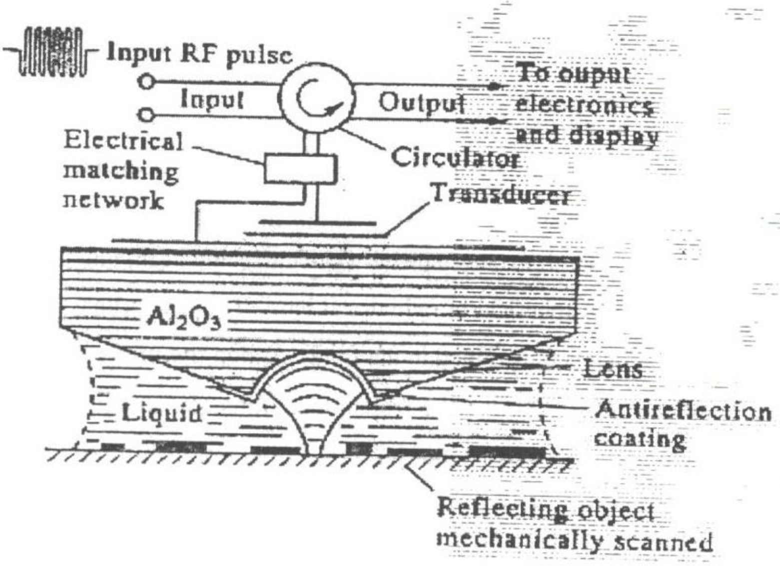

Fig. 1 The Transducer-Lens of A Scanning Acoustic Microscope

3.0 SAMPLE PREPARATION

The acoustic microscope is very sensitive to surface topography than to any other specimen characteristic. Thus, to avoid topography masking the contrast from the elastic properties, the specimen prepared for acoustic microscopy must have a flat and smooth surface. Thus the imaging samples for this study are ground and polished to satisfy this requirement. The samples proposed for this study are divided into three main groups.

3.1 Vickers Hardness Test Indention Samples

These samples are basically prepared for initial imaging with the scanning acoustic microscope. The samples under this group will serve the purpose of familiarisation in the operation of the scanning acoustic microscope. The samples are subjected to the process of grinding, polishing and finally to the Vickers hardness test. The indention on the surface of the samples will serve as flaws for imaging with the scanning acoustic microscope. Materials involved in this group of samples are stainless steel, brass and aluminium.

3.2 Quenched Samples

The second group of samples consists of mild steel with carbon content 0.3%-0.5%. The mild-steel samples were austenised into the pre-heated furnace, at a temperature of 900°C, for 25 minutes. This was to ensure that all the phases in the mild-steel samples were completely transformed into austenite. The samples were taken out of the furnace and immediately quenched in the ice water at the temperature of 6°C. The purpose of rapid quenching the mild steel in ice water was to induce cracks in the mild steel specimen. The objective of preparing this batch of samples was to investigate the ability of the scanning acoustic microscope of detecting random cracks.

3.3 Porosity Samples

This group of samples is made up of aluminium casted from the foundry of Universiti Teknologi Malaysia. Samples produced that have a considerable amount of porosities were selected for the purpose of imaging with scanning acoustic microscope. The porosities of the samples selected were well distributed on the surface of the samples. Observation of the cross-sectional area of the samples revealed that the porosities also existed in the sub-surface region. Thus this group of samples serves the purpose of investigating the sub-surface imaging of the scanning acoustic microscope.

4.0 THE EQUIPMENT: SYSTEM CONFIGURATION

The equipment used in this project is THMUT-2 Miniaturised Multipurpose Ultrasonic Test System (see figure 2). The scanning acoustic microscope is the work of nearly 20 years by the electronic engineering department in Tsinghua University in China. In the development of the THSAM (Tsinghua Scanning Acoustic Microscope) series product, the purpose was to gain stabilised performance of the microscope. On the base of THSAM serial products, new THMUT (Tsinghua Miniaturised Multipurpose Ultrasonic Test System) products have been developed.

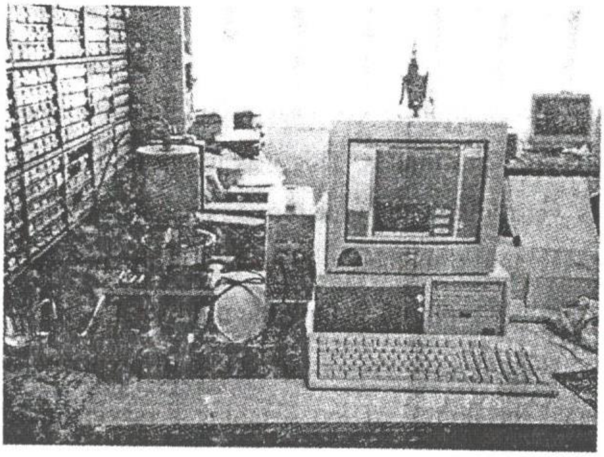

Fig. 2 THMUT_2 Miniaturised Multipurpose Ultrasonic Test Syatem

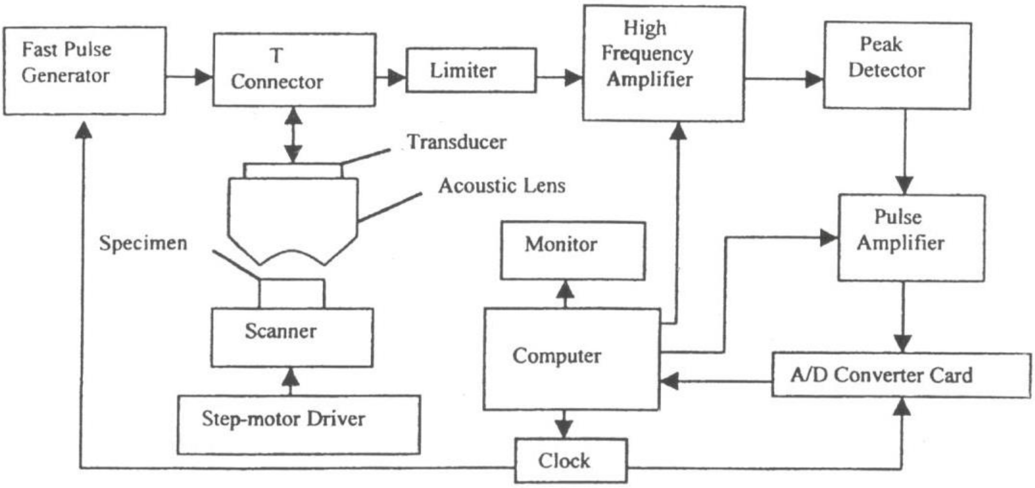

Fig. 3 Schematic of THMUT-2 [4]

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The structural outline of the scanning acoustic microscope used is illustrated in Figure 3. The system as seen in the schematic diagram is mainly composed of the following sections; the acoustic lens, the fast pulse generator/signal receiver card, the high-speed A/D converter card, the mechanical scanning and adjusting system, the step-motor driver, the computer and the system exclusive software. The high-speed A/D converter card generates signals, which trigger fast pulse generator circuit to generate fast pulses with amplitude larger than 300V and width of about 10 ns apart. These acoustic pulses will then excite the acoustic transducer to create high-frequency acoustic pulses. The pulses are then reflected on the specimen's interface or inhomogeneous part inside the specimen. The reflected waves are then received by the acoustic lens and converted to electronic signals. Transmitted through limiter, high-frequency amplifier and pulse amplifier, these electronic signals will finally be converted to digital signals by the high-speed A/D converter card.

The acoustic lens emits an acoustic pulse to the specimen. This pulse will be reflected by the specimen and later converted to one-dimensional A-scan data. Utilising the scanning system and the step-motor driver, the line-by-line scan of the specimen being imaged can be obtained. The three-dimensional data of the specimen can also be produced. The system controlling and signal processing software is programmed in Visual C++ language. This software controls the step-motor driver besides displaying the A-scan, B-scan and C-scan images on the monitor of the computer during the test. The result from various specimens can be saved on the hard disk of the computer. These data can be processed further to produce of multi-layer B-scan, C-scan image display and 3-D image construction.

The configuration of the scanning acoustic system used can be summarised as follows:

1) Mechanical scanning and adjusting system
2) Acoustic lens
3) High-speed A/D converter card
4) Fast pulse generator/signal receiver card
5) Step-motor driver

6) Computer
7) THMUT-2 exclusive software

5.0 RESULTS AND DISCUSSION

The frequency used for the imaging procedure was 20 MHz and the focal length of the acoustic lens used was 7cm. All the images are in C-scan format. The C-scan image is the image created when the transducer is scanned over the surface of the samples.

Figures 4 to 6 are the images of the samples with Vickers hardness test indention.

Fig. 4 Aluminium Sample with Vickers Hardness Indention

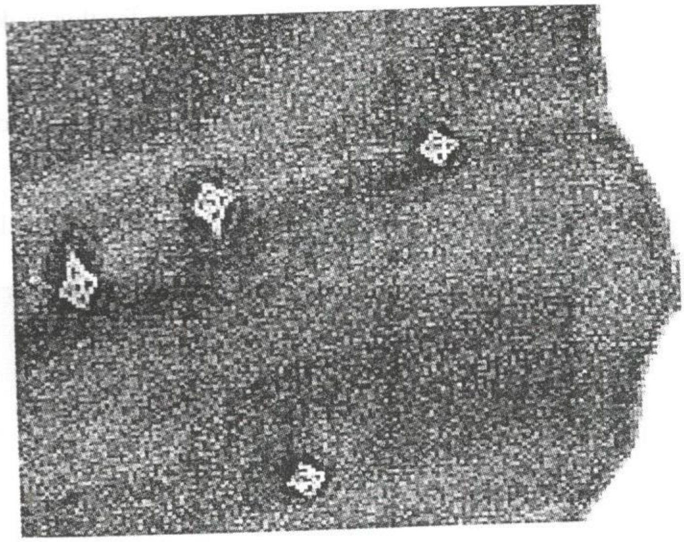

Fig. 5 Brass Sample with Vickers Hardness Indention

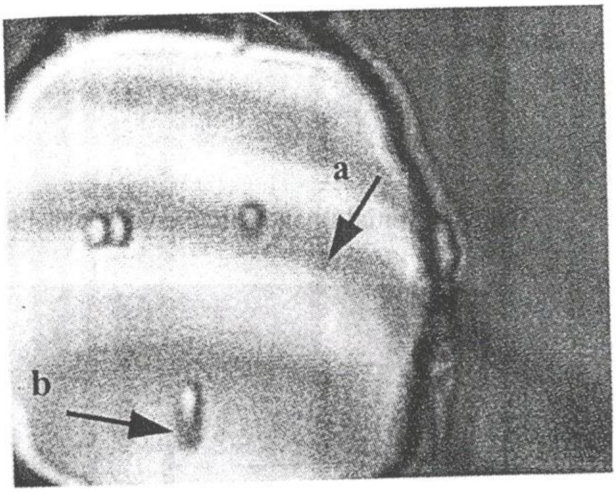

Fig. 6 Stainless Steel Sample with Vickers Hardness Indention

The images obtained for the first group of samples' areas shown in figures 4 to 6 were encouraging. All the indentions induced on the surface of the three samples were imaged with considerable amount of success.

Two setbacks were identified in the initial imaging with the equipment:

1) The formation of fringes as indicated by the black arrow labelled **(a)** in figure 6. The possible cause is the sample surface and the lens are not completely parallel.

2) The image of the indention becomes distorted as shown by the black arrow labelled **(b)** in figure 6. The only possible reason for this is due to the backlash of the mechanical scanning system.
3) The equipment sensitivity was quite low and thus the magnification obtained for the image was not very satisfactory.

Figures 7 and 8 show the images obtained for the quenched samples.

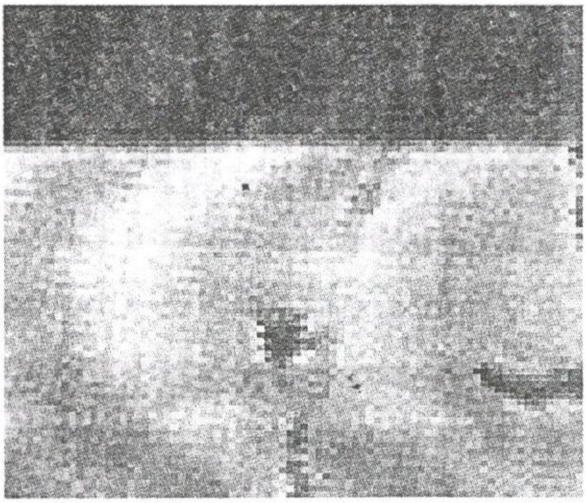

Fig. 7 Initial Image Obtained of Quenched Sample

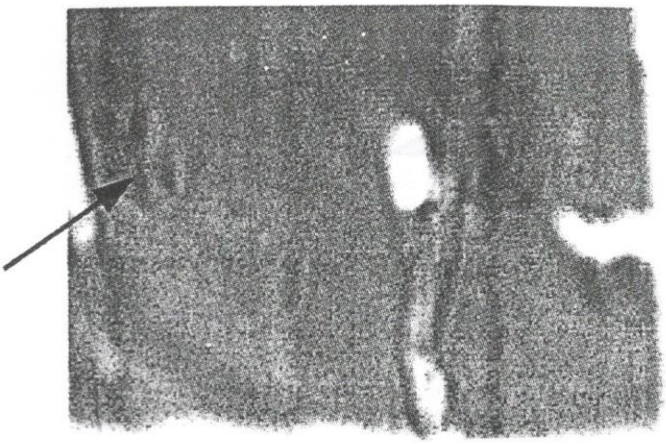

Fig. 8 Image of Quenched Sample at Higher Magnification

Figure 7 shows the initial imaging of the quenched sample. Although at low scanning precision, the crack was clearly noticeable. Figure 8 displays the image of the same sample at a higher value of scanning precision. The crack is clearly displayed. Apart from that, additional features are revealed as indicated by the black arrow in figure 8, when compared to figure 7.

Interference fringes due to oblique sub-surface cracks were unfortunately not observed in the quenched samples. Interference fringes are observed when certain acoustic ray is refracted at the specimen surface so as to strike the oblique crack normally and is reflected back along its own path.

Figures 9 and 10 are images of the third group of samples, which is the porosity samples. Figure 9 shows the attempt at surface imaging of the sample. The surface porosities could be observed clearly. Figure 10 is the image obtained when attempting sub-surface imaging of the same sample.

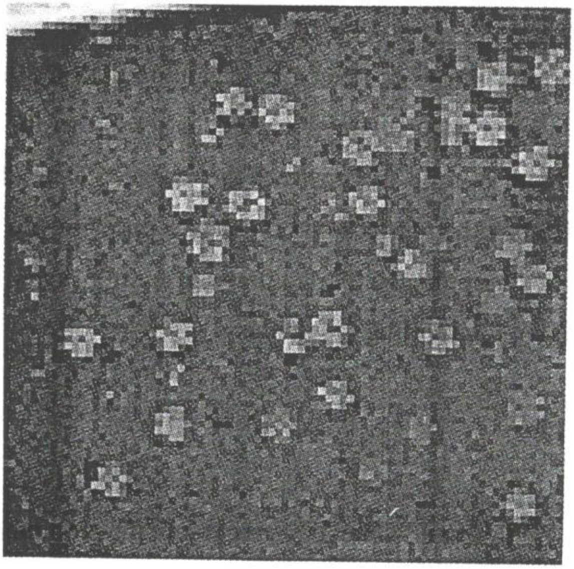

Fig. 9 Surface Imaging of Porosity Sample

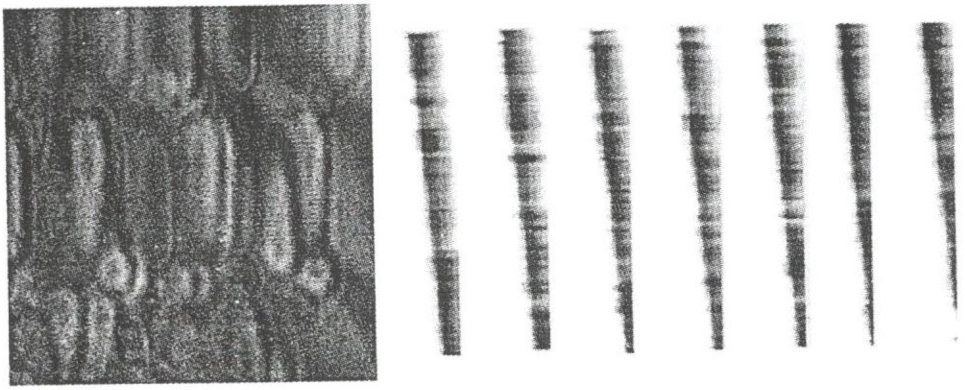

Fig. 10 Subsurface Imaging of Porosity Sample with 7 Layers of B-scans

The C-scan image is supplemented with its B-scans. B-scan is a cross-sectional display of the sample. B-scans resemble an actual cross-section of the part except that the image is constructed from acoustic data. In this instance, 7 layers of B-scans is obtained using the software of the THMUT-2. The B-scans should be viewed from left to right, which represents the cross-sectional display from bottom to top of the C-scan image.

The sub-surface imaging is produced by changing the sampling depth of the imaging process. The C-scan value extraction mode is set so that the largest value in within the sampling depth is used to construct the image. Thus all the porosities within the sampling depth, either surface or sub-surface porosities, will appear in the image, and this results overlapping of the features. The multi-layer B-scans will be a helpful factor to assist in interpreting the image.

6.0 CONCLUSION

The results obtained in this study are dependent on the equipment used. The THMUT-2 used to image the samples is restricted by its operating frequency of 20MHz. Thus the magnification factor of the images obtained need to be further improved. However, a number of advantages of imaging using scanning acoustic microscope were established.

First is the sub-surface imaging ability of the equipment. This is established when imaging the porosity samples. Where steps should be taken to improve the sensitivity of the equipment to eliminate the overlapping of the features in the images obtained, so that more accurate image can be produced and interpreted without the aid of the B-scans.

The second advantage is the distinctive origin of the contrast in the mechanical properties of the specimen, which is displayed in all the images obtained. All the images showed good contrast and the surface scan images could be interpreted accurately without much trouble.

The present advantages gained when imaging with scanning acoustic microscope make the equipment an ideal method for crack detection and also other non-destructive evaluation. The only restriction is that the surface of the samples must be flat and smooth.

Another aspect that should be taken into consideration is the operating software of the equipment. Designing user-friendly software should be given top priority. The software should also be able to fully utilise all the acoustic signals collected.

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