 Imaging of Defects in Hexcan Welds Using Ultrasonic Guided Waves and Phased Array Techniques

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ABSTRACT

Inspection of seal welds in fuel assemblies of fast breeder reactor is very critical. Structural integrity of the seal welds and the hexcan sheath is very important as failure of these welds during service may result in separation of the fuel pins from the bundles. Qualifying such welds demands non-destructive inspection techniques. Radiographic technique limits the sensitivity due to the complex geometry and large material thickness in the cross section of the seal weld as compared to the thickness of the sheath. Hence an ultrasonic guided wave methodology was developed for the study of the seal weld quality. The use of guided waves and phased array techniques to perform inspection of these plates presents an interesting solution for defect detection and localization. Using the ultrasonic guided wave immersion technique, reference defects of the order of 6mm (L) x2mm (W) x1mm (D) were clearly detected in the hexcan sheath. Compared to the conventional angle beam inspection this methodology reduces the total amount of time required for scanning and is quite fast. The same method was employed on a hexcan seal weld having natural defects. In addition, imaging of ultrasonic guided wave results using color coded B-Scans is also considered a highly valuable tool for data interpretation. While the advantages of a commercial phased array ultrasonics include improved defect detection and imaging, easier interpretation of the defect signals displayed in an image format, faster inspections and identification of cracks. They have both the ability to perform focusing and present data in B or S-Scan formats. In this paper we present an experimental study for the implementation of ultrasonic guided wave and phased array systems for the inspection of weld defects in hexcan structures. The considerations for guided wave imaging are outlined in this work.

Introduction

The hexcans of Prototype Fast Breeder Reactor (PFBR) are made up of 3.3mm thick cold worked austenitic stainless steel. The fuel assembly consists of a seal weld which joins the 3.2mm thick hexcan sheath to the thick head sections of the fuel assembly. Due to the small dimension of the weld involved, the NDE technique employed should be very sensitive to detect defects of very fine size. However, the inspection of thin materials presents limitations mainly because of the combination of the required higher frequencies and the dead zones inherent to ultrasonic inspections. Guided waves in plates that are known as Lamb waves have great attention for the large area non-destructive inspection of thin plates. Guided waves provide a rapid mean of inspecting large areas of a structure with minimal measurement points. However, their interpretation often requires skilled inspectors, mainly because of their multimodal and dispersive nature. The use of Phased Array focusing as a mean to perform ultrasonic inspections has become very popular in the last few years. Representing the results of an inspection as an image often represents an excellent solution which helps in the easy identification of defects. Hence, a new methodology based on ultrasonic guided waves and phased array is developed for the inspection of the hexcan sheath as well as seal welds. Linear scan (depth focusing) was performed using a commercial phased array system. The developed methodology substantially reduces the total amount of scanning time required as compared with conventional angle beam inspection. The results of this study are presented for samples containing artificial defects in a 3.3mm stainless steel plate and the hexcan. Good detectability is obtained on both samples, highlighting the potential applications of guided waves and Phased Array.

Specimens for the experimental study

The material used for the inspection is an austenitic stainless steel. Three samples were inspected for the experimental study. Because of the hexcans complex geometry two reference samples were taken and named as B and C in order to select suitable frequency of the ultrasonic wave and establish required sensitivity.

Sample A

Shown in Fig. 1(a) is a hexcan welded sample which has natural defects like porosity. The hexcan consists of a 25mm thick region called the head and it is joined to the 3.3mm thick outer sheath by TIG welding process. Fig. 1(b) shows the position of the welds in the sample.

Sample B

In sample B, a 3.3mm plate is welded to a 16mm thick region as shown in Fig. 2. Reference defects like holes were...
made at a depth of 1.5mm in the weld region. Also notches of 300 micro meter width with varying length and breadth were made on the surface of the sample.

Sample C

In this sample EDM notches of 6mm (Length) x 2mm (Width) x 1mm (Depth) were created near the edges in the OD of the 3.3mm thick hexcan sheath as shown in Fig. 3

Table 1: Details of EDM notches with respect to a 3.3mm thick hexcan sheath in sample C

<table>
<thead>
<tr>
<th>Defect Number</th>
<th>Type</th>
<th>Orientation along the scan surface</th>
<th>Distance from the probe (mm)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surface breaking</td>
<td>Parallel</td>
<td>40</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Surface breaking</td>
<td>Perpendicular</td>
<td>42</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Surface breaking</td>
<td>Parallel</td>
<td>45</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Experimental Procedure

(1) Methodology for an ultrasonic guided wave based inspection

Lamb waves represent a group of guided ultrasonic wave modes propagating in an elastic plate. The wave propagates along the full thickness of the plate and is guided by the two surface of the plate. Such waves are also called as “Guided Waves” and are gaining sufficient importance in inspection of thin walled components. In order to select an appropriate angle and frequency a dispersion curve was plotted with the help of DISPERSE software. The modes can be represented in velocity versus frequency times thickness of the plate called dispersion curves as shown in Fig. 4. Phase velocity can be controlled by the angle of incident so that the phased velocity dispersion curves could be used to find the excitation conditions, such as frequency and angle of incident, of a desired mode. Group velocity indicates the wave propagation velocity so that it is possible to predict the wave propagation velocity of an excited mode under certain excitation conditions obtained from phased velocity dispersion curves. Since there are infinite Lamb wave modes in a steel plate, it is necessary to select a proper mode for the experimental purpose. Figure 4 shows the dispersion curves plotted for a stainless steel plate of 3.3mm thick.

The experiment was done by an ultrasonic guided wave immersion pulse echo method. An appropriate incident angle of 30 degree was selected for a probe frequency of 1 MHz from the dispersion curve shown in Fig. 5. A B-scan image is plotted by placing the probe at a distance of 40mm away from the notch as shown in Fig. 6 and moving the transducer parallel to the surface. Table 2 gives the various parameters chosen for Ultrasonic guided wave inspection.

![Fig. 4: Group and Phase velocity dispersion curves for a stainless steel plate of thickness 3.3mm.](image)

![Fig. 5: Dispersion curves for incident angle Vs Frequency thickness of a stainless steel plate of thickness 3.3mm](image)

Table 2: Parameters for Ultrasonic Guided wave Inspection

<table>
<thead>
<tr>
<th>Technique</th>
<th>Mode</th>
<th>Angle</th>
<th>Frequency</th>
<th>Scan Resolution</th>
<th>Phase Velocity</th>
<th>Group Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersion Guided Wave</td>
<td>S0</td>
<td>30°</td>
<td>1 MHz</td>
<td>0.2 mm</td>
<td>3019 m/s</td>
<td>2280 m/s</td>
</tr>
</tbody>
</table>

(2) Imaging by Phased Array

Phased array ultrasound has emerged as a rapid nondestructive evaluation technique for detection and imaging of crack like defects in structural components due to the flexibility it offers in varying the angle of inspection and/or focusing of the beam to a point of interest. The principle of phased array ultrasonic beam generation is based on the use of individual transducer elements that can each be independently driven with controlled phase delays of excitation. Using this phase delay, the parameters of the ultrasonic beam, such as the depth of focus and/or the beam angle can be varied while the testing is being carried out. The potential advantages of the phased array ultrasonics include improved defect detection and imaging, easier interpretation of the defect signals displayed in an image format, faster inspections and identification of cracks and metal loss due to corrosion and discrimination between metal loss and crack-like defects.

The illustration below shows how a beam can be focused at an angle and a given distance by firing the left elements...
slightly ahead of the corresponding elements on the right. It is possible to change the angle, focal distance, or focal spot size, simply by changing the timing to the various elements. Beam focusing and simultaneous beam steering-focusing is shown in Figs. 7(a) and (b) respectively. Figure 8 shows the block diagram of a typical phased array beam forming process.

**Experimental setup**

The experimental setup used in this study consists of the R/D Tech Omniscan MX ultrasonic Phased Array system. The main components of a Phased Array system are presented in Fig. 9(a) and the experimental setup of Phased Array system with hexcan sample is presented in Fig. 9(b).

**Experimental procedure for phased array inspection**

The experimental setup used in this study consists of the R/D Tech Omniscan MX ultrasonic Phased Array system. The data presented in this paper were acquired using a 17MHz, 128 elements probe. The inspection was carried out by fixing the phased array probe on to a probe holder which is immersed in water and manually moving the probe over the specimen. Defects were imaged by a linear scan mode over the weld region. Inspection was also carried out by contact method using a 60 degree shear wave plexi glass wedge as shown in Fig. 10. The wedge is placed on the region of 3.3mm thick away from the weld.

**Results and discussions**

Experiments were carried out by ultrasonic guided wave immersion pulse echo method as shown in Fig. 6. The B-Scan image of the 3.3mm thick hexcan sheath with the notches (sample C) is shown in Fig. 11. The reflections from the notches were clearly seen from the B-Scan image. The amplitude of the parallel notch 1 is higher because it is nearer
Fig. 9 : (a) Basic components of PA system (b) Experimental Set up

to the transducer compared to notch 3. The dimensions of the notches from the B-Scan are comparable with the theoretical values.

The notches in the edges of the seal welded hexcan are also detected. Figure 12 shows the A Scan image from the defective and non defective edge of the sample C. Figure 13. Shows the B-Scan image and the corresponding A-scan from the welded region of different faces of the welded Hexcan (sample A)

Experiments were carried out on the reference samples A and B using Phased array probe. The testing was carried out using 17MHz immersion probe which is placed normal to the sample. The B scan image of the hole of length 15mm from sample B is shown in fig 14. Here the probe axis is perpendicular to the weld axis. The reflection from the defect can be clearly seen in the B scan.

There were some notches with various length and width on the surface of the sample B. The notches are also clearly seen by the immersion PA method using 17MHz as shown in Fig. 15.

Same experiment was conducted on the Hexcan (sample A). Face 2 of the sample had multiple porosities which can

Fig. 10 : Inspection using 60 degree SW wedge

Fig. 11 : B Scan image of the Hexcan sheath (sample C) of 3.3mm thick stainless steel.
Fig. 12: A Scan image from the edge of the Hexcan (sample C) of 3.3mm thick stainless steel.

Fig. 13: B Scan image and the corresponding A scan at different faces of sample A.
Fig. 14: B scan Image of the 1.5mm dia hole from sample B. (a) Probe axis perpendicular to weld axis (b) Probe axis parallel to weld axis

Fig. 15: B-Scan image of notches on the surface

Fig. 16: B scan image of Sample A

Without defect (Face 1)                With defect (Face 2)

Fig 16. B scan image of Sample A
be clearly seen. Fig 16 shows a comparison between a defective weld and a non defective weld.

Conclusion

Defects like porosities and surface breaking defects like notches on the edges of the hexcan were imaged clearly using both guided wave ultrasonic immersion and phased array technique. Since phased array gives a live B scan image it is easy to position and size various defects. We are able to vary the focal length in a phased array system which gives an additional advantage over conventional UT methods. Simulated defects in reference samples were helpful in optimizing the method for conducting the test on the actual hexcan welded sample.

References

2. Ultrasound Phased Array Inspection Technology for the Evaluation of Friction Stir Welds André Lamarre, Michael MolesR/D Tech