ULTRASONIC IMAGING FOR TUBE TO TUBESHEET WELD JOINT IN HEAT EXCHANGERS

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Introduction

Larsen & Toubro (L & T) Limited is a reputed manufacturer of heat exchangers for many industries. One of the critical areas in heat exchangers, which should be addressed by non-destructive examination, is the tube-to-tubesheet weld joint. So far the industrial practice is to qualify the welding procedure by metallography on mock-up samples. The finished welds are tested by Liquid Penetrant Test and leak test (Pneumatic, Hydro or Helium). The QA & NDE Group of L&T has developed an ultrasonic examination technique to detect flaws such as lack of fusion, root run defect, porosity, inclusions and wormholes in the weld pool, etc. A conventional flaw detector, which presents the data in the form of A-scan, was used for this purpose. The ultrasonic examination is based on scanning the entire volume of weld by immersion normal beam technique. The objective of the present study is to assess the feasibility of generation of ultrasonic images by digitizing, storing and processing the A-scan data using the ULTIMA 100 + Ultrasonic Imaging System, developed BARC. This report describes the experimental set-up used for this study, the salient features of ultrasonic imaging system and the methodology used for generation of ultrasonic images. The results obtained during the above investigation are also discussed.

Ultrasonic Imaging Using ULTIMA 100+ System

The conventional flaw detector used for routine ultrasonic examination presents the data in the form of A-scan. It gives the information about the depth of the defect (X-axis) and amplitude of reflected wave from the defect (Y-axis) on an oscilloscope. The A-scan presentation is unique to a particular location, and with the conventional flaw detector this information is lost as the probe is moved to another location.

With the advancements in the electronics and computer technology, it is possible to present the ultrasonic data in the form of images. Ultrasonic imaging of components offers many advantages. The information regarding presence or absence of flaws in the inspected volume of the component is presented in the form of a single image. Sizing of defects or any other feature like weld length can be done more easily and accurately from ultrasonic images. However, special instruments are required for data collection and analysis. The ULTIMA 100+ ultrasonic imaging system, developed by Electronics Division, BARC, consists of (i) Pulser-Receiver module, (ii) 100 MHz Analog to Digital Converter (ADC), and (iii) Data Acquisition and Processing Software. The Pulser-Receiver module generates high frequency signals for exciting ultrasonic probes. The reflected signals from the component are amplified by receiver circuit and sent to Analog-to-Digital Converter. These A-scan signals are sampled at the rate of 100MHz (max.) and, if required, stored in computer’s memory. The Data Acquisition Software generates ultrasonic images, viz. B-scan and C-scan from A-scan data.

The B-scan image is generated by moving the probe along a line (or circumference for tubular products). During this motion, A-scan data is collected at fixed intervals and stored in the computer’s memory. The data acquisition software processes all the A-
scans to form the B-scan image. In ULTIMA 100+ system, the horizontal axis on the B-scan image represents the probe travel and the vertical axis represents the depth. Since the B-scan image corresponds to the data collected along a line, it gives the cross-sectional view of the object. B-scan image gives information regarding depth of the defect, its size along the probe motion and amplitude of reflected signal in terms of colour or gray scale on the image. In ULTIMA 100+ system, the B-scan image can be collected by moving the probe either manually or through stepper motors. However, for sizing of the indications from the image (defect or any other feature), it is required that the speed of probe movement is same as the speed of data acquisition. This is achieved by using stepper motors for probe movement and interfacing the motor drivers with the imaging system.

The C-scan image is generated by moving the probe along several lines over the surface of the component in a raster-type manner. During the motion, B-scan data is collected and stored for individual lines. The data acquisition software processes all the B-scans to form a C-scan image.

Since the C-scan image corresponds to data collected over a surface, it gives the plan view of the object. It is similar to the view obtained in radiography. In ULTIMA 100+ system, the horizontal axis on the C-scan image represents the principal direction of probe movement while the vertical axis represents the direction in which the increment is given. Unlike B-scan imaging, C-scan imaging requires movement of probe through stepper motors.

For tubular products, C-scan is generated by first moving the probe through 360°, then indexing it by fixed amount in axial direction and then again moving it by 360°. This cycle is repeated till the entire region of interest is covered. Alternatively, the probe can also be moved first in axial direction with the indexing in the circumferential direction. The amount of increment (indexing) is decided by the size of the ultrasonic beam and the overlap required.

Experimental Set-up

The ultrasonic examination of the tube-to-tubesheet weld joint is carried out from inside surface of the tube. During the examination, a constant water column was maintained between the probe and the tube inside surface. Fig. 1 shows the experimental set up used for carrying out present investigation. It consists of (i) ultrasonic normal beam immersion probe (15 MHz frequency, point focussed), which acts as both transmitter and receiver, (ii) acoustic mirror, which reflects the beam coming from the probe so that it is incident at 90° to the tube ID surface, (iii) sealed water jacket for providing water column between the probe and the tube ID surface, since this inspection is carried out in immersion condition, (iv) DC motor for rotation of the mirror, so that entire volume of the weld is inspected, (v) probe fixtures assembly for sealing and holding the probe, (vi) pulse-preamplifier for amplification of received signals, and (vii) ULTIMA 100+ system.

The tube used for this study was AISI 316 Stainless Steel, having 25mm OD and 2.7 mm wall thickness. It was welded to the tubesheet by TIG welding process. Four reference defects, viz. (i) three side-drilled holes of 0.8 mm dia., 1.5 mm dia. and 2.0 mm dia., and (ii) a flat bottom hole 2.0 mm dia., were introduced in the weld. In addition to this, the weld also had a natural defect got introduced in it during welding. These defects were at different circumferential orientations.

To begin with, A-scan data is collected at various locations in the tube. This also included the locations, where natural and artificial defects are present. This is done to set up the instrument parameters like sampling rate, amplifier gain, delay, averaging, high & low pass filters, etc. for getting a clear signal from the defects.

For B-scan imaging, the probe is moved axially along a line so that it intercepts the defect along its path. This movement is made manually. The B-scan image is collected both while pushing the probe into the tube and retracting it.
Results and Discussion

At any location in the tube, the ultrasonic beam first encounters the tube ID producing a strong interface signal on the screen. Any other indication, either due to defects in the weld or due to lack of fusion at tube OD, will appear after the interface signal. Fig. 2 shows the A-scan presentation at an axial tube location away from the weld. The first indication is from tube ID and the successive indications (of smaller amplitude) are from tube OD. The distance between these indications represents the wall thickness of the tube. This presentation indicates that the probe is not in weld region. Fig. 3 shows the A-scan presentation at the weld region. At this location, only the indication from tube ID is obtained. Since there is no other indication following the tube ID indication, it indicates that the weld is sound in this region. Fig. 4 to 7 represent A-scan presentations at reference defects viz., 0.8 mm diameter side-drilled hole (SDH), 1.5 mm dia. side-drilled hole, 2.0 mm side-drilled hole and 2.0 mm flat bottom hole (FBH). In all these cases, a distinct indication is obtained after the tube ID indication.

Fig. 8 represents A-scan display at the location of natural weld defect. This defect got introduced in the weld pool during welding. In this case too, a distinct indication is obtained after the tube ID indication. The depth of this defect from tube ID surface can be found out from the A-scan display with the help of cursors. In all the above cases, the defect indications were clearly resolved from the tube ID indication. Fig. 9 represents the B-scan image, when the probe is pushed from the location of weld to deep inside the tube. Fig. 10 represents the B-scan image while retracting the probe from the tube. The A-scan display at flat bottom hole location is shown alongside. At any location during the probe movement, the first indication is from tube ID. This indication appears throughout the scan length and is shown by the top line on the image. The step in this indication at some locations is due to the change in water path because of improper centering of the probe during movement. This change was observed to be of the order of 0.15 mm. Due to the high sampling rate of the system, this minor change was also evident on the image. Indication from flat bottom hole appears on the image as the probe is moved to this location in the weld. Similarly, indication from tube OD is observed when probe is taken out of the weld region.
**Conclusion**

The above study indicates that,

1. The ULTIMA 100+ system is able to detect the defects in the tube-to-tubesheet weld joint.

2. The indications from these defects are clearly resolved from the tube ID indication.

3. It is possible to generate B-scan image by using ULTIMA 100+ ultrasonic imaging system for tube-to-tubesheet weld joint.

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**Fig. 2** A-scan at tube location showing multiple reflections from tube OD

**Fig. 3** A-scan in the weld region free of defects

**Fig. 4** A-scan at 0.8mm dia. SDH location

**Fig. 5** A-scan at 1.5mm dia. SDH location
Fig. 6  A-scan at 2mm dia. SDH location

Fig. 7  A-scan at 2mm dia. FBH location

Fig. 8  A-scan at natural defect location

Fig. 9  B-scan image of tube to tubesheet weld mock-up showing 2mm dia. FBH

Fig. 10  B-scan image of tube to tubesheet weld mock-up showing 2mm dia. FBH