Proceedings of the National Seminar & Exhibition on Non-Destructive Evaluation
NDE 2011, December 8-10, 2011

FUEL TUBE SPACER-PAD SPOT-WELD QUALITY ESTIMATION USING GUIDED ULTRASONIC WAVES

P. Suresh and Krishnan Balasubramaniam
Centre for Non Destructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology, Chennai 600 036, INDIA

ABSTRACT

A guided wave technique for quality analysis of the spot weld spacer pad on the Pressurized Heavy Water Reactor(PHWR) fuel tubes using the strength of signal energy that is reflected from the welds is discussed here. The development of a real-time ultrasonic system for spot weld quality monitoring for the fuel tube, potentially allows for the elimination of expensive destructive testing, reduce the amount of time-consuming off-line ultrasonic inspections and ensures quality and reliability during operation. Due to the rather small spot size of these welds (less than 2 mm in diameter), the current methods such as ultrasonic scanning were found to be difficult to implement, particularly under production conditions Hence, a guided wave method was explored in this work that has the potential to be implemented in the welding . A fixture was developed in order to generate L (0, 1) mode in the wall of the tube and travelling along the length of the tube. Couplant was not used and instead uniform pressure was applied to ensure the coupling of the wave into the tube. The experimentally obtained guided wave reflected signals were correlated destructive assays. The main goal of such testing systems is to reduce operational time and provide reliable means of quality inspection.

Keywords: Ultrasonic Guided Waves, Fuel Pin, Fuel Tube, Spacer Pad, and PHWR, Non-Destructive Testing.

INTRODUCTION

The spacer pads are spot welded on to the fuel tubes in the Pressurised Heavy Water Reactors (PHWR), also often called as the CANDU reactors. Spacer pad welding is basically resistance spot type welding. The spacers are used to provide necessary spacing between the fuel pins in a fuel pin subassembly. The spacer pad allows for the coolant fluid to flow un-hindered around the fuel pins/tubes. However, due to the vibration during operation, that causes fretting stresses on the weld, the welds undergo severe dynamic loading. Any failure of the welds can lead to contact between the fuel pins/ tubes, and more importantly a loose pad in the fluid poses a serious risk of collateral damage. Typically, there are 5 spacer pads in each fuel tube and each spacer pad is welded in two spots to the fuel pin/tube. Hence, each tube has 10 welds around the circumference of the tube, at mid-length region of the tube as shown in Fig.1. The aim this work will be to explore the feasibility of using guided ultrasonic wave modes as a tool for quality control of the spot welds, with the long term objective for implementation of the findings in developing an on-line tool for the in-process control of the spot welding.

PREVIOUS WORK ON FUEL TUBE AND SPOT WELD INSPECTION

Stocco et al [1] has explored a technique that incorporates the ultrasonic probe inside the welding electrode thus allowing longitudinal ultrasonic waves to pass through the spot weld during the welding process. The time separation between the waves reflected from different boundaries of the weld was shown to be proportional to the physical distances between

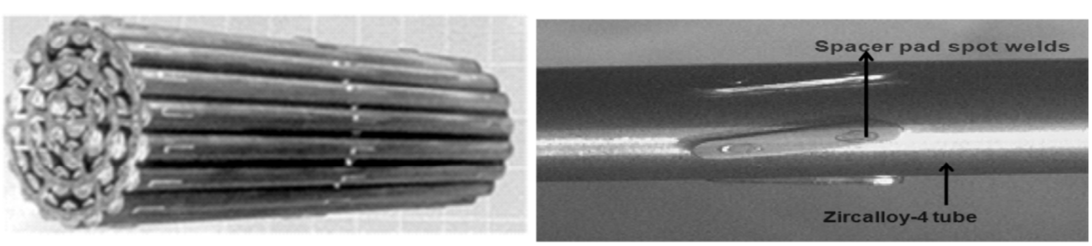

Fig. 1 : Bundle of fuel tubes and single spacer pad welded fuel tube used in the PHWR.

these interfaces. Based on the time of flight measurements, it is shown to be possible to determine the degree of penetration of the nugget into each of the welded plates and the thickness of the weld relative to the total stack-up thickness. Cheong et al [2] has explored, they made artificially notches in the fuel tube along the axis and circumferential direction of the PHWR pipes and implementation of axial guided wave technique and circumferential guided wave techniques were used to examined the signal from both notches with help of L(0,1), L(0,2) and F(1,1) and F(1,2) guided wave modes. Polajnar et al [3] reports on an acoustic emission technique for the weld quality monitoring. They have correlated the welding parameters with acoustic emission signal features. The acoustic emission signal features were said to be related to the physical changes of the weld spot and the electrodes, due to heating as well as cooling. However, the application of this technique in the manufacturing facility may be limited unless the detrimental aspects of the ambient noise levels present during manufacturing can be addressed.

GUIDED WAVES IN TUBES

Guided waves as such excited in a hollow cylindrical structure like pipe, at a particular frequency, may result in generation of number of wave modes travelling at different velocities. Not all modes are sensitive to defects or flaws to the same degree and the dispersive (i.e. variation of group velocity with frequency) nature of certain modes makes it difficult to interpret the signal. [4-8] Due to dispersion effect, the compact nature of the input pulse is modified and the signal duration increases, which in turn reduces the detectable zone for defects. So it is necessary to identify the modes that are somewhat non-dispersive in nature, which helps in better interpretation of signals that may be reflected from the spot welds on the fuel tube.

The dispersion curve for the Zircalloy fuel tube is shown in Fig 2 a, b. In can be observed that, two modes i.e. the longitudinal L (0, 2) and the flexural F (1, 2) are generated together and the two modes are relatively non-dispersive within a particular range of frequencies (1.0 MHz to 2.5 MHz). These wave modes travel at a group velocity of around 2300 m/s. The ultrasonic guided wave technique, longitudinal L(0, 2) propagates along the axial direction to the tube and will be influenced by boundary conditions such as a spot weld. If this wave mode can be used to continuously monitor the welding process then incremental change in the ultrasonic guided wave reflected signal from that is expected to provide information on the quality each spot weld. Conventionally, during fabrication of the spot welds, the weld quality has been optimised by selecting the appropriate average normal pressure, as applied by the welding electrodes, the duration of the welding, and the amount of electric power provided across the electrodes. In this paper, a feasibility study was conducted to correlate the ultrasonic guided wave signals, which are reflected from the welds, with the welding parameters, such as the pressure and power provided to the welding electrodes.

EXPERIMENTAL SETUP

The experimental setup was developed to generate and receive L (0,2) guided wave as shown in Fig 3. The Pulser-Receiver Olympus NDT 5077 that produces a square wave input to a 2.25 MHz normal transducers was employed for generating the wave modes. The NI DAQ USB5133 8 bit digitizer was used for data acquisition at its maximum sampling frequency of 100MHz. The data was collected, archived, and analysed in a PC using Lab view software. This software also computes the average reflected sound energy and the peak-to-peak amplitude of a gated signal that was received from the weld. No Couplant was used in the experiment. Instead the apparatus was designed to produce a controlled axi-symmetric pressure between the transducer face plate and the end of the fuel tube. The other end of the tube was butted against a high contrast material. Since Longitudinal wave transducers were used axially in the tube, as shown in Fig 4, which produced out-of-plane displacements of the face-plate, when coupled to the end of the tube, the L (0, 2) mode guided wave propagates along the axial direction of fuel tubes. When there is a change in the impedance, caused by any change in the cross-sectional geometry (such as the spot welds) or by defects in the tube or by discontinuities such as at the far end of the tube, the propagating wave reflects and travels in the opposite direction. These reflected wave modes are detected by the same transducer (that was used for generation) in a pulse-echo mode.

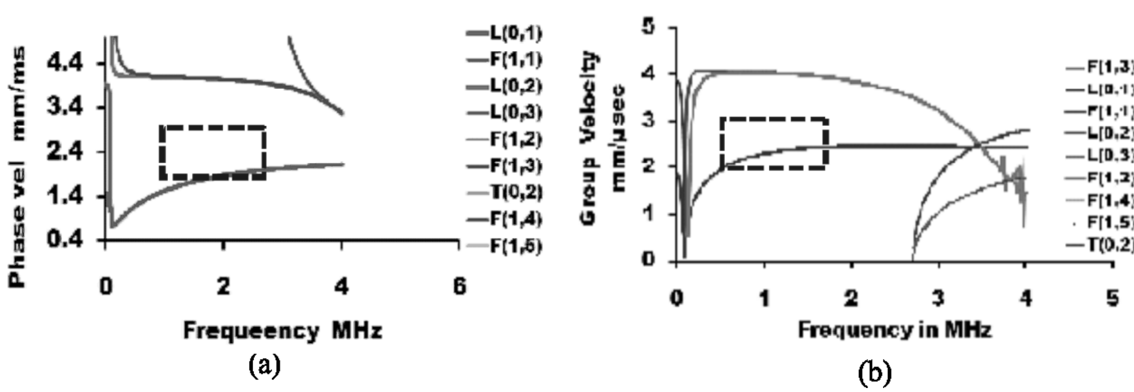

Fig. 2 : Dispersion curves for Zircalloy-4 tube (diameter 15.25mm and thickness 0.5 mm) (a) phase velocity, and (b) group velocity plots.

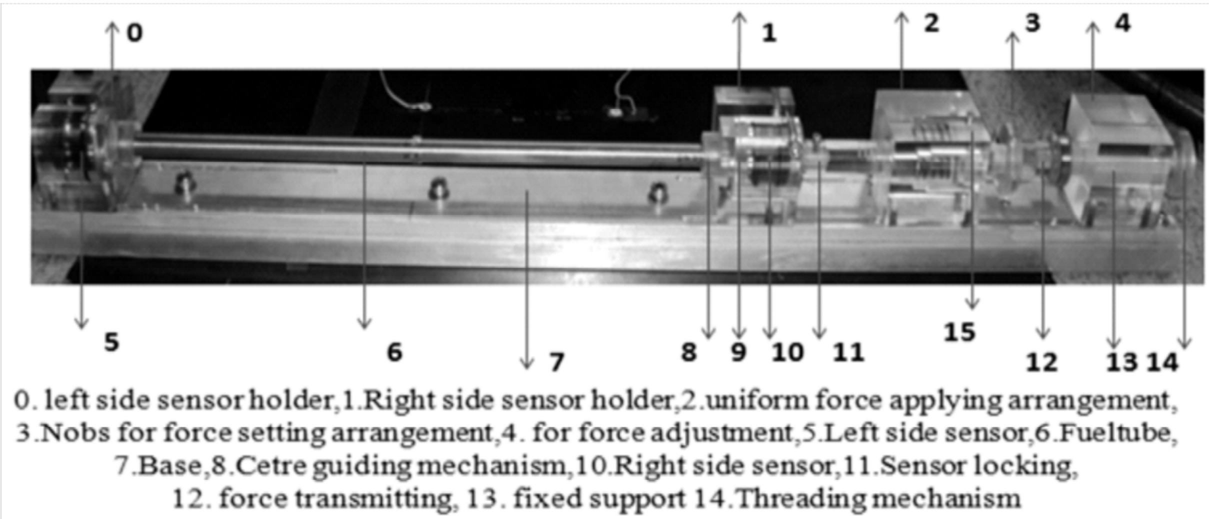

Fig. 3 : Photograph of the experimental setup used for generation and reception of guided waves.

The different reflected wave modes are distinguished by computing the time-of-arrival of the individual mode packets. During the interactions of the wave with discontinuities, the possibility of mode conversions to other wave modes is a possibility. However, in this case, the primary modes that are generated will be either the L (0, 2) mode or the F (1, 2) modes, both travelling at the same velocity. Hence, the reflected and the mode-converted modes were found to arrive together and were not distinguishable.

SAMPLE PREPARATION DESCRIPTION

Two sets of samples were prepared. In the first set, the weld parameters were fixed, power 110 Ws and pressure at 2 kg/cm^{2,} but with different number of spot welds were Prepared as shown in Table 1. Subsequently, in the second set, samples with varying weld parameters (Pressure, in kg/cm^2, and Power, in Ws, applied on the electrodes) using a design-of-experiments (DoE) was fabricated as shown in Table 2. Each tube has 5 spacer pads at the middle of tube along the circumferential direction; each spacer pad has two spot welds and distance between the two spot welds are approximately 4.75 mm to 5 mm. length. The diameter and thickness of the both tubes (welded tube, plain tube) are same.

Table 1 : No of pair of weld and weld parameters on the fuel tube

No of Pair of weld	*Weld parameter in Ws & kg / cm^2*
Single pair	110 , 2
Double pair	110 , 2
Triple pair	110 , 2
Six pair	110 , 2

RESULTS AND DISCUSSION

A 2.25MHz transducer was used to generate the ultrasonic guided wave mode L(0,2) in the axial direction to the tubes during pulse echo mode and the received signal was filtered using a band pass filter with a low cut off frequency of 1.00 MHz and a high cut off frequency range of 4MHz. The ranges of filter frequency and the amplified gain value should be constant for all the tubes for all experiments conducted. The velocity of the wave was measured, using a fuel tube without any welds, to be equal to 4030 m/s. A typical A-scan screen-shot of the signals obtained from a weld free tube is shown in

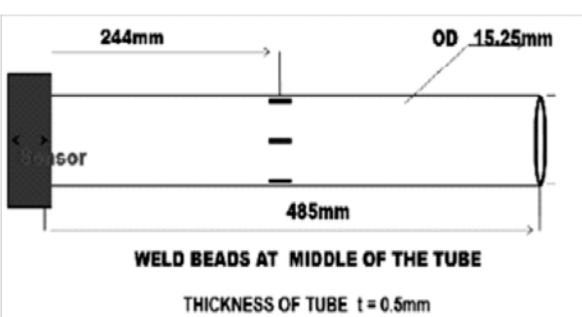

Fig. 4 : Dimensions of the fuel tube

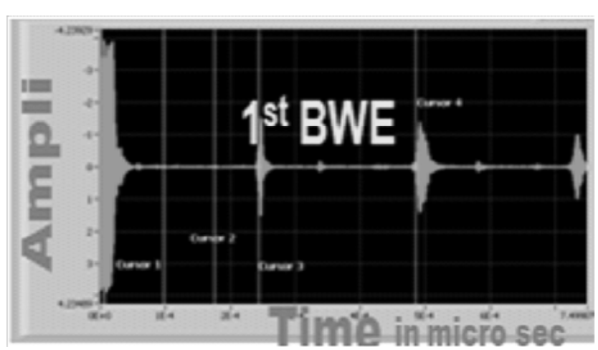

Fig. 5

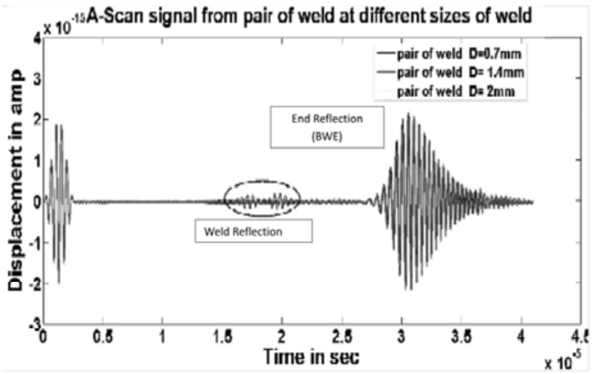

Fig. 6

Fig. 5. The presence of multiple reflected echoes (called back wall echo or BWE to maintain the conventional pulse echo inspection terminologies) shows that there is minimal loss in the wave energy and the fact that there is broadening of the wave packet which shows that the wave mode is dispersive.

In Fig. 6, the simulated signal from a tube containing a 3pair of weld with 3 different diameters of the pair of spot weld is shown along with the end reflection (i.e. 1st BWE). It can be observed that as the size of the spot welds increases, the energy in the weld reflections increases.The results from the 1st set of samples with fixed weld parameters i.e. power 110 Ws to produce heat and applied pressure 2 kg/cm^2, but with increasing number of weld pairs is summarized in Fig. 7. It can be observed that as the number of welds increases, the average energy of the signal reflected from the weld increases.The reflected sound energy were collected from the 2nd set of samples all of which had 5 pairs of welds at middle of the tube and the weld parameters for each tube was varied using the DoE as shown in the Table 2.

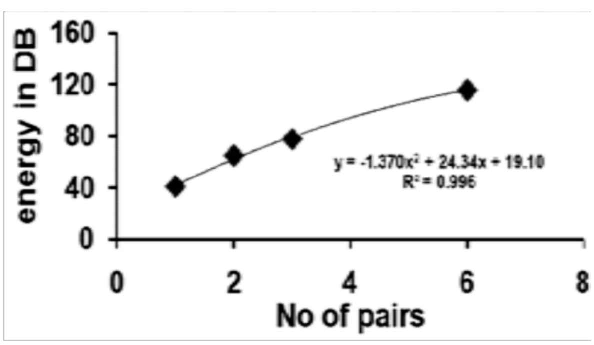

Fig. 7

Table 2 : Variable parameters of weld and the correspondingly reflected energy from the welded tube

No of Pair of weld	*Weld parameter In Ws& kg / cm^2*	*Reflected sound energy(RE) from weld in dB*
Five pair	90 , 1.5	47
Five pair	90 , 2.5	59
Five pair	90, 3.5	84
Five pair	110 ,1.5	73
Five pair	110 ,2.5	86
Five pair	110, 3.5	102
Five pair	150, 1.5	88
Five pair	150, 2.5	108
Five pair	150, 3.5	124

Fig. 8 shows the reflected energy vs. applied pressure for the 9 welded fuel tubes, as described in the Table 2, for three different power settings. The 3 plots show that at each power, there is a monotonically increasing relationship between the applied pressure and the ultrasonically measured reflected energy parameter. In Fig. 9, the same data is plotted with all the data on the sample plot in order to understand the relationship between the ultrasonic reflected energy and applied pressure and applied power during the welding. It is clearly observed that as the power or the pressure increases, the reflected energy increases, which may be attributed to an increase in the size of the spot weld diameter.

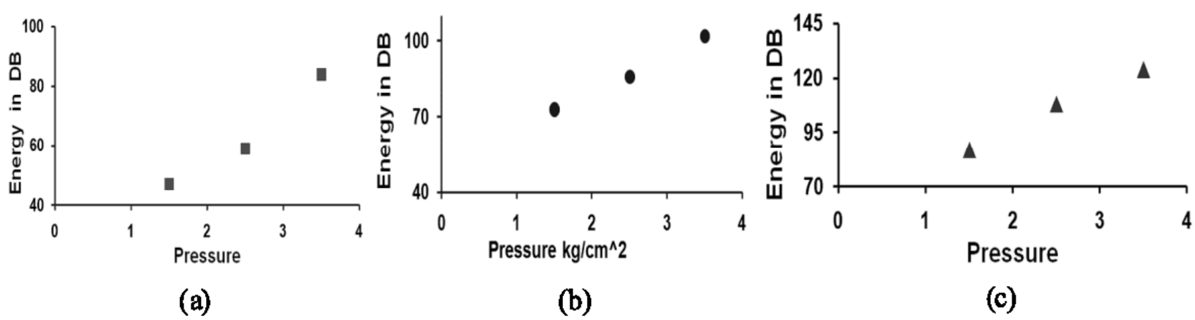

Fig. 8 : Pressure vs. reflected energy from welded tube based on table 2. (a). 90Ws, (b).110Ws, (c).150Ws

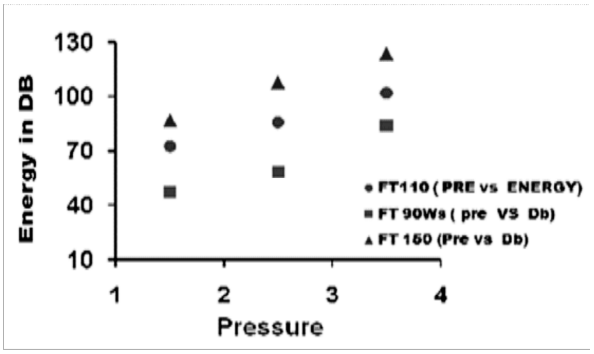

Fig. 9 : Shows the Energy of the reflected signal vs. Applied Pressure and Power to the electrodes for the 9 welded tubes of sample set 2.

CONCLUSIONS

An guided wave technique using the L (0,2) mode was used to related the energy of the signal reflected from spot welds in PHWR spacer pad welds to the welding parameters was explored here. Using a set of samples, it was shown that as the number pairs of weld increases, correspondingly the reflected energy also increases. Using a second set of samples, it was observed that as the welding power or pressure (applied to the welding electrode) increases, the ultrasonic reflected energy also increases. Thus, by measuring the reflected energy from the weld region, it should be feasible to classify whether the welding parameters are within a specified values. Since the experimental setup was designed to work without any ultrasonic Couplant, this technique has the potential for implementation in the manufacturing line as an online weld process control tool.

ACKNOWLEDGEMENT

The authors thank Mr. B. Prahlad and his colleagues at NFC, Hyderabad, for fabrication of the test samples and BRNS, Mumbai for funding this project.

REFERENCES

1. D.Stocco., R. Gr., Maev., A. M.,Chertov, G. F. Batalha, “Comparison between in - line ultrasonic monitoring of the spot weld quality and conventional NDT methods applied in a real production environment.17th World Conference on Non-destructive Testing, Shanghai, China. (2008)
2. Y. Cheong., D. Lee., H. Jung. “Ultrasonic guided wave parameters for detection of axial cracks in feeder pipes of PHWR nuclear power plants”, Ultrasonics 42 883–888(2004).
3. I. Polajnar., E. A., Esmail., T. Kek., J. Grum.,**”** Effect of various sensor setting up for Acoustic Emission detection during resistance spot welding”, The 10th International Conference of the Slovenian Society for Non-Destructive Testing-Application of Contemporary Non-Destructive Testing in Engineering« September 1-3,Ljubljana, Slovenia, 399-406 (2009).
4. S. Furuhashi., K. Sorimachi., and T. Sugiura., “Change in mode configurations and propagation velocity of guided waves through an elbow section of a pipe, IEEE International Ultrasonic Symposium. 2211-2214 (2010).
5. J L. Rose, “Ultrasonic waves in solid Media”, Cambridge University Press, 1999, pp. 24.
6. W. Mohr., P. Holler. “On Inspection of Thin-Walled Tubes for Transverse and Longitudinal Flaws by Guided Ultrasonic Waves”, IEEE transactions on Sonics and ultrasonics, su-23, no. s, (1976).
7. J. L. Rose., P. Catton., P. Mudge., D. D’Zurko., Improved Methodology for Guided Wave Inspections of Pipelines, Pipeline Gas journal, June(2008).
8. Ik-Keun PARK., Yong-Kwon KIM., Sae-Jun PARK., Yeon-Shik AHN., Application of Ultrasonic Guided Wave to Heat Exchanger Tubes, Inspection 17th World Conference on Nondestructive Testing, Shanghai, China, 25-28 Oct 2008.
9. J. Ruisz., J. Biber., M. Loipetsberger., Quality evaluation in resistance spot welding by analysing the weld fingerprint on metal bands by computer vision, Int J Adv Manuf Technol 33; 952 -960(2007).