Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Improved Defect Detection Capability of Guided Wave Testing Boiler Spines at Heysham 1 and Hartlepool Nuclear Power Station

John Jian
NDT Group, SIB
EDF Energy
Gloucester, UK
john.jian@edf-energy.com

***Abstract*— Teletest Guided Wave Testing (GWT) has been used to inspect the boiler spines at EDF Energy nuclear power plants in the UK. The Teletest tool used is intended to generate and receive torsional mode waves and the operating software calculated the relevant GWT modes. Due to the complexity of the boiler spines, received responses are very complicated and quite individual across of the 32 spines under inspection. A new data processing technique called "Full Wave" is developed and has been used to process all Finite Element Modelling data [1, 2], showing better defect detection capability, and on real inspection data [3] shows smaller variability for measurements on an individual spine and good reproducibility across the 32 spines.**

Keywords—guided wave testing, torsional mode, defect detection capability, full wave

I. Introduction

Since 2004, Guided Wave Testing (GWT) has been applied to the 32 pod boiler spines, as shown in Fig 1, at Heysham and Hartlepool Advanced Gas-cooled Reactor power stations, using a removable guided wave bracelet. Following the discovery of a defect in 2013 on the boiler spine 1D1 at Heysham 1, High Temperature Permamount (HTP) bracelets were installed in 2014 on all of the 32 boiler spines at both stations, except for HYA 1D1, which allows for on-load monitoring and quick cold data collection at a refueling outage.

The removable and permanently installed GWT tools are designed to generate and receive torsional mode guided waves and the operating software calculates the relevant GWT modes. Torsional mode suitable for the long range guided wave measurements, with desirable defect detection capability was identified through modelling and then and used for defect detection. TWI developed the Finite Element Method (FEM) modelling software for the GWT inspection of the boiler spines and quantified indicative defect detection capabilities at the welds concerned [1], based on criteria of 6dB signal amplitude increase of torsional mode responses over a defect free baseline signal from the region concerned.

II. Problem Statement

Some spines produce weak GWT signals from the mid-section change in spine geometry (around weld 12.3) as shown in Fig 2, and some spines produce weak GWT signals that are reflected from the spine end as shown in Fig 3. It has been observed that there is a high degree of variability in the guided wave response for some spines, over a period of several years. It would be good that the root cause is understood and a solution is found so that signal to noise ratios and consistency of GWT responses across the 32 spines is improved.

III. Improvement

A HTP tools is composed of 3 rings and each ring contains several transducers. In total, there are 24 channels. The dispersion curves and the required array transducer excitation drives for the symmetric torsional mode, horizontal and vertical flexural modes can all be calculated theoretically.

Unlike a simple pipe, the boiler spine to be inspected has a complicated geometry as shown in Figure 1. There are many attachments to the spine, such supporting arms and tubes, and section wall thickness changes and penetrations from where a HTP tool sits on the end of the spine.

The received GWT response is very complicated. Mockup trials has been carried out to find out how these modes change with defect cross section area and a torsional mode was selected because torsional mode amplitude increases with defect cross section area. Self-normalization is introduced so that the effect of variable transducer generation and receiving efficiency, and coupling can be reduced. However, even with these measure in place, the SNR is not optimal.

A new data processing technique has been proposed, named "Full Wave", which aims to reduce the variability and to improve the signal to noise ratio. Initial results were presented at the Quantitative Non-Destructive Evaluation (QNDE) conference in 2018. As shown in Fig 2 and 3, improvements in signal to noise ratio and consistency of guided wave signals have been achieved [2].

IV. Results

A. Defect detection capability study using FEM data

The TWI FEM modelling data [1] was processed with the Full Wave technique and the conventional torsional mode technique, and Table I presents the results of indicative defect detection capabilities of fully penetrating and part circumferential defects. Much better defect detection capability has been achieved with the Full Wave technique.

B. Defect detection capability study suing mockup trial data

Then the 2015 boiler spine mock-up trial data was processed. Again better detection capabilities with the Full Wave technique were found [4].

C. GWT variability study using real inspection data

The criteria of 6 dB signal amplitude increase has been applied in previous work based on finite element modelling, mockup trial and experience of evidences from data analysis.

All real GWT inspection data on the 32 spines from 2014 to 2019 was processed with the Full Wave technique and the conventional torsional mode technique. Enhancement, in terms of signal amplitude and signal to noise ratio for GWT responses from weld 12.3 and spine end across the 32 spines, has been demonstrated [4]. Shown in Table II are standard deviations of GWT response amplitudes from weld 12.3 [4]. Some points can be made here

- For most spines, standard deviations with the Full Wave technique are smaller, 1.5dB in average compared to 1.7dB with the conventional torsional technique.
- For those spines of higher standard deviation with the Full Wave technique, it is just about 0.1 or 0.2dB (0.3dB for HRA 1A2 at 1.5dB).
- With the torsional technique, 6 spines have a standard deviations bigger than 2dB, compared to 2 spines (2.0 and 2.4 dB respectively) with the Full Wave technique.
- The maximum standard deviation is 3 dB (HRA 1D1) with the conventional torsional technique. This justifies the criteria of 6dB signal increase at 95% confidence.
- The maximum standard deviation is 2.4dB (HRA 1D1) with the Full Wave technique. A criterion of 5dB may be applied implying a further improvement on defect detection capability as shown in Table I [4].

V. CONCLUSIONS

Improvements are needed on GWT inspection of the 32 pod boiler spines at two EDF Energy nuclear power stations. A new data processing technique named the Full Wave has been developed and used to process FEM modelling data, mockup trial data and real inspection data, from 2014 to 2019, across all the 32 boiler spines at EDF Energy nuclear power stations, resulting in enhanced responses from weld 12.3 and spine end and improved signal to noise ratio and reduced variability.

A criterion of a 6 dB signal amplitude increase has been justified, for use with the conventional torsional wave technique and the Full Wave technique. Significant enhancement of defect detection capabilities has been achieved with the use of the Full Wave technique over the conventional torsional technique. At 95% confidence level, a criterion of 5dB may be applied, which implies a further improvement on defect detection capabilities.

TABLE I. RESULTS OF FEM MODELL OF FULLY PENETRATING AND PART CIRCUMFERENTIAL DEFCETS IN CROSS SECTION AREA (CSA)

Technique	W12.3 upper heat affected zone	W12.3 centre line	W12.3 lower heat affected zone
Full wave @ 6dB criteria	≈17.4%CSA	≈24.4%CSA	<17%CSA
Torsional @ 6dB criteria	≈27%CSA	≈36-45%CSA	≈23% CSA
Full wave @ 5dB criteria	≈9.8%CSA	≈19.1%CSA	<13.4%CSA

TABLE II. STANDARD DEVIATIONS IN DB OF REAL INSPECTION OF 32 SPINES AT EDF ENERGY NUCLEAR POWER PLANTS

Index	**Spines**	**torsional mode**	**full wave**
1	**HRA 1A1**	1.9	1.3
2	**HRA 1A2**	1.2	1.5
3	**HRA 1B1**	1.4	1.6
4	**HRA 1B2**	1.5	1.5
5	**HRA 1C1**	1.8	1.9
6	**HRA 1C2**	1.8	1.7
7	**HRA 1D1**	3.0	2.4
8	**HRA 1D2**	1.6	1.2
9	**HRA 2A1**	1.8	1.9
10	**HRA 2A2**	2.8	1.7
11	**HRA 2B1**	0.9	0.8
12	**HRA 2B2**	1.8	1.7
13	**HRA 2C1**	2.3	1.6
14	**HRA 2C2**	1.7	1.0
15	**HRA 2D1**	2.7	1.5
16	**HRA 2D2**	1.9	1.9
17	**HYA 1A1**	1.4	1.2
28	**HYA 1A2**	2.2	2.0
19	**HYA 1B1**	1.0	1.0
20	**HYA 1B2**	1.2	0.9
21	**HYA 1C1**	1.5	1.6
22	**HYA 1C2**	1.0	1.1
23	**HYA 1D1**	0.8	0.8
24	**HYA 1D2**	2.0	1.3
25	**HYA 2A1**	1.0	1.0
26	**HYA 2A2**	2.0	2.0
27	**HYA 2B1**	1.9	1.4
28	**HYA 2B2**	1.3	1.2
29	**HYA 2C1**	1.5	1.7
30	**HYA 2C2**	1.7	1.9
31	**HYA 2D1**	2.7	1.3
32	**HYA 2D2**	1.9	1.5
Average		**1.7**	**1.5**

Fig. 1. Diagram of a pod boiler.

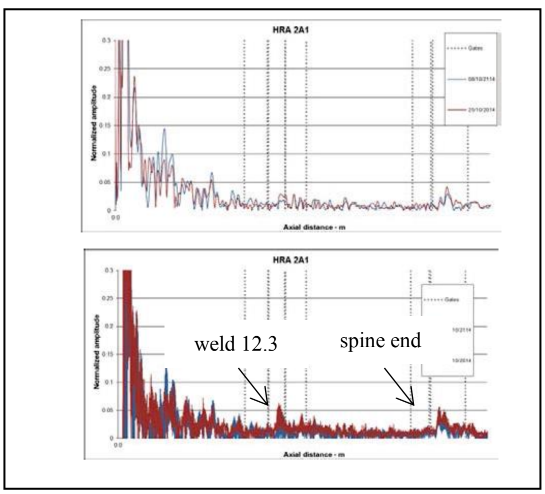

Fig. 2. Weak response at weld 12.3 with torsional mode (top) and enhancement with Full Wave (bottom) .

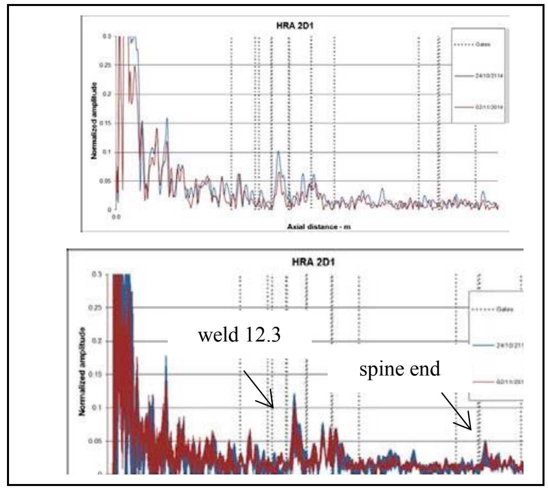

Fig. 3. Weak response at spine end with torsional mode (top) and enhancement with Full Wave (bottom) .

ACKNOWLEDGMENT

Thanks are due to Nick Farrant from Eddify/TWI for his high quality work on GWT inspection of boiler spines at EDF Energy nuclear power plants for more than 20 years.

REFERENCES

[1] R Sanderson, E Hutchison, J Allwright, TWI report 24441-9-15 V06, Parametric modelling study to investigate guided wave inspection sensitivity in boiler spines, CDMS 2015.

[2] J Jian, A Stansfield, D Chapman, Improved Guided Wave Inspection of Complicated Components – EDF Energy Heysham 1 and Hartlepool station boiler spine, Quantitative Non-Destructive Evaluation (QNDE) 2018, Burlington, Vermont, July 2018.

[3] J Jian, Investigation of Guided Wave Inspection Sensitivity of Part Circumferential Defect in Boiler Spine, EDF Energy E/EAN/BBIB/0218/AGR/18, 2018.

[4] J Jian, Review of Cold GWT Boiler Spine Inspections at Heysham 1 and Hartlepool Power Station, EDF Energy E/REP/BBIB/0063/GEN/19, 2019.