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Improved Guided Wave Inspection Of Complicated Components – Pod Boiler Spines at EDF Energy Heysham 1 and Hartlepool Advanced Gas-cooled Reactor Power Stations

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Abstract. Guided Wave Testing (GWT) has been widely applied in pipe line screening for corrosion, where torsion mode T(0,1) and flexural mode F(1,2) are used, yet there is very few publication of its use for inspection in nuclear industry. GWT inspection of 32 pod boiler spines of the 4 Advanced Gas-cooled Reactors at Heysham 1 and Hartlepool Power Stations started in 2004 and indicative inspection capability was developed through Finite Element modeling based on amplitude increase of 6dB of the torsion mode from a defect free baseline in 2015.

There are many uncertainties associated with the technique for real inspections. GWT inspections from the 32 spines were found quite individual, some spines didn't see evident reflections from some geometric features at middle and end of a spine as are expected, variabilities of historic inspection on some spines are high. These uncertainties are addressed and a new technique has been developed and used to process real inspection data. Reflections from weld 12.3 and spine end and their signal to noise ratios were enhanced and variability of amplitudes of historic GWT inspections on a spine was reduced. These improvements potentially result in an enhanced inspection capability.

INTRODUCTION

Heysham 1 and Hartlepool power stations have same design and each station has 2 Advanced Gas-cooled Reactors (AGR). Each AGR has 8 pod boilers around the reactor and there are 32 pod boilers in total at these two power stations. Figure 1 shows schematically the pod boiler and boiler spine. The boiler is hung vertically and is supported by the boiler spine. Failure of the boiler spine would have potential significant nuclear safety consequence.

Guided Wave Testing (GWT) of the 32 boiler spines started in 2004. Guided waves in a cylinder are dispersive and their ultrasonic velocity is frequency dependent [1, 2]. The GWT bracelet used for the inspection is designed to generate and receive dominantly axial symmetric torsion modes guided waves [1-3] and inspection capability was developed in 2015 based on an amplitude increase of 6 dB of torsion mode echo. Cooling modification, basically introduction of ceramic beads into the annulus between the shroud and the spine as shown in Figure 1, was installed in 2015. Purpose of the cooling modification is to reduce the thermal load and temperature on the weld 12.3 with the intention of reducing future creep damage.

There are many uncertainties associated with the inspections. Such a boiler spine is not perfectly axial symmetric and there are many attachments to it. These will cause mode conversion of axial-symmetric torsion mode to other mode [4, 5]. Along the length of the spine, there are many sections of different wall thickness causing guided wave local reverberations. The guided wave bracelet is not perfectly axial-symmetric. Transducer efficiency in terms of guided wave generation and receiving, acoustic coupling, and aging of transducers may not be uniform across all the transducer in a bracelet. The calculation of torsion and flexural modes of guided is not perfect.

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Study on cooling modification performance monitoring using guided wave was carried out in 2015 immediately after the cooling modification. However, it was found that accuracy of time of flight measurement using guide wave was not good enough [6].

In this study, the uncertainties are assessed and considerations are given to address the issues to enhance signal to noise ratios and reduce variabilities of amplitudes of reflections from the welds of interest to improve defect detection capability, and enhance time of flight measurement accuracy of spine end echo allowing for cooling modification performance monitoring.

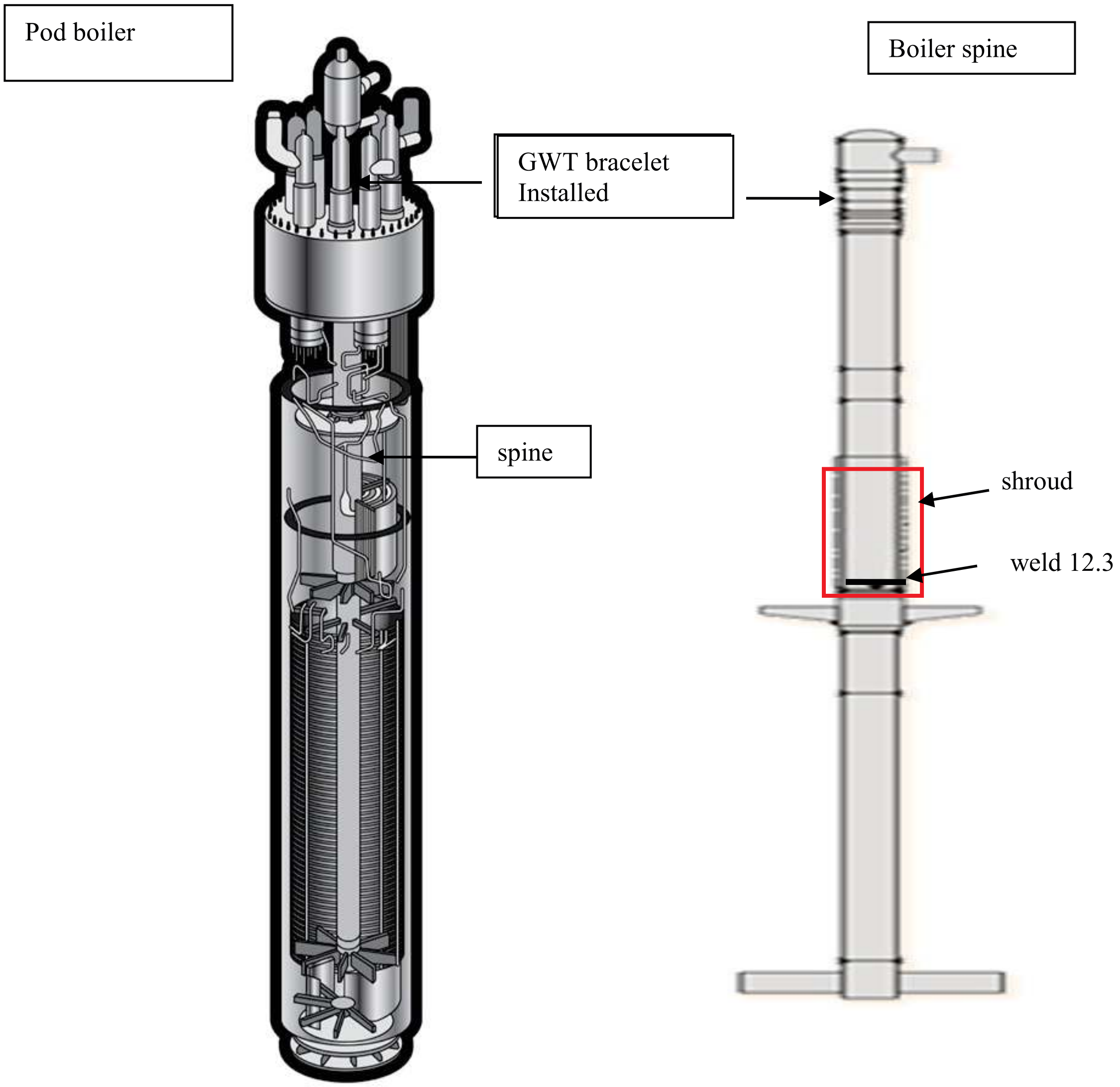


FIGURE 1. Schematic diagrams of pod boiler and boiler spine of an AGR at Heysham 1 and Hartlepool power stations.

METHOD

GWT inspections from the 32 spines have similar characteristics but show individual variations. Some spines didn't have evident reflections from some geometric features at middle and end of a spine as expected and variabilities are high across the 32 spines and over years. The contributing factors to the uncertainties are listed below

- A boiler spine is complicated and not axial-symmetric;
- A bracelet itself is not perfectly axial-symmetric;
- Control of GWT propagation direction is not ideal;
- Transduction across all the transducers in a ring and across all the rings may be not even;
- Acoustic coupling may be not uniform across all the probes;
- Probe degradation over time;
- Calculation of symmetric torsion mode and flexural mode are not perfect;
- There are reverberations near the bracelet, around the 12.3 weld, and spine end;
- Conversion between torsion modes and flexural modes.

A new technique was developed by taking following measures to address the issues above

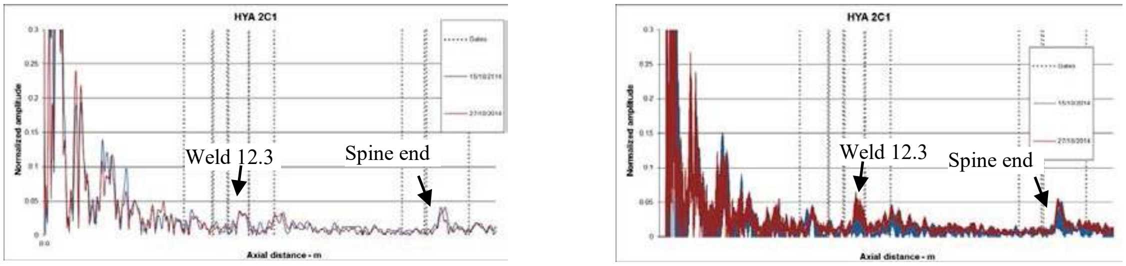
- Inspection standardization;
- Self-calibration and normalization;
- Removal of reverberations;
- Selection of directional response;
- Mode calculation.

RESULTS

The historic real inspection data on 31 of the 32 spines (except the spine 1D1 at Heysham 1 power station) was processed with the new technique and the results are presented below.

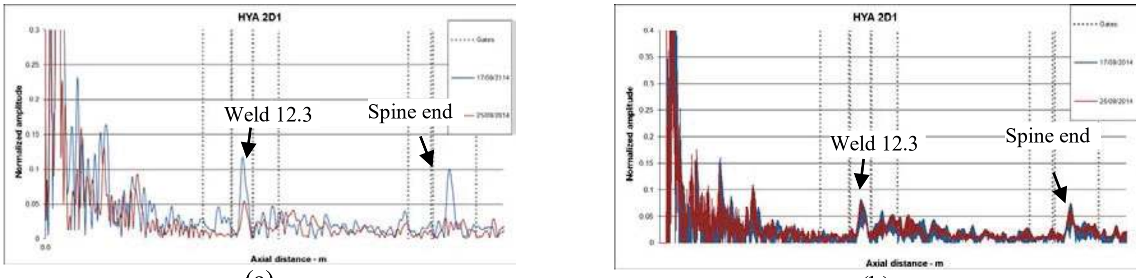
Shown in Figures 2-10 are examples of GWT inspections of boiler spines at Heysham 1 and Hartlepool power stations. The signals shown in sub-figure (b) are obtained by processing inspection raw data with the new technique and are compared with the torsion modes (a) that are obtained by processing inspection raw data using Teletest software. It can be seen that the signals from weld 12.3 and spine end have been enhanced and variability of the amplitudes has been reduced.

Signal to noise ratios of weld 12.3 and spine end reflections were calculated and are presented in Table 1. In general, signal to noise ratios have been improved, in particular, for the cases where the relevant signals were just above the noise level.



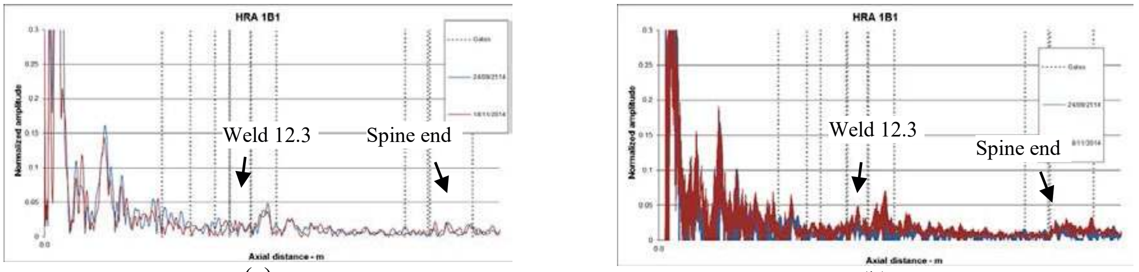
(a) (b)

FIGURE 2. Real historic GWT inspections on spine 2C1 at Heysham 1 power station. (a) Torsion mode by Teletest; (b) This study.



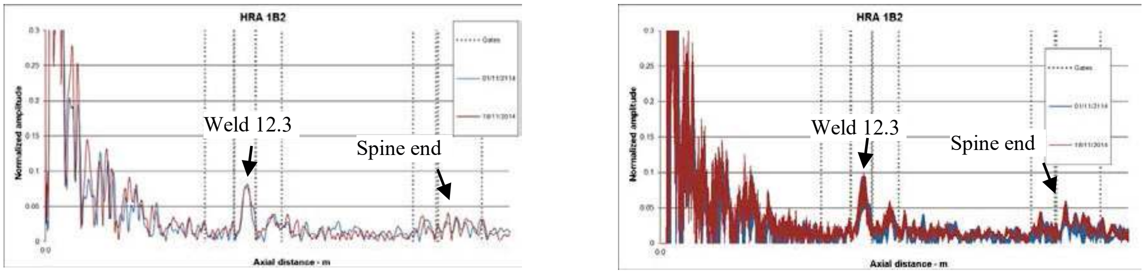
(a) (b)

FIGURE 3. Real historic GWT inspection on spine 2D1 at Heysham 1 power station. (a) Torsion mode by Teletest; (b) This study.



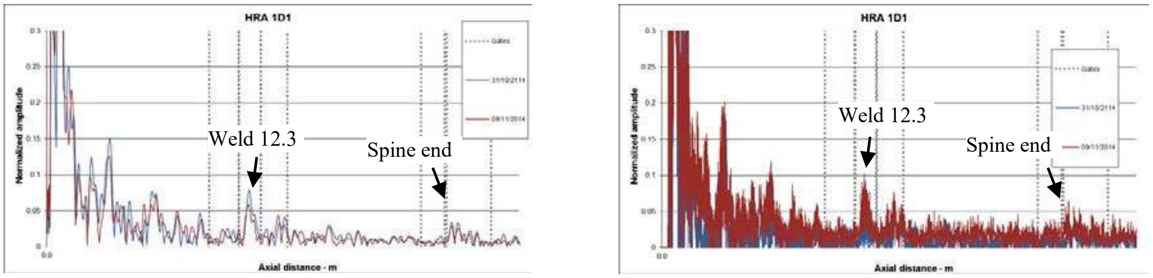
(a) (b)

FIGURE 4. Real historic GWT inspection on spine 1B1 at Hartlepool power station. (a) Torsion mode by Teletest; (b) This study.



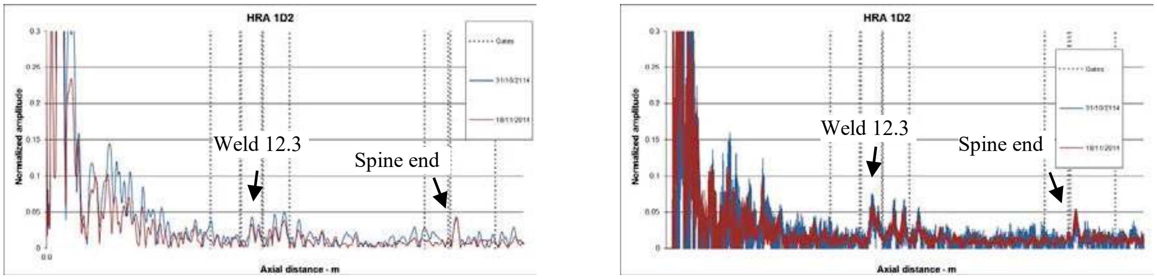
(a) (b)

FIGURE 5. Real historic GWT inspection on spine 1B2 at Hartlepool power station. (a) Torsion mode by Teletest; (b) This study.



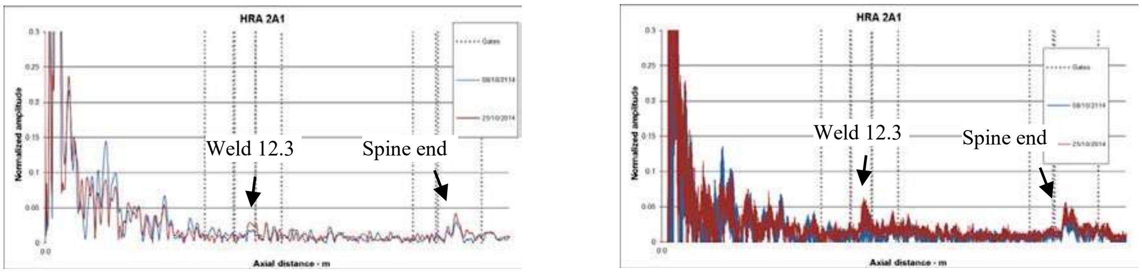
(a) (b)

FIGURE 6. Real historic GWT inspection on spine 1D1 at Hartlepool power station. (a) Torsion mode by Teletest; (b) This study.



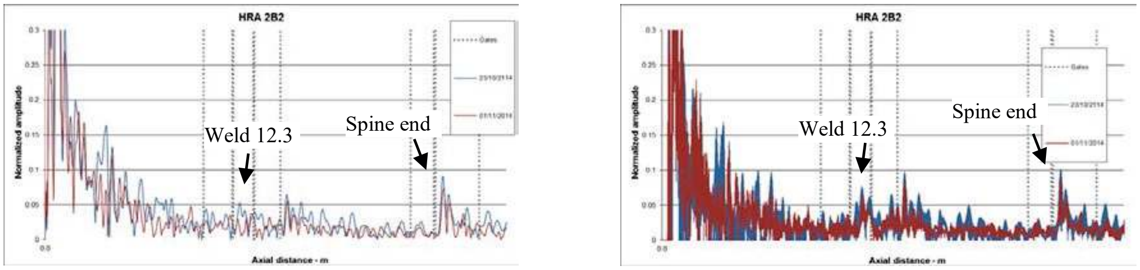
(a) (b)

FIGURE 7. Real historic GWT inspection on spine 1D2 at Hartlepool power station. (a) Torsion mode by Teletest; (b) This study.



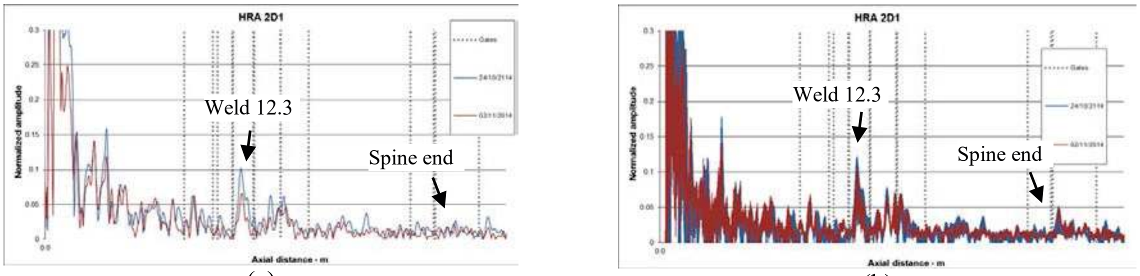
(a) (b)

FIGURE 8. Real historic GWT inspection on spine 2A1 at Hartlepool power station. (a) Torsion mode by Teletest; (b) This study.



(a) (b)

FIGURE 9. Real historic GWT inspection on spine 2B2 at Hartlepool power station. (a) Torsion mode by Teletest; (b) This study.



(a) (b)

FIGURE 10. Real historic GWT inspection on spine 2D1 at Hartlepool power station. (a) Torsion mode by Teletest; (b) This study.

Tables 1 Signal to Noise Ratio (SNR) – real inspections

Spines	SNR @12.3 (Torsion)	SNR @end (Torsion)	SNR @12.3 (this study)	SNR @end (this study)
HYA 2C1	6.7	12.9	15	18.4
HYA 2D1	13.1	3.6	11.5	7.2
HRA 1B1	0.1	7.7	4.9	7.3
HRA 1B2	9.2	0.9	8.6	2.6
HRA 1D1	8.2	10.6	7.6	4.3
HRA 1D2	6.5	9.8	9.1	8.5
HRA 2A1	3.4	9.8	6.5	7.8
HRA 2B2	0.8	12.5	4.9	10.2
HRA2D1	10.2	2.1	9.9	8.3

Real inspection data on boiler spine 1B1 at Heysham 1 power station over a period of 100 days covering hot, cold and hot periods was processed and the calculated signals with the new technique are shown in Figure 11 as a B-scan image. It can be seen that time of flight of spine end reflection is quite consistent when the reactor is at steady power. Variability of time of flight of spine end reflection is good enough allowing for accurate measurement of time of flight and assessment of cooling mod level/performance.

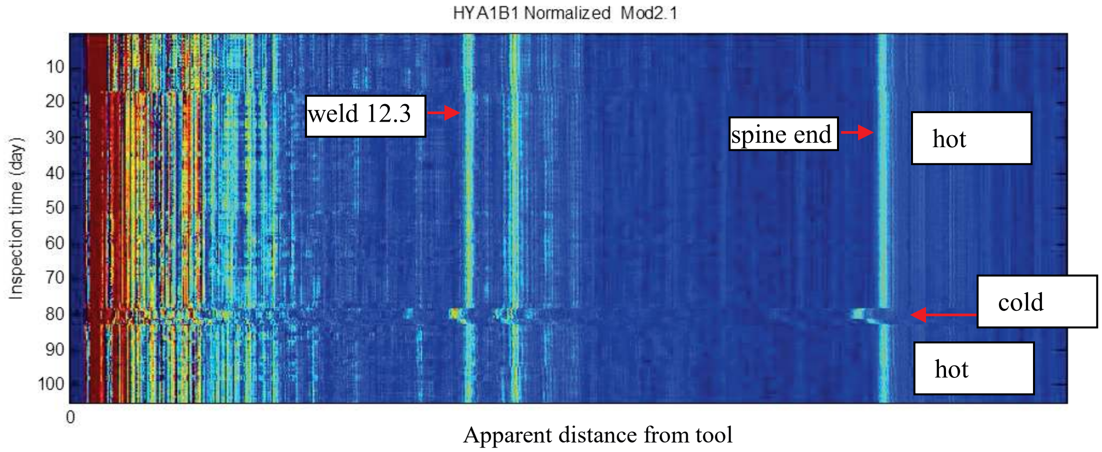


FIGURE 11. B-scan image of real GWT inspection on spin 1B1 at Heysham 1 power station. Measurements were taken when the reactor is hot on power, cold off and hot on power again.

CONCLUSIONS AND DISCUSSION

Real inspection raw data on 31 boiler spines at Heysham and Hartlepool power stations has been processed and the results were compared with the results obtained by processing the data using Teletest software.

Reflections from geometric features and their signal to noise ratios have been enhanced across all the 31 spines, and variability of historic inspections on a spine has been reduced, which indicates potential improved defect detection capability. Time of flight of spine end reflections were measured accurately, which allows for cooling modification performance and temperature reduction to be monitored. All these contribute an improved GWT inspection capability and a reduced probability of false call.

FURTHER WORK.

Finite element modelling of boiler spine GWT was carried out by TWI for EDF Energy and inspection capabilities based on torsion mode was developed in 2015 [7]. The modelling data will be processed with the new technique and the results with be compared with the indicative inspection capabilities reported in the TWI document hoping for better inspection capabilities [7].

REFERENCES

1. J.L. Rose, "Ultrasonic waves in solid media," *Cambridge University Press* (1999).
2. J.L. Rose, "Dispersion curves in guided wave testing", *Materials Evaluation* **61**(1), 20-22 (2003).
3. J.L. Rose, L. Zhang, M.J. Avioli, P.J. Mudge, "A natural focusing low frequency guided wave experimental for the detection of defects beyond elbows," *ASME Journal of Pressure Vessel Technology* **127**, 310-316 (2005).
4. M.J.S. Lowe, D.N. Alleyne, P. Cawley, "The Mode Conversion of a Guided Wave by a Part-Circumferential Notch in a Pipe," *Journal of Applied Mechanics* **65**, 649-656 (1998).
5. D.N. Alleyne, M.J. Lowe, P. Cawley, "The reflection of guided waves from circumferential notches in pipes," *Journal of Applied Mechanics* **65**, 635-641 (1998).
6. P. Jackson, P.J. Mudge, K.J. Thornicroft, A.G. Haig, R. Sanderson, E. Hutchison, C.R.A. Scheider, "Use of Guided Wave Inspections to Monitor the Integrity of Nuclear Power Station Boilers," in *Proceedings Review of Progress in Quantitative NDE*, Atlanta, 2017. [Abstract Only]
7. R.M. Sanderson, D.A. Hutchins, D.R. Billson, P.J. Mudge, "The investigation of guided wave propagation around a pipe bend using an analytical modelling approach," *JASA* **133**, 1404-1414 (2013).