NON-DESTRUCTIVE METHOD FOR INNER SCALE MEASURING OF BOILER TUBES

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ABSTRACT

Boiler tube failures may cause forced shutdowns on facilities, and the thickness of the oxide deposited on the wall tubes inner surface, is the main cause of overheating damages. Generally, in the past, the inner scale deposit was measured only by laboratory testing with sample tubes (destructive test). MITSUBISHI HITACHI POWER SYSTEMS (MHPS) group has been developing methodologies and techniques to estimate the remaining life of boilers manufactured following trends, and needs of their global customers. CBC Heavy Industries with the recent acquisition of equipment developed by MHPS for ultrasonic thickness measurements, made possible to measure the thickness of both the wall of the boiler tubes and the oxide inner scale deposited. Currently, this method of inspection has been applied to furnace carbon steel tubes and superheaters alloy steel tubes. Thus the rapid determination of oxide inner scale thickness allows to adopt more effective countermeasures, to guarantee mechanical integrity of the components and to contribute to a safer operation between the intervals of inspections. The current paper presents a comparison between the results of measurements of oxide inner scale thickness verified by non-destructive ultrasonic technique and the destructive technique associated with optical microscopy in different thickness of the magnetite layer. The experience of MHPS, combined with the studies performed, confirms that it is possible to measure, by ultrasonic, oxide inner scales from values of 0.1 mm (100 μm) under field conditions.

Keywords: *Oxide scale, ultrasonic testing, remaining useful life, boilers.*

1. INTRODUCTION

The extension life of industrial plant boiler components is a matter of high interest and is directly linked to components operating at high temperatures. Among the failure mechanisms in tubing and boiler components operating under creep regime, the overheating due to oxide inner scale formation has high influence on the components life [1]. The presence of these deposits on the tube wall up to a certain limit plays a fundamental role in the corrosion resistance. However, if this limit is exceeded, there is a deficiency in the thermal exchange due to the accumulation of deposits, which increases the temperature of the metal and accelerates the damage mechanisms, reducing drastically the material life.

Figure 1 illustrates the occurrence of leakage in the primary superheater of MHI boiler with two (2) drums type after 6 years of operation caused by creep due to the accumulation of oxides on the tube inner surface. At the collapse time the oxide scale was 0.3 mm thick.

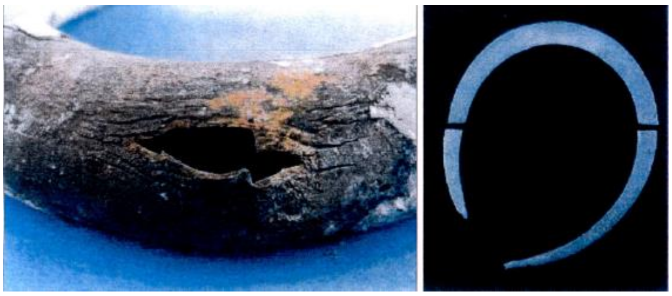

Figure 1: Leakage due to creep caused by oxide accumulation on the tube inner surface

Source: Mitsubishi Hitachi Power System, Japan [6]..

Below are the mechanisms of iron oxides scale formation in the presence of high temperature steam, which are the basic conditions for this layer to form and remain adhered to the steel surface in contact with water:

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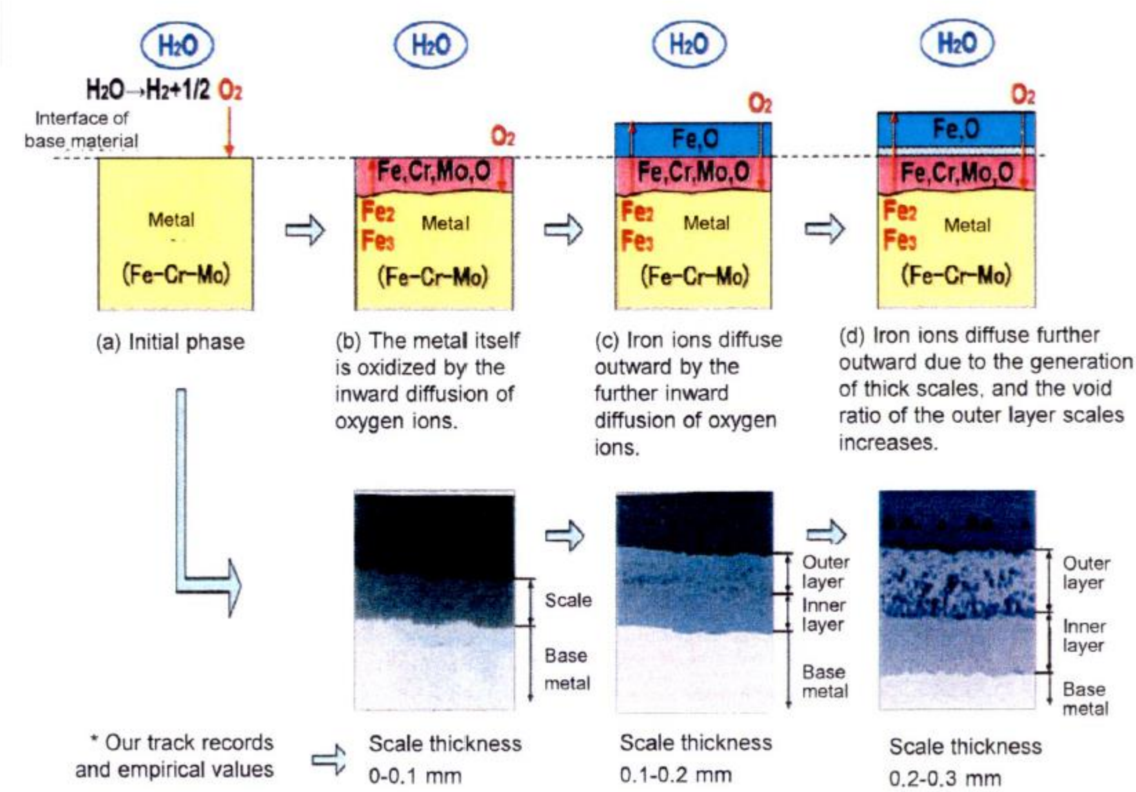


Figure 2: Mechanism of oxide scale formation at boiler inner alloy steel tubes
Source: Mitsubishi Hitachi Power System, Japan [6].

The more traditional methods for evaluating tube integrity requires the removal of samples for visual examination, metallographic analysis and creep testing [2]. The main limitations of these traditional methods are: difficulty of taking samples, which requires cutting tubes sections and have to be replaced later, and the delay in obtaining the analysis results [3].

The alternative method studied in this paper was based on the fact that the thickness of the oxide inner scale, particularly magnetite, may be used as a parameter to evaluate both the tube thermal conductivity and its degree of deterioration [4]. Ultrasonic is a fast and reliable non-destructive testing that makes possible to measure oxide inner scale in a large number of tubes at a low cost compared to traditional methods [3].

Therefore, due to the need of increasing the boiler reliability, reduce the unscheduled shutdowns and the search for higher safety, a special ultrasonic hardware was developed for measurement of oxide scale on tubes inner surface, which allows higher accuracy in the results, contributing to a more effective boiler maintenance plan.

2. MATERIALS AND METHODS

The ultrasonic method appears as a positive alternative to the destructive method. Measurements may be performed on equipment with traditional A-Scan data, which consists of visualizing echoes of wave reflection at the interfaces of the inspected component [5].

The oxide scale thickness is calculated by measuring the time interval of ultrasonic wave between the reflected echo at the interface steel / oxide scale and reflected echo at the tube inner surface. The echo interface of the steel / oxide scale is much smaller than the echo interface of the oxide scale / air or liquid on the tube inner surface. The highest difficulty of measurement is to separate these echoes and measure the time interval between them [5].

Faced with possibility of expanding the range of non-destructive tests that could aid the integrity evaluations results of the most critical boiler components, CBC has acquired a special hardware to measure tube wall thickness along with oxide inner scale thickness, precisely the magnetite. According to the manufacturer, the minimum thickness obtained with such a system is 0.1 mm (100 μm). The principle of measurement is shown in figure 3:

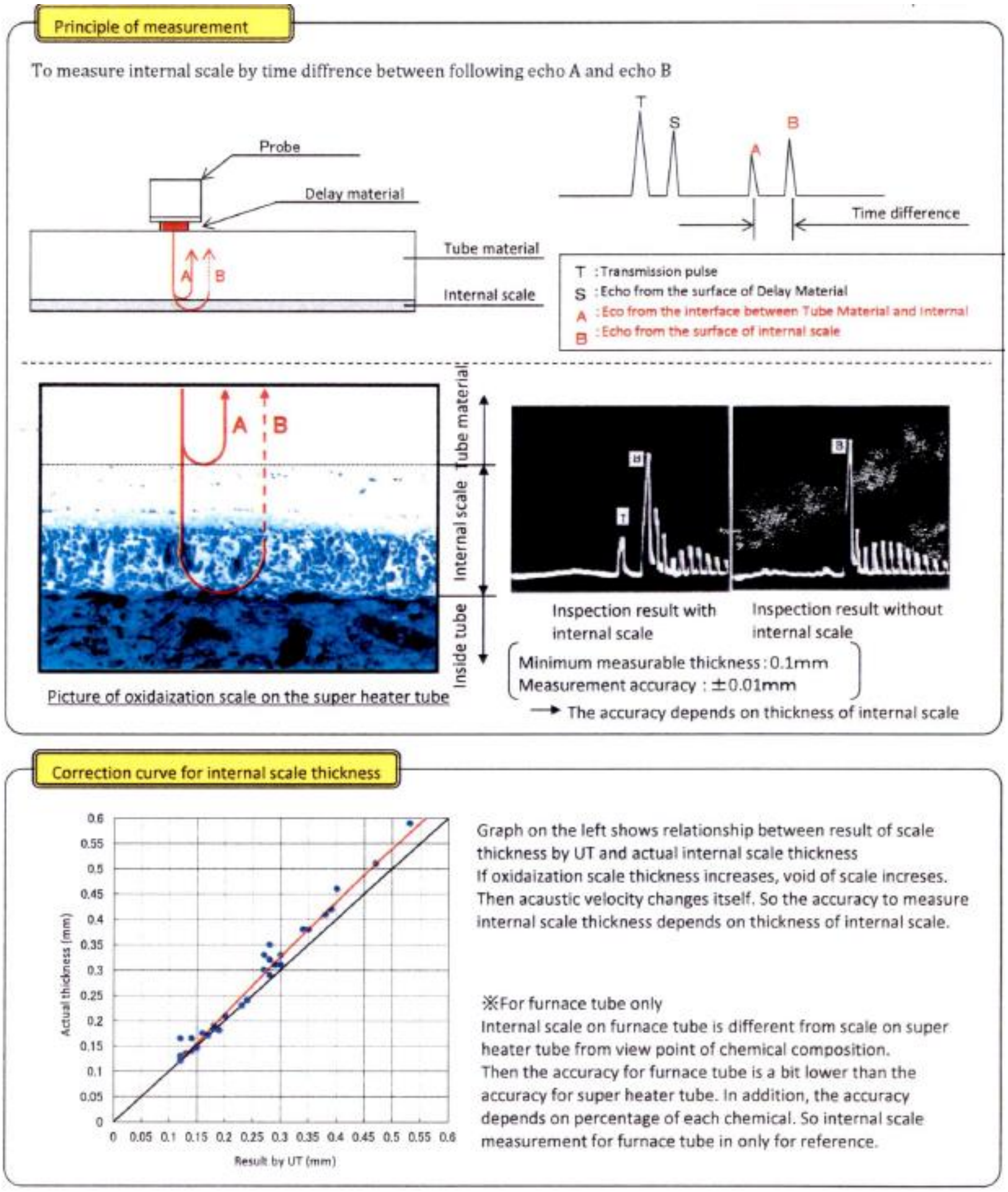


Figure 3: Principle of thickness measurement via ultrasonic method

Source: Mitsubishi Hitachi Power System, Japan [6].

The components of measurement system are:

- Ultrasonic hardware (figure 4);
- Longitudinal wave transducer (figure 5);
- Probe connecting cable
- Ultrasonic couplants

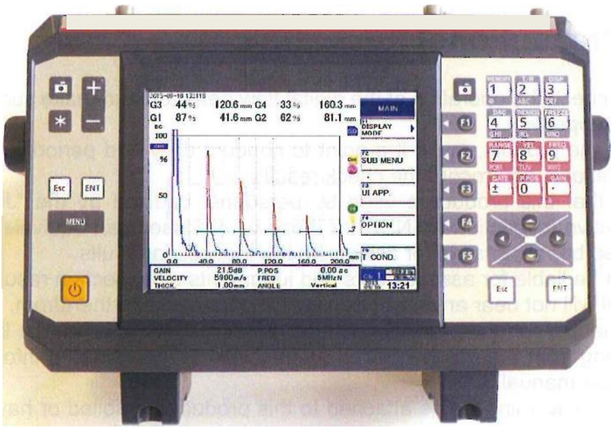


Figure 4: Ultrasonic main unit

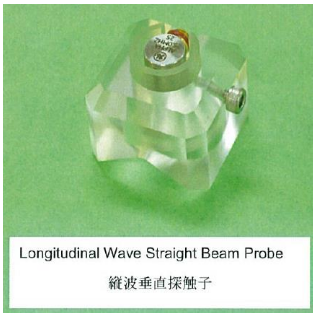


Figura 5: Longitudinal wave straight beam probe

One of the purposes of this paper is to validate oxide scale thickness measurements, thus this type of test may safely be used in field applications.

To validate the results obtained by the hardware, were used tubes removed from superheater and furnace of a steel mill boiler, in consideration of these components exposed to failures due to overheating, caused by inner oxide scale formation. The samples used were stored in CBC metallography laboratory. Table 1 shows the analyzed tube data.

Table 1: Analyzed tubes data

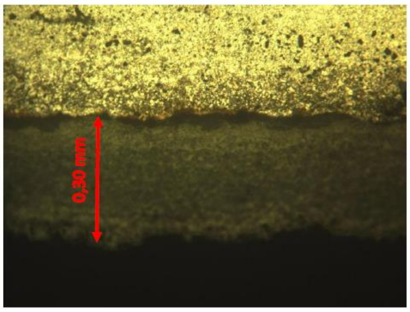
Sample 1 - Secondary Superheater Tube	
Material	SA-213-T91
Dimension	Ø50,8 x 5,4mm

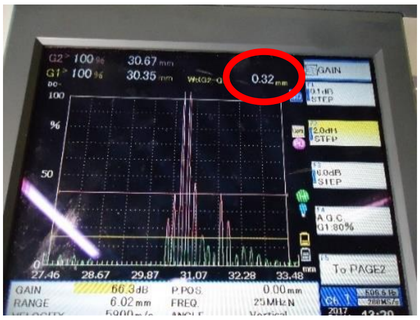
Sample 2 - Furnace Tube	
Material	SA-210-A1
Dimension	Ø76,2 x 4,6mm

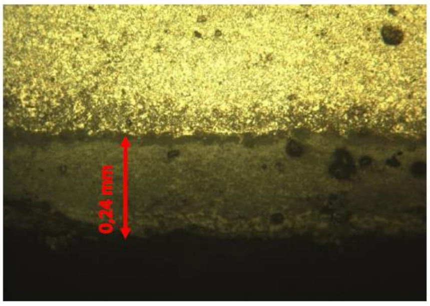
3. RESULTS AND DISCUSSION

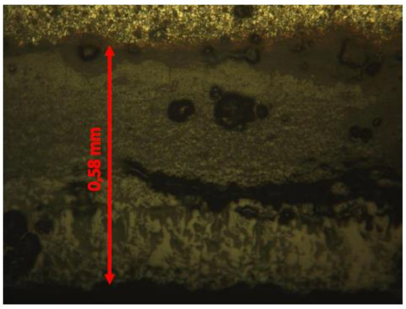
The results of inner tube oxide scale measurements performed by the optical microscopy method compared to the ultrasonic method are shown in tables 2 and 3 below:

Table 2: Sample 1 - Secondary Superheater Tube

<table>
<tr><td colspan="2"></td></tr>
<tr><th>Metallography Method</th><th>Ultrasonic Method</th></tr>
<tr><td>• POINT 1


Measured thickness: 0,30mm</td><td>

Measured thickness: 0,32mm</td></tr>
<tr><td>• POINT 2


Measured thickness: 0,24mm</td><td>
Measured thickness: 0,21mm</td></tr>
<tr><td>• POINT 3


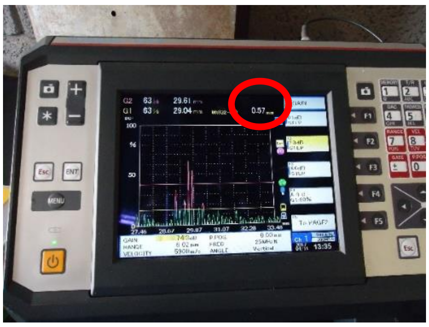
Measured thickness: 0,58mm</td><td>
Measured thickness: 0,57mm</td></tr>
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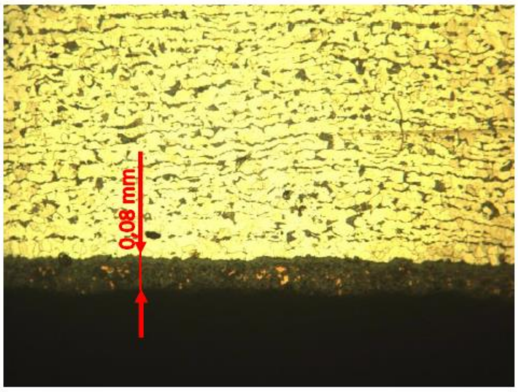
Table 3: Sample 2 - Furnace Tube

Metallography Method	**Ultrasonic Method**
• POINT **1**  Measured thickness: 0,08mm	 Measured thickness: 0,1mm

It is possible to observe that the measurements made by ultrasonic and optical microscopy in samples 1 and 2 show very close values and similar behaviors.

For thicknesses less than 0.1 mm, it is not possible to identify a separation between the echoes referring to the steel / oxide scale and the oxide scale / air. However, in this case, the probability of metal values being within the design values is high.

Because of the innovative technique recently introduced in Brazil, the authors encourage more research to form a database that considers the characteristics of boilers in Brazil.

4. CONCLUSION

According to the results obtained the ultrasonic testing proves to be effective and reliable for measurement of superheaters alloy steel tubes oxide inner scale. For furnace tubes, due to the oxide inner scale morphology, inspection results need to be confirmed by removal of sample tube.

The technique described in the present paper may be applied in the field without major difficulties, contributing in an effective way to the decision-making during a scheduled shutdown for inspection of industrial plant boilers.

REFERENCES

[1] ASM, METALS HANDBOOK, Failure analysis and prevention – vol. 11, Ohio, Metals Park, ASM International, 2002.

[2] David N French, Failures of Boilers and Related Equipment – Metals Handbook – Vol. 10 – Failure Analysis and Prevention – ASM – 1975.

[3] BRAGA, R. M. Medição da Camada de Óxidos em Tubos de Superaquecedores de Caldeiras Aquatubulares por Ultrassom, Porto Alegre, 2009. 1p. Tese para Obtenção do Título de Doutor em Engenharia – Universidade Federal do Rio Grande do Sul, Porto Alegre, 2009.

[4] R. Viswanattan, J. R. Foulds, and D. A. Roberts, Methods for Estimating the Temperature os Reheater and Superheater Tubes in Fossil Boilers, in Proceedings of the International Conference on Life Extension and Assessment, The Hague, June 1988.

[5] CARDOSO, B.R.; COMELI, F.W.; SANTANA, R.M.; FURTADO, H.C. Previsão de vida em tubos de caldeiras com base na medição da espessura da camada de óxido por ultrassom, Rio de Janeiro, 2011 – Matéria (Rio J.) vol. 16 no.4 Rio de Janeiro 2011, on-line version ISSN 1517-7076.

[6] MHPS, MITSUBISHI HITACHI POWER SYSTEMS Co., LTD. Cases of Boiler Trouble and the Importance of Preventive Maintenance, Yokohama Power Systems Service Department, Power Systems Service Headquarters, Japan, 2016.