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Application of Heads with the Water Coupling for Measuring Thicknesses of Tubes Used in Coal-Fuelled Power Engineering Systems

Part 1. Primary Issues

Abstract: The first part of the article presents basic information concerning measurements of corrosion thickness measurements (mapping) in respect of issues accompanying the combustion of biomass in currently operated power boilers. The article emphasises issues related to the degradation of the surface of waterwall tubes and stresses the necessity of applying a technique enabling the performance of reliable measurements through the destroyed surface of the boiler tube. The article also presents issues possibilities of using Spot weld types of transducers and the water column as a method enabling the non-contact of the rube surface.

Keywords: corrosion thickness measurements, power boilers, power engineering, degradation of waterwall tubes

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Introduction

The operation of power boilers is accompanied by the reduction of their wall thickness triggered by natural processes connected with the intensive combustion of coal dust. Frequently, the aforesaid processes are additionally intensified by the combustion of biomass. Previously, the only analysis performed on a regular basis involved the thickness gauge-based measurements carried out at spots designated by services responsible for safety. As a supervising regulatory body, the Office of Technical Inspection specifies the scope of inspections connected with scheduled close-downs of boilers for necessary repairs and inspections. Membrane boilers as elements of a coal-fuelled power unit are exposed to intense operation-related degradation. The problem concerns both the combustion of coal dust and, increasingly often, that of biomass, additionally translating into the intensification of degradation processes affecting boiler elements. A two or three-ingredient fuel mixture containing biomass is characterised by similar contents of ingredients, yet also by a different chemical composition [1]. In accordance with the definition contained in the Bill on Renewable Energy Sources of 9 October 2012, the term designates manufacturing side products undergoing biodegradation [2]. The different chemical composition of biomass than that of the classical mixture of coal dust and air directly lead to the excessive degradation

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Fig. 1. Thinned wall of a boiler tube [4]

of the surface and the faster abrasion of the boiler tube wall on the furnace side (Fig. 1). Wall thickness reductions resulting from the above-named processes frequently lead to failures generating significant costs triggered by unplanned close-downs of the power unit [1, 3]. Related scientific publications state that more than 12% of the biomass content in the composition mixture noticeably accelerates unfavourable phenomena including slagging, erosion and the formation of corrosion centres [3]. An over 30% growth in the content of biomass in fuel increases the risk of the occurrence of detrimental phenomena and, consequently, unscheduled close-downs of the boiler, necessary for performing repairs and cleaning heated surfaces [1, 3, 4].

According to the Pro Novum company, analysing the wear of power boiler elements, frequent cases of cracking tubes of heated surfaces during boiler operation may result from reduced wall thicknesses, the presence of sediments etc. [6]. The phenomenon is also triggered by the combustion of biomass [1]. The above-named issue is addressed in publication [1].

This article aims to present issues related to measurements based on previously used testing techniques based on point measurements and the possibility of using continuous measurements based on the coupling of ultrasonic transducers with the water column.

The attempt to apply another approach is dictated by the need for developing a more reliable technique enabling the performance of measurements along the entire length. The “classical” measurement is encumbered with errors resulting from its very concept, i.e. the fact that it is solely based on selected points. As a result, it is possible to “miss” zones characterised by the greatest reduction of wall thickness as well as erosion or corrosion-triggered defects. Another problem is the very possibility of detecting corrosion pits or eroded areas on the wall, located both on the internal and external surface of the tube (Fig. 2).

Figure 2 presents areas of reduced wall thickness in relation to the tube surface and the axis. Point measurements do not enable the detection of all tube areas characterised by reduced thickness.

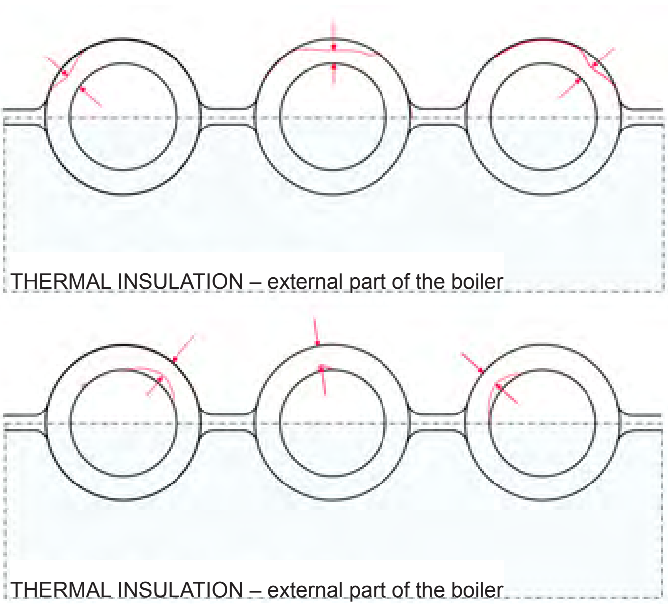

Fig. 2. Areas of wall thickness reduction on the internal and external surface of the tube

The measurement itself only provides the approximate information on the degree of boiler tube wall wear. Measurements usually involved selected pipes divided into levels (as presented in Figure 3), in the scope specified by supervisory services on the basis of regulations of the Conditions of the Office of Technical Inspection (WUDT).

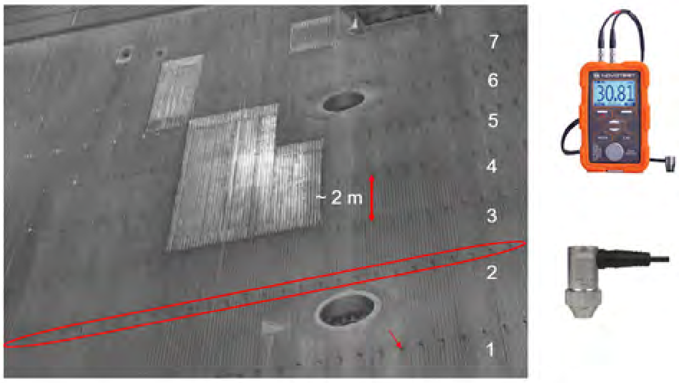

Fig. 3. Classical measurement of boiler waterwall thickness [5]

There are no unequivocal solutions enabling the performance of measurements (of the entire profile) along the length of a given tube. In cases of flat surfaces such as storage containers, ship plating or larger diameter pipeline, presently used techniques are based on measurements involving the use of transducers propagating waves across the stream of water.

Currently tested solutions involve other methods enabling thickness measurements and can be divided as follows:

- UTT – use of ultrasonic waves generated both by one and many piezoelectric transducers,
- EMAT (Electro Magnetic Acoustic Transducer) – use of transducers generating ultrasonic waves in a test element using Lorentz force and the phenomenon of magnetostriction,
- MFL (Magnetic Flux Leakage) – recording of magnetic flux leakage.

Each of the above-named methods has both its advantages and disadvantages. As a result, the methods require separate use-related analyses as regards the identification of tube wall thickness reduction. The tests exclusively aimed to present the possibilities of the method based on the use of ultrasonic waves generated by piezoelectric transducers. An important aspect of the aforesaid technique is the possibility of testing elements in operation, i.e. often characterised by damaged or soiled surface. It should be noted that, in comparison with the EMAT and MFL methods, the ultrasonic technique requires the preparation of a surface to be tested. The scope and limits concerned with the use of the ultrasonic technique will be extensively discussed in the second and third part of the publication, presenting results of tests involving segments of reference specimens and those of actual waterwall tubes.

Automated scanning robots

Tube wall thickness measurement solutions include a TOKA 4.0.1 device (Gecko Robotics), made and patented in the USA, enabling measurements of waterwall tube thicknesses. According to information provided by the company, the device is composed of 8 sets of ultrasonic transducers. The test is performed in eight tubes within one run. Measurements are made every 24 mm (1 inch) in three areas of the tube circumference. The device makes it possible to detect wall thickness reduction, erosion, corrosion and pits. The ultrasonic transducer itself is also patented [8]. However, as mentioned above, the device by Gecko Robotics makes point measurements every 24 mm; it does not perform continuous measurements [8].

Primary objective of tests

The primary purpose of the research work carried out at Instytut Spawalnictwa was to verify the possibility of using a special module of ultrasonic transducers. Assumedly, the adopted module should enable the performance of measurements using three ultrasonic transducers performing the measurement of the wall thickness along the entire length subjected to scanning using non-contact wave propagation through the water column.

Adopted solution

The primary method adopted in the tests assumed the use of ultrasonic waves in the pulse-echo (P-E) technique. The measurement is performed on a continuous basis through the recording the scanned path using an encoder. The ultrasonic transducers mounted in the module work on a non-contact basis, using the water column as the primary manner of coupling the transducer with an element subjected to the test. The above-presented solution based on transducers used in immersion technique enables the performance of the continuous measurement of wall thickness reduction and collect the wide range of information. The technique makes it possible to analyse the wall thickness reduction both on the external and internal surface of tubes subjected to scanning. The possibility of distinguishing the reduction as present on the external or internal surface of the tube wall enables the more extensive interpretation of types of defects. The analysis involves the TOF times concerning both the input impulse entering a given wall as well as times during which the wave passes through the wall. In theory, the above-presented solution should enable the obtainment of the precise measurement of the wall thickness both in terms of the internal and external side of tube wall.

The selection of the above-named solution resulted from the effect connected with the natural phenomenon of the concentration of beam in the near field, translating into the possible concentration of the beam in the element subjected to the test. Previously used techniques have been based on measurements involving the direct contact of the transducer and the wall being tested. Such a solution is encumbered with errors resulting from the fact that measurements are performed on the non-parallel and, frequently, damaged tube surface. Another unfavourable aspect of the technique is the impossibility of analysing the location (external or internal) of wall thickness reduction, precluding the proper interpretation of the wear of an element subjected to the measurement.

Transducers are connected to the defectoscope by means of separate conduits in a multi-channel arrangement. Such a solution enables the continuous recording of the wall thickness during the passage of the module along the entire length of the tube. Calibration is performed in a standard manner, using standard specimens with reference thicknesses within the range of measured thicknesses.

Previously, the above-presented method has been used when mapping the corrosion of storage tanks and pressure vessels. The devices used to perform tests feature submersible transducers mounted in a casing with the water column. The measurement is performed in the same manner, i.e. on the basis of the pulse-echo technique. The method differs from other techniques which make it possible to only test flat elements and not tubes around their entire circumference. The tests aimed to verify the possibility of performing a continuous measurement enabling the detection of wall size reduction along the entire length of a tube being tested. The measurement was performed using the water (columnar) coupling technique, enabling the analysis of the tube wall both on the internal and external surface of the tube.

Scanning module

Ultimately, the scanning module (transducer) will be made of stainless or similar steel, characterised by abrasion resistance. To obtain appropriate coupling, the shape of the sliding surface of the transducer module will be adjusted to the diameter of a tube being tested. A very important element will be an irrigation system providing the continuous water coupling with an element being tested. In addition, the module will be provided with a water capture system.

The geometry of the transducer module will significantly depend on a transducer used in the water column system with a delay line (Fig. 4).

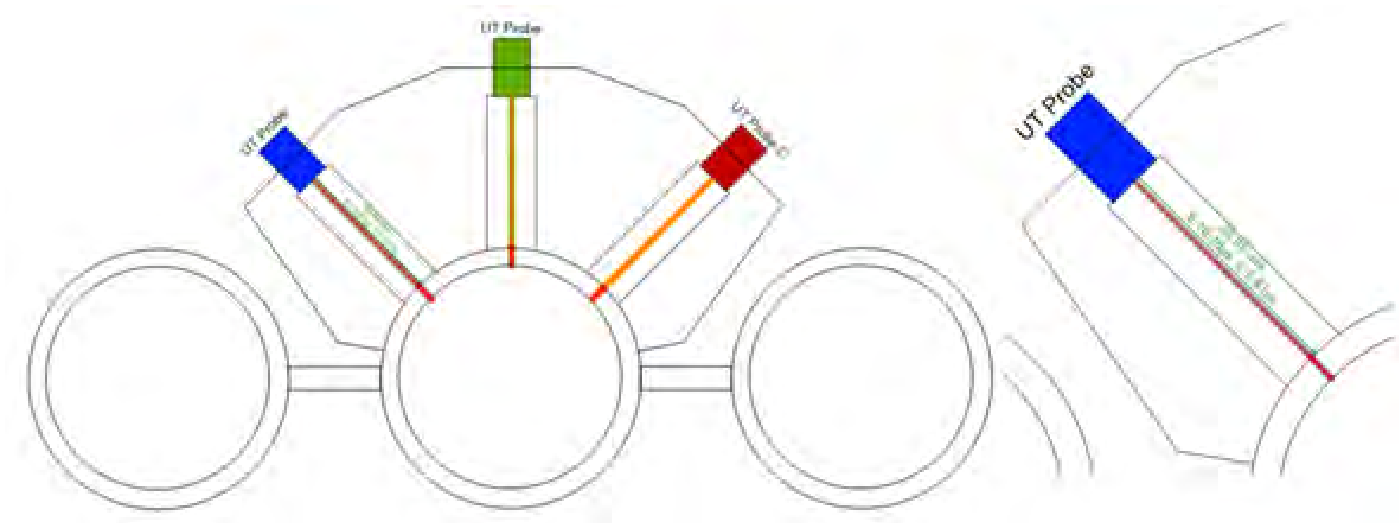

Fig. 4. UTG-Scanner scanning module

UT transducers

The most important element of the adopted solution is a transducer enabling the generation of waves through the water column. The market offers special submersible transducers, successfully used in automated submersible systems. Usually, such transducers are rather large, which undoubtedly makes it difficult to use them in a relatively small transducer module of a scanner under consideration (Fig. 4).

The above-named type of transducers is also characterised by the relatively long near field of N-wave, which, during immersion tests, is compensated by an appropriate distance from an element being tested (Fig. 5).

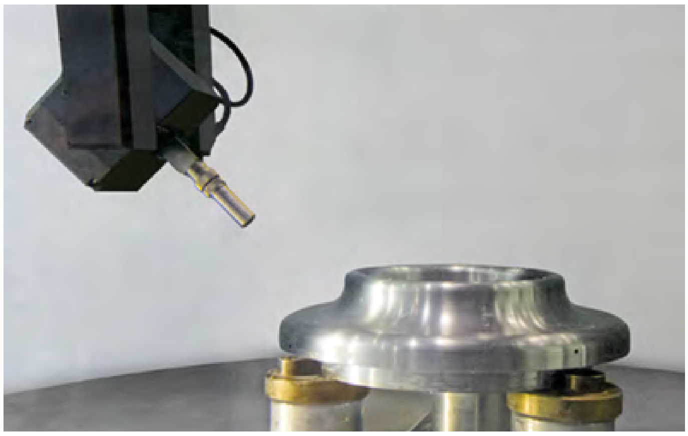

Fig. 5. Immersion test [9]

Spotweld-type transducers

The analysis of appropriate transducers resulted in the selection of Spotweld type transducers, widely used in tests of spot welds in the automotive industry.

Spotweld type transducers (Fig. 6) are widely used in tests involving welded joints of steel sheets. The transducer enables the identification of the joint thickness in relation to individual sheets making up the joint and makes it possible to thoroughly verify if the sheets are actually joined. The application of the above-named solution also enabled the analysis of other joints of very thin sheets.

Spot Weld types of transducers available on the market are manufactured by several companies (Olympus; GE Krautkramer; Scanmaster; SIUI). Primary specifications are concerned with the following parameters (Fig. 6):

- frequency restricted within the range of 10 MHz to 20 MHz,
- transducer size restricted within the range of 2.5 mm to 8,0 mm,

Fig. 6. Spot Weld transducers [9]

– water column size – depending on the transducer size (d, mm).

The selection of the aforesaid types of transducers was dictated by the possibility of propagating waves through the water column and should enable the observation of the input impulse at the interface between the water column and a material subjected to the tests as well as make it possible to identify an echo reflected against the opposite wall of the tube being examined. The delay line enables the use of high frequency waves, the frequency of which is restricted within the range of 10 MHz to 20 MHz, which, in turn, enables the analysis of the thickness of relatively thin walls. As in the classical immersion technique, the water column enables the detection of significant changes of acoustic pressure in the near field (N), located in the water column, and not in the material being tested (Fig. 7).

Another aspect of the test involving the use of the delay line in water is the possibility of the formation of the beam in the material itself. The ultrasonic wave is naturally concerned in the near field (N), which contributes to the even higher concentration of the wave in the material being tested (Fig. 8).

The selection of the size of the transducer depends on the size of the delay line (affecting scans). For instance, a transducer having a diameter of 4 mm and a frequency of 15 MHz is characterised by the near field (N) in water having a length of approximately 34.2 mm [14].

$$N = \frac{D^2}{4\lambda} \quad \text{where} \quad \lambda = \frac{v}{f}$$

(V – wave velocity in water, m/s; f – transducer frequency, MHz)

The selection of an appropriate transducer in relation to a wall being examined will be taken into consideration in relation to the length of the near field (N). A proper distance between the transducer and an element being tested will be determined following the performance of initial tests involving the use of a given transducer type. The objective of the experiment will be to identify parameters enabling the obtainment of an optimum quality scan when measuring the thickness of a boiler tube. The thickness of boiler tubes varies and is restricted within the range of 3 mm to 10 mm. For this reason, the transducer will be selected in relation to the diameter (of the tube) and the length of the delay line as well as the nominal thickness of the wall of a tube being examined. The analysis of test results consists in the interpretation of A and B-scans.

The A-scan presents the propagation of waves. The time of wave propagation (in milliseconds)

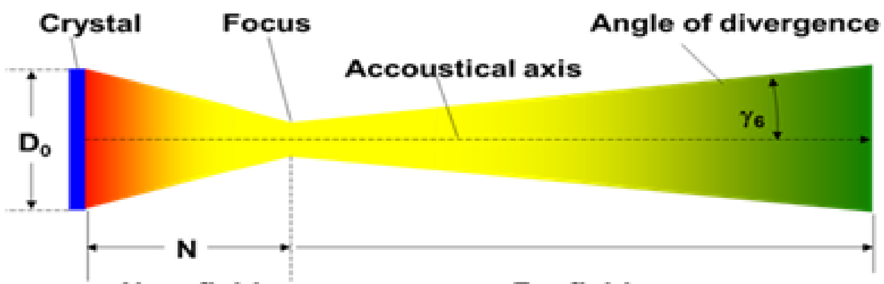

Fig. 7. Schematic diagram of the waveform – near and far field [10]

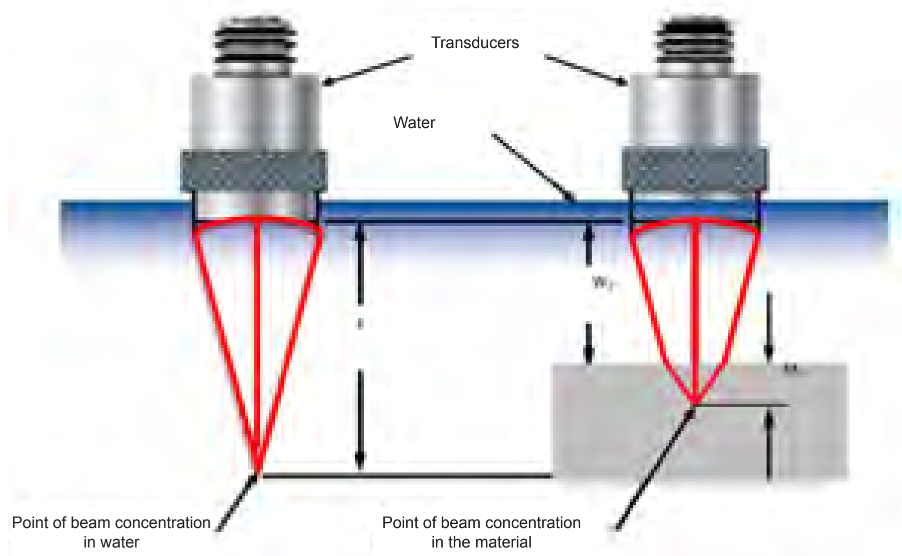

Fig. 8. Schematic diagram of waveform propagation – concentration of the UT beam in the element subjected to the test [12]

in a given medium indicates the relative thickness of an element being tested. The use of the delay line in the form of the water column makes it possible to distinguish echoes (Fig. 9):

- N – transmitting echo,
- 0 – input impulse at the interface between the water column and the material,
- 1 – impulse reflected against the opposite wall,
- 2, 3, 4 … – subsequent reflected echoes.

The time of wave propagation between impulse A and B (presented in Figure 9) will enable the detailed analysis of the wall thickness taking into consideration the reduction of the wall thickness on the test side as well as of the opposite wall.

The possibility of identifying echo A, B and subsequent ones enables the dynamic measurement of wall thickness by recording the time of passage in milliseconds (Fig. 9). For instance, the time of wave propagation in water amounted to approximately 17 µm, whereas that in the element amounted to approximately 4.2 µm. Such an approach enables the precise analysis of the wall thickness also in cases of wall thickness reduction on the furnace side (connected with boiler operation) (Fig. 5). The path of the wave in the water column changes dynamically, yet this fact does not affect the analysis of the time of wave propagation in a given element. The velocity of wave propagation depends on the type of medium (Table 1). The tests concern the waterwall tube on the furnace side. Related zones are marked red in Figure 10. The selection of the above-named type of transducers is directly connected with the possibility of identifying and precisely analysing the time of wave propagation in respect of the input impulse and the impulse reflected in a given element.

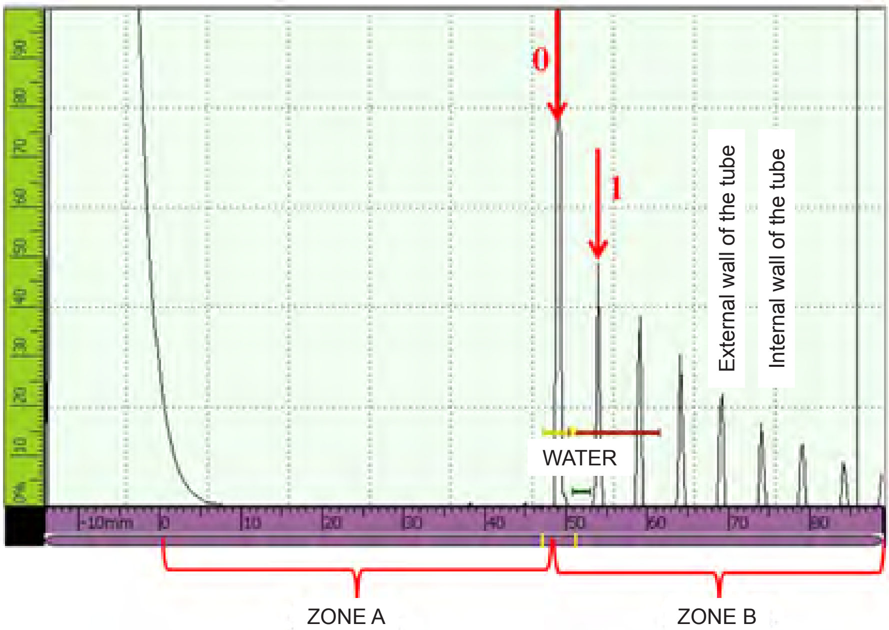

Fig. 9. A-scan

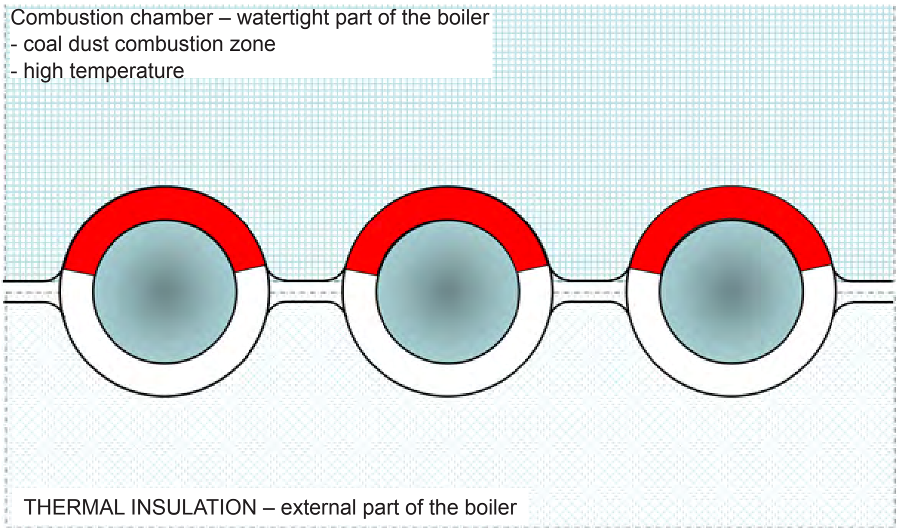

Fig. 10. Range of boiler waterwall subjected to analysis during the measurement of thickness

Table 1. Velocity of wave propagation in various media

Medium:	Propagation velocity, m/s
Air	332
Oxygen	313
Hydrogen	1300
Water	1480
Ethanol	1180
Ice	3980
Iron	5820
Marble	6150
Silica glass	5570
Porcelain	5340

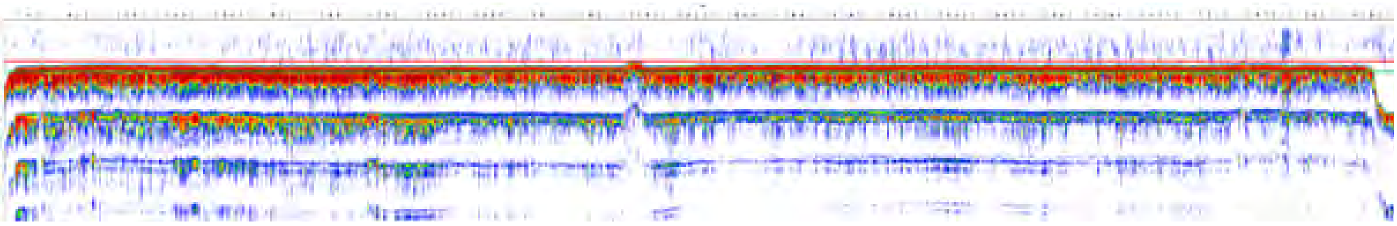

Fig. 11. Exemplary B-scan [13]

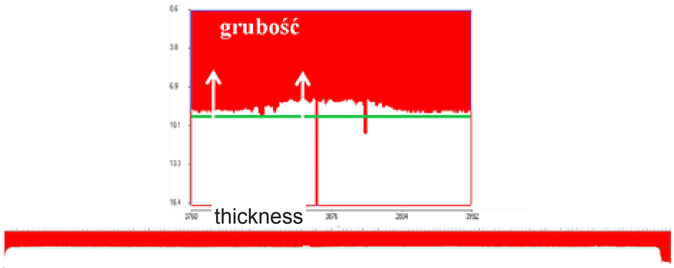

Fig. 12. Other types of the B-scan [13]

Fig. 13. Range of boiler waterwall analysis during thickness measurements

Figure 12 presents the wall profile in relation to the identified thickness reduction on the internal surface of the tube.

The y-axis presents the recorded tube wall thickness in millimetres, whereas the x-axis presents the length of the tube in in millimetres. The B-scan will enable the identification of areas characterised by nominal wall thickness reductions. The test should enable a continuous measurement along the entire length of the waterwall tube (Fig. 8). The tests involved the use of the module provided with 1 Spotweld type transducer (Fig. 13).

Ultimately, the module will be provided with three identical transducers performing measurements in three areas around the circumference (Fig. 14). An important element of the scanning system is a properly working irrigation system. The proper coupling of the transducer with an element subjected to the test is crucial as regards the stability and repeatability of measurements.

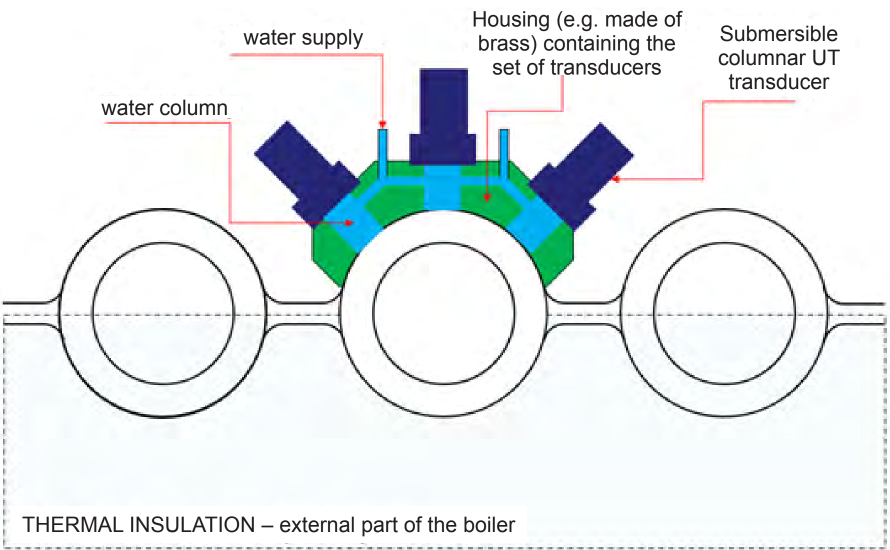

Fig. 14. Range of boiler waterwall subjected to analysis during the measurement of thickness

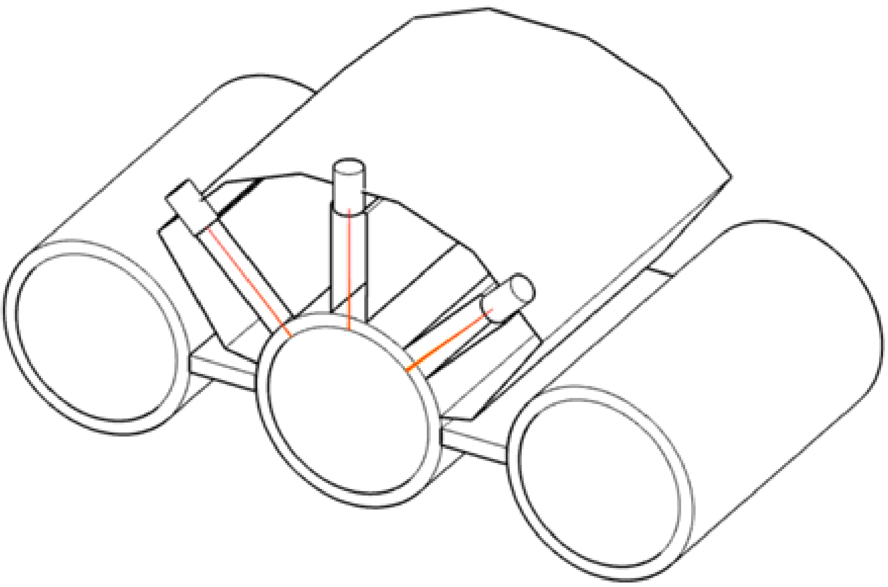

Fig. 15. Schematic diagram of tests involving boiler tubes

The adjustment of the module is of significant importance in terms of the appropriate perpendicular positioning of the transducer in relation to the tube surface and the proper seal of the irrigation system (Fig. 15).

Summary

The selection of the testing technique based on Spotweld-type transducers was dictated by the test conditions and the surface subjected to examination (i.e. the surface of tubes exposed during the operation of the power boiler). The idea behind the selection of the solution was the possibility of performing reliable continuous measurements. The choice of the non-contact transducers aimed to enable the observation of wall thickness reduction both on the external and internal surface of the tube. The interpretation connected with the location of the wall thickness reduction is important in respect of progressing degradation. Services responsible for maintenance and quality control should possess the most extensive knowledge about wall thickness reduction and its location.

The possible application of the above-presented solution will be discussed in the subsequent parts of the publication. Verification measurements involving the reference specimens and the actual segments of tubes revealed both the advantages of the solution and the limitations connected with the quality of the surface. The subsequent parts of the publication will discuss the issue of measurement accuracy and the possibility of obtaining unequivocal information about the location of wall thickness reduction.

Tests discussed in Part 2 will be connected with the calibration of the device and the demonstration of measurement reliability in relation to standard specimens and reference specimens. Part 3 of the publication will discuss test results concerning actual segments of waterwall tubes. The tests will be performed on a specimen characterised by the worst surface quality.

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