WALL THICKNESS MEASUREMENT OF LARGE TUBE DIAMETERS USING PHASED ARRAY TECHNOLOGY

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1.0 Introduction

The Vallourec & Mannesmann Tubes rolling mill Déville is located near to the city of Rouen in Normandy in the northern part of France. The mill manufactures seamless steel tubes within the dimension range from 177.8 mm to 339.7 mm and within the wall thickness range from 4.6 mm to 32 mm. Along with an extension of the dimensional program from approx. 250 mm to 339.7 mm, the systems were converted to mass production. Today, the program mainly includes casings, standard line pipes and line pipes for projects, as well as hollows for elbows, gas cylinders, and pressure vessels.

Since the steel tube is a product subject to high requirements regarding compressive strength, leak-tightness and dimensional accuracy, a reliable quality assurance is a prerequisite.
The possible consequences of a component failure with regard to human lives, environmental damages and unforeseeable consequential costs require a conformity to process tolerances. In order to determine these product properties as early as possible and to be able to make any necessary corrections to the production process, a „multiple test block“ (Figure1) was installed immediately behind the cooling bank of the rolling mill. The „multiple test block“ consists of a leakage flux test for longitudinal flaws and transverse flaws and of a wall thickness measurement including a lamination test type ROWA from GE Inspection Technologies . This multiple test block helps to accomplish two tasks with the system firstly serving for in-process inspection and, secondly, allowing for the products delivered as rolled to be subjected to an acceptance test. The installation site of the system as near to the rolling mill as possible enables the early recognition of repetitive flaws and the a quick reaction to them. As less than 100 „tubes“ are in process between the start of production, the rotary hearth furnace, and the testing device, systematic flaws due to e.g. groove deposits or roll breakdowns on a forming machine can be identified early enough, the rolling process can be stopped, and the corresponding measures can be taken.
The wall thickness measurement has a special status in improving the rolling process and consequently the process tolerances.
A „quality loop“ is achieved by the feedback of the results to the rolling mill. The early measurement in combination with large rolling lots allows to have a direct feedback and therefore a continuous improvement of the process.
The benefits of ROWA (**Ro**tating **Wa**ter coupling) are presented both by the costs of acquisition and by the costs of operation.
As opposed to this, EMUS rotation systems for this dimension range are characterized by high service expenditure and a considerable probe consumption because distances between the tube and probe of less than 2 mm must be observed in this case. On the other hand, the permanent operation of ROWA mainly incurs costs for rubber seals which are negligibly low. Due to a delay line of at least 23 mm, the Phased Array elements are at an adequate distance away from the tube and are only subject to their natural ageing. Moreover, a subdivision into single arrays having 32 elements is favorable in view of service and operating costs.

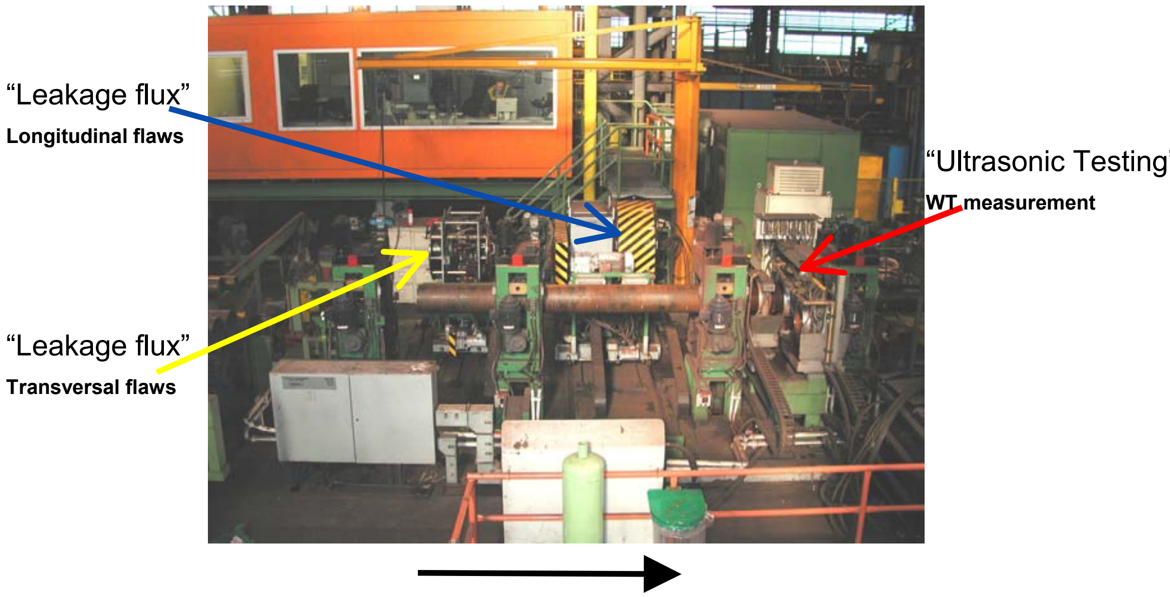

Fig 1: testing machine, overview

2.0 Test technique

2.1 Principle solution

The Phased Array technique in combination with the ROWA test mechanisms has already been used satisfactorily and efficiently for a variety of applications. Beside the full body inspection of bars, also wall thickness measurements of tubes have been performed.
In the past, the testable range ended at a maximum diameter of 177 mm. Thanks to the present application, the testable range has been extended up to 339 mm (see fig. 2). In the future, even larger diameters are imaginable.

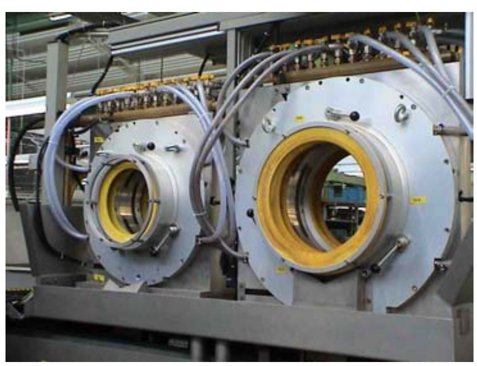

Fig.2: ROWA - Mechanism

Whereas until now the number of Phased Array channels – and thus the number of probes – has set the limits for the testable diameter range, now the Array electronics in its second generation offers a much larger number of test and evaluation channels.

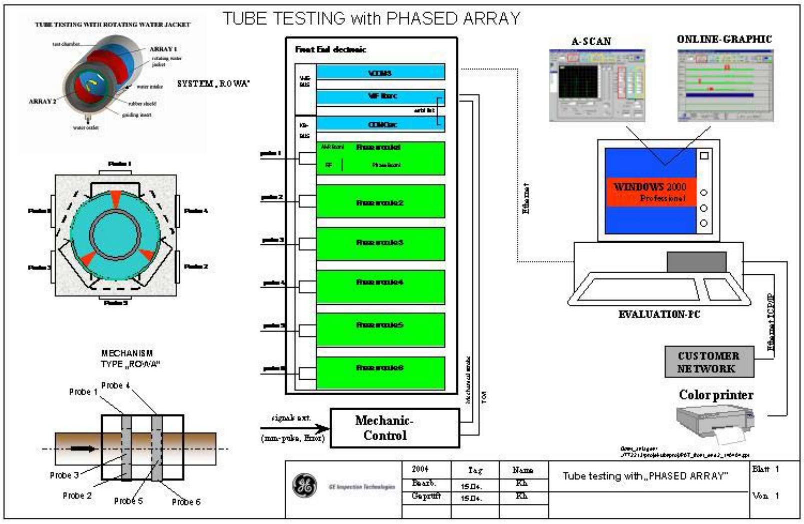

Fig. 3: Schematic Diagram wall thickness measurement

Fig. 3 shows the schematic diagram for test data acquisition and evaluation.
At this point, we do not want to go further into details of the electronics or the evaluation algorithms, since detailed explanations have already been presented in other lectures.
The same restrictions existed for the ROWA applications. Whereas the ROWA technique uses rigid guide bushes for the inspection of small diameters, the concept had to be modified for the large tube diameter ranges. Flexible rubber seals (see fig. 4) offer a larger clearance for larger tube straightness tolerances. A prewetting system allows a constant ultrasonic coupling.

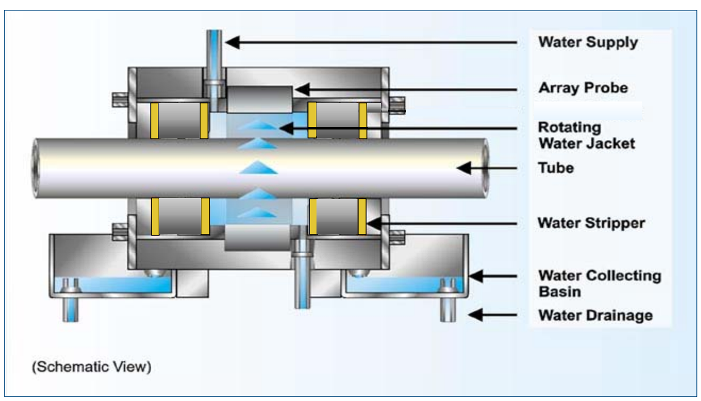

Fig. 4: Schematic sketch "ROWA-system"

The distance between the array and the tube surface varies between 23.0 and 72.5 mm. A constant rotating water jacket is generated by a tangential arrangement of the water nozzles.

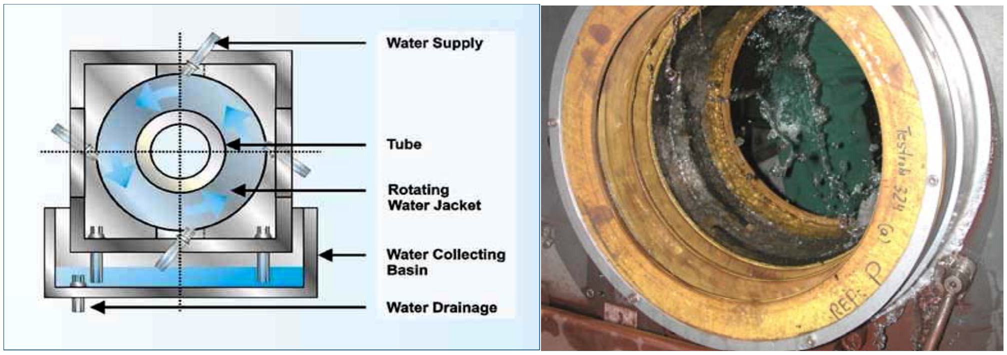

Fig. 5: Rotating water ring with rubber sealings

Each of the two ROWA test mechanisms contain 6 mechanically overlapping probes. Each of these probes consists of 4 blocks of which each block contains 32 single transducer elements. The virtual probe can be composed of 1 up to 32 elements; in practical use, typically 5 (up to 8) elements are interconnected. Using this configuration, transducer widths of 9 mm (up to 14.4 mm) can be achieved. The near field length in water then amounts to 67 (up to 174) mm.

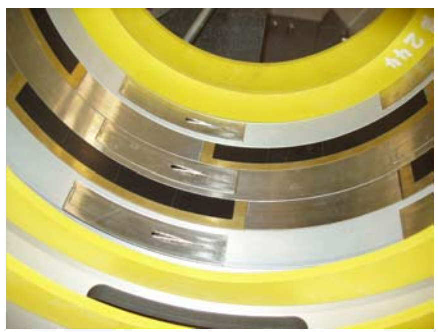

Fig. 6: 6 probes; 4 blocks per probes, 32 elements per block

For obtaining the overlap of the virtual probes and of the mechanical arrangement, the following cycling scheme has been realized (see Fig. 7)

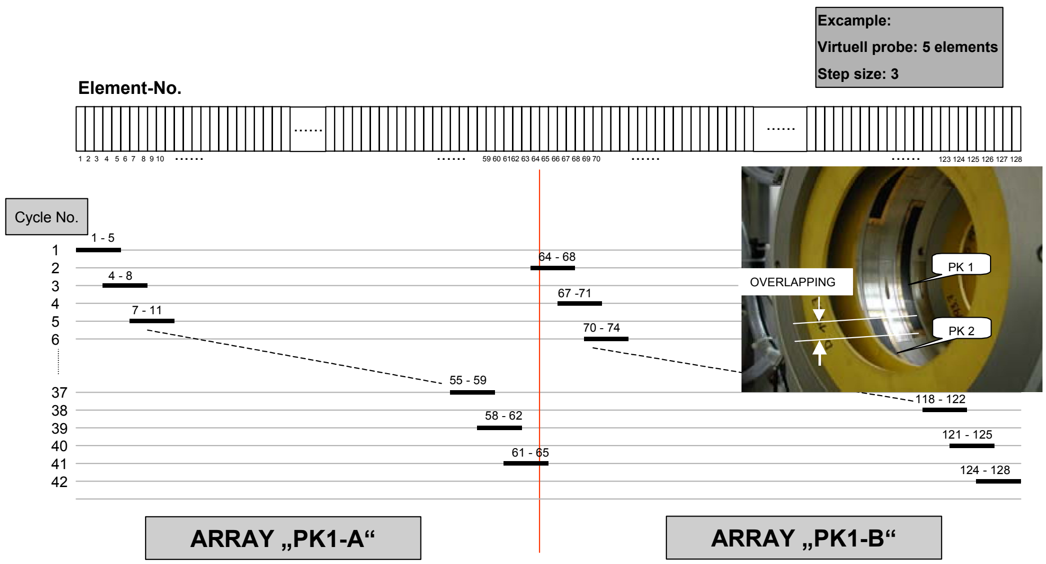

Fig. 7: Cycle diagram; bisection in two Array groups

With the division of the probes in 2 groups (“PK1-A” and PK1-B”) a shorter clock sequence and a higher scan- RPM can be obtained.

3.0 Inspection and dimensional changeover of the installation

Here it has to be distinguished between a dimensional changeover **within** the diameter range of the currently used ROWA test mechanism, and, on the other hand, a necessary changeover of the test mechanism itself.
For the first kind of changeover, the adequate sealing of the water chamber has to be ensured. That’s why the 4 rubber seals must be exchanged. To this purpose, either only the screwed-on rubber seal rings can be replaced, or prepared complete seal sets can be used with quick-release fasteners. In this case the changeover can easily be realized in less than 3 minutes.

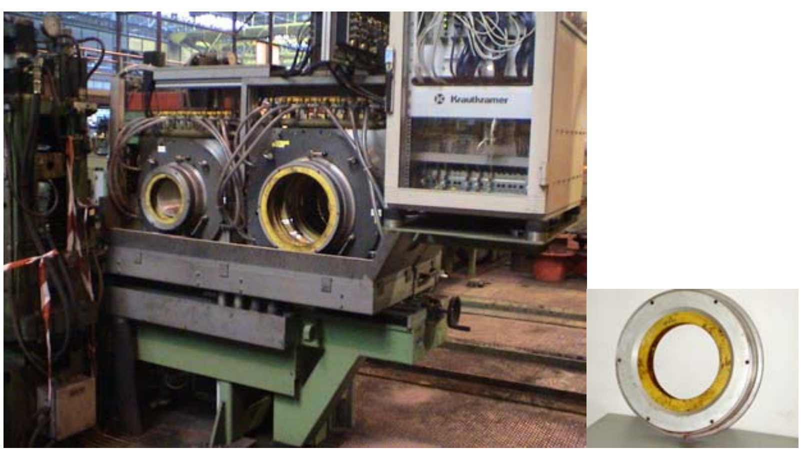

Fig. 8: Lifting / sliding table with a set of rubber sealing (in- and outside)

For a dimensional changeover of the second kind with a change of the ROWA test mechanism, the fixed test position must be abandoned by unlocking the fixation. The two mechanisms will

then be moved horizontally by hand via a spindle drive. The exchange of the mechanism and the seals takes approx. 5 minutes.
Beside these mechanical works, a new test parameter data set must be loaded for the new test task.
Normally, the calibration of all virtual probes is done at a reference tube or production tube of known wall thickness.

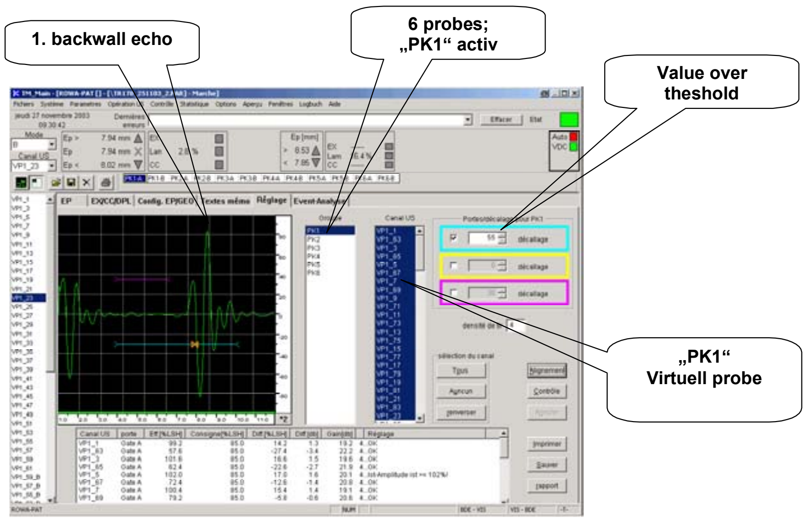

Fig. 9: Operator menu for calibration “virtuel probe”

To the purpose of probe setting, the 6 probes are selected individually, and the amplification of all virtual probes of a system is set to the desired signal amplitude in one calibration run. This procedure takes approx. 5 minutes, and then the test can start.
During a regular inspection or after exchange of a probe (or probe block), all single elements will be adjusted to the same gain level by means of a normalization (see fig. 10).

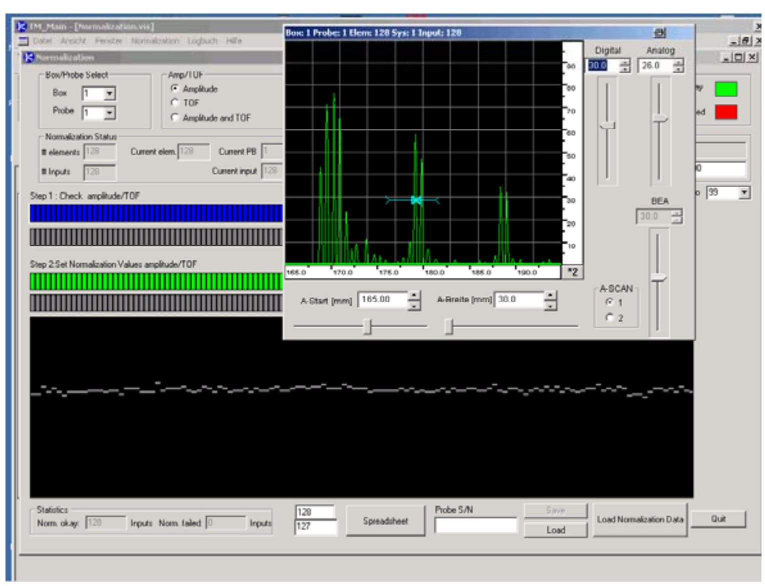

Fig. 10: Single element consideration before and after Normalization

In addition, the time of flight is adjusted by means of the reference tube segment used for the normalization.
The normalization procedure including mechanical mounting (and dismounting) of the reference segment and respective rubber seal sets will take approx. 30 minutes for all 6 probes.
If 2 or more adjacent single elements are defective, the probe block or probe must be replaced.

4.0 Test sensitivity and reproductibilty

At a test speed of 1.0 m/s, a complete wall thickness measurement over the entire circumference must be guaranteed with a reproducibility tolerance of less than ± 0.05 mm.
In order to verify that these demands are met, three reference tubes with the sizes

- 177.8 x 8.05 mm
- 241.0 x 12.5 mm
- 323.9 x 16.0 mm

were manufactured and provided with flat bottom holes (6.3 mm, 30 % drill depth) and local wall thickness reductions (area 1 inch, starting 100 mm from the tube's front end).
In 10 testing machine passages (the tubes were turned), all flat bottom holes as well as the wall thickness reductions were detected with the required reproducibility.
In addition, the wall thickness values (Min., Average, and Max. value) were determined five times for another reference tube sized 219.10 x 9.5 mm over the entire length of 7 m and combined to form 100 mm length segments. This means that there are 69 values for the minimum, average, and maximum wall thickness from every run. The difference between the largest and the smallest value for each segment is determined for the (minimum, average, and maximum) wall thickness.
The evaluation of these differential values is shown for the minimum wall thickness in Figure 11. The percentage of differential values from the five runs is shown as a bar graph in each case. The curve indicates the added-up frequency values, e.g. 91% of differential values for the 69 segments are within the accuracy of
0.06 mm.

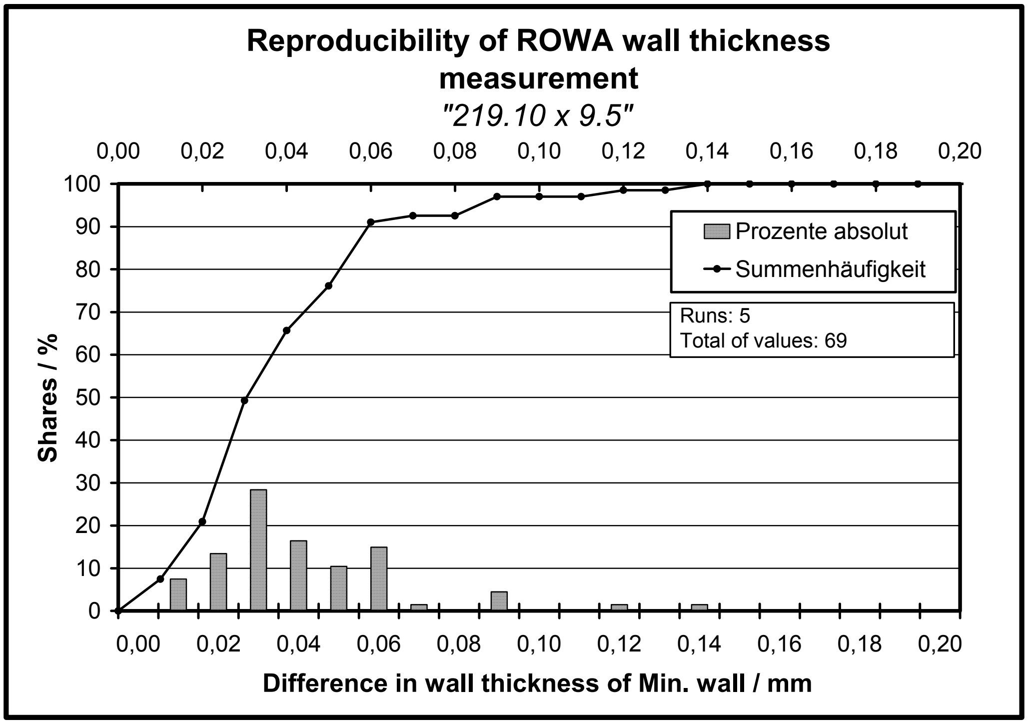

Fig. 11: Frequency distribution of differential values for the single 100mm segments

In this statistical evaluation method of reproducibility, it cannot always be ensured that exactly the same 100 mm long segments are compared with each other. The reproducibility is assessed as very good under these conditions.

5.0 Project final status

The preacceptance test in Huerth was performed on February 13, 2004.
After commissioning and operator training, the testing machine was put into trial operation on March 17, 2004. Since the final acceptance test on April 29, 2004, the enduser has been using the testing machine in 3-shifts operation without problems.