Phased-Array ROWA-SPA: High-performance testing machine for combined, 100-percent automated testing of square and round bars

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Abstract
The presented ultrasonic testing (UT) machine is based on Phased-Array probes in immersion technique. It consists of two independent sub-systems that enable a combined testing of both square and round bars in one production line. The basic concept facilitates a very short changeover time of only several minutes to switch from round to square material.
The UT system provides 100-percent coverage for volume tests in order to evaluate inclusions in the material. In addition, surface tests enable a detection of cracks at the surface. Testing can be performed over a large range from 10 up to 260 mm in diameter (round material) and a dimension of 45 to 250 mm (square material). Dimension-specific changes of the test mechanics are fully automatic. Implemented electronics and software render possible to detect defect sizes in a sub-millimeter range at high test speeds up to 1.4 m/s.

Keywords: Round and square bar, Volumetric inspection, ultrasonic testing, Phased-Array, 100-percent testing, Automated testing

1. Introduction

Phased-Array Technology (PAT) for ultrasonic non-destructive testing (NDT) is a well-established technology in the industrial sector, in particular for quality inspection of material. Speed, flexibility and electronic setups are main characteristics of this technology, which can be efficiently applied for detection of core, surface and subsurface flaws in the material.
Thanks to the PA technology the ultrasonic beam can be focused and steered according to the specific inspection requirements.
The ROWA-SPA PAT is an innovative machine which combines two independent sub-systems, allowing testing both square and round material in the same production line in automatic mode. This machine meets the needs of those manufacturers whose production ranges from round to square material and therefore requires a double system with short changeover time for high performance and line productivity.
While the ROWA machine is a long standing GE product [1], [2], the SPA is a new development, with at the moment 4 installed and working machines in the world.
Both systems are based on immersion technique. Thanks to the use of water delay path between probe and bar the arrays can be matched to different bar diameters. Automatic calibration and testing allows better reproducibility and precision. Computer supported data management and evaluation, on-line graphics and off-line function analysis are implemented.
In the next sections the testing principle and possible performance of the ROWA-SPA machine are described. Finally, the results related to the first three machines installed between end of 2013 and the first quarter of 2014 are presented.
2. Testing principle and performance of the machine

2.1 ROWA-Bar PAT

The ROWA testing machine is a well-known machine for the quality inspection of round material. PA probes are arranged in the test chamber around the circumference of the bar. One array probe sets can accommodate a wide range of bar diameters. The main feature of the system is that the rotation of the sound beam is electronically accomplished by the corresponding control of the elements in the array. Thus a mechanical rotation of the bar is not necessary.

The adjustment of the system is performed by means of manipulator, allowing for adjustment in automatic mode after the first settings.

For core flaw inspection, the elements of the array are activated in such a way to send a vertically oriented beam into the bar. For detecting flaws on or near to the surface, the elements are activated with time delays in such a manner that an angle beam occurs with the bar. Figure 1 shows the way the bar is scanned by the ROWA. This procedure ensures testing 100% of the volume.

![Figure 1: ROWA scans allows to test 100% of the bar volume](image)

2.1.1 Test performance

Depending on the dimension of the test object and of the required performances, the ROWA can be designed with 4 to 18 PA probes, covering the range from 10 up to 260 mm in diameter. The biggest ROWA (18 probes) is able to detect Flat Bottom Holes (FBH) starting from 0,7 mm diameter in the lower diameter range up to 1,6 mm diameter in the upper range; notches of 0,3 mm depth and Side Drilled Holes (SDH) of 0,8 mm diameter, with a maximum speed of 2 m/s.

The performance strongly depends on the material properties, which have an influence on the pulse repetition frequency.

2.2 SPA PAT

In the SPA machine, the probes are installed in an immersion tank and arranged from all four sides round the billet. For the volume test the elements are activated so that a vertical scanning into the object is carried out. The advance of the individual elements combined into virtual probes provides the axial scan process along one test object side, e.a. a virtual axial movement.

The focusing of the sound beam is also achieved by the electronic control of the individual array elements. By this it is possible to adjust the focus for materials with different depths to
have always the optimal testing sensitivity. Figure 2 shows the three scans of one side of the billet:

- Scan 1: perpendicular sound propagation for core flaw and sub-surface inspection
- Scan 2: sound propagation with small angle left (longitudinal wave) for corner inspection, it can also be used for surface inspection by the use of transversal waves
- Scan 3: sound propagation with small angle right (longitudinal wave) for corner inspection, it can also be used for surface inspection by the use of transversal waves

![Figure 2: Scans from one side of the billet](image)

Figure 3 describes the test performance in radial and axial direction. For the radial direction the element pitch of the probe is a measure for the flaw detectability whereas in axial direction the flaw detectability is given by the transport speed and PRF (Pulse Repetition Frequency).

![Figure 3: Schematic representation of the test conception virtual probe](image)

### 2.2.1 Test performance

Depending on the dimension of the test object and of the required performances, the SPA can be designed with 4 or 8 PA probes, covering the range from 45 up to 250 mm in cross-sectional width. The SPA is able to detect FBH from 0.8 mm diameter, notches of 0.5 mm depth and side drilled holes of 0.8 mm diameter. The maximum test speed of the SPA is 1.4 m/s and depends on the test requirements. The untested ends are ≥ 50mm. As for the ROWA, the performance strongly depends on the material properties.
3. Feedback from experience

Up to now, GE has installed a total of four machines in the world: one in Turkey, two in the USA and one in Germany. Figure 4 shows the complete testing machine in its final design.

3.1 Commissioning results with SPA PAT

In this section some examples of flaw detection are presented. The operation of the front end electronics of the testing machine and the visualization of the test results is handled by an industrial PC. The integrated graphic user interface allows the display of digitized A-scan (amplitude-scan) and the evaluation of the ultrasound signals in an online graphic. Figure 5 shows the A-scans for core and surface flaw detection in a 70 mm square bar width. The x-axis represents the depth of the bar, while the y-axis represents the amplitude of the ultrasound signal. On the right side, the digital and analog offset values applied are shown. They are set during adjustment of the system by means of test bars with artificial flaws. On the left side, the group of elements of the PA probe detecting the flaw is highlighted in red, for a first rough localization of the flaw in the test object. The positioning of the blue and yellow gates in the depth zone to be tested defines the criteria for the display of the results on the online graphic.
When the amplitude of the echo generated by the flaw passes the threshold fixed by the gate, the online graphic shows a red line for easy and fast interpretation of the test results. For instance, the online graphic in Figure 6 shows the results of a test performed at a speed of 0.44 m/s and untested ends of 50 mm. In particular, the graphic shows:
1. FBH of 0.8 mm diameter in depth of 35 mm
2. FBH of 0.8 mm diameter in a depth of 60 mm
3. SDH of 0.8 mm diameter, 10 mm length in a depth of 35 mm

In addition, as represented in Figure 7, for analysis of the inspection results a cross sectional 2D-view shows the flaw position in the cross section of the billet. By moving the cursor in axial direction each 10mm cross section can be displayed. The position in billet transport direction, depth and amplitude of the flaw can be shown as well.
4. Conclusion and outlook

The combination of two different testing machines in the same line is an innovative solution which works and increases the efficiency of the production. The lessons learned during the long-year experience of the ROWA have been applied to this combined system, extending GE portfolio of testing machines to square material. Future projects and the feedback on the currently working ROWA-SPA PAT will be used to improve the quality of this product and in particular to implement additional features to facilitate the use of the machine and the analysis of the results.

References
