ECHOGRAPH Ultrasonic Testing of Helical Submerged Arc-Welded (HSAW) Pipes

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Summary Borusan Mannesmann Boru is the largest pipe producer in Turkey having a production capacity of a million tons of welded pipes and employing more than 1200 people. The company was founded in 1958 and more than 50% of the shares are privately owned. A new spiral pipe plant is under construction in Gemlik, Turkey. The main line supplier was Danieli W+K with plants in Italy and Germany. The inauguration of the new plant is planned for September 2011. Full production will start in early 2012. The Gemlik plant is located directly at the sea which facilitates transportation of raw materials and finished pipes by ship. Three ultrasonic testing systems from KARL DEUTSCH were ordered to fulfil the highest requirements of the oil and gas industries.

The test of the pipe body is performed in the strip stage before welding. The strip widths range from 1100 to 2050 mm. The testing speed corresponds with the uncoiling process, i.e. max. 10 m/min. The test specifications in recent years require a high percentage of ultrasonic coverage. In order to reach a solution with 100% coverage without any mechanical oscillation a total of 41 probe holders was chosen. Each probe holder contains a special broad-beam probe with one common transmitter and two receivers (TR-probe with 2 test channels), thus providing a test track of more than 50 mm per probe. Steel rollers guide the two outmost probe holders along the strip edges. Three additional probes are provided to measure the wall thickness at both strip edges and the strip middle. Thus, a total of 85 test channels is provided. The test results can be viewed online in real-time during the test. Each probe can be monitored either in the strip chart representation (amplitude versus strip length) or in the C-scan representation (top view of strip with colour-coded amplitudes). Since an endless strip is tested, the results scroll through the screen. The spatial resolution can be chosen by the operator as convenient for the supervision of the test. The test mechanics can be moved offline above a test plate with artificial defects where a dynamic calibration with full test speed can be performed.

After the strip test, the pipe forming and welding process takes place. The pipe diameters range between 20 and 64” (508 mm – 1625.6 mm) and the wall thicknesses between 6.35 mm and 25.4 mm. The pipes are then cut to their final length and undergo a first ultrasonic test with 6 ultrasonic probes. Longitudinal and transverse defect detection are the respective test tasks. The weld crown is automatically tracked by a laser-based seam tracking system which keeps the probe pairs centered with respect to the weld. A line laser pointer produces an illumination parallel to the weld crown which is always monitored by a camera. The camera image is transferred to the operator panel and is checked by the operator for proper functioning. The test mechanics is mounted to a machine stand with horizontal boom. The boom must be adjusted in height in accordance with the pipe diameter to be tested. The pipe is transported by a carriage where linear and rotational speed must be chosen such that the test position of the weld is always in twelve o’clock position.

After further production steps (pipe end bevelling, hydrostatic test, etc.), the final ultrasonic test is performed. Concerning longitudinal and transverse defects, the same probe arrangement is chosen. Additional lamination probes for the heat affected zone and pipe ends are provided. The final test consists of three steps: Test of front pipe end with rotation of pipe, helical weld test and test of rear pipe end, again under rotation.
Ultrasonic Testing of the Pipe Body (in the Strip Stage)

For some test specifications it is sufficient to inspect only the pipe weld seam. More stringent requirements also require the inspection of the pipe body. Two alternatives within the production flow are possible. Either the inspection is carried out directly after uncoiling and before welding (i.e. strip stage), or the test is executed after welding (i.e. in the pipe stage). The ultrasonic coverage typically varies between 12.5% and 100%. The higher the required coverage, the more ultrasonic probes must be provided accordingly. Oscillating probes can increase the coverage during the test, but the oscillating mechanic is always a critical issue in terms of service. Since the cost for electronic testing channels could be reduced in recent years, and 100% coverage was desirable for Borusan, a solution without oscillation was chosen for the new plant.

Testing mechanics with a large number of probes are easier to mount before the welding station. Therefore a strip testing concept was chosen. A challenge for this approach is the waviness of the strip after uncoiling, which is taken into account by robust probe holders with gimbaled joints and robust pressure rollers to be integrated into the production flow. Also, water at the welding point must be avoided and is blown away with water air nozzles after the test. The coupling water is collected in tubs, filtered and fed back into the water circulation system. The uncoiler must be able to move in accordance with the weld angle. Despite the large dimensions and weights of testing mechanics, operator panels and water filter system, all components must be mounted onto the carriage of the uncoiler. This is difficult to realise for a retrofit of an existing production line. Since this production line was newly planned, the uncoiler was extended in length and width to properly mount the strip testing system.

Special attention was given to a convenient and reliable calibration of the system. All probes can be calibrated automatically and fast within one step by using a specially prepared test plate which is mounted on a movable table. This calibration unit allows a linear movement of the test plate with respect to the probes with the maximum welding speed up to 10 m/min – a difficult task due limited space on the carriage of the uncoiler. For that purpose the testing system is twice as wide as the maximum strip width so that all probes can be moved from the test position (online) to the service and calibration position (offline). The specified test sensitivity for the lamination detection is a 5 mm FBH (EN) or 6.4 mm FBH (¼ “ acc. API). The calibration reflector is a notch over the entire plate width (5 mm width in plate transportation direction, depth 50% of the wall thickness). This allows a uniform sensitivity calibration for all probes. The specified sensitivity can be adjusted electronically and automatically.
Each probe uses two receiving elements with a test track of more than 25 mm each. A total of 41 probes was used. The probes are TR-probes (dual-element principle), suitable for the inspection of fairly thin strips and providing small dead zones on top and bottom surface. Three additional probes monitor the wall thickness along the entire strip. The test results are visualized online in strip-chart and C-scan format.

Figure 1: Probe Configuration for Strip Test. a) separate probes for both strip edges and two rows of overlapping probes for the strip middle, b) the probes for the strip edges are guided with steel rollers, c) overlapping probes for the strip middle.

Figure 2: Strip Testing System. a) ECHOGRAPH-BAPS testing system before shipment in KARL DEUTSCH workshop with probes in calibration position above test plate, b) system at Borusan plant in Gemlik with operator panels on both sides for convenient access.
**First Ultrasonic Testing of the Pipe Weld (Before Hydrotest)**

In many HSAW-pipe mills the first ultrasonic test is carried out directly after welding on the endless pipe (so-called online test). The new Gemlik plant is designed for a high production rate and operates one high-speed tack welding station and three parallel welding stands. Therefore, the pipes are already cut to customer-specific lengths and the ultrasonic test is carried out pipe by pipe (so-called offline test). The probes are hanging from a height-adjustable boom which is mounted to a machine stand. The pipes are fed into the test position by means of a pipe carriage, which must provide a smooth transport without vibrations in the linear and circumferential direction. The weld test position is in 12 o’clock. Due to unavoidable tolerances regarding the pipe diameter and ovality due to the production process, the seam tracking unit is of highest importance for the inspection of helical welds (in comparison to longitudinal welds).

The probe pairs are positioned perpendicular and parallel to the weld. The entire testing mechanics can be rotated by means of an extremely robust toothed wheel to allow a large weld angle range and to inspect left- and right-welded pipes. Especially in case of small pipe diameters, strong surface curvatures must be taken into account. This problem is becoming crucial if many ultrasonic probes are used. Therefore, the entire testing mechanics must be designed as compact as possible in order to mount as many probes as possible. This again requires a compact design of the probe holders and seam tracking unit.

Most crucial for weld testing are longitudinal defects (defects parallel to the weld, e.g. lack of fusion). Typically four probes are provided, one probe pair for internal defects and one probe pair for external defects. This is especially true for recent systems where the pipe wall thickness exceeds 12.7 mm (½”). The test defects are N5-Notches (internal and external, length 25 mm) in the weld centre and next to the weld in the heat-affected zone (HAZ). Unfortunately, in many projects test specifications are incorrectly mixed for different pipe types. This is also true for the SHELL specification. On page 32 and 33 in the edition of December 2000 only longitudinal welds are specified (not helical). Therefore, no tandem setup was provided in this case.

Many existing test machines use off-bead probes for the detection of transverse defects. Within the well-known K-setup two probes are used for the detection of transverse defects in pitch-catch-mode (with 90° sound reflection from the defect). An alternative is the X-setup (with 4 off-bead probes), where a proper coupling can be monitored continuously. Both solutions are difficult and time-consuming to adjust for the operator. Especially the X-setup requires a lot of space within the test mechanics. Therefore, a new approach with two on-bead probes was designed which is also suitable for higher wall thickness. A compact double-probe holder using water jet coupling is guided above the pipe weld by means of steel rollers. The test angles are fixed to 45°. The v-reflection (pitch-catch mode) is used for constant coupling check. Only minor mechanical adjustments are required in case of changing the pipe dimension.
To summarize, a compact machine with six probes was chosen to be sufficient for all relevant specifications.

Figure 3: Probe Configuration First Weld Test. a) test principle with six probes, b) on-bead transverse probes.

Figure 4: Mechanics for First Weld Test. A operator panel, B probe holders, C pipe carriage, D horizontal boom, E machine stand, F drainage for excess coupling water and runway for pipe carriage, G water filter system.
Automated Laser-Based Seam Tracking

It was mentioned before that especially for helically welded SAW-pipes, the seam tracking unit is essential for proper functioning of the testing machine. Unlike in case of ERW-pipes, where the weld crown (burr) is removed, the weld crown of SAW-pipes will cause geometrical reflections and respective pseudo-indications in case of misalignment of the ultrasonic probes. Modern SAW-pipes should have a shallow external crown which makes the use of conventional electromagnetic seam tracking more difficult. Despite the fact that many laser-based seam tracking units are available, most of the engineering and software work was carried out by KARL DEUTSCH. The total cost of the unit is one issue. Secondly, a convenient operator interface is desirable which prevents the use of two industrial PC’s (one for ultrasonic control and one for seam tracking control). A direct interface to the ultrasonic electronics and the Siemens PLC was programmed. All relevant menus and seam tracking images can then be shown on the PC-screen of the operator panel(s). For most testing machines, two operator panels are provided (one near the probes, one in the operator cabin or in the office of the quality department) – one more reason to only use one PC and screen. The seam tracking unit is working fully automatically. The operator can supervise the process by means of a real-time camera image and can take corrective action if necessary.

Figure 5: Laser-Based Seam Tracker. A laser line across the weld, B holder for seam tracker which can be pneumatically moved between safety and test position.
Figure 6: Seam Tracking Result. a) distance to the pipe surface is shown within an angular range of $\pm 6.9^\circ$, the minimum distance corresponds to the weld crown and is marked with a small circle, b) the plot is distorted by means of a pen which is held above the pipe surface, the seam tracker will try to follow as fast as possible.

Figure 7: Supervision of Seam Tracking. a) a laser line is projected parallel to the weld, b) seam tracking result as above, c) additional real-time camera image showing the laser line with respect to the weld position.
Final Ultrasonic Testing of the Pipe Weld and Pipe Ends (After Hydrotest)

The final test is crucial for the end customer of the pipe and produces a test protocol for each pipe. The same probe arrangement for the angle beam probes is used as for the first weld testing machine.

Additional lamination probes are provided for the heat-affected zone (HAZ). A test track of 25 mm on both sides of the weld must be covered and due to the pipe curvature, this test task is split into two probe pairs. Dual-element probes with a test track of 18 mm are employed such that sufficient overlap is ensured.

Due to the compact design of the probe holders and the seam tracking unit, a total of ten ultrasonic probes could be mounted to the same testing mechanic. Therefore, a second machine stand (often found in combination with the X-setup for transverse defects) to accommodate additional probes is avoided.

The pipe ends deserve special attention because they will be the joints within a pipeline later. A test track of 50 mm is required and laminar defects shall be detected. Since the long side of the dual-element probe is oriented parallel to the pipe axis, a test track of 25 mm per testing channel is possible. A dual-channel probe (one transmitter and two receivers in the same probe housing) is mounted to the respective probe holder. Two steel roller guiding units are used for the respective pipe end. The test procedure consists of three steps: first pipe end, helical weld, second pipe end. The rotational speeds for the pipe end test are typically 6 - 10 m/min. The helical weld test is carried out with speeds of 10 - 20 m/min.

Figure 8: Probe Configuration Final Ultrasonic Test. a) test principle with 11 probes, b) probe holders.
Figure 9: Pipe End Test. a) probe holder for pipe end is guided by a set of steel rollers (second set on the left in idle position), b) lamination test is carried out within one pipe rotation.

Figure 10: Mechanic for Final Pipe Test. a) probe holders, operator panel and provisional pipe carriage at KARL DEUTSCH workshop, b) machine stand with testing mechanics, pipe carriage and operator platform at BORUSAN plant in Gemlik.
**ECHOGRAPH 1155 Testing Electronic**

The evaluation of the ultrasonic signals is carried out with a multi-channel testing electronic. The electronic can be programmed according to all previously mentioned testing tasks. In general, a multitude of channels is necessary and each channel can be individually configured. The harsh environment in a pipe mill suggests the use of external pre-amplifiers close to the ultrasonic probes. The probes cables have to be well shielded and the electronic needs a large amplification range with high signal-to-noise ratio.

Even though the testing electronic did not change its name for several years it is constantly reworked and adapted to the customer-specific requirements. All three testing machines are equipped with separate electronics. The weld testing machines operate one standard module which can drive up to 16 channels.

The strip testing machine requires 85 test channels and is built from several modules. Since the strip testing process is continuous, also the test results scroll through the image in a continuous manner. A strip chart representation and a C-scan representation are possible, where zooming into regions of interest is possible. The C-scan representation is a convenient tool to supervise the calibration procedure. The probe holders for the strip middle are positioned in an overlapping manner in two rows with respect to the transportation direction. This can be clearly seen in the C-scan when the long notch in the calibration plate is picked up by all probes.

![Figure 11: Calibration Test Results. Operator screen, A = C-scan moving from left to right, B = red indications from test notch for all probes (indication positions in accordance with overlapping probe arrangement), C = strip chart representation with amplitude versus strip length (each box represents a group of probes, red zone = above threshold).](image-url)
Also a matrix is provided after the automated calibration procedure where one cell represents one receiver channel. A cell marked in green shows a receiver channel with an ultrasonic amplitude within the pre-defined tolerance band. A cell marked in red requires further calibration work.

Figure 12: Ultrasonic Amplitudes for Each Probe. A = all probes are within tolerance, B = some probes are marked in red and require further adjustments.
References


