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Automated Ultrasonic Pipe Weld Inspection

Wolfram A. Karl DEUTSCH, Peter SCHULTE,

Michael JOSWIG, Rainer KATTWINKEL

KARL DEUTSCH Instruments, Sensors & Systems for NDT, Wuppertal Germany,

Phone: +49-202-7192-0. Fax: +49-202-714-932, info@karldeutsch.de, www.karldeutsch.de

Summary

This article contains an overview on automated ultrasonic weld inspection for various pipe types. Some inspection steps might by carried out with portable test equipment (e.g. pipe end test), but the weld inspection in all internationally relevant specifications must be automated. The pipe geometry, the production process, and the further pipe usage determine if NDT is required and thus, the number of required ultrasonic probes. Recent updates for some test specifications enforce a large number of ultrasonic probes, e.g. the SHELL standard. To save production cost, seamless pipes are sometimes replaced by ERW (electric-resistance welded) pipes and LSAW (submerged-arc welded pipes with longitudinal seam) pipes by SSAW (submerged-arc welded pipes with spiral seam) pipes, the inspection methods change gradually between the various pipe types. Each testing system is optimized for the specific application and its properties have to be discussed by the system manufacturer, the system user and the final customer of the pipe.

The presentation for the WCNDT in Shanghai focuses on three ultrasonic testing systems which were shipped to BAOSTEEL in 2007 and which are currently under installation. Two ECHOGRAPH weld testing systems for large diameter pipes with longitudinal submerged arc weld (LSAW) and one ECHOGRAPH pipe-end testing system enable the pipe mill to inspect their products with high throughput. Testing speeds for the pipe weld of up to 1 m/s are feasible due to the customer-specific system design and the respective pipe transportation devices.

1 Introduction

This paper discusses various applications where the ultrasonic weld inspection is carried out in an automated manner. The highest throughput rates are required in pipe mills where the testing systems are part of the production line and should not limit the capacity of the mill. This is mostly the case for ERW-pipe mills, where a large number of pipes is produced in dependence of the weld speed (typical 10-35 m /min). The systems often work in 3-shift operation with a rate of availability of more than 90%. Therefore, robust testing mechanics are combined with sophisticated multi-channel ultrasonic electronics which allow trouble-free operation in an industrial environment with many electro-acoustical noise sources (motors, transformers, welding equipment).

2 Ultrasonic Coupling techniques

Since air is a poor conductor for ultrasound, **water is commonly used for the ultrasonic coupling**. This usually governs the design of every testing system. The principal ways to couple ultrasound into the specimen during an automated weld inspection are now discussed:

Immersion testing is a very common method for smaller specimens being inspected piece by piece, e.g. automotive components. For an on-line inspection of long profiles, a specially designed immersion chamber can be used (patented HRP-setup). Only a short section of the profile is then immersed. Small-diameter ERW-pipes (or seamless pipes) can be tested with such systems. The pipe diameters range up to approximately 170 mm. If the weld position is known, the immersion chamber can also be partially equipped with ultrasonic probes to cover only the weld seam area.

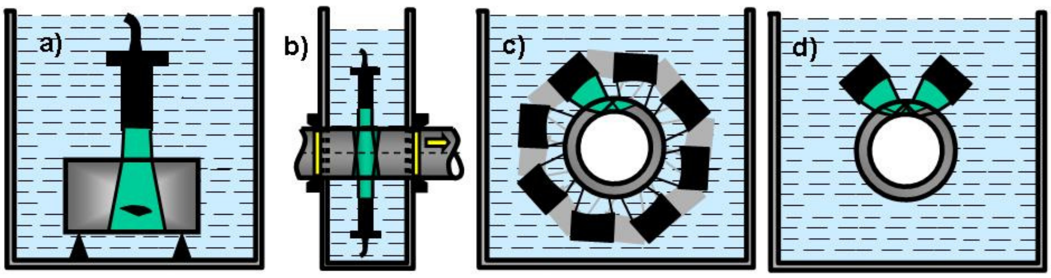

Fig. 1: Immersion Testing. a) Immersion testing for component test, b) HRP-immersion high-speed testing for long profiles (bars & pipes), c) HRP-immersion testing of small diameter ERW-pipes with setup for seamless pipe, and d) HRP-immersion setup with probes only for weld inspection in 12 o'clock position.

For larger pipe diameters the growing ovalities require a probe guidance on the pipe surface and therefore other coupling concepts. Two coupling methods are mostly encountered in industrial applications. One technique is commonly called **water gap coupling**. The probe is mounted into a probe holder and the distance of the probe face to the pipe surface is in the order of 0.5 mm. The probe holder is guided along the pipe surface by rollers or by shoes. For strong curvatures of the pipe surface, i.e. small pipe diameters, curved shoes have to be used and the gap might need fine adjustment within the probe holder. There are some advantages to this technique: Dual-element probes can be applied, thus offering only small untested zones at the front and back surface of the pipe. Secondly, large face probes can be used in order to achieve a wide test trace per probe. Typically, the test trace should be limited to 25 mm for one probe in order to ensure stable coupling conditions and to find the required defect size. The amount of coupling water for gap coupling is rather small which reduces the requirements on the water circulation system.

If the weld geometry (weld width, pipe wall thickness) requires various incidence angles, probes with the respective incidence angles have to be mounted (resulting in long change-over times for the testing system and a large number of required probes). The disadvantage of rather high probe and shoe wear (especially for rough or black pipe surface), the need of many sets of curved shoes and probe angles and the limited test speed (typically 0.5 m/sec) have led to the introduction of **water jet coupling** (also called squirter technique) by KARL DEUTSCH in the 1970's. Water jet coupling offers a higher near-field resolution and a longer lifetime of the probes. A water jet is guided within a plastic nozzle towards the component surface. The jet diameter has to be large enough to carry the entire ultrasonic beam and has to be without air bubbles and turbulences for a good ultrasonic signal-to-noise ratio. Straight-beam immersion probes are used. A fairly long water column (30 – 50 mm) between probe and component guides the ultrasound. In order to produce angular incidence, the entire probe holder is mechanically tilted with respect to the component surface. This technique is almost free of wear. Only the shoes or rollers which guide the probe holder along the pipe surface have to be changed from time to time but in general, they don't have to be changed for different pipe curvatures (diameters). Testing speeds of up to 2 m/sec are possible. With this technique, compact multi-probe holders were patented by KARL DEUTSCH more than 25 years ago for the inspection of pressure cylinders. Other common applications of water jet coupling are bar testing and billet testing.

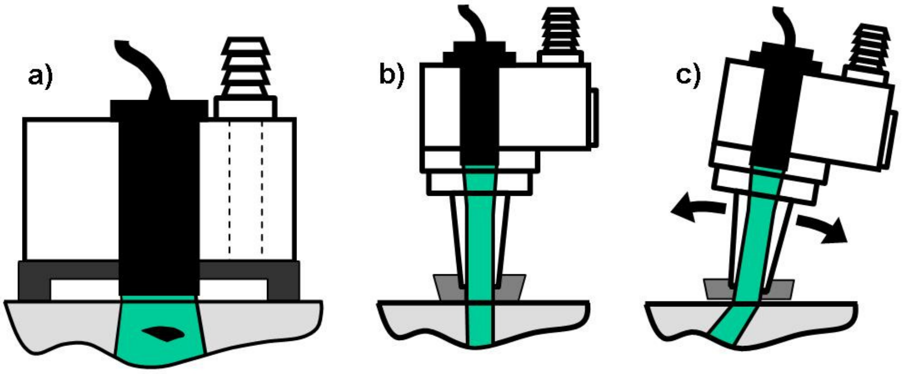

Fig. 2: *Gap and Jet Coupling, **a)** gap coupling, typically used for lamination and strip testing with dual-element probes, **b)** wear-free jet coupling with straight-beam incidence, **c)** jet coupling with angular incidence for high-speed weld inspection and convenient angle adjustment.*

Several alternate methods have been explored to avoid water for ultrasonic coupling. Wheel probes, electromagnetic transducers (EMAT) and laser ultrasound are such approaches. Each approach has shown advantages and disadvantages. It remains to be said, that water coupling dominates in industrial use.

3 Common Test Tasks for the Ultrasonic Inspection of Welded Pipes

For weld inspection in pipes, the cross-section to be tested is reduced to the weld itself and to the heat-affected zones (HAZ) besides the weld. The welding process is already automated in order to make an automated testing system worthwhile. The common detection and measurements tasks are:

- Longitudinal defects (internal, external, mid-seam)
- Longitudinal Defects with perpendicular orientation with respect to pipe surface (tandem setup)
- Transverse Defects (internal, external)
- Lamination Testing within the Heat-Affected Zone (HAZ)
- Wall Thickness Measurement (over weld for ERW-pipes, in HAZ for SAW-pipes)
- Pipe End Inspection for Laminations (and sometimes also for Longitudinal Defects)

Each test task requires the respective incidence angle resulting in a testing system with a multitude of electronic channels and probes. The **use of probe pairs centred with respect to the weld** ensures a high probability of detection for oriented (oblique) defects within the weld and also permits to use the through-transmission signal for constant coupling check between the two probes. If the V-transmission signal is missing or weakened, either the coupling, the ultrasonic probe or the entire system is not working correctly. Thus, the transmission signal is constantly supervised and ensures the stable operation of the system.

3.1 Detection of Longitudinal Defects

Lack of fusion is the most dangerous and most common defect in a pipe weld and therefore makes the testing for longitudinal defects the most important test. **Longitudinal defect detection** requires approximately one probe pair for every 7-10 mm of pipe wall thickness. Thin walled ERW-pipes can therefore be inspected with one probe pair. Most testing systems make use of two probe pairs, using one probe pair for the internal pipe wall and the second pair for the external pipe wall. Many common international test specifications can be fulfilled with this setup. Heavy-walled pipes might require additional probes for the detection of **longitudinal mid-seam defects**. For LSAW-pipes with heavy pipe walls up to five probes pairs (test levels) are used. The calibration defects are external and internal notches of longitudinal orientation and varying length and depth.

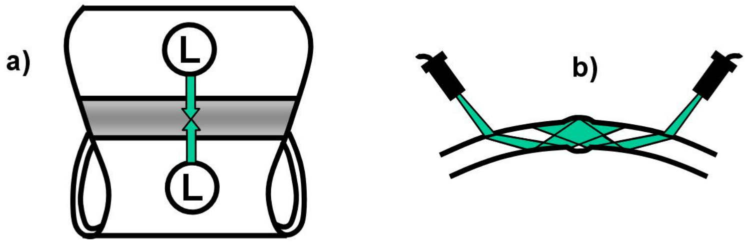

Fig. 3: ***Longitudinal Defect Detection. a)*** *top view of probe pair with angular incidence with respect to weld,* ***b)*** *cross-sectional view of probe pair and pipe, here shown for the detection of external defects.*

If defects with perpendicular orientation to the pipe surface might occur, one or more **tandem setups with four probes** (two probes on each side of the weld) can be used (SHELL specification).

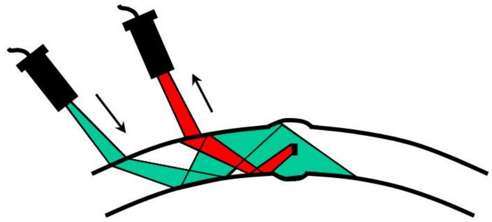

Fig. 4: ***Tandem Testing.*** *Longitudinal defects in mid-seam are detected with a two-probe setup, one probe acting as a transmitter and one probe as a receiver.*

3.2 Detection of Transverse Defects

Transverse defects are less often during the production of welded pipes. Inclusions within submerged-arc welds might occur and therefore, most SAW-pipe testing systems include probes for the transverse defect detection. The on-bead inspection is the best-possible way to insonify transverse defects since each probe can be used in pulse-echo mode and probe positioning is comparatively easy. Another advantage is the fact that the entire pipe wall in the weld area is covered by only two probes.

Conventional testing systems for SAW-pipes use the **K or X-configuration** where two or respectively four probes are mounted next to the weld. Two probes work in transmitter – receiver arrangement and their V-reflection signal is used to detect the transverse defects. This setup then requires perfect positioning of two probes with respect to the weld and also a rather complicated mechanical adjustment with respect to the pipe geometry (wall thickness, pipe diameter and respective curvature).

Therefore, modern testing systems for SAW-pipes employ water jet coupling for an **on-bead transverse flaw detection**. Since the weld bead of SAW-pipes is not machined, the coupling and guidance of the probes is rather difficult and requires a sophisticated testing mechanics. Good ultrasonic coupling can be achieved by proper design of the probe holders and the water nozzles. The incidence angle is typically 45 degrees. Only the distance of the two probes might need adjustment for coupling check purposes (V-transmission) in dependence of the respective pipe wall thickness.

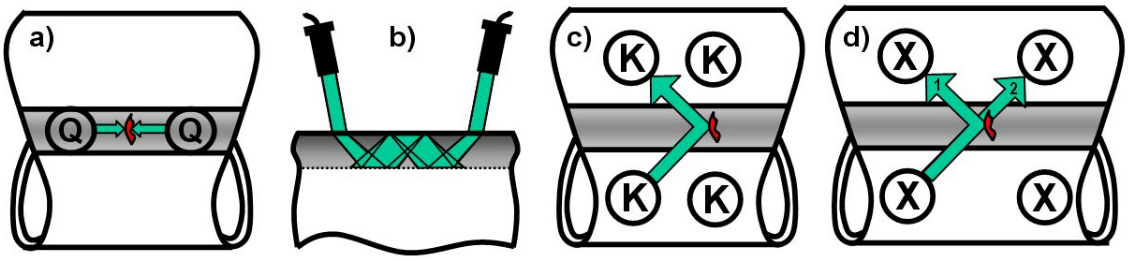

Fig. 5: ***Transverse Defect Detection. a)*** *Top view of on-bead probe pair with respect to weld,* ***b)*** *cross-sectional view of on-bead probe pair and pipe wall, c) K-setup where 2 probes are used for transverse defect detection in transmitter-receiver arrangement, and d) X-*

setup where coupling check (testing function 2 in picture) and an optional oblique defect detection is possible (not shown).

3.3 Detection of Laminations

Besides the weld itself, the heat-affected zone (HAZ) deserves special attention. In many cases, pre-inspected strips or plates are used for the pipe production. In that case, the **inspection for laminations within the HAZ** might be omitted. Most international specifications allow for either inspection of the strip edges before pipe forming OR the lamination inspection on the welded pipe. Dependent on the type of pipe and the used test specification, a test trace of 15 – 50 mm on both sides of the weld is inspected. For strong pipe curvatures (i.e. small diameters), several probes should be used on both sides of the weld to ensure straight-beam incidence. Dual-element probes are used in order to ensure small dead zones on internal and external pipe surface, which is important especially for a small pipe wall thickness (e.g. s < 10 mm). If high testing speeds are required, jet coupling with straight-beam probes can be employed.

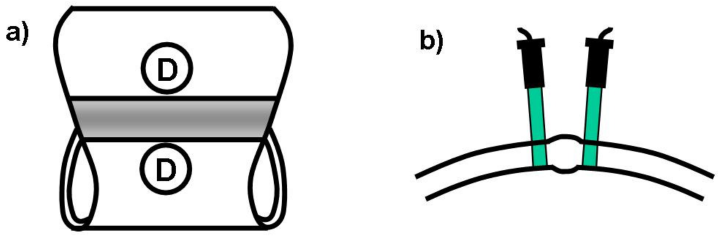

Fig. 6: ***Lamination Testing within heat-affected zone. a)*** *Top view of probe pair position with respect to weld,* ***b)*** *cross-sectional view of probe pair and pipe.*

Dependent on the type of pipe, the pipe body might require further lamination inspection (**full-body test**). If an ERW-pipe is used instead of a seamless pipe, also the ultrasonic inspection is similar to seamless pipe testing. This will not be further discussed in this paper.

The pipe body of electrically welded pipes (**ERW-pipes**) is either inspected in strip form or on the finished pipe after the hydrotest. In the latter case, helical test traces (rotating pipe, linear probe movement) and a coverage between 12.5 and 25% of the pipe body is typical. Dependent on the desired throughput, the number of probes is chosen accordingly. Typical setups have eight to sixteen dual-element probes and a probe spacing of 100 mm. Rotational testing speeds also with dual-element probes up to 1.5 m/sec are possible (dependent on the straightness of the pipes).

Helically submerge-arc-welded pipes (**HSAW-pipes**) use steel coils as input material. The coils are usually not pre-inspected. For those coils, the full-body inspection is often carried out after the welding process in an oscillating manner. A strip inspection before pipe forming is rarely used. The problem of strip testing directly before welding is the coupling water. The water has to be entirely removed before welding for not disturbing the welding process. Limited space on the uncoiling machine makes this a difficult task.

Longitudinally submerge-arc-welded pipes (**LSAW-pipes**) for later pipeline usage are mostly produced from heavy plates which are pre-inspected for laminations with high coverage in the strip mill. Therefore, in the LSAW-pipe mill, the pipe body is not further tested with ultrasound.

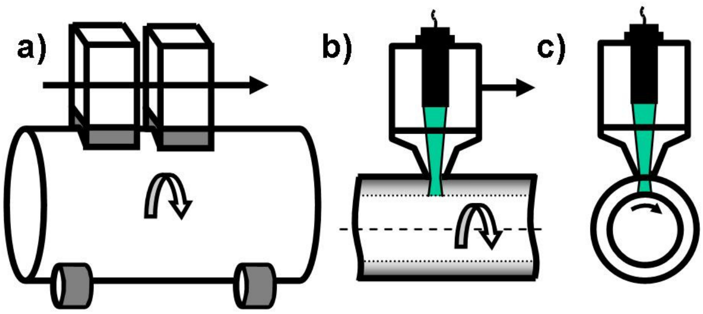

Fig. 7: *Full-Body testing and/or pipe end test with helical test traces.* ***a)*** *one or more probe holders move along the rotating pipe,* ***b)*** *straight-beam incidence, and* ***c)*** *cross-sectional view of full-body and/or pipe end test.*

3.4 Wall Thickness Measurement

The **wall thickness measurement** on welded pipes is not as common as for seamless pipes since in most cases the strip or plate thickness does not change much during the production process and the minimum strip thickness is usually guaranteed by the strip mill. An exception could be the weld area where the deburring (ERW-pipes) or the strip edge pre-bending (LSAW-pipes) might reduce the wall thickness in an unwanted manner. Therefore the probes for the lamination test within the HAZ might also carry out a wall thickness measurement.

3.5 Pipe End Testing

The **pipe ends** deserve special attention. If the pipes are used for pipelines and the transportation of fluids (water, oil or gas), they are circumferentially welded in the field. In most cases, an inspection for laminations is carried out covering a test track of 50 mm. Secondly, the portions of the weld which were not covered by the automated weld testing system must be further inspected. This could be done with a portable ultrasonic flaw detector. Many test specifications require an additional magnetic particle test of the end bevel and the weld close to the pipe end.

4 Ultrasonic Inspection of ERW-Pipes

The production of ERW-pipes includes several steps of NDT. The usage of NDT has two major goals: Early information about the welding procedure as a feedback for the production line and secondly, the final inspection of the finished pipe. **Up to four ultrasonic systems** are typically encountered during the production process.

A **strip tester** is used if the steel coils were not tested at the strip mill before. Linear or oscillating test traces of the probes are possible. The strip edges (typically 25 - 50 mm) are tested with separate probes and 100% ultrasonic coverage.

Directly after welding, a first **online weld test** is carried out with ultrasound. It is common to check for longitudinal defects only. Sometimes, an oscillating deburring check is added to verify the proper descarfing of the internal pipe wall. One probe holder with a straight-beam probe oscillates across the weld while the pipe is linearly moved. Setups with shockwave immersion probes (highly damped echo form) and water jet coupling are used. The oscillating range covers the weld and the region besides the weld (parent strip material). The oscillating frequency is in the order of 1 Hz while the endless pipe is transported with a speed between 10 and 35 m/min. If the internal pipe wall is not parallel to the external pipe wall due to wear of the descarfing tool, no ultrasonic signal is received. In that case, this method only produces a good/poor-information about the deburring process.

After pipe cutting and the hydrostatic test, the final weld inspection is carried out (**offline weld testing**). A testing portal with moveable carriage is commonly used. The testing portal shows the advantage that the weld is inspected without pipe movement, thus avoiding vibrations which could degrade the test results.

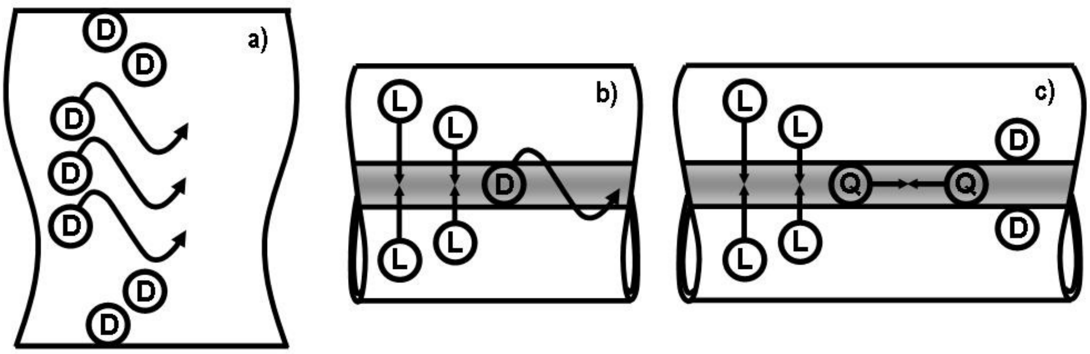

Fig. 10: Typical Probe Configuration for ERW-pipe inspection. ***a)*** *Strip inspection with edge probes and oscillating strip middle probes,* ***b)*** *online weld test with 4 probes for longitudinal defect detection and an oscillating deburring check, and* ***c)*** *offline weld inspection with 4 probes for longitudinal defect detection, 2 on-bead probes for transverse defect detection and 2 probes for lamination testing in the heat-affected zone.*

Dependent on the required throughput and the test specification, the same or a separate testing system is used for the **pipe end and/or full-body inspection**. This example shows how the offline weld test and the pipe end testing is carried out in a testing portal. The probes are usually placed onto the external pipe wall in the 12 o'clock position.

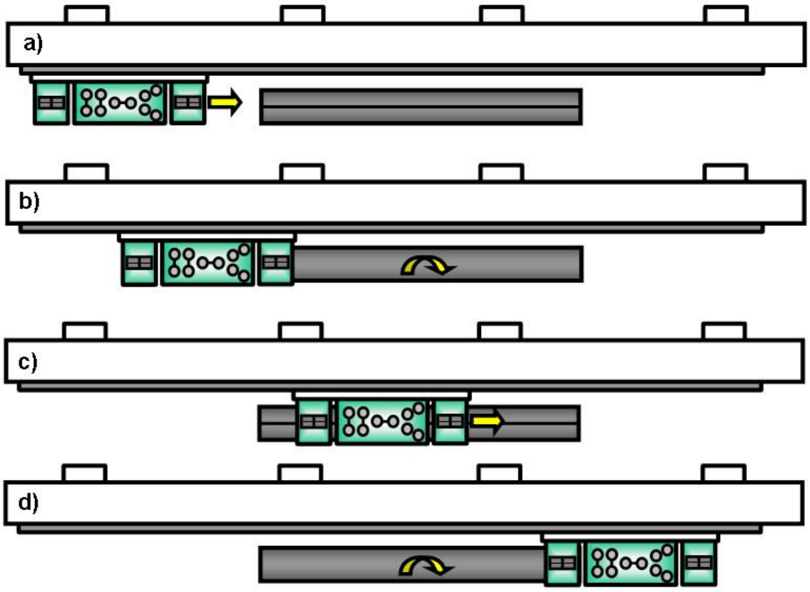

Fig. 8: ***Testing Portal*** *for offline weld- and pipe end testing.* ***a)*** *approach of testing carriage towards resting pipe,* ***b)*** *test of front pipe end,* ***c)*** *weld testing with weld in 12-o'clock-position, and* ***d)*** *test of second pipe end.*

If separate pipe end systems are used, the pipe end can either be inspected from the internal or external pipe wall. Using the internal pipe wall allows for a probe movement closer to the pipe end (no bevel on internal pipe wall) and therefore producing shorter untested ends (<10 mm).

5 Ultrasonic Inspection of HSAW-Pipes

Helically welded pipes are typically produced from diameters from 350 – 2500 mm. They are used for water pipelines, but also for the transportation of other fluids (e.g. oil and gas). More or less extensive NDT is carried out in accordance to the later pipe usage. In comparison to LSAW pipes, spiral pipes are fairly easy to produce, because the width of the input strip material can be used for a large pipe diameter range, dependent on the weld angle. On the other hand, the control of the welding head and the weld test require careful position control. The pipe wall is limited to about 25 mm.

The first ultrasonic weld inspection is carried out directly after welding (online weld test). The probes are mounted to a stationary machine stand which is height-adjustable in accordance to the pipe diameter. The test position is in 12 o'clock. The motor for the seam tracking is mounted to the cantilever beam to centre the probe pairs with respect to the weld. It is always checked for longitudinal defects with one or two probe pairs. Transverse defect detection (K-arrangement) and lamination detection are often added.

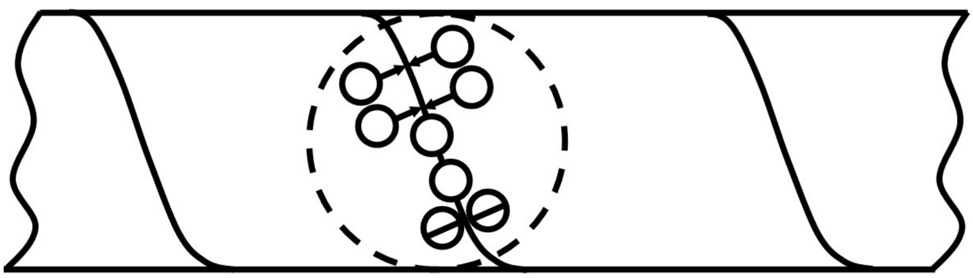

Fig. 13: ***Online-Ultrasonic Weld Test*** *directly after welding with six probes (4 longitudinal, 2 on-bead transverse, 2 laminations).*

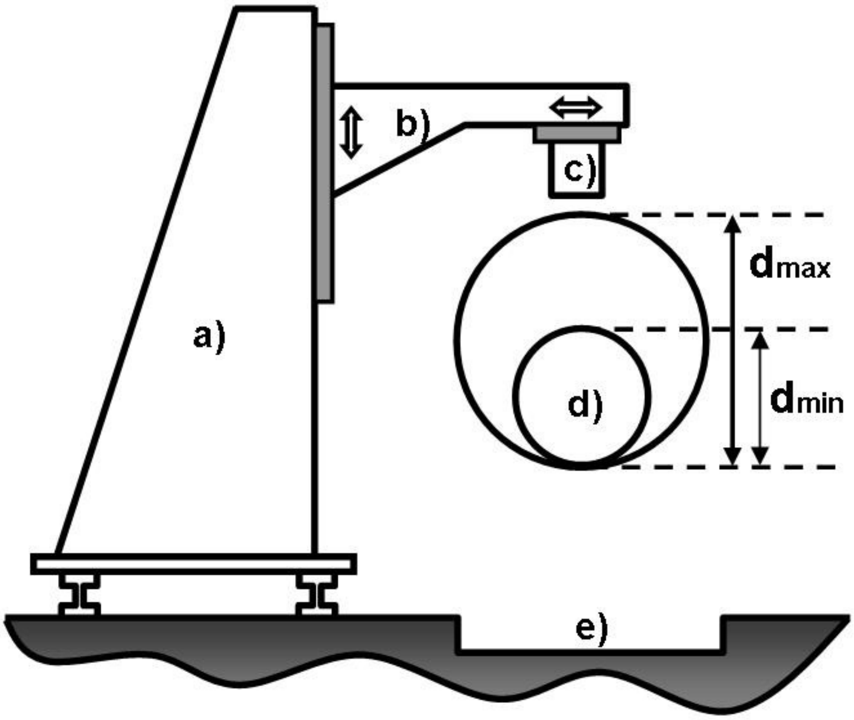

Fig. 14: *Testing mechanics for spiral pipe inspection.* ***a)*** *Machine frame (stand),* ***b)*** *cantilever beam (horizontal boom) with vertical position adjustment,* ***c)*** *probe holders with horizontal position adjustment,* ***d)*** *spiral SAW-pipe, and* ***e)*** *foundation with water drainage (closed water circuit).*

After pipe cutting, a second ultrasonic test is performed (offline weld test). The number or probes is equal or higher than during the first inspection, because this inspection is important for the final customer of the pipe. Since the testing mechanics have to be adjustable in accordance to the weld angle, space is rather limited and for more than four probe pairs, a second weld testing mechanics and a second machine stand is employed.

Since water is critical to the welding process, the strip inspection is often carried out after the hydrostatic test and is combined with the offline weld test in one common testing system. To increase the coverage for each probe, oscillating probe movements are typical. The weld and strip inspection requires a smooth helical pipe movement with respect to the probes, making the seam tracking a difficult and important task.

The pipe end inspection can also be performed in the same setup and requires one pipe rotation for each pipe end. The probe holders are typically guided by rollers on the pipe end for short untested ends.

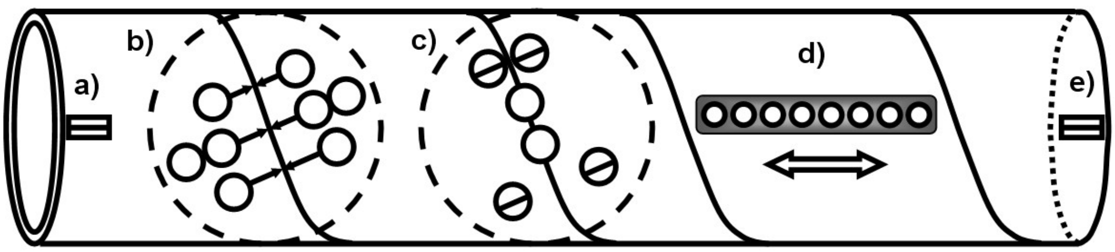

Fig. 15: ***Ultrasonic offline test*** *after hydrostatic test with 22 probes.* ***a)*** *front pipe end testing,* ***b)*** *longitudinal defect detection – internal, external and mid-seam tandem,* ***c)*** *on-bead transverse defect and lamination detection,* ***d)*** *oscillating strip inspection between the welds, and* ***e)*** *second pipe end testing.*

6 Ultrasonic Inspection of LSAW-Pipes

Most LSAW-pipes are heavy-walled (25…35 mm or higher) with typical diameters between 500 – 1600 mm for the transportation of oil and gas, and therefore extensive NDT is carried out. The production of LSAW-pipes is divided into two major parts – before and after the hydrostatic test. This test is an important step within the production process, because the pipe can still be repaired if defects are found in an early stage. Once the hydrostatic test is performed, a defective pipe can not be saved. NDT on both sides looks rather similar. An initial ultrasonic test produces early feed back about the production and welding quality. Sometimes, the first ultrasonic test is carried out with higher sensitivity than the second and final test. Defective areas are double-checked with X-rays. The same sequence of nondestructive tests (UT and RT) is carried out after the hydrostatic test. Finally, the pipe ends are checked for laminations with ultrasound, X-rays and sometimes also with magnetic particles.

The inspection for longitudinal and transverse defects within the weld is always mandatory. Heavy pipe walls might require several (typically up to 5) pairs of longitudinal probes. If SHELL has to be fulfilled, also tandem testing for longitudinal mid-seam defects might be applied. Even though the heavy plate is usually pre-inspected, the lamination probes are typically supplied for such systems.

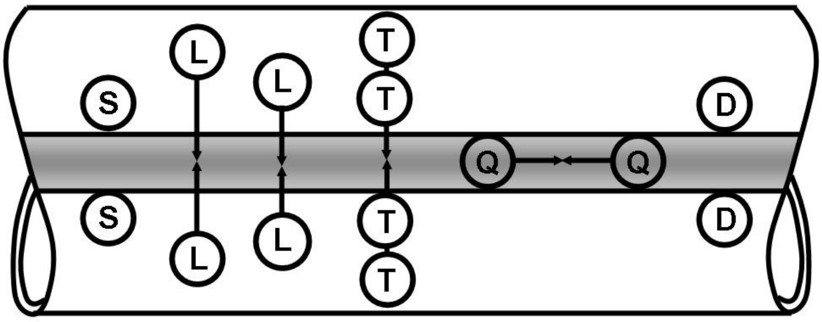

Fig. 17: *Typical Probe Configuration for LSAW Pipe Inspection, S = seam-tracker, L = Longitudinal defect detection on internal and external pipe wall, T = tandem testing for mid-seam longitudinal defects, Q = on-bead transverse defect detection, and D = lamination testing within heat-affected zone.*

In 2007, two weld testing systems in portal were shipped to Baosteel in Shanghai. The testing portal allows for an inspection with high speeds and without pipe vibration due to the transport scheme. Meanwhile, these systems were successfully put into operation. The system for the final inspection uses up to 30 ultrasonic probes.

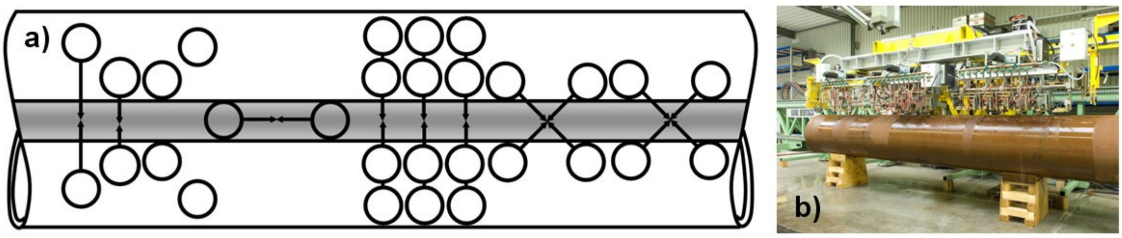

Fig. 18: *LSAW Pipe Inspection at Baosteel,* ***a)*** *probe configuration (total of 30 probes) and* ***b)*** *testing portal during in-house assembly in KARL DEUTSCH systems workshop.*

7 ECHOGRAPH Ultrasonic electronics

The evaluation of the ultrasonic signals is carried out with a multi-channel testing electronics. The electronics 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 robust 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 electronics need a large amplification range with high signal-to-noise ratio.

8 Summary

This article contains a brief overview on automated ultrasonic welded inspection for various pipe types. Some inspection steps might by carried out with portable test equipment (e.g. pipe end test), but the weld inspection in all internationally relevant specification must be automated. The pipe geometry, the production process, and the pipe usage determine the number of required probes. Recent updates for some test specifications enforce a large number of ultrasonic probes, e.g. the SHELL standard. Since seamless pipes are sometimes replaced by ERW pipes and LSAW pipes by SSAW pipes (in both cases to save production cost), the inspection methods change gradually between the various pipe types. Each testing system is unique and shows its specialties which have to be discussed by supplier, testing system user and final customer of the pipe.

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