

Ultrasonic Pipe Testing Machines – Comparison of Conventional UT With PAUT & PWI

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Abstract

In recent years, Phased Array Ultrasonic Testing (PAUT) is widely employed for automated ultrasonic inspection of pipes. The test requirements for seamless, ERW-, HSAW- and LSAW-pipes are presented.

The specifications can normally be fulfilled with conventional and with PAUT testing machines. Although PAUT testing machines are more costly and PAUT probes are expensive spare parts, the PAUT technique offers several technical advantages which are illustrated in this paper.

New algorithms for the evaluation of PAUT signals such as PWI allow for a higher inspection speed. The principle of PWI is explained and its application for pipe testing is discussed.

Inspection of Seamless Pipes

Ultrasonic inspection is an important method for the quality assurance during the production of seamless pipes. Pipes which are later used in automotive, oil and gas and chemical plants are normally tested with ultrasonics. In addition, eddy current or stray-flux testing is carried out for the detection of surface defects.

Pipes of “moderate” diameter (e.g., up to 170 mm) are often tested in a linear motion. The probes can rotate around the pipe body creating helical test tracks. This requires a fairly complicated rotational mechanics where the probe signals are fed to the stationary part of the testing mechanics by means of slip rings or by capacitors. Proper maintenance is crucial for rotating systems with rotating probes.

A testing concept with stationary probes avoids all rotating parts and the maintenance is simplified. Two probe rings are employed for the clockwise and CCW insonification to detect longitudinal defects. The standard setup uses 16 to 20 mono-element probes for each ring. A PAUT version of this concept is under development. Another probe ring contains the wall thickness probes. Additional probe rings must be added if transverse defects shall be detected. The probes are mounted in water tanks – so local immersion is used for the coupling. Testing speeds between 0.5 m/s and 2 m/s are possible, depending on the pipe diameter.

A versatile testing concept for larger pipe diameters uses a helical pipe conveyor and water tanks below the pipe with ultrasonic probes. In order to separate the acoustics, the different test tasks (L = longitudinal, T = transverse, WT/LAM = wall thickness/lamination, O = oblique) use separate tanks. The probes are either multi-channel probes or phased array probes. Having a conveyor with perfect helical pipe feeding and without slippage is a challenge. Therefore, more testing systems are now built with the gantry design.

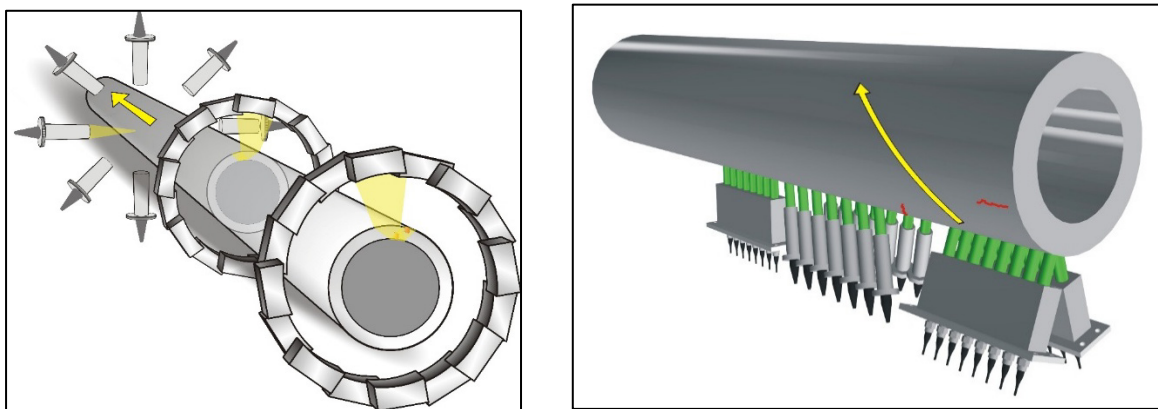


Fig 1. Linear pipe testing using several rings of ultrasonic probes in local immersion (left) and helical pipe testing with three water tanks below the pipe (right).

The last testing concept commonly used is the gantry. It can be used for pipes with diameters above 60 mm. Seamless pipe testing needs to work with the production speed of the pipe mill, meaning that fast testing times are required. The pipe is put into rotation and probe holders are fed along the pipe in a linear motion. Again, all test angles need the respective probes: L, T, WT/LAM, O. If mono-element probes are used, clusters with five probes are commonly used (L, T, WT/LAM). If PAUT probes are used, each probe holder contains one or two probes for the respective test task. The longitudinal probes can also be used to detect oblique defects up to approx. 25 – 30°. Larger oblique angles need separate probes.

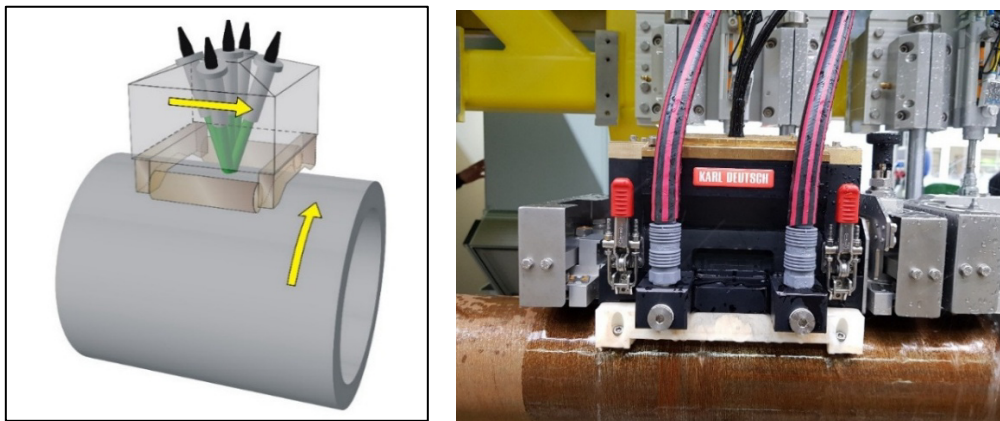


Fig 2. Probe holders (clusters) for pipe testing gantries. Conventional systems often use five probes in one cluster (left). PAUT systems use probes with, for example, 128 elements to provide a large test track.

If more (oblique) angle defects shall be detected with a reasonable number of probes, special test techniques must be employed. One useful algorithm is plane wave imaging (PWI). This approach fires all elements of the PAUT probe such that a powerful plane wave is generated. In the reception mode, the reconstruction is carried out for multiple angles and therefore valuable inspection time is saved.



Fig 3. Super-Karl is creating a powerful plane wave to insonify the test object. Multiple angles are evaluated using the received signals (which requires a powerful PAUT architecture).

The described pipe testing gantry is designed as an open bridge. Cross conveyors or walking beams are used for the pipe transportation. In the test position, the pipe is first lifted and then put into rotation using double rollers. At the base position of the gantry, a calibration station is provided. Short pipe segments with artificial defects are fed into the calibration station and the sensitivity of the ultrasonic probes is checked.



Fig 4. Testing bridge for pipe inspection before shipment. The pipe to be tested is positioned on a set of double rollers. The yellow testing carriage is linearly moved along the rotating pipe.

The testing carriage contains cabinets with the PAUT electronics and the probe holders which are moved up and down pneumatically. The coupling of large PAUT probes is a challenge. Therefore, an acoustically transparent membrane was used to seal the water chambers. The probe holders need highly flexible joints in order to compensate for the straightness tolerances of the pipes.



Fig 5. Inspection of black pipes with seven probe holders. The diameter range was 60 – 270 mm, the wall thickness was up to 50 mm and oblique defects up to 75° were detected.

Inspection of ERW-Pipes

Electric-resistance welded pipes (ERW) are produced from steel coils. Normally, up to three ultrasonic systems are encountered in the ERW pipe mill. While the weld inspection is mandatory for safety-relevant pipes, the pipe body is optionally tested. The most convenient position for the pipe body inspection is before welding. After uncoiling and levelling the steel strip, an ultrasonic strip testing system is employed. Depending on the customer requirement, 25%, 50% or 100% ultrasonic coverage is provided.

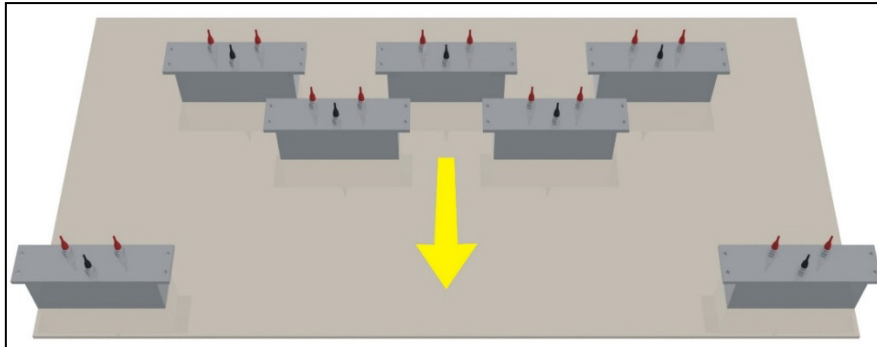


Fig 6. Testing principle of strip testing system with overlapping probes and 100% coverage. Additional probes are provided for the strip edges which are later crucial for the welding.

The strip testing system is designed as a testing bridge. In this example, a calibration position is on the left and the test position is on the right. The probes can move between the two positions. The typical strip width is up to 2 m and more than 100 UT channels are employed.

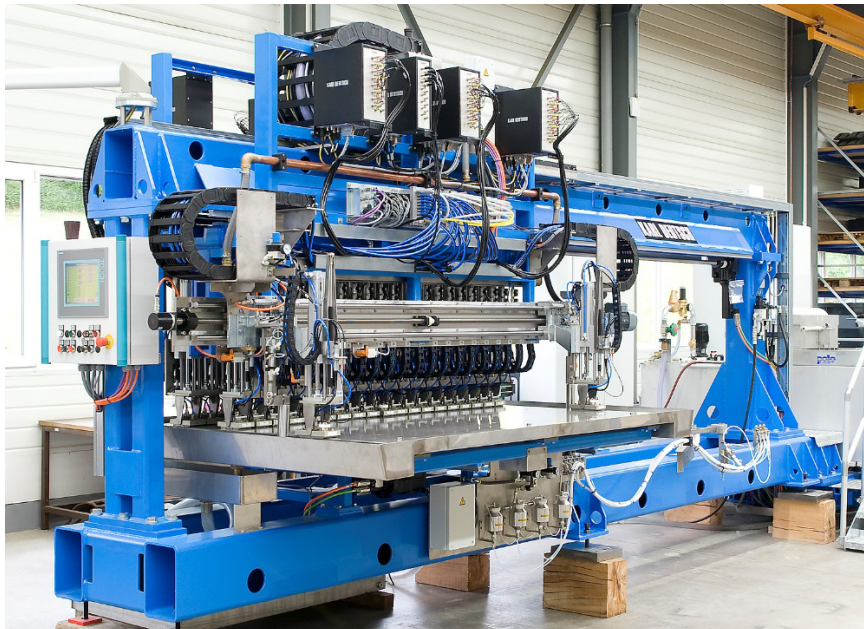


Fig 7. In the example, the probes are moved into the calibration position. The calibration station can drive a calibration plate below the probes, thus proving a dynamic check of the sensitivity of all probes.

The endless strip is then formed into the pipe shape and longitudinally welded. The first ultrasonic weld testing system is an important tool for the process control. The minimum setup contains four mono-element longitudinal probes (2 for external defects, 2 for internal defects). An oscillating straight-beam probe for checking wall thickness and descarring is also typical. Additional probes for mid-beam L defects or T probes are sometimes desired by our customers.

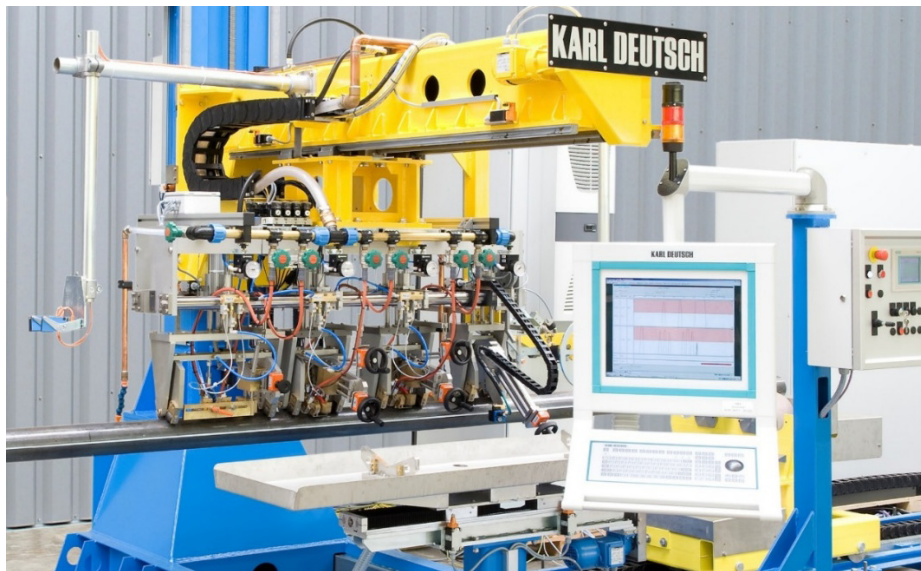


Fig 8. The blue machine frame holds a yellow horizontal boom. The probe holders are mounted to the boom. The boom can be moved between test position (see figure) and calibration position (stainless steel tray). This testing system has six probes (4 L, 2 T).

It is very difficult to track the weld seam by optical or electromagnetic means. Therefore, a so-called pilot line (paint line) is applied on the side of the pipe. A camera is tracking the pilot line, and the PLC ensures that the probe holders are centred with respect to the weld. The probe holders use water jets (squirters) for coupling. The skids therefore are not curved and do not need to be changed with varying pipe diameters. This yields fast change-over times.

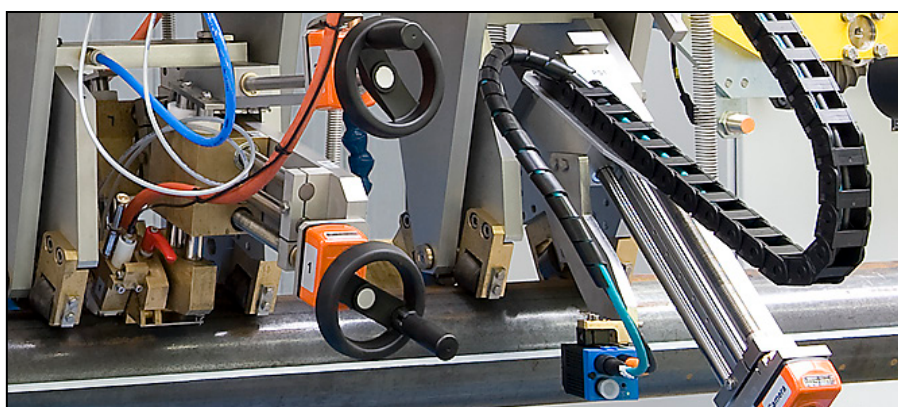


Fig 9. A camera (blue) is tracking the pilot line for perfect probe positioning. A combination of rollers and skids ensure smooth probe holder guidance along the pipe (left).

Some customers request to use a PAUT solution for the ERW-pipe weld test. The advantage is the larger probe size in circumferential direction. This simplifies the seam tracking, or it can even be omitted. The following challenges must be accounted for: The inspection is often carried out in a stage where the pipe is still hot (80 °C). Coupling of large probes using a water chamber is not simple. Also, the pipe is not always perfectly round. Thus, advantages and disadvantages must be carefully evaluated. The conventional setup using water jet coupling is a robust and reliable solution where the water jets ensure cooling of the ultrasonic probes.

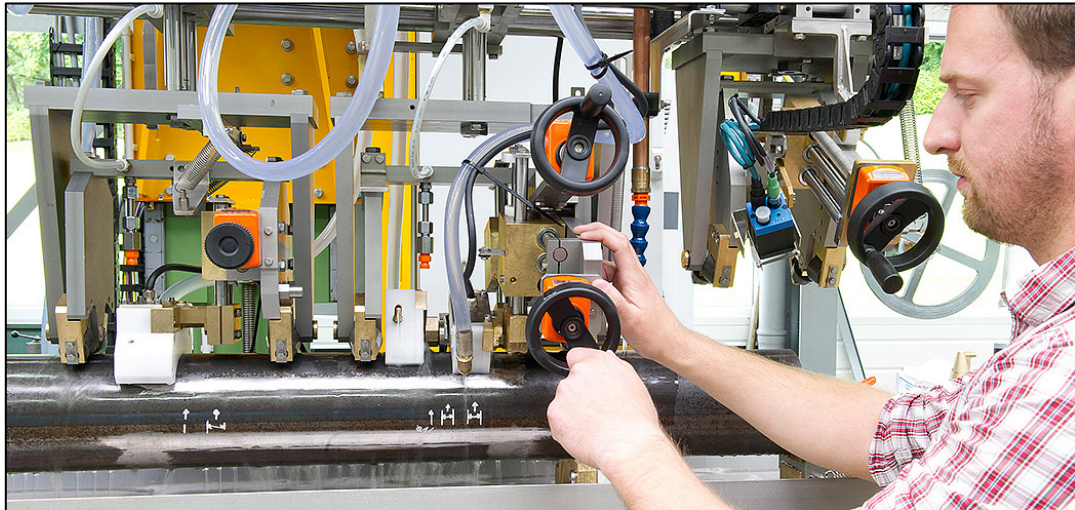


Fig 10. PAUT testing system for online ERW pipe weld testing using 3 probes (2L1WT).

Smaller ERW-pipes (automotive sector) can be tested effectively with one PAUT probe. Three test angles are produced: L CW, L CCW and WT. The probe holder is manipulated by means of a robot. This system design requires very little space in the production line and is useful for a retrofit solution. In addition, the robot can easily move the probe holder into the calibration position and perform a dynamic check of the sensitivity.



Fig 11. Online ERW-pipe weld test using a robot (left), dynamic sensitivity check on calibration tube (right).

After cutting the endless ERW-pipe and undergoing further production steps, the final ultrasonic inspection (offline test) is carried out. It ensures that a flawless pipe is shipped to the final customer. The production speed in an ERW-pipe mill is high, and therefore, a high-speed inspection is required. The fastest system design is a testing gantry (example: open bridge). After transverse pipe loading, the pipe is rotated until the weld is in the 12 o'clock position. The testing carriage is moved with a high speed (1 – 2 m/s) along the pipe. The pilot line is again used for the seam tracking.



Fig 12. Testing bridge for offline ERW-pipe weld testing (before shipment). The yellow test carriage is travelling along the pipe at a high speed. A calibration station is on the left.

Sometimes, a rotational full-body inspection is carried out on the finished pipe. This test can be performed with a gantry as described for seamless pipes. Normally, only WT/LAM probes are used. The gantry in figure 12 has a second carriage on the rear for this purpose.

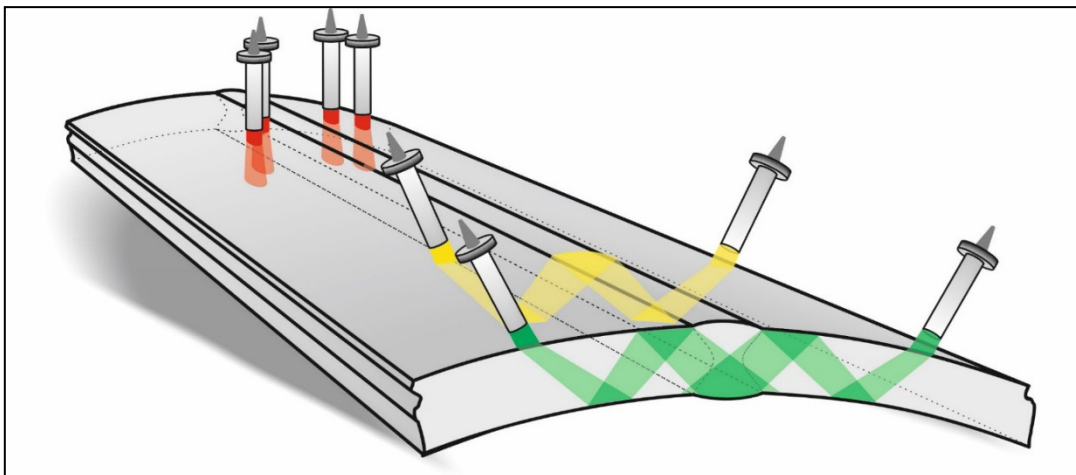


Fig 13. Typical probe configuration for the offline ERW-pipe weld inspection. Four probes detect longitudinal defects (internal, external) and four WT/LAM probes inspect the heat-affected zone.

Inspection of HSAW-Pipes

Large diameter pipes with helical weld for the oil and gas industries require an ultrasonic inspection. The typical diameter range is between 500 mm and 2 m and the wall thickness is up to 25 mm. The strip is often tested similarly to ERW-pipes with strip widths of up to 2 m. After welding, again an endless pipe is produced, and the first weld test (online) is carried out. Usually, 4 L probes are used and either an X configuration or an on-bead probe pair is used for the transverse defect detection, e.g., 6 – 8 probes. The pipe is moved by a pipe carriage and the probes are mounted to a horizontal boom.



Fig 14. HSAW-pipe weld testing using horizontal boom and pipe carriage.

Similar to ERW-pipes, the pipes are cut and undergo further production steps before the final ultrasonic test is performed. In addition to L and T probes, LAM probes for the heat-affected zone and LAM probes for the pipe end (PE) are normally used.

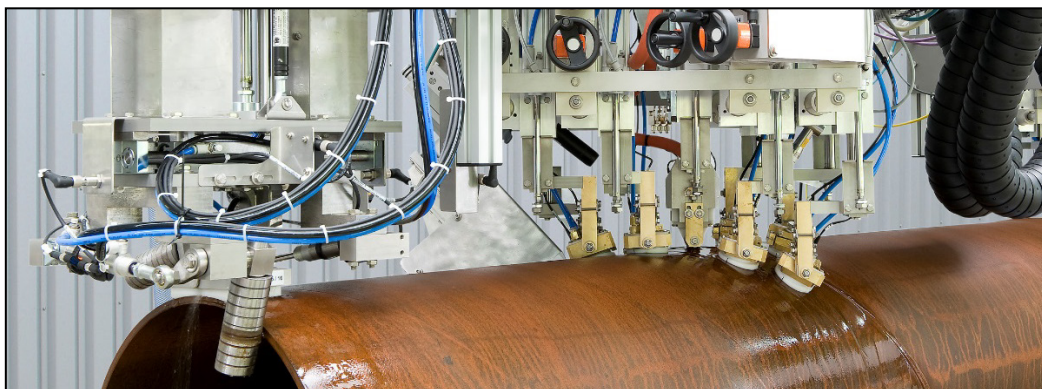


Fig 15. Offline test of HSAW-pipes with eleven probes (4 L, 2 T, 4 LAM, 1 PE). The seam tracking is carried out optically by tracking the weld seam crown and centring the probes accordingly.

Inspection of LSAW-Pipes

LSAW-pipes are produced not from coil but from heavy plate and the wall thickness can be significantly higher. Since the testing volume is increased, the number of probes grows accordingly. The heavy plates come pre-tested from the plate mill. They are formed and welded longitudinally and a first ultrasonic test is carried out. Pipe conveyors and horizontal booms are commonly used. Sometimes, a gantry design is implemented which offers a higher throughput and isolates the inspection from vibrations from the pipe transport. This test is an internal process control and as a minimum, L and T probes are used. After the expander, the final ultrasonic test is performed. Mid-seam defects are detected with up to four tandem configurations (SHELL spec). Between 16 and 30 probes are commonly used.



Fig 16. LSAW-pipe weld testing with horizontal boom and pipe carriage

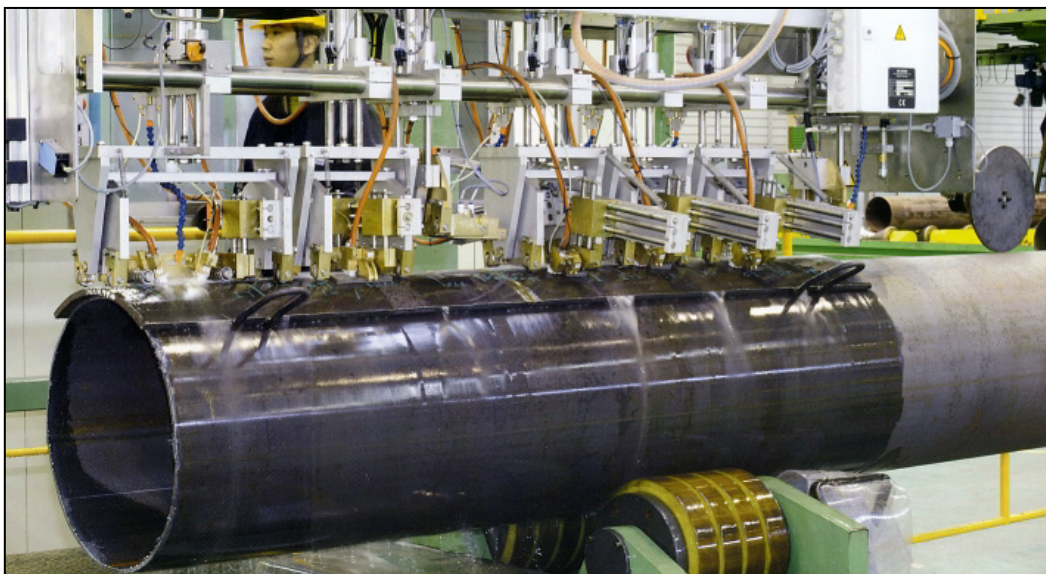


Fig 17. Calibration of test system with pipe shell. Probe holders with squirter coupling and a total of twelve probes (4 L, 4 TANDEM, 2 T, 2 LAM). Seam tracking is done optically.

The higher the wall thickness, the larger the number of ultrasonic probes needed. Some specifications impose calibration reflectors in the weld centre. Other specs require off-bead reflectors. This again is a challenge for high wall thicknesses and mono-element probes. Therefore, PAUT can help to solve the test task efficiently. By electronic beam steering, several test angles can be generated with the same probe. A combination of mono-element and PAUT probes can be a useful setup.

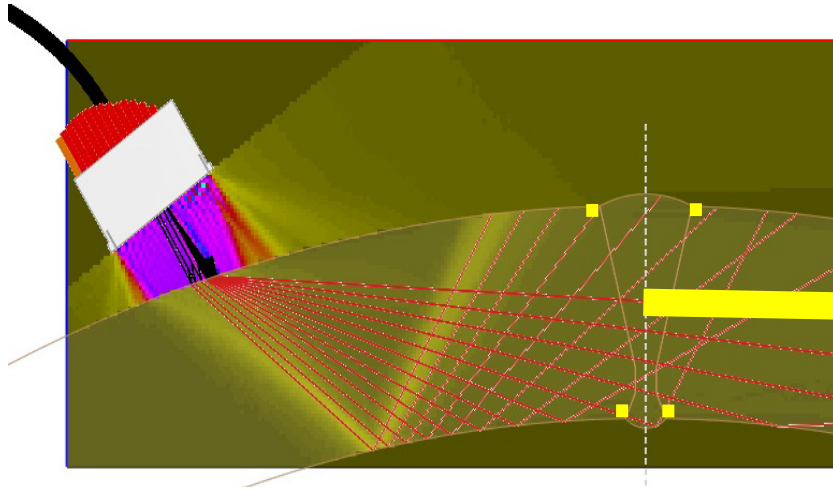


Fig 18. One PAUT probe can generate multiple test angles. In any case, it must be ensured that the ultrasonic shot hits the weld bevel and calibration defect under a suitable angle. Off-bead longitudinal notches and a mid-seam flat-bottom hole can be detected with the same probe in this example.

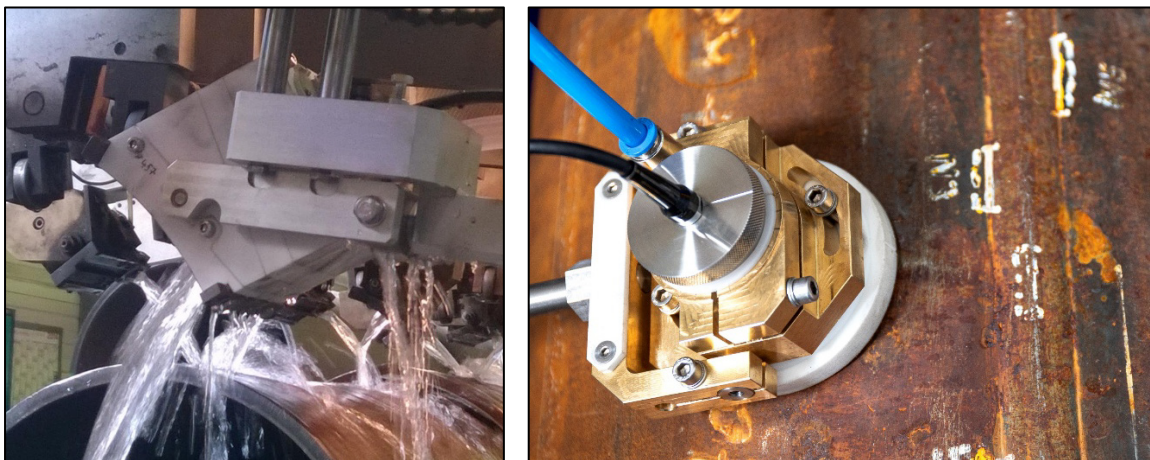


Fig 19. Depending on the customer requirements, different coupling techniques were realized: A water column and a large 32-channel probe (left) and water gap coupling of a 16-channel probe (right).

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