Automated ultrasonic testing of submerged-arc welded (SAW) pipes using phased-arrays

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Abstract
Longitudinally or helically SAW welded pipes are still the major component for pipeline constructions around the world. Within the manufacturing process, the pipes have to be ultrasonically tested according to common standards. Applying the standard technology with single crystal ultrasonic transducers, depending on parameters like wall thickness and weld geometry, a set of transducers and testing positions can be deduced from the specification in order to design a testing machine in accordance with the relevant regulatory and customer-specific requirements.

The use of phased-arrays for this application, as is already well established for manual weld testing. There are a number of significant advantages which make its application favorable, either as a unique phased-array solution or in conjunction with standard single-crystal techniques.

Keywords: SAW Pipe, Weld Testing, Ultrasound, Phased-Array

1. Concepts of weld testing

1.1 Approach with Single-Crystal Transducers

Ultrasonic testing of the weld seam is well established within the manufacturing process of both types of pipes, longitudinally- and helically-welded. While for comparably thin-wall thicknesses of the pipes, which go up to approximately 20 mm, electro-resistive welding is advantageous, for thicker walls in most cases; the surface arc-welding process is applied. Most newly constructed pipelines for oil and gas transportation are planned at large diameters, i.e. in the range of 24" or even larger. At this diameter, the walls need to be planned sufficiently strong in order to withstand the high pressures, which are applied within the transportation process, typically making the SAW-welded pipes the product of choice.

The ultrasonic test is typically located at the end of the manufacturing process, and can be regarded as a final verification of quality, before the product is finished and approved for shipment to the customer. As a consequence of the final use of these pipes, the reliability of this test needs to be very high: it may happen, that after final construction the pipeline is located such, that a repair or later exchange is not easily possible any more. To ensure this several standards have been published the testing process needs to be compliant with [1].
From these specifications, the selection and arrangement of ultrasonic transducers can be defined. The main targets can be summarized within three categories of defects:

1. Longitudinal defects aligned along the weld axis
2. Transversal defects perpendicular to the weld axis
3. Laminations within the heat-affected zone

In particular for the defects of type 1 and 2, the arrangement shall be chosen to cover the complete weld cross section, to not miss particular critical defects, e.g. those of the lack of fusion type. As an example how to achieve this, the typical arrangement for a longitudinal defect is illustrated in Figure 1.

Typically, 4 transducers are used to test welds of medium wall thicknesses. They are typically equipped with a wedge and slit coupled to the material or use a wedge at a fixed angle whose water chamber needs to be filled in order to establish ultrasonic coupling to the pipe. Within a typical arrangement, one transducer is used to test the lower part in first skip and another transducer is used to test the upper part in second skip. Transducers from left and right are typically used within one plane, which allows the through-transmission signal to be used as coupling check.

For thicker walls, the use of Tandem systems is applied, to cover the mid-area of the weld, which may, depending on the situation, not be reached with 4 transducers alone. This is illustrated in Figure 2.

If more than one tandem zone is needed, additional sets of 4 tandem transducers each need to be considered.
To test for transversal defects, 4 transducers need to be configured as X-formation, shown in Figure 3.

![Figure 3: Arrangement of transducers for transversal defect detection](image)

The number of applied transducers gets high, even for simple configurations. Depending on specifications to be considered to match production constraints, the transducer arrangements described above in addition need to be multiplied, so accordingly, the number of transducers needed increases significantly.

### 1.2 Approach with phased-array transducers

Within the approach described in chapter 2.1, the large number of transducers is considered to be a subject of further optimization of the test concept. Large transducer numbers are naturally connected with a relatively large mechanical system. In situations, where the shop floor area is limited, this becomes a serious limitation. In addition, fixed-angle transducers bear the disadvantage that on production changes the optimum test angle may be influenced, for example if new plates have undergone different rolling or heat treatment processes. In such a case, all transducers or respectively all water wedges have to be recalibrated or exchanged. This means mechanical work in order to test with the new optimized angles. This is undesirable especially in environments where many specialized pipe types with different features are manufactured.

The application of phased-array transducers offers potential solutions for both problems:

1. The angle can be varied within the limits of the transducer from approximately 70° down to 30°, depending on the transducer design. For certain designs, even 0° incidence is possible, allowing a different concept for the coupling check. With different angles, larger areas of the weld can be covered. If more than one test shot is used and the angle is electronically steered. This can allow a significant reduction of the number of transducers.

2. Optimization in terms of varying the angle can be carried out with appropriate reference test pieces, without the need of working manually on the transducers. Apart from the cost issue of various transducer sets, the reduction in setup time by not exchanging the transducers/wedges is significant.

The following figures illustrate the test concept with phased-array transducers. Figure 4 shows the test for longitudinal defect testing. For medium walls, it is possible to access both parts of the weld seam with one transducer from one position.
For thicker walls, the use of 4 transducers may still be necessary. In this case, the use of tandem systems is essential and that implies, that by applying more than one angle shot, the number of tandem zones can be minimized, again resulting in a reduction of the overall number of transducers. Figure 5 illustrates the example of testing for two tandem zones with the same set of transducers.

Finally, as well for the transversal defect detection, the number of transducers may be reduced. In this case again, two weld positions can be accessible from the same position. Only the transducer arrangement with regard to the weld is again defined as X.

Depending on the system needs, combinations of the above described principles are possible. Though in general a reduction to a phased-array-only machine is possible, practical approaches also foresee the combination of both principles, conventional and phased-array.
2. Systems for automated Inspection

2.1 General setup

Several testing machines based on above principles have been designed, manufactured and installed worldwide. Here, one example shall be mentioned, to describe the key features.

Figure 7 shows the typical arrangement of the transducer systems, which are applied within one testing machine. The test for longitudinal defects has been separated into three parts: One standard system to test for internal and external defects and two tandem systems, one of which is particularly made in order to test the middle of the weld (50% of wall thickness), while the other one is used for specific applications. Depending on the wall thickness, this ensures a sufficient coverage of the weld cross section in accordance with existing standards.

The test of transversal defects has been separated in two parts. One is laid out according to the principles described above; the other one is designed as “on-bead” system. On-bead systems allow additional information about transversal defects, since they are arranged in a more conventional way. Depending on the characteristics of the defect, one of the methods will give better results.

The lamination test system was chosen as single-crystal transducers. Depending on the specification, a phased-array system can be employed. The same is true for the pipe-end testing unit. This unit is used in a separate mode to test the pipe-end for laminations only, directly during the test procedure of the pipe, making the use of a separate system for pipe-end testing obsolete. For both of these systems the use of phased-arrays did not bear any advantage for this installation. In general, any type of combination of standard transducers and phased-arrays can be used depending on the material and test specifications.
Figure 8 shows two examples of testing machines applying these concepts.

Figure 8: Image and CAD drawing of testing machines

Figure 9 shows either a conventional testing machine as well as a phased-array testing machine configuration for the same testing purpose. It shows how phased-array can reduce the mechanics without changing the test requirements. With this approach two longitudinal and one transversal system are saved and also the related mechanical calibration work.
2.2 Features of the software system

An integrated software environment was developed with particular respect to the key features relevant for this type of test. Since all of these machines are inline production machines, a three-level software system separates the different views for the operator from that of an engineer and finally the supervisor level. This allows a comfortable, but necessarily intensive configuration of the machine, and the simplest approach for the operator to work with the testing machine.

All test levels are referenced by their corresponding test-level names, so they can be easily managed. Ultrasonic test angles can be setup independently from the configuration supported by a software wizard who controls the ultrasound delays for the relevant test system only, or for groups of test systems. An additional visualization tool shows the operator the calculated propagation of ultrasound main beam in the pipe weld seam considering the pipe bend.

![Image](image-url)

Figure 10: Sector Scan and A-Scan from setup menus

In case of recalibration for new product features apart from changing the wall thickness, a sector scan can be used as a comfortable tool to visualize the optimum angle for a defect to be found as well as to estimate the area of coverage within the weld. During the operation of the test, the conventional A-Scans are used. This bears the major advantage that the operators can easily transfer their knowledge from conventional UT systems to the phased-array system.

The same is true for the test data visualization. Since all of these machines are production machines, the main focus is on providing an easy and clear overview of the obtained results. For this reason, only analog charts are used. The application of higher-order visualizations, such as e.g. C-Scans, is not needed in most cases, though possible. Future systems may need to be designed according to different specifications by the customer and may therefore also require different visualizations.
2.2. **Optional features of the system**

Additionally all spindles which turn the transducers perpendicular or parallel to the weld seam can be motorized. This means if the machine is once calibrated for a specific pipe, all current positions of the transducers can be stored within the ultrasonic parameter file. By loading of an existing data set and confirming via operator all transducers will move automatically to their stored location according to the reference defects to be detected. Using this feature the calibration time for a previously tested pipe dimension is reduced significantly.

The height adjustment of the test mechanics to different pipe diameters is motorized as well. The current position of the mechanics can be stored within the ultrasonic parameter files. This feature also helps to reduce the calibration and production time. Machines of this type have already been delivered and placed into production.

3. **Conclusions**

Automatic ultrasound weld testing machines for pipeline tube inspection utilizing phased-array technology, optionally added by conventional technology, offer specific advantages over fully conventional systems such as:

- Higher probability of defect detection due to electronic optimization of angles
- Smaller false call rates due to higher defect amplitude caused by optimized beam angles
- Faster set-up time for tube dimension change due to less mechanical set-up and more electronic set-up
- Smaller mechanical dimension of testing machine
- Increased future capabilities by electronic beam angle steering taken notice of expected increasing end customer demands

4. **References**