# Practical Application of the Phased-Array Technology with Paint-Brush Evaluation for Seamless-Tube Testing

R.H. PAWELLETZ, E. EUFRASIO, Vallourec & Mannesmann do Brazil, Belo Horizonte, Brazil, R. PRAUSE, B. KARBACH, S. FALTER, GE Inspection Technologies, Huerth, Germany

**Abstract.** Modern testing machines for full-body tube and weld testing are carried out in Phased-Array Technology. To fulfill the extensive testing requirements, a fast and versatile machine adjustment concerning various specifications and defect types is required.

Longitudinal defects including directions up to ±20° deviation from the longitudinal direction are detected without gaps. To achieve this, the paint-brush technique is applied. Up to 32 test-modes are implemented within the software allowing a variable adaptation of the machine parameters for various testing-environments. The testing-process can include more to 400 virtual probes, each in single evaluation-channels and up to 1200 test-functions. Additional optimization features include the variation of virtual-probe size and focal-laws, definition of overlapping test-tracks, different number of paint-brush evaluation cycles and individual probe normalization and calibration.

Three Phased-Array probes are packaged in one compact probe-tank performing the complete test task, allowing minimal untested tube ends. The testing-results are presented in strip-charts and various presentations according to the need for the test-task and be transferred into a data-storage network.

Typical tests include transversal and longitudinal defects up to 20° bandwidth, as well as wall-thickness and eccentricity measurement, lamination and internal wall deformations. Practical results for seamless tubes in a diameter range of 88.9 to 350 mm including defect detection capability and reproducibility will be presented.

## Introduction:

The testing of seamless tubes in immersion technology with helical tube transport requires in addition to detection capabilities of longitudinal and transversal defects, laminations and wall thickness monitoring the inclusion of variations from the longitudinal direction. For economical reasons, high test speed and a compact assembly are constraints applied to this type of machine. The phased array technology gives the opportunity to fulfill these specifications. It allows parallel operation of a large number of probes, multiplexing various virtual probes for different positions and different test modes and contributes significantly to the test speed by parallel processing a high number of test channels. The key procedure herein is the implementation of the paint brush method.

It has been realised in the system for automatic testing of seamless tubes. Using the Paint-Brush Method allows to cover a range up to ±20° in addition to the tests for longitudinal defects at advanced speed. Further, one single phased array probe for transversal flaw detection and wall thickness monitoring is included in the same tank. Herein, big advantages can be achieved by variable overlapping of virtual probes and adjustable virtual probes in size, focus and angle. The versatility of phased arrays allows further the testing of laminations, internal wall deformations (Molly Whopper) and coupling checks in a very compact test tank.

The tubes to be tested have diameters from 90mm to 400mm and a wall-thickness in the range of 5mm to 30mm. All phased array probes are located within one tank, which is located in 6 o'clock position under the tube, as is illustrated in figure 1.

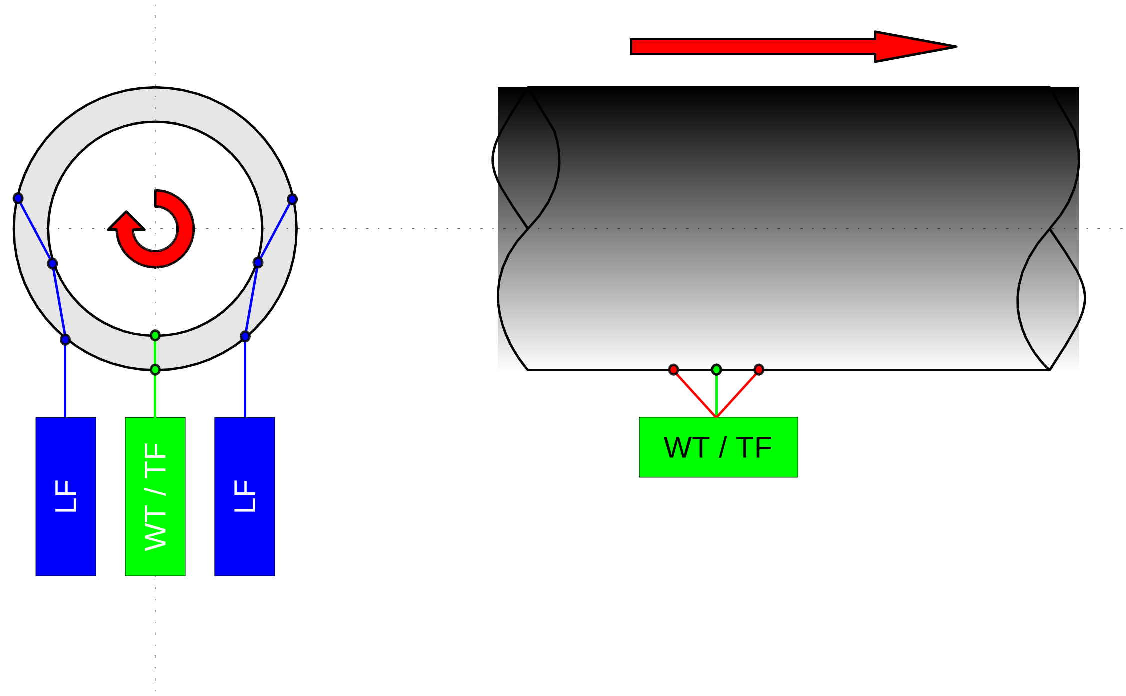
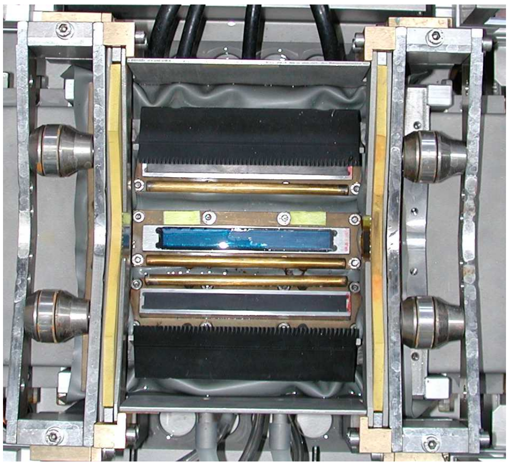


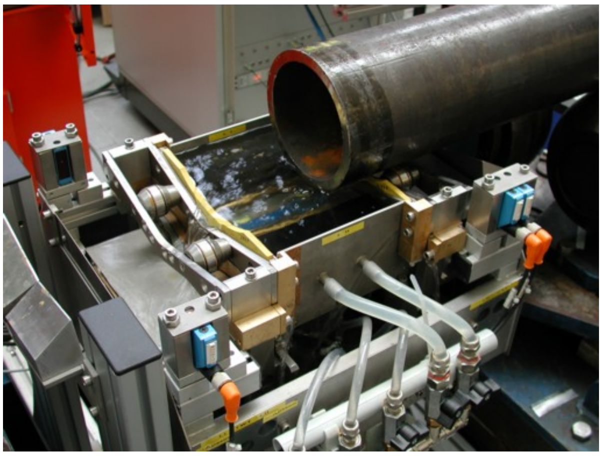

Fig. 1: Sketch of the test tank

Two phased-array probes are used for longitudinal defect testing and one phased array probe is used for transversal defect, lamination and Internal wall deformation testing, as well as for wall-thickness measuring. All probes can be rotated along the probe axis, allowing on the one hand a perpendicular positioning of the probe for WT / TF measurement and on the other hand an angular incidence of the sound field at approximately 19° for longitudinal flaw detection.

Figure 2 shows the test mechanics in the test line. The tube transport is helical and as the tube passes, the tank is pressed from below to the tube. Because of the fact, that only one tank is needed, not much space on the line is needed. For the operator, only 4 components need to be altered in case of a dimension change.



Test tank, top view



Test tank with tube

Fig 2: Testing Line with tube

To allow transversal flaw testing with angular incidence and the tests with perpendicular incidence with one probe the classical phased array approach is used:
Applying delays to the element transmissions and receptions the sound beam is steered within a specified range, as is illustrated in figure 3, which contains the combined plot of two tank measurements with the same phased array probe, one without delays and one with delays for 17° deflection.

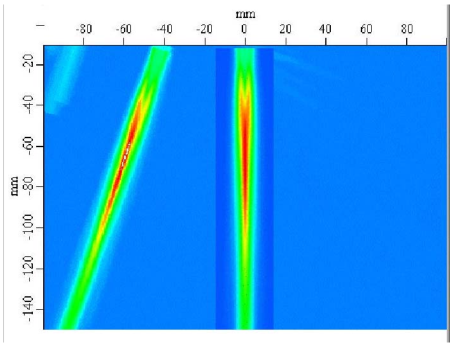
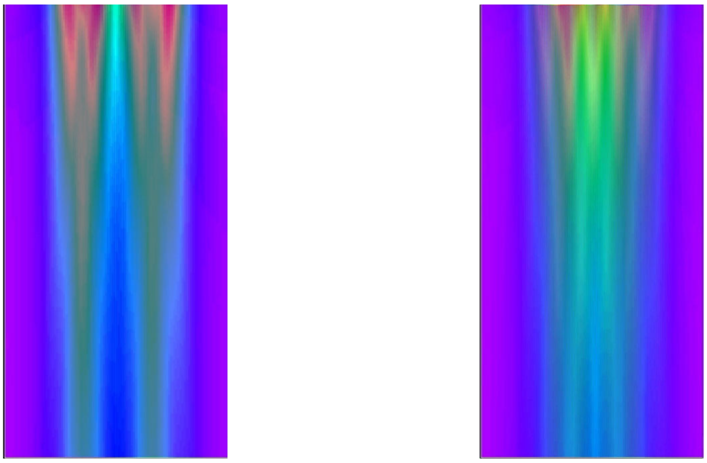



Fig. 3: Combined Angular and perpendicular sound beam

The test for transversal defects and Wall-Thickness is carried out in conventional Phased-Array technology. Up to 6 virtual probes are formed on one Phased-Array probe with 224 elements. This allows calculational overlapping of virtual probes of 75%. In cycle sequences, the shots are installed and sequentially executed. The probe has a frequency of 3 MHz, which allows good resolution for wall thickness measurement and at the same time good Phased-Array operation. To do all tests with one probe allows keeping the tank compact, since in opposite to conventional testing technologies, no separated tilted probes are needed. Figure 3 and Figure 4 illustrate examples, how this probe can be setup. Due to the Phased-Array Nature, the setup is fully configurable. In particular, this means, that one is enabled, to adjust it to the necessities of the test. If, for example, one needs to detect small pittings, the overlapping for the lamination could be increased.



No overlap 66% overlap

Fig. 4: Effect of virtual probe overlapping

**Principles of the Paint Brush testing method**

This method is applied in the tests for longitudinal with and without components of higher angles than zero. A realistic testing scenario can be described in the following way: if defects from –12° to 12° in steps of 2° are to be tested, there results a total number of 13 shots including the 0° shot for longitudinal defects.
Assume the following parameters:

| | | |
|---|---|---|
| 1 | Shot distance: | 1mm |
| 2 | Tube surface speed: | 1.5m/s |
| 3 | Water path: | 40mm -> 54µs |
| 4 | Wall Thickness | 20mm -> 35µs |

With assumptions 1 and 2, a pulse repetition frequency of **1.5Khz** needs to be realized.
With assumptions 3 and 4 a total time for 13 measurements results to:

13*(54µs + 35µs) = 1157µs = **0.864kHz**

The discrepancy is obvious: it is not possible to perform these tests with a conventional technology.

The Paint Brush method resolves this discrepancy. It works in the following way:

1. Parallel transmission of all elements without delays
2. Parallel Reception of all elements without delay
3. Digitization of all elements' signals in time and amplitude
4. Evaluation regarding longitudinal defects
5. Storage of all signals in a RAM
6. Evaluation of stored data regarding deviations from the longitudinal direction in electronic evaluation cycles with reduced cycle time

The key to higher processing speed is in the cycle time: the full physical path is needed only one time and the evaluation for signals from defects with components larger than zero is performed in an electronic cycle, which is very fast.
Assuming an electronic cycle time of 35µs, one finds:

1*54µs +35µs + 12*35µs = 509µs → 1,965kHz,

which over specifies the required PRF in the example. Thus, using the Paint-Brush principle allows a much faster processing, or equivalently, allows a deeper evaluation of data at the same throughput.

The principles can be best understood looking at the B-Scan build by all elements. Figure 5 shows this B-Scan from a lab experiment. The same defect was tilted from 0° to 20° and the 5 plots shows, how the received signal changes. On the one hand, the position moves and on the other hand the signal front rotates relative to the general incidence, what is clear from the reflection characteristics of the defect. This effect is used in the evaluation, where in certain channels a test for one direction is made and compression to an A-Scan channel is carried out. Figure 6 illustrates this compression.

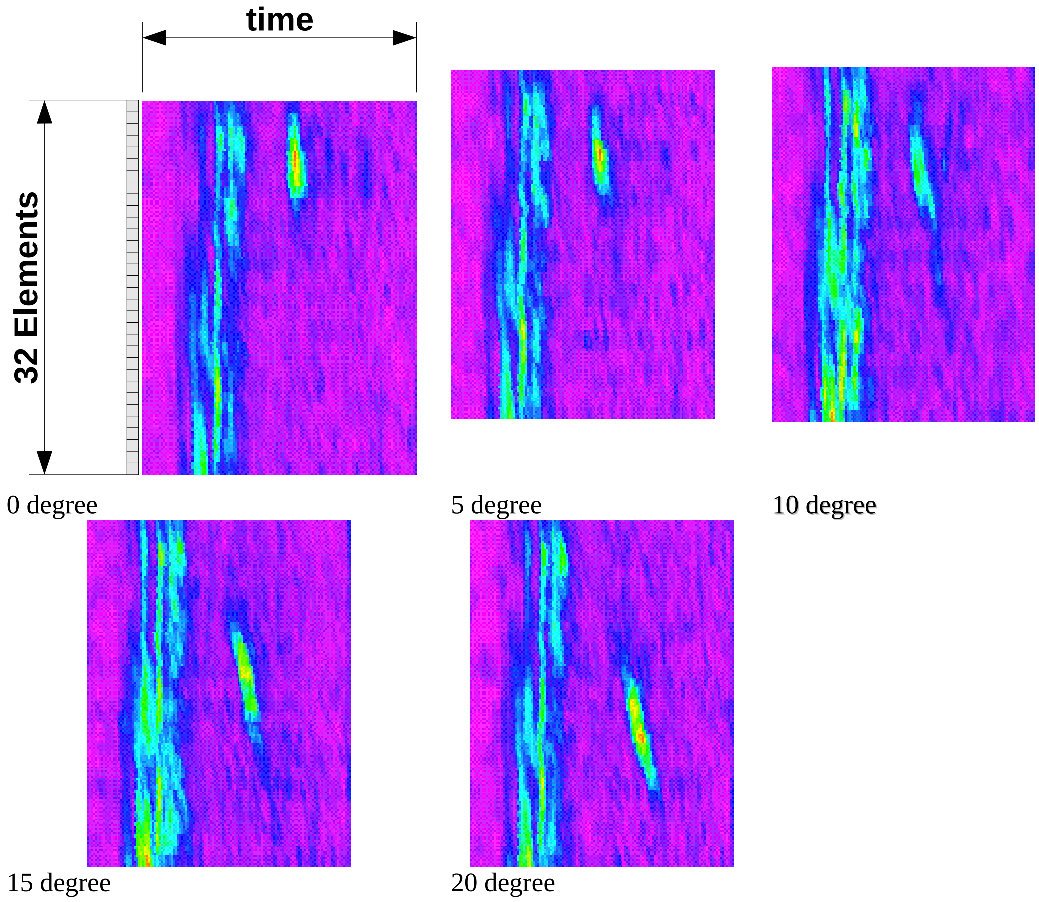



Fig. 5: Characteristics of reference notches

The machine uses a phased-array probe with 52 elements + 16 overlap elements. The signals of these 52 elements are compressed to sections of 8 elements with a general overlap of 50% hence there are 12 virtual probes. Each of these virtual probes undergoes the evaluation cycles, resulting in 156 Channels for the above example.

| Evaluation Angle / ° <br> reference angle / ° | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | **90** | 77 | 56 | 45 | 20 | | | | | | |
| **2,5** | 90 | **95** | 85 | 67 | 58 | 45 | 35 | | | | |
| **5** | 45 | 62 | 81 | **90** | 85 | 74 | 48 | | | | |
| **7,5** | 52 | 80 | 94 | **96** | 86 | 75 | 31 | | | | |
| **10** | | | | 40 | 54 | 65 | **70** | 56 | 40 | | |
| **12,5** | | | 25 | 35 | 43 | 60 | **85** | 50 | 38 | | |
| **15** | | | | | 27 | 34 | 42 | **46** | 45 | | |
| **20** | | | | | | | 20 | 21 | **25** | 25 | 21 |

Tab. 1: Signal Amplitudes for reference notches with different evaluation angles

Due to the changes in angle incidence for increasing angles, the relative signal in case of deviated contributions is smaller than that of the longitudinal defects. Experiments have been carried out in the Laboratory investigating this effect. Table 1 shows a typical result of these measurements. It demonstrates in particular one important feature: A reference defect can not only be detected, if the evaluation law is chosen accurately, but has a certain bandwidth, thus is usually seen in the adjacent evaluation channels. Choosing the evaluation channels carefully, allows not only covering the accurate exact values, such as 5°, 10° but also the values in between. One possible choice of evaluation angles from the results in table 1, would be the angles 1°, 3°, 6° and 7°. With these angles and a suitable gain correction, all references can be detected.

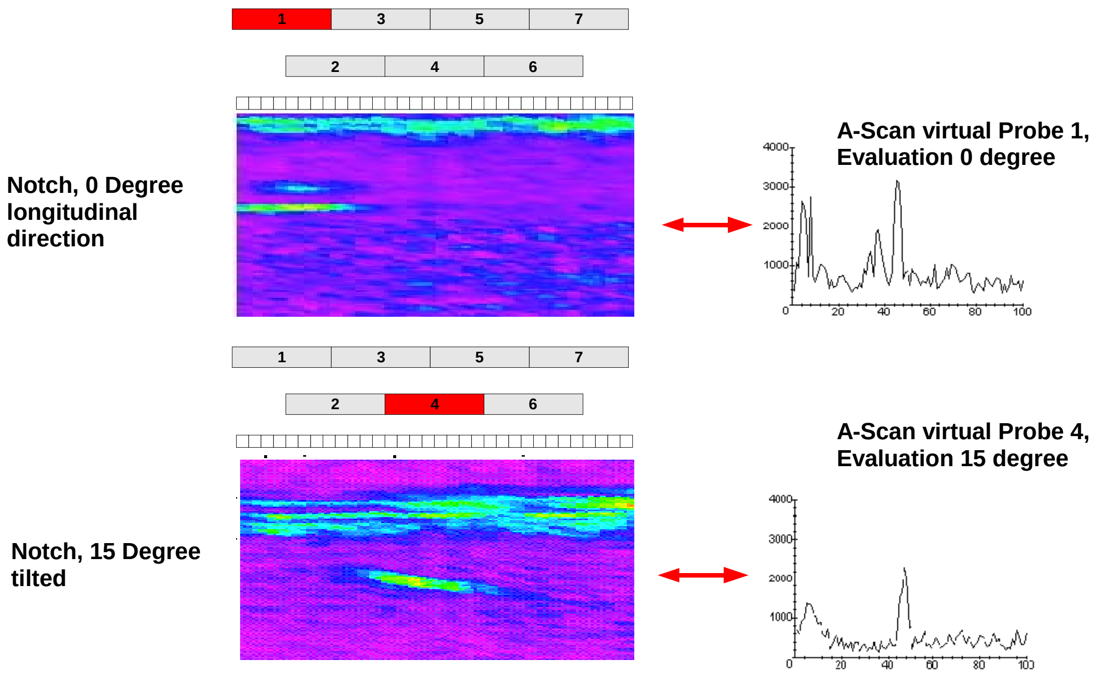



Fig. 6: Data Reduction to A-Scan Channel

**Testing principle for Wall-Thickness Measurements, Transversal defect detection, Lamination and Molly Whopper testing**

This test is carried out in conventional phased-array technology. Up to 6 virtual probes are formed on one phased array probe with 224 elements. This allows calculational overlapping of virtual probes of 75%. In cycle sequences, the shots are installed and sequentially executed. The probe has a frequency of 3 MHz, which allows good resolution for wall thickness measurement and at the same time good phased array operation. To do all tests with one probe allows keeping the tank compact, since in opposite to conventional testing technologies, no separated tilted probes are needed. Figure 3 illustrates one example, how this probe can be setup. Due to the Phased-Array Nature, the setup is fully configurable. In particular, this means, that one is enabled, to adjust it to the necessities of the test. If, for example, one needs to detect small pittings, the overlapping for the lamination could be increased.

The complete test procedure is organized in test modes. For each mode, the complete machine setting may be altered. This allows the user to setup conditions for various sensitivities and processing speeds. Table 2 illustrates 3 examples of such configurations used for the testing.

Test Mode 1 uses relatively large virtual probes for all tests, giving a large coverage and fast processing. Test Mode 2 works with virtual probes half as wide as in Test Mode one. This is of advantage for thinner walls and higher resolutions.

| | Transversal defects | Lamination and Molly Whopper | Wall-Thickness measurement |
|---|---|---|---|
| Test Mode 1 | Probe width: 16mm<br>Overlapping: 75% | Probe width: 16mm<br>Overlapping: 50% | Probe width: 16mm<br>Overlapping: 0 - 50% |
| Test Mode 2 | Probe width: 8 mm<br>Overlapping: 50% | Probe width: 8mm<br>Overlapping: 50% | Probe width: 8mm<br>Overlapping: 0 - 50% |
| Test Mode 3 | Probe width: 16 mm<br>Overlapping: 50% | Probe width: 8mm<br>Overlapping: 50% | Probe width: 8mm<br>Overlapping: 0 - 50% |

Tab. 2: Test Modes

Test Mode 3 finally, is a mixture from the first 2 Test-Modes and is the one, which can uses larger probes for transversal testing, which is needed for thicker walls, but keeps the resolution for the wall thickness channels. This mode is suitable for most of the situation. The other two modes are suitable for high resolution or fast processing. The test mode is generally fixed. The single flexibility existing is to change the probes themselves.

## Conclusion

The Phased Array Technology offers many significant advantages for online testing of tubes. Due to the high versatility of the Phased-Array probes, it is possible to execute test functions with one probe, which formerly needed to be performed with several single element probes and thus allows it, due concentrate all tests in one tank. The variable overlapping, apertures and delay-laws for deflection and focusing permit the accurate optimization of the UT-operation to the test requirements.

Applying the Paint-Brush Method extends the longitudinal testing in a way, that without any reduction of test speed, defects with contributions up to ±20° can be detected. Practical tests in the production line verify excellently the results in the laboratory. Measurements have been carried out with reference tubes comprising reference defects with suitable test defects, among them longitudinal flaws, transversal flaws and laminations.

Defect detection proved to be very reliable under production conditions. During the test runs, defects could be detected in Paint-Brush Mode, which were not found with conventional methods or pure longitudinal evaluation. These defects could be safely verified after tube reversion and retesting. The angle deviations found therein even exceeded the 20° limit and are presented herein.

The easy operation and adjustment means integrated in mechanics, software and hardware allow fast and versatile operation and dimensional changes, and thus together with the compact mechanical dimensions characterizing the Phased-Array testing machine as a highly productive tool for online tube testing facilities.