High Resolution Phased Array Imaging using the Total Focusing Method

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Abstract. Ultrasonic Phased Array techniques are applied in medical and technical fields for many years now. Due to increasing computer performances nowadays also advanced imaging techniques can be applied, delivering higher image resolutions compared to traditional sector scans and linear scans which are only based on focused sound beams. The total focusing method (TFM) is a signal processing algorithm using data acquired in full matrix capture mode (FMC). All computations are achieved at a refresh rate up to 30 frames per second. With TFM imaging different ultrasonic modes can be defined for longitudinal waves, shear waves and even sound paths with mode conversions, like Long-Long-Trans (LLT), for example. The LLT-technique has the potential to replace traditional tandem techniques due to its advantage concerning space requirements, as only one array probe is needed. Practical results will be demonstrated and discussed within the presentation.

Introduction

The well-known traditional Phased Array Techniques “Sector Scan” and “Linear Scan” provide acoustical images with lateral resolutions of 2 or 3 wavelengths, if the sound beams are focused accordingly.

By means of the Total Focusing Method (TFM) a resolution of 1 wavelength can be obtained, if a large aperture with e.g. 64 elements is applied.

1 The Total Focusing Method

1.1. Principle

The total focusing method (TFM) is a signal processing algorithm using data acquired in full matrix capture mode (FMC). A computation zone is specified for the data reconstruction. This zone is meshed, and for each point on this grid, the focal laws are calculated for the entire set of elements of the phased array probe. All recorded signals are time-shifted accordingly before summation at every point of the grid. The loop ends when the reconstruction is done for each point of the mesh. The main advantages of FMC-TFM are direct imaging of a large area in one probe position combined with optimal focusing and spatial resolution.

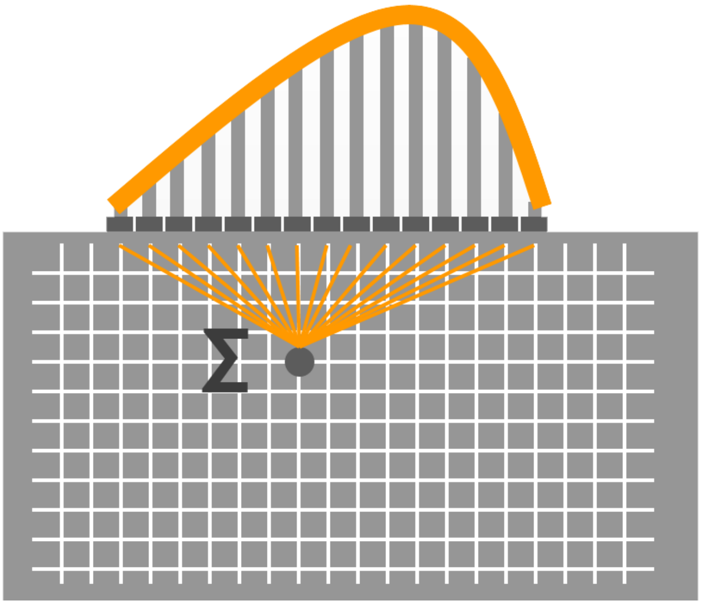

Fig. 1: TFM principle

Although a lot of calculations are performed, scanning is possible at a refresh rate of 30 frames per second.

TFM can provide a lateral resolution of 1 wavelength, if enough elements, e.g. 64, are applied. Figure 2 presents a test result on the phased array calibration block according to ASTM E 2497 with a vertical row of side drilled holes of 1 mm diameter. In the actual case a probe was used with a sound frequency of 5 MHz, which yields a wavelength of 1.2 mm. The TFM-B-Scan image clearly resolves the 1 mm holes.

Furthermore TFM enables the linear array probe to “look” into all directions, due to the fact that each element with its small pitch generates a sound beam with an extremely large divergence. Figure 2 proves that the entire vertical row of holes is imaged with the sideward probe position:

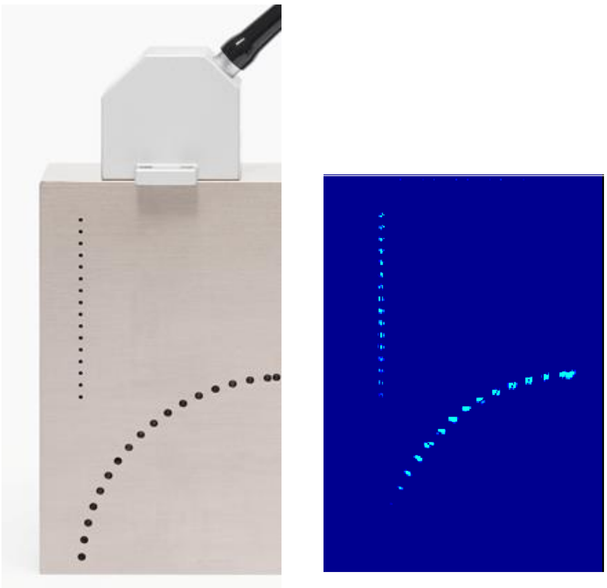

Fig. 2: ASTM block and TFM result

1.2 Analysis and Sizing capabilities with TFM

The above mentioned ASTM calibration block also contains a row of holes with a diameter of 1.5 mm. A TFM-B-Scan is presented in Figure 3. If 2 cursors are selected in the B-Scan, the distances are indicated, here: $\Delta x = 1.5$ mm:

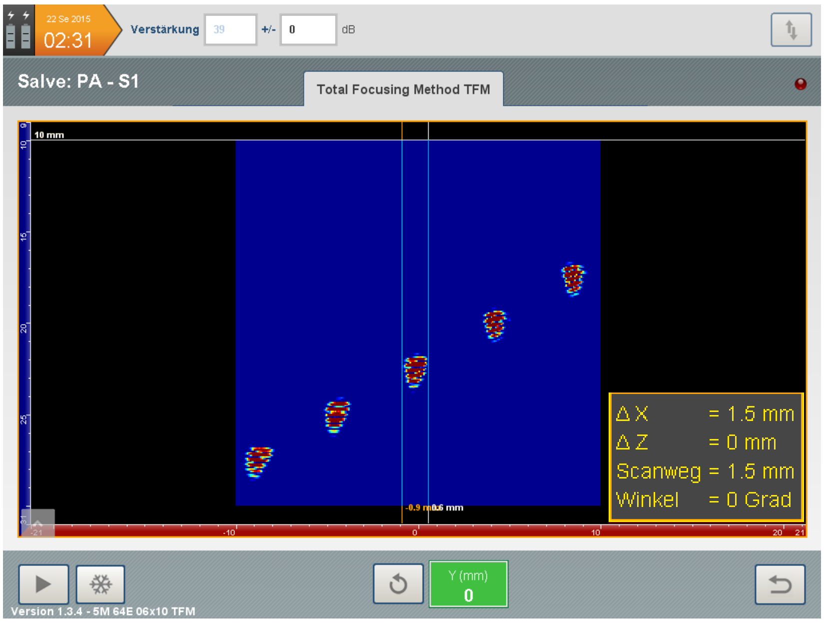

Fig. 3: Reflector size determination

2 TFM Applications

2.1 Inspection of a welded T-Joint

In the following the inspection of a welded T-Joint is presented. T-Joints are often critical concerning insufficient through-welding (in the actual case the weld contains an artificial disbond).

Fig. 4: Inspection of a T-joint using an array probe with 64 elements

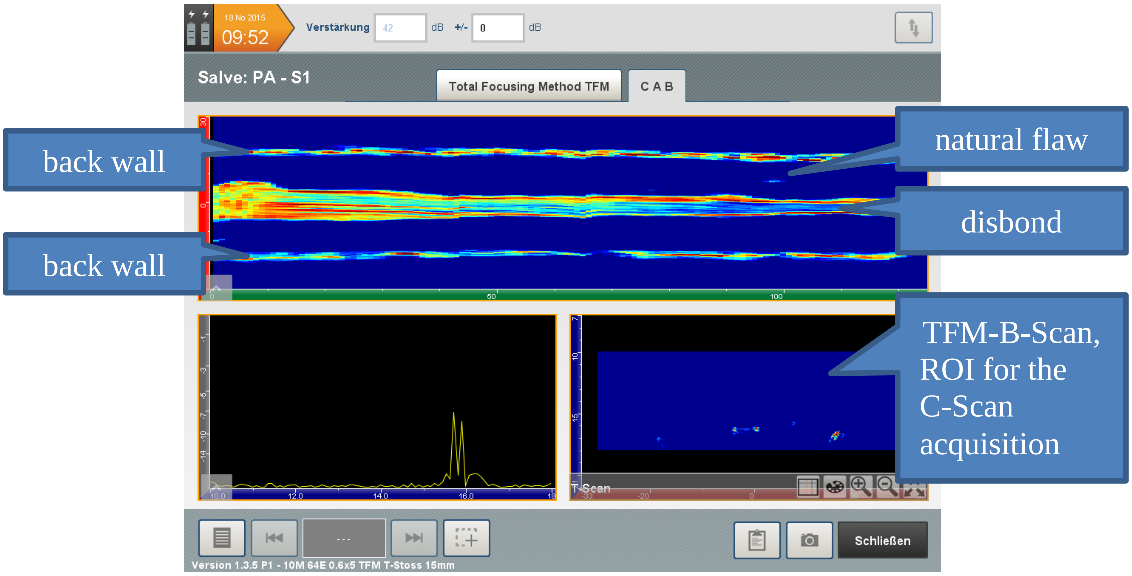

Fig. 5: C-, B- and A-Scan obtained with TFM

Fig. 6: Complete TFM-B-Scan: Even the weld contour is imaged

2.2 Inspection of a friction weld on a tow-bar of vehicles

Another type of weld inspection concerns the weld of tow-bars of vehicles. The bar with the tow-ball is welded to the shaft, which is mounted on the car. This weld has to provide highest strengths concerning all types of stresses.

The test is carried out using a 5 MHz array comprising 32 elements. The wedge is adapted to the shaft diameter of 40 mm. Water irrigation ensures a constant coupling. Using TFM the probe can be mounted very near to the weld.

The customer has designed a mechanical system with the probe holder which enables the shaft rotation. A complete testing around 360° needs 10 seconds, at a scan speed of approx. 13 mm/s

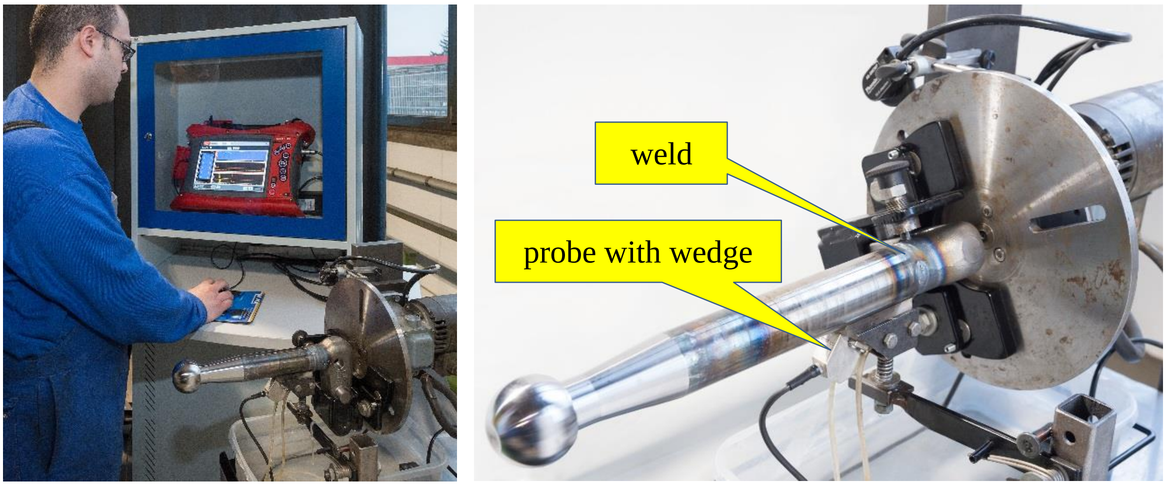

Fig. 7: Test setup for the weld inspection on tow-bars

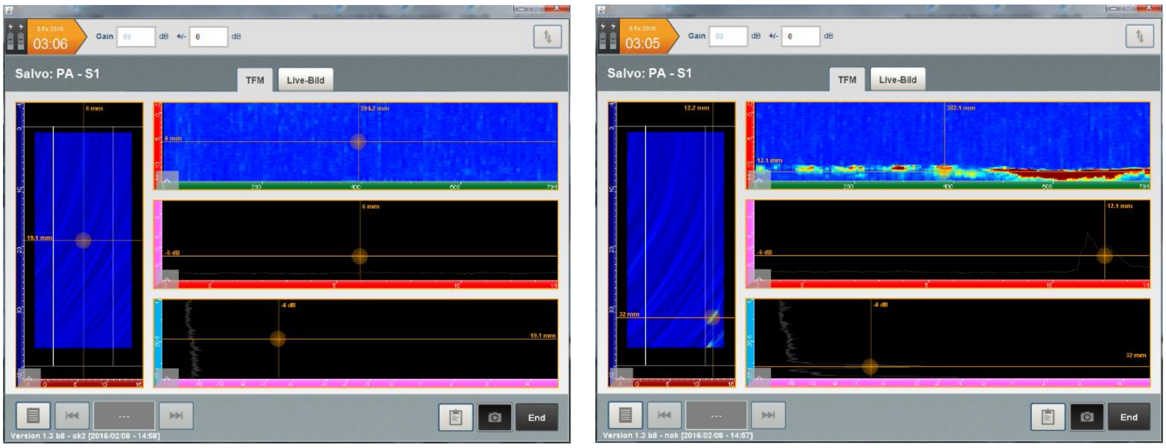

Fig. 8: TFM test results, left OK, right NOK

2.3 Testing of Bearing Rings

For the ultrasonic testing of bearing rings very high test sensitivities are required, e.g. FBH's with a diameter of 0.5 mm and a depth of 0.5 mm in front of the back wall. The GEKKO provides a high contrast and signal-to-noise ratio, due to a very low inter-channel crosstalk of -50 dB, thus fulfilling this requirement.

However, if the back wall is inclined, which is often the case with bearing rings, the small echoes close to the back wall interfere with the echo of the inclined back wall. Therefore, such reflectors cannot be detected, neither with conventional monoelement probes nor with the traditional phased array sector and linear scans. In this case, TFM is the only successful method, see following figures:

Fig. 9: Test block with inclined back wall containing 2 FBH's Ø 1 mm (1 mm deep) and Ø 0.5 mm (0.5 mm deep)

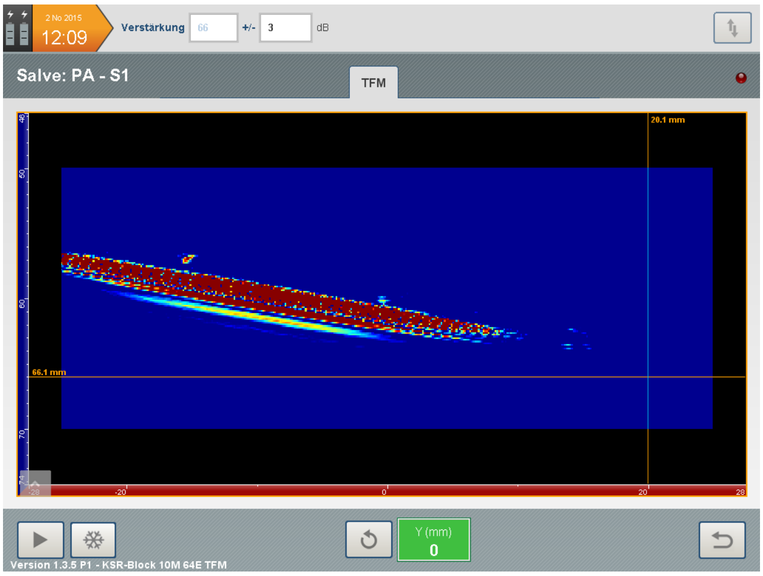

Fig. 10: Indications of the 2 FBH's at the inclined back wall

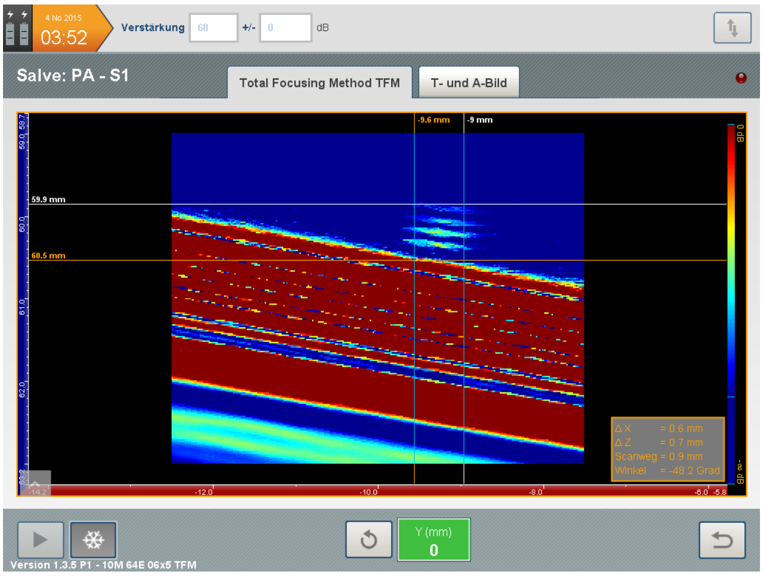

Fig. 11: Acoustically zoomed image of the FBH Ø 0.5 mm with depth 0.5 mm

2.4 Testing of castings

Steel and light alloy castings often contain shrinkage cavities. Due to their dendritic surfaces the ultrasonic reflection is poor. If the DGS or DAC method are applied for defect size estimation according to the testing standards for castings, we often find a severe under-sizing.

TFM however, transmits in and receives from various directions, thus enabling a much better reflection of the dendrites, which ensures a more acccurate defect size determination, compared to the conventional amplitude based methods DGS and DAC.

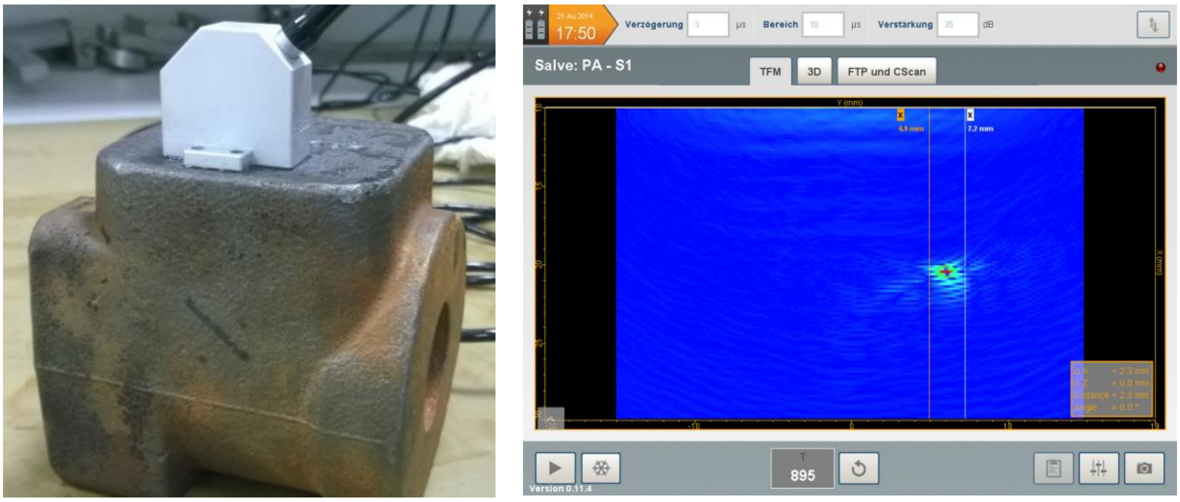

Fig. 12: Testing of castings with TFM

2.5 TFM with mode conversion

The GEKKOalso supports TFM-techniques which consider mode conversions. One example is presented below:

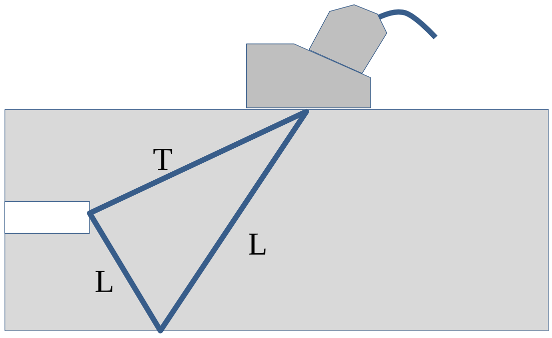

Fig. 13: Test block with vertical FBH

The test block according to Figure 13 contains a vertical FBH which is traditionally used as test reflector for tandem techniques with two angle beam probes. For different depths the distance between the tandem probes must be changed or various probe pairs must be applied, which makes the tandem technique often cumbersome.

With a linear array probe and the LLT-technique (Long-Long-Trans) only a single probe is needed, simplifying the probe handling.

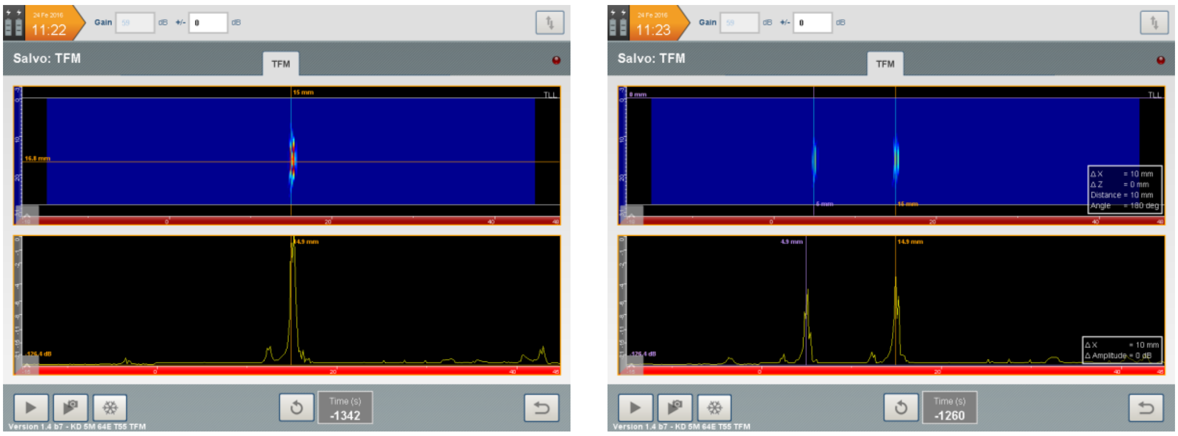

Fig. 14: Left: Indication of vertical wall, Right: Indication of vertical FBH, 10 mm in front of the vertical wall

Summary

In contrast to the traditional phased array sector scans and linear scans the Total Focusing Method provides lateral image resolutions of only one wavelength if arrays with 64 elements are applied. The Total Focusing Method permits sideward imaging of reflectors due to the fact that each array element generates a divergent sound beam, thus “looking” into all directions.

Beside a short description of the basic principle of TFM several practical examples are shown concerning the inspection of special welds, bearing rings with special geometries and castings, where TFM yields a better sizing of shrinkage cavities.