Practical Examples of Ultrasonic Testing (Manual, Semi- and Fully Automatic)

Wolfram A. Karl DEUTSCH, Stefan KIERSPEL, Helge RAST
KARL DEUTSCH Pruef- und Messgeraetebau GmbH + Co KG, Wuppertal
Contact E-Mail: w.deutsch@karldeutsch.de

This paper presents several industrial ultrasonic inspection applications. It describes manual conventional testing and examples for modern phased array inspections including acoustical imaging. Such semi-automatic methods still require the operator's decision for the evaluation. Finally, two systems for a fully automatic testing of steel billets are described.

Today, many inspections are done using conventional ultrasonic testing (UT with mono-element probes) or phased array ultrasonic testing (PAUT). The number of sales and a peek into workshops show, that conventional UT still dominates. Although the prices of PAUT systems have reduced drastically (many instruments range between 20 and 25 k€). But conventional equipment still is much cheaper, particularly with regard to the prices of the probes. Furthermore, there are high accumulation needs concerning technical standards and training. We must also consider that the conventional state of art with standardized acceptance criteria has proved itself over decades. Therefore, the following questions arise: Is it really wanted or even a must to inspect more sensitively? In addition, does the "normal" UT inspector fulfill the requirements concerning PAUT? This means that in the future PAUT will only be applied for sophisticated and discerning inspection tasks.

This is different in case of fully automated systems, where reference reflectors have to be detected without a preference of UT or PAUT. In many areas, PAUT solutions are established. However, it may enable an electronical focusing to only the region of the test reflectors neglecting the rest of the object volume. Therefore it is necessary to carefully design the array sensors and the acoustical parameters (e.g. with CIVA), in order to find reasonable compromises concerning scanning speeds, pulse repetition frequencies and scan indexes.

1 Manual UT with A-Scan, B-Scan and weld visualization with TOFD

Today, digital instruments have replaced the analog instruments. In case of huge forgings however, the analog instruments were preferred for a long time. Nevertheless, the modern digital equipment provides storing of parameter sets and test results. Modern signal processing, low noise receivers, square wave pulsers and Time Corrected Gain (TCG) reveal good signal to noise ratios in the A-Scan.

Today commercially available instruments provide further tools. With the option of a position encoder easily readable B-Scans as images of object intersections can be generated, which enables also a non-skilled operator to interpret the result, due to the higher information content compared to a single A-Scan.

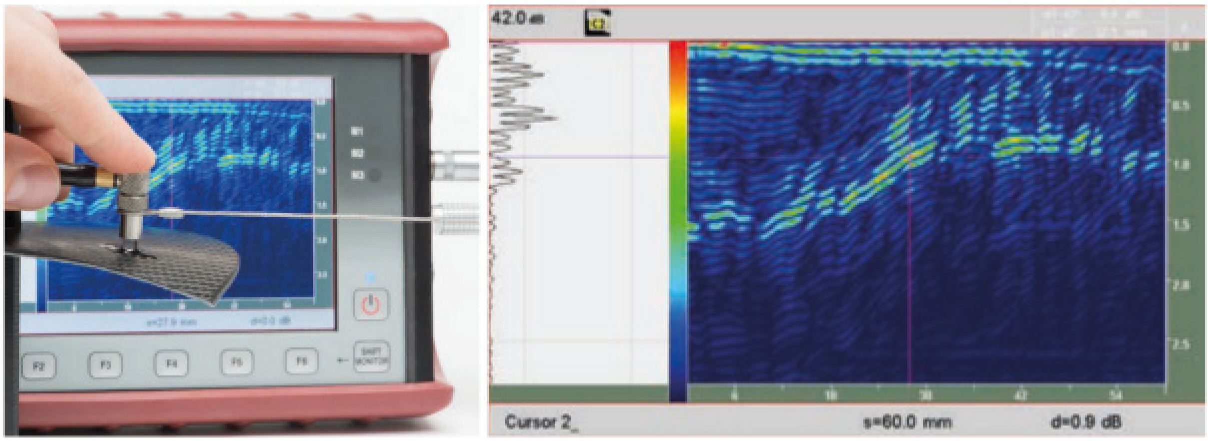

Fig. 1: Inspection of a CFRP object with a wire encoder and B-Scan output, which presents clearly the changing object thickness and structure indications in the volume.

For weld inspections, further new tools are available: The graphical display of sound beam skips and echo dynamic curves (strip charts) which are generated using a position encoder. TOFD testing is standardized and implemented in instruments for manual UT.

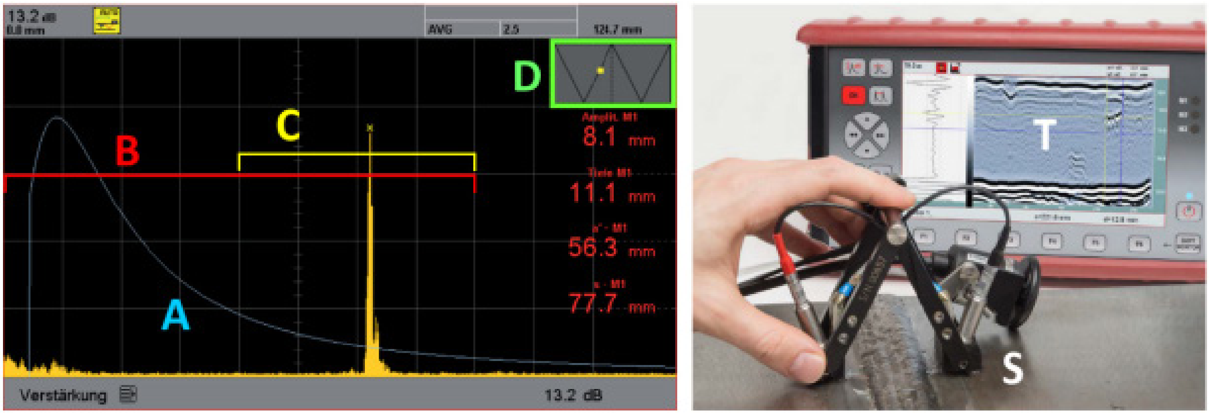

*Fig. 2: Weld testing with the ECHOGRAPH 1095. **Left**: A-Scan with adjusted DGS curve (A), Red Gate (B) indicating a full skip, Yellow Gate (C) indicating a half skip, and visualization of the reflector position (D) presenting the position in the center of the weld. **Right**: TOFD Scanner and a TOFD Scan presentation on the instrument.*

2 Standard Instruments for Automatic Testing

Digital instruments for manual testing are sufficiently fast, enabling the application also in automated systems. Features like “Echo Start” (important for immersion technique), TCG (Time Corrected Gain, important for long sound paths) and signals for sorting and color marking purposes are available via a special interface. Of course, every channel must be configured separately and the testing is done without documentation of the results. However, this is accepted, as such testing systems are relatively inexpensive.

Alternatively, the multichannel instrument ECHOGRAPH 1170 supports a customer specific data processing by means of the software ECHOVIEW.

Fig. 3: A two-channel rf-weld inspection for the process control on endless tube (below right in the picture)

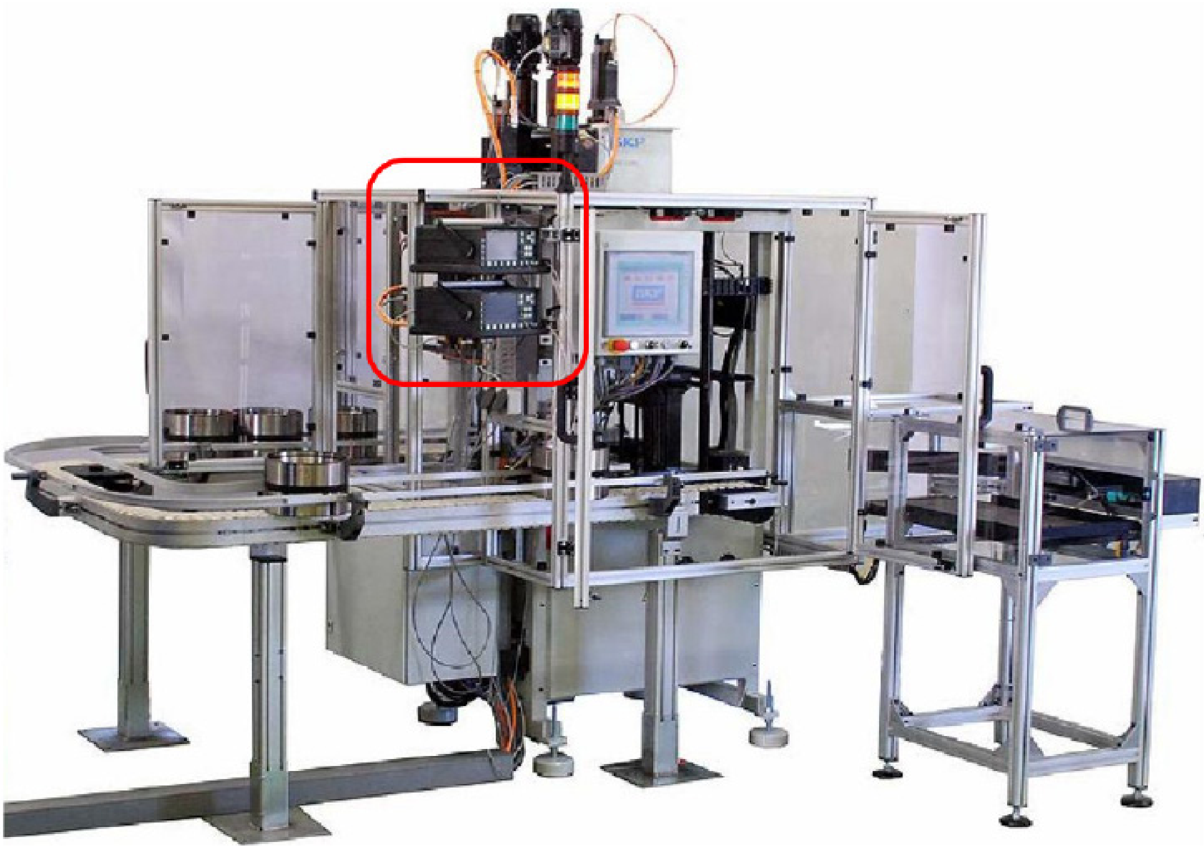

Fig. 4: A two-channel UT-inspection of bearing rings in immersion technique with automatic transportation with two instruments ECHOGRAPH 1091 (© Brochure of the company SKF-QTC)

3 GEKKO & MANTIS: Mobile Phased Array Instruments with TFM Algorithm

Since 20 years, mobile PAUT instruments are available. During that time, further developments lead to spreading applications. Important is a simple user guide, because of the larger number of parameters compared to conventional UT. Comfortable wizards guide the operator through the menus.

The GEKKO with 64 parallel channels (available since 2014) and the more compact MANTIS with a 16/64 channel configuration (available since 2017) support the Total Focusing Method (TFM), which generates B-Scans with extremely high resolution in the range of one wavelength. The inspectable volume can be larger than the length of the array probe, due to the high sound beam divergence of the single elements, see figure 5.

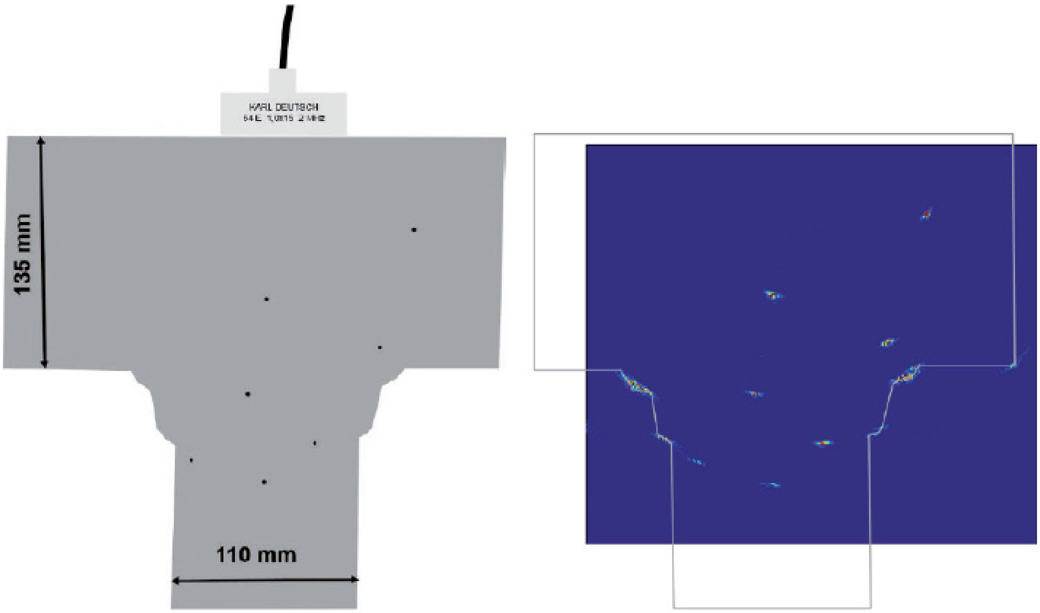

Fig. 5: Testing of a thick-walled welded T-joint with TFM, providing space correct images. Not only the 2 mm side drilled holes but also the weld contour are imaged very well.

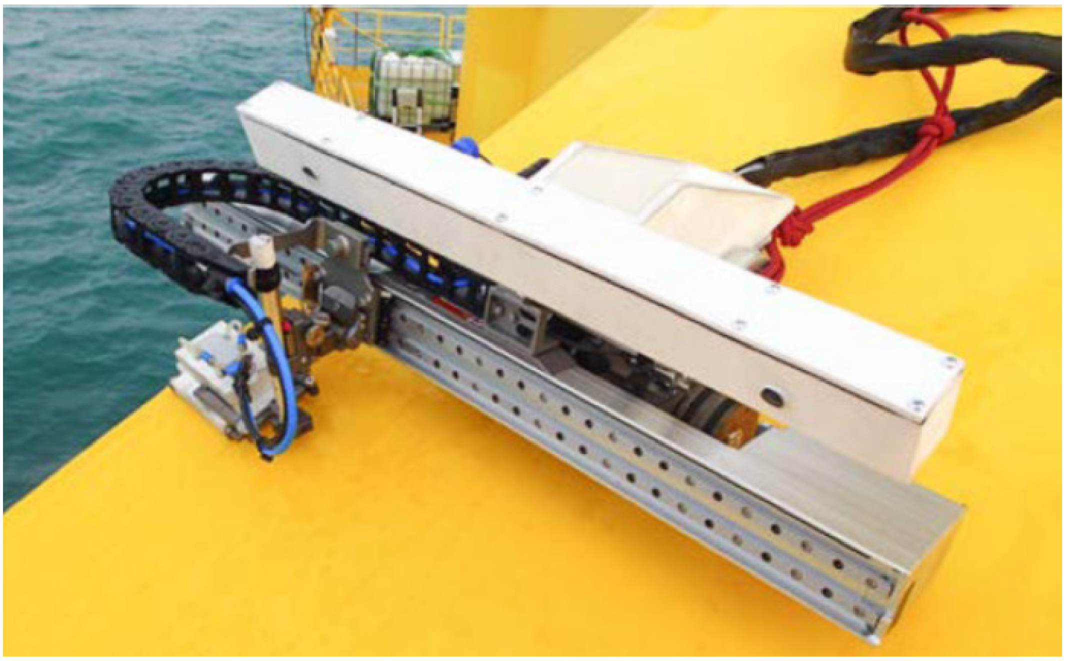

Fig. 6: Inspection of T-joints on offshore wind energy systems using a motorized scanner and cable lengths of 35 m.

4 Semi-automatic PAUT of railway wheelset axles with the GEKKO at S-Bahn in Berlin

In 2018, the S-Bahn in Berlin purchased three GEKKO instruments with compact motorized scanners. The scanner is fixed magnetically at the axle end. The tight space condition at the axle end was a challenge. A small motor drives the array probe over 360°.

The sound beam divergence ensures an all-over inspection, thus closing the gaps due to the three holes, which lie in the red hatched coupling area in figure 7 right. The 64 parallel channels of the GEKKO provide enough sound energy, thus enabling the inspection of more than half of the axle length from the two axle ends.

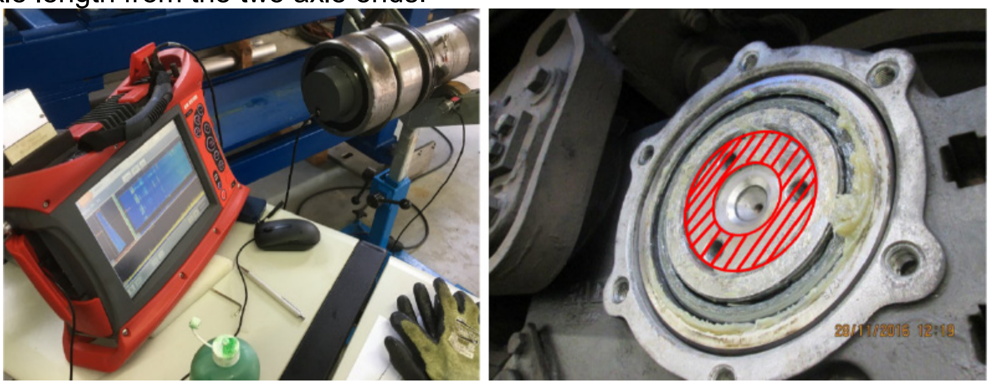

Fig. 7: Wheelset axle testing with PAUT with a compact scanner (left) and view of the axle end with hatched coupling area (right)

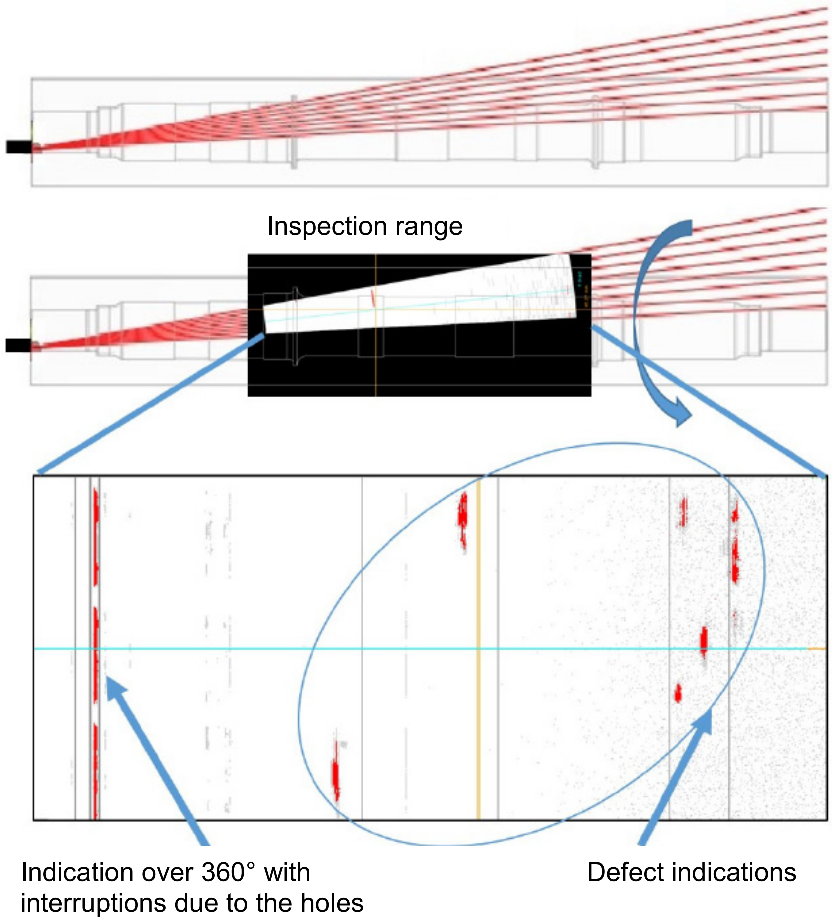

Fig. 8: Principle of the wheelset axle testing. ***Above****: Sector Scan from the axle end with 3° to 10°.* ***Middle****: Inspection range on the shaft.* ***Below****: C-Scan presentation over 360°. The positions of the indications can be determined via cursors.*

5 Semi-Automatic inspection of electrofusion fittings at polyethylene pipelines with the MANTIS

In pipeline systems for the gas and water supply and the disposal of wastewater, polyethylene tubes are in use since 1957. The special features are high resistance against corrosion, chemicals and cracks as well as light weight and simple bonding techniques. One of these techniques for the impermeable, friction-locked and permanent connection is the sleeve welding with incorporated heating elements in the polyethylene sleeves. Two tube ends are sticked into a sleeve. Heating the wires by electric current, the tube ends and the sleeve get thermoplastic, thus forming a durable connection.

After cooling this connection must be tested non-destructively. A safe and simple method is given with the total focusing method (TFM), supported by the GEKKO and MANTIS. Meanwhile the MANTIS is applied at Stadtwerke Wesernetz in Bremen. The MANTIS is only slightly slower than the GEKKO, but more compact and less expensive, thus being best suited for this inspection task. An array probe with 5 MHz is positioned and moved with some coupling gel on the fitting and the MANTIS calculates the TFM E-Scan image with a repetition rate of up to 80 pictures per second. The presentation of the results is so clear that even unexperienced operators are able to determine the weld quality. Also the TFM configuration on the MANTIS (or GEKKO) is quite simple: The operator selects the probe from the database, the material and thickness of tube and fitting, defines an inspection range

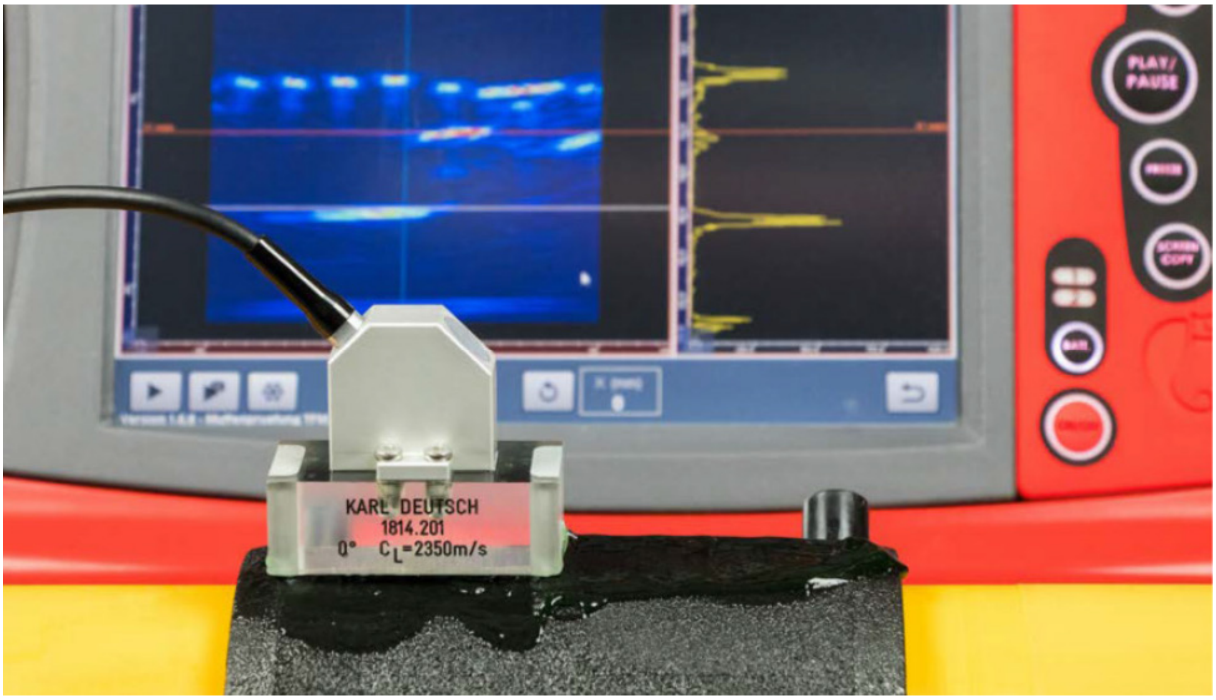

Fig. 9: Linear 5 MHz array probe positioned on the fitting (black), which connects two yellow tubes. The TFM E-Scan image is presented in real time while scanning along the long side of the fitting. The B-Scan clearly visualizes the heating elements. By means of a cursor additionally the according A-Scan can be evaluated.

and then starts the inspection.

6 ECHOGRAPH STPS for Steel Bars with Phased Array and Linear Throughput

The concept of conventional ECHOGRAPH STPS systems has proven itself since decades. The system is available in different sizes in order to cover a large diameter range between 10 mm and 130 mm (on customer demand also 150 mm). In most cases, 3 to 15 probes inspect the bars, thus covering highly the area of the cross-section.

The advantages of these systems are:

- High inspection speed (linear throughput with 0.7 – 2 m/s)
- Robust and relatively simple mechanics
- Fast adjustment to other diameters with a central toothed drive belt for all probe holders and displacement via hand wheel or motor
- Spring loaded probe holders to balance straightness tolerances of the bars
- Contact-free coupling via water jets (therefore low probe wearing also in case of black material)

The use of Phased Array techniques increases further the number of shots, thus revealing a complete covering of the cross-section area. The system comprises five array probes with each 24 elements, operated on 120 parallel channels. The five probes generate sector scans with up to 20 shots, which ensure a complete coverage of the cross-section with an adjustable peak-ripple factor (sound pressure variation in dB over the cross-section). The operator optimizes the throughput speed, the scan index and the peak-ripple.

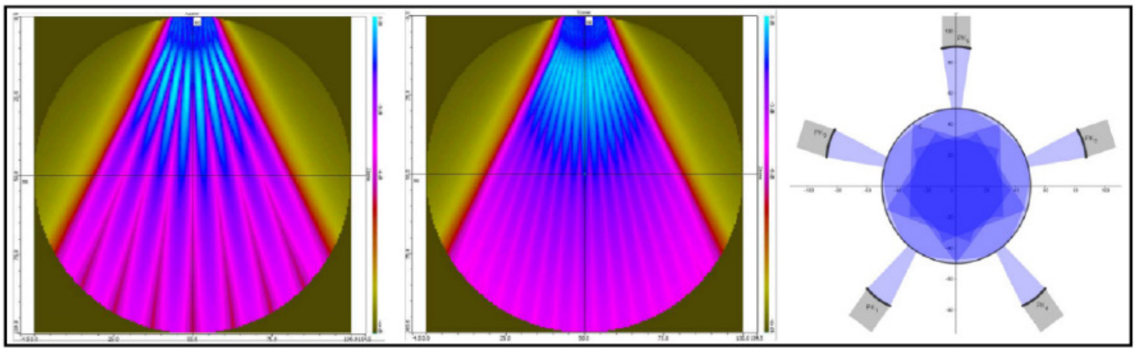

Fig. 10: Sector scans with 8 shots (left) and 17 shots (middle) and arrangement with five PAUT probes (right) which ensures a complete coverage of the cross-section (example for a 100 mm bar)

The system features low replacement costs for spare and wearing parts and needs less electronics and sensors compared to immersion systems with a complete sensor ring.

Fig. 11: ECHOGRAPH STPS PAUT system with five PAUT probes and water jet coupling

7 ECHOGRAPH RPTS Rotating Steel Bar Testing with Testing Bridge (Ø up to 500 mm)

Not every inspection task requires PAUT. Systems for steel bars use mono-element probes with frequencies between 1 and 5 MHz, depending on the material, applying even 10 MHz for surface near regions. The following example describes a conventional testing system with straight beam insonifications for the detection of core defects and surface near defects and with angle beam insonification in both circumferential directions with different sound frequencies and satisfactory testing speed.

The inspection of bars with lengths up to 18 m and the necessary sideward loading of the bars required a self-supporting testing bridge with a calibration station at the left end of the bridge. The reference bars have a length of 6 m. The testing machine has an impressive overall length of 31.5 m.

In order to ensure a complete inspection with required track overlaps and testing speed, the system contains six identical probe carriers. Every carrier comprises double probe holders for ferritic and austenitic steels with different frequencies. A dedicated quick change mechanism enables the adaptation to the material, that is to be tested. The system contains 48 probes with 24 active probes at a time. Four probes in each carrier are working with following sensitivities: TR-probe with FBH 0.8 mm (Flat Bottom Hole) in the surface near region, straight beam probe with FBH 1 mm for core defects and two angle beam probes with a sensitivity of SDH 3 mm (Side Drilled Hole). All probes are working with water gap coupling and are mounted in separate gimbal holders to provide an optimal guiding on the bar surface. Furthermore the system contains a camera survey of the bar end, a Return-To-Defect-Function, a comfortable C-Scan software with 12 o'clock recognition and a color marking device.

Fig. 12: Testing Bridge for steel bars at BGH-Siegen Edelstahl GmbH. The bars are loaded from the right side crosswise below the white bridge via lifting bars. The roller conveyor for sorting purposes and the station for reworks are shown left in the figure.

References

[1] V. Deutsch, M. Platte, M Vogt: Ultraschall-Prüfung – Grundlagen und industrielle Anwendungen, Springer-Verlag, 1997.

[2] W.A.K. Deutsch: Neue Geräte zur Ultraschall-Prüfung, DGZfP-Jahrestagung, 2014

[3] W.A.K. Deutsch, W. Roye, H. Rast, P. Benoist: High-Resolution Phased Array Imaging using the Total Focusing Method, 19th WCNDT Munich, 2016

[4] W. Roye, W. Deutsch, V. Deutsch: Ultraschall-Prüfung – Grundlagen und industrielle Anwendungen, Castell-Verlag Wuppertal, expected 2018.