Ultrasonic Immersion Testing of Aerospace Bars

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Introduction

VDM Metals GmbH have invested in a new workshop in Unna, Germany for the production of high-quality titanium and nickel-alloy products for the aerospace industries. Part of the investment was a new ultrasonic testing system for bars.

Bar diameters between 90 and 405 mm, lengths between 900 and 6000 mm, weights up to 4 tons and a high-precision test mechanics were requested in the duty book. Immersion testing is a common test method and usually straight beam testing is carried out. Many aerospace specifications suggest extreme test sensitivities down to 0.4 mm FBH (flat bottom hole reflector). This can only be achieved by dividing the test volume into separate depth zones. Each depth zone is then covered with a strongly focused probe which can reach such stringent sensitivity requirements.

It is difficult to manufacture defects with a size of 0.4 mm FBH. Therefore, the system calibration is carried out with 0.8 mm FBH. Adequate dB-offsets are then added to achieve the required test sensitivity. Four calibration bars were provided for the mentioned diameter range. Each calibration bar contains three artificial defects (FBH) per depth zone. The electric control of testing system was programmed to optimize the calibration time and to ensure that each probe is automatically placed above all relevant calibration reflectors. The maximized echo heights are recorded and the respective TCG-curve (TCG = time-corrected gain) is automatically created.

The test results are provided in C-scan format and various display formats are available. They can be presented separately for each depth zone or for the entire bar depth (result for all depth zones). Common specifications from the aerospace industries were taken into account (e.g. SAE AMS 2628, SAE AMS-STD-2154, SNECMA DMC, MTU MTV 1033).

Testing mechanics

A large immersion tank was designed for specimen weights of up to 4 tons, diameters between 90 mm and 405 mm and lengths between 0.9 m and 6 m. The tank dimensions were 10.75 m by 2.14 m. The weight of the testing mechanics was 19 tons. The tank is filled with 25 m^3 water which is kept on constant temperature of 25 °C with a 40 kW heating system.

Figure 1. Total view of immersion tank testing system for aerospace bars at the VDM Metals GmbH workshop in the town of Unna, Germany.

Three roller stations with rubber-coated wheels put the bars into rotation. A fixed roller station is mounted at the left side (zero position). A movable roller station is supporting the right end of the bar. Another movable station can be driven towards the bar center in order to avoid bending of long and thin bars.

The probe holders are mounted to robust linear drives. The height adjustment of the probe holders corresponds to the bar diameter and the required water path. Rotating bars and linear probe movements result in helical test tracks and 100%-coverage of the bar volume.

Aerospace requirements stipulate extreme precision of the test mechanics. The axis of the probe manipulator and the bar axis need to be perfectly in parallel. The XY-frame of the mechanics must be perfectly rectangular and the probe positioning accuracy is recorded regularly. The testing system was already approved in accordance with Nadcap.

Figure 2. Probe holders above a calibration bar with a length of 1.5 m. In case of short bars, only two out of three roller stations are used. The rubber-coated rollers avoid damaging of the bar surfaces.

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Testing principle

High demands on the testing sensitivity are common in the aerospace industry. The toughest requirements demand 0.4 mm FBH. This is only possible by using the multi-zone examination method. Dependent on the bar diameter four up to seven depth zones are defined, each covered by one strongly focused straight-beam probe.

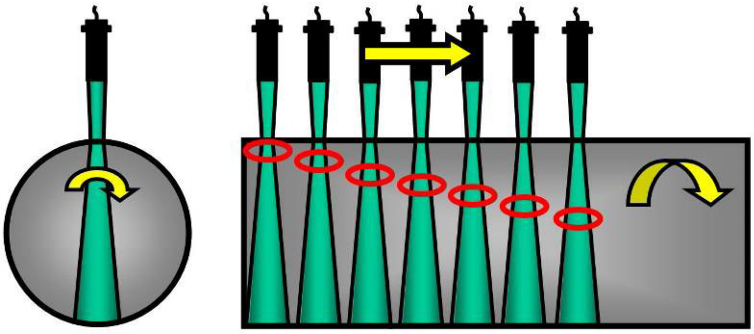

Figure 3. The bars are tested in helical test tracks. Each depth zone is covered with one special probe providing strong focusing characteristics. In case of bars with large diameters (up to 405 mm) the testing volume is divided into seven depth zones.

Quick change-over between the diameter ranges is achieved by using probe holders with quick-release fixtures. Two clamps are used for locking and unlocking them. The probe holders are equipped with hooks for convenient handling by crane.

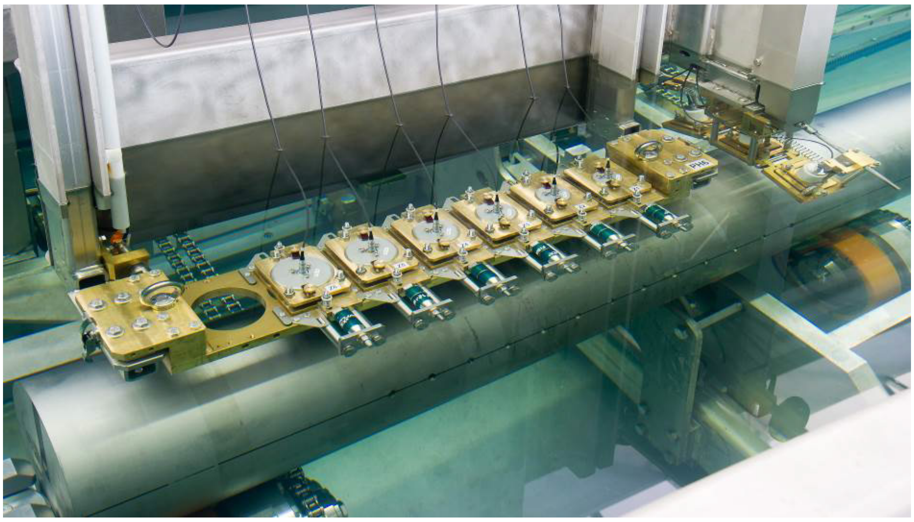

Figure 4. Probe holder with six straight-beam probes above a calibration bar with artificial defects.

In total, four probe holders for multi-zone inspection were provided (with 4, 5, 6, and 7 focused straight-beam probes respectively).

Figure 5. The testing system was equipped with four probe holders, which can be changed by quick-release fixtures. Three probe holders which are currently not in use can be seen in the foreground of the photograph.

Another (always mounted) probe holder provides angle beam incidence in both circumferential directions (shear waves) and a constant supervision of the backwall echo amplitude. Three probes are used for that purpose. The mechanical probe position can be adjusted such that the shear wave incidence angle is ± 45° for all bar diameters.

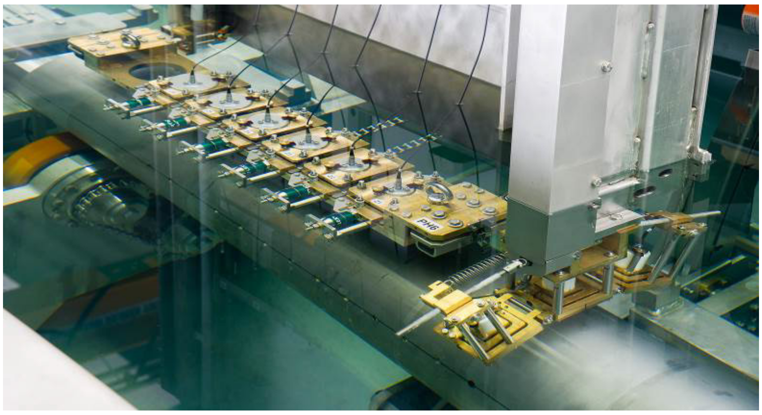

Figure 6. Another probe holder (on the right side of the photograph) contains 2 angle-beam probes for the detection of near-surface defects and one straight-beam probe for constant monitoring of the backwall echo.

Testing sensitivity

The required testing sensitivity of down to 0.4 mm FBH is regularly checked by using artificial defects with the size of 0.8 mm FBH and adding a respective dB-offset. Two possibilities were realized. Defects in all relevant depths were eroded into round calibration bars. The probes of the respective depth zone pass across the defect and the TCG-curve is automatically recorded. The electrical control of the testing system was prepared in such a way that the entire procedure is fully automated. After readiness of the calibrated testing system, the calibration bars are removed and the production bars are tested. Every two hours, the probe holders are moved above a test block fixture in accordance with ASTM E428. The fixture contains certified test blocks which also contain 0.8 mm FBH's. Two fixtures were provided, one for titanium test blocks and another one for nickel-alloys. As with the probe holders, these fixtures can be quickly exchanged.

Figure 7. A test block fixture at the base position of the tank is used for periodic check of the test sensitivity in intervals of two hours.

In order to achieve the extreme test sensitivity, a powerful test electronic must be employed. The following picture shows an A-scan with good signal-to-noise-ratio of the ECHOGRAPH 1155 test electronics.

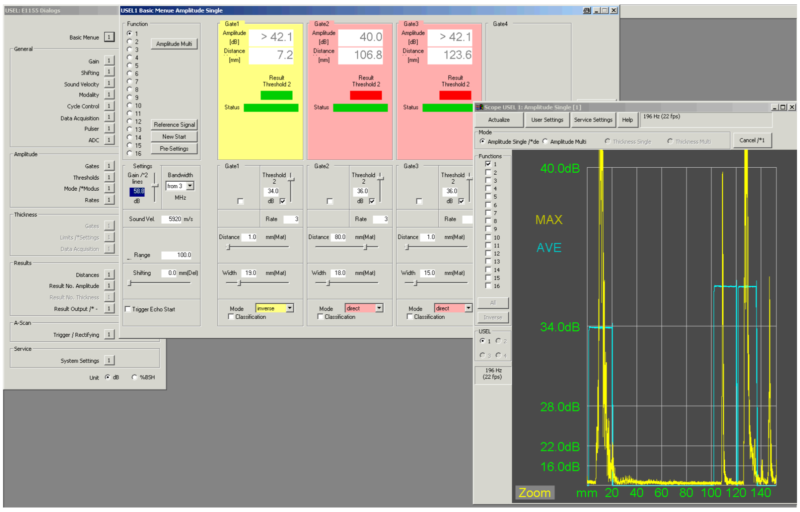

Figure 8. Test result (A-scan) of an 0.8 mm FBH with good signal-to-noise ratio for a bar diameter of 203 mm and a defect depth of 97 mm. On the left side within the A-scan, the interface echo is monitored (first blue gate). In order to machine an 0.8 mm FBH in the bar center, a larger hole is pre-drilled. The bottom of the larger hole is seen in the third blue gate at a depth of 130 mm. In between, the second gate contains the 0.8 mm FBH at full screen height.

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Processing of the test results

Many testing systems for semi-finished products do not provide a detailed representation of the test data. The ultrasonic amplitudes are often recorded versus the length of the test piece (strip chart representation). On customer request, different test tasks (e.g. test angles or depth zones) can be shown in separate strip charts.

Figure 9. The test results are presented as a strip chart and separately for each test task. The X-axis shows the bar length in meters. For each test task, the red zone marks the amplitudes above the threshold. In this example, seven depth zones are shown (with four active zones). The indications of many holes in the calibration bar are clearly visible. The backwall echo supervision is represented in a green strip chart. Both angle probes (± 45°) are marked in blue color.

Large bar diameters and increased customer requirements suggest the representation of test results in C-scan format. The bar surface is visualized in 2D-format: Y-axis for the circumference and X-axis for the bar length. The entire bar volume and the defect positions are clearly arranged. The color code is adjustable and allows for a quick evaluation of the signal-to-noise-ratio.

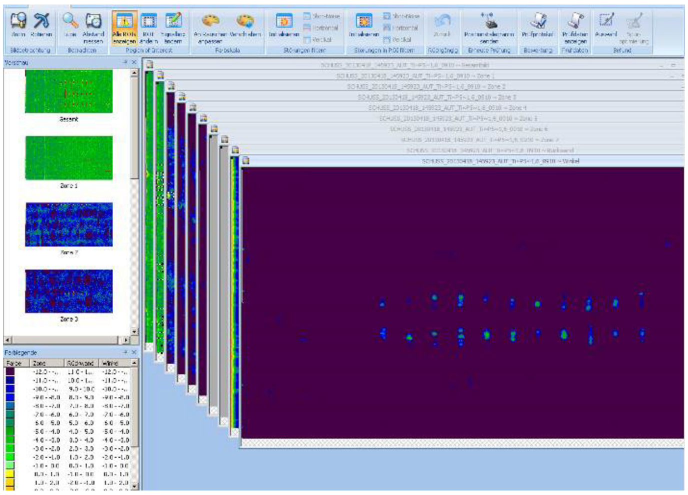

Figure 10. Separate C-scans are available for each test task (test data versus bar surface for each depth zone). The color code (see lower left side) is adjustable for optimum setting of the dynamic range. A combined C-scan for all test tasks provides a quick overview for the entire bar.

The shot distance is perfectly synchronized with the rotation of the bar and the linear probe movement along the bar. Therefore, each pixel of the C-scan represents a clearly defined test volume. A 12 o'clock mark is monitored during each rotation in order to take slippage into account, which possibly might occur. Detected defects are listed in a defect table. The exact defect position, the size, the depth and the amplitude with respect to the pre-set threshold are recorded. For doubtful cases, a return-to-defect-function was realized. The probes are automatically moved to the defect position and the relevant bar segment can be re-checked.

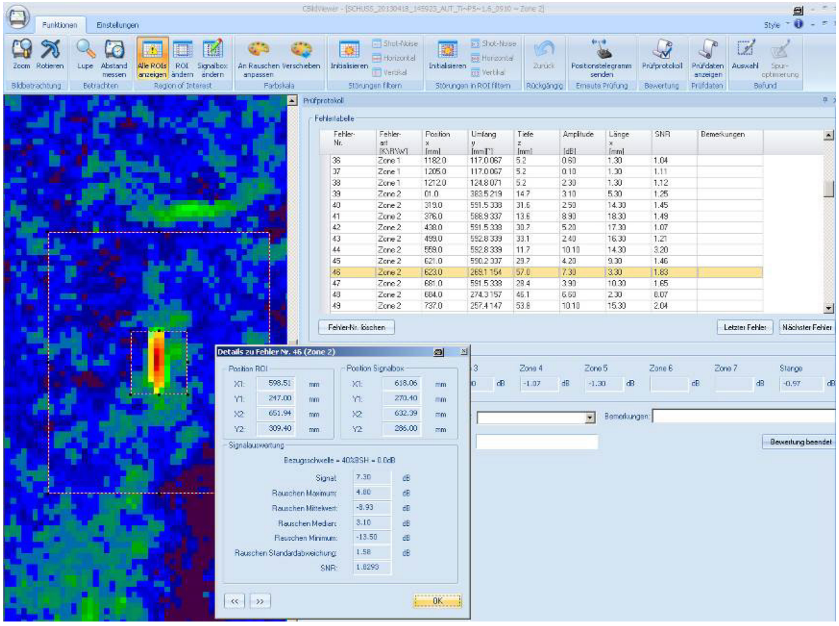

Figure 11. Table of all detected reflectors where detailed information for each defect is available.

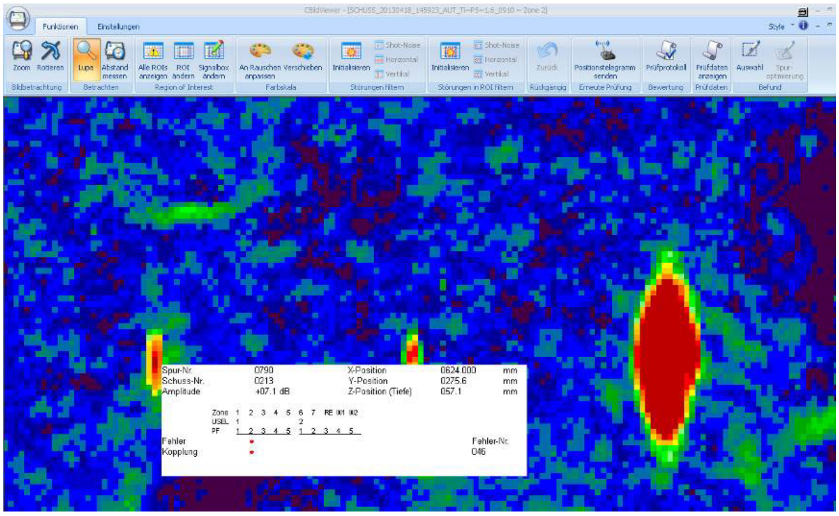

Figure 12. Evaluation of a defect (one out of three FBH's in calibration bar). The data for each ultrasonic shot is clearly arranged (example shot no. 0213). The amplitude shows the difference with respect to the pre-set threshold (example +7.1 dB). The axial and circumferential defect position and the defect depth are given in mm. All probes (up to 10) are monitored for flaw detection and coupling (example: probe no. 2 is marked with red dots).

A bar code scanner is used for error-free correlation of the bars and the respective test results. The marking of the bar is then stored in the protocol together with the test results. A paperless and consistent documentation for each bar is therefore provided.

Figure 13. Barcode-scanner for error-free bar tracking during the production and testing process.

Manual post-checking of the bars is carried out with several portable ultrasonic flaw detectors, type ECHOGRAPH 1090.

Logistics

The high precision requirements and the large testing mechanics were a challenge for the mechanical construction. Already in the design stage, the transportation and re-assembly of the testing system were taken into account. It was desirable that the entire immersion tank would fit onto a truck.

Figure 14. Readiness of shipment at the KARL DEUTSCH systems workshop in Wuppertal, Germany.

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Figure 15. Onsite assembly at the VDM Metals GmbH workshop in the town of Unna, Germany.

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