Agnieszka Bicz, Wiesław Bicz, Marcin Korzeniowski, Tomasz Piwowarczyk, Andrzej Ambroziak

Ultrasonic Tests in the Analysis of the Quality of Tubular Welded Elements

Abstract: The article presents currently used ultrasonic tests of elements having tubular cross-sections, joined by means of various welding methods. In addition, the article discusses various ultrasonic signals in industrial (primarily automatic) applications in relation to selected technological solutions as well as presents existing industrial stations for testing pipes, machinery parts/components and mechanical elements as well as parts connected with the acquisition of ultrasonic signals.

Keywords: non destructive testing, ultrasonic tests, tubular welded elements

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Introduction

Tubular elements transmitting significant axial forces and torques used in the production of automotive vehicles include, primarily, shock absorbers, axle shafts and drive shafts. Because of vehicle weight reduction tendencies and the use of components having thicknesses below 3 mm, the market has seen the introduction of alternative joining methods to friction welding, e.g. magnetically impelled arc but (MIAB) welding (MIAB), used in the production of axle shafts and drive shafts.

For many years, ultrasonic tests of thin-walled elements have been used in the production of automotive vehicles. Ultrasonic testing has been primarily used for the quality control of spot welds [1-5] and adhesive bonded joints [5-10]. Due to the relatively uncomplicated design of such joints and relatively easy access to surfaces being tested, the wave most commonly used in such tests is longitudinal, not undergoing any transformations. The presence of flash on the surfaces of friction welds and those made using the MIAB method significantly reduces the application of waves striking perpendicularly to the surface of a weld subjected to tests as the energy of such waves gest dissipated on the surface of flash. One of the methods enabling the "by-passing" of this limitation is the use of pseudo-surface waves, also referred to as frontal or lateral waves. According to many theories [11-13], these types of waves are connected with interferential phenomena, dissipation and losses of energy in propagation centres. Because of these phenomena, according to the laws of geometric acoustic, the distribution of

mgr inż. Agnieszka Bicz (MSc Eng.); mgr inż. Wiesław Bicz (MSc Eng.) – Optel Ltd., Wrocław;
dr inż. Marcin Korzeniowski (PhD (DSc) Eng.); dr inż. Tomasz Piwowarczyk (PhD (DSc) Eng.);
prof. dr hab. inż. Andrzej Ambroziak (Professor PhD (DSc) Hab. Eng.) –Wrocław University of Technology, Division of Materials Science, Welding and Strength of Materials

reflected wave beam pressure changes, and, as a result thereof, the reflection pressure coefficient decreases sharply [14,15]. On the water-air boundary, this corresponds to an angle of approximately 310 in relation to the normal [11].

Methodology of Ultrasonic Testing of Tubular Elements

Equipment for the testing of friction welds in Miab welded shock absorbers and drive transmission elements uses lateral waves propagating along the walls of a pipe being tested, in parallel to its axis. In cases of elements free from imperfections, an ultrasonic impulse generated by the excitation of a transducer only gets reflected against the flash, giving a response characteristic of a given element, depending on the geometry of the element and that of the measurement system. Any deviations from the reference measurement can be treated as reflections or dissipations of the ultrasonic beam against an imperfection or deviations from the pipe geometry. The ultrasonic beam of the transducers in the measurement probe was focused in a controlled manner enabling the detection of imperfections, the diameters of which are not less than 0.2 mm. The settings of measurement cursors determining the size of signal reflection or dissipation amplitude in individual measurement channels are configurable and depend on design guidelines or company standards.

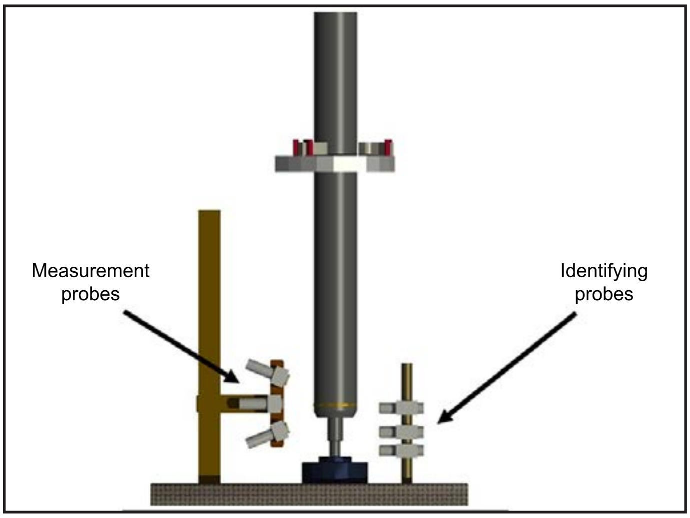

Fig 1. Schematic diagram of the rig for the ultrasonic testing of shock absorbers

An element subjected to a test, usually placed in a so-called seat and held in a vertical position, is measured using two units of ultrasonic transducers (Fig. 1). One unit consists of an identifying probe, whereas the second is composed of a weld parameters measurement probe.

Identification Unit

Measurements performed using the identification unit involve the use of three ultrasonic transducers located at various heights corresponding to characteristics of individual types of shock absorbers subjected to measurements. The concept of identification involving the use of the developed probe is illustrated in Figure 2. In addition, the track of identification also verifies the proper orientation of an element.

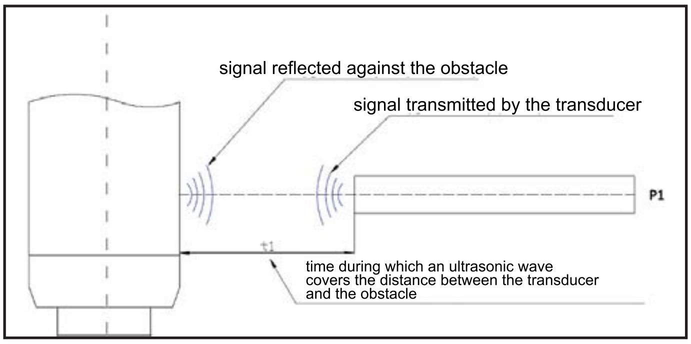

Fig. 2. Manner of measuring the distance between a shaft and the probe using one measurement probe

Each transducer transmits a short ultrasonic impulse and receives an echo generated after the reflection of a wave against an obstacle where the measurement system measures the time after which the previously transmitted signal returned. The above named time-related measurement is used for calculating the distance between the pipe element and the identifying probe. The measurement of characteristic distances between the surface and the identifying probe performed at three points is sufficient for the identification of the type of an element subjected to the measurement. An example of the identification of an element on the basis of a measurement performed using a set of three probes is presented in Figure 3.

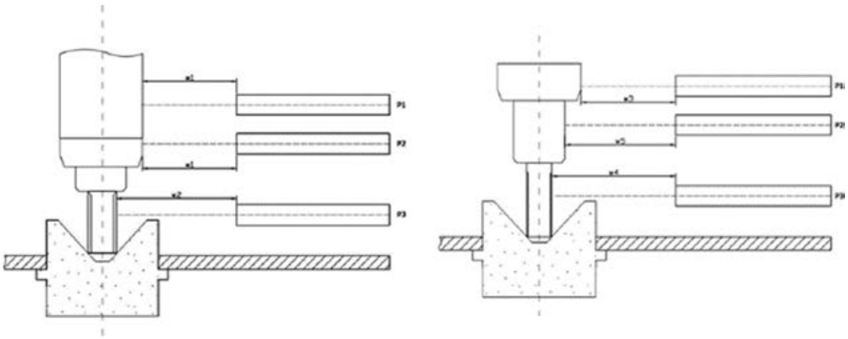

Fig. 3. Concept of element identification based on the ultrasonic method

Unit of Measurement Probes

Assessments related to the quality of welds are based on measurements performed using three ultrasonic transducers positioned at various angles in relation to the weld plane. One of the transducers is positioned on the plane perpendicular to the weld (angle 0° in relation to the normal), the second at an angle of 31°, whereas the third at an angle of 36°. The positioning of the transducers is presented in Figure 4.

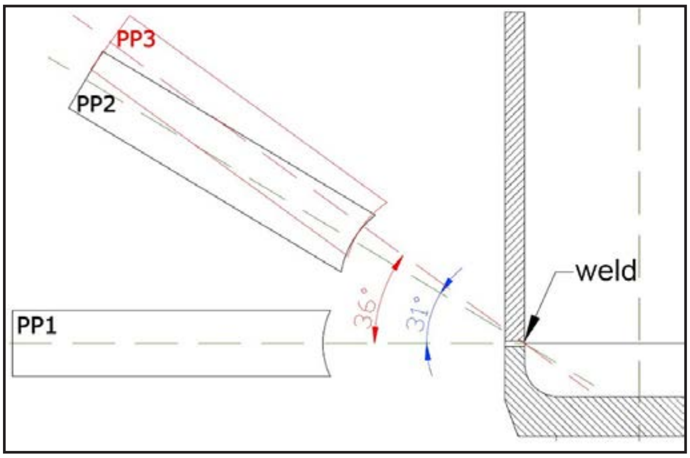

Fig. 4. Arrangement of measurement probes when testing tubular elements

Figure 5 schematically presents signals emitted by the transducer fixed at an angle of 0° in relation to the normal when a weld is continuous, i.e. without welding imperfections and when a weld contains an imperfection.

During measurements, the ultrasonic transducer (PP1) sends out a short impulse (1) directed perpendicularly in relation to a weld being tested (7). In cases of imperfection-free welds, the measurement window (4) records reflection (5 and 6a accordingly) on the water-steel (2) and steel-air boundary (3). If a weld (7) contains an imperfection, the measurement window (4) shows an impulse (5) demonstrating the discontinuity of a joint. It should be noted that measurements performed using transducers oriented perpendicularly in relation to a surface being tested are only useful if flash is removed from the weld surface.

Measurements involving transducers positioned askew in relation to the weld plane are presented schematically in Figure 6. Figure 6a presents the trajectory of a wave transmitted,

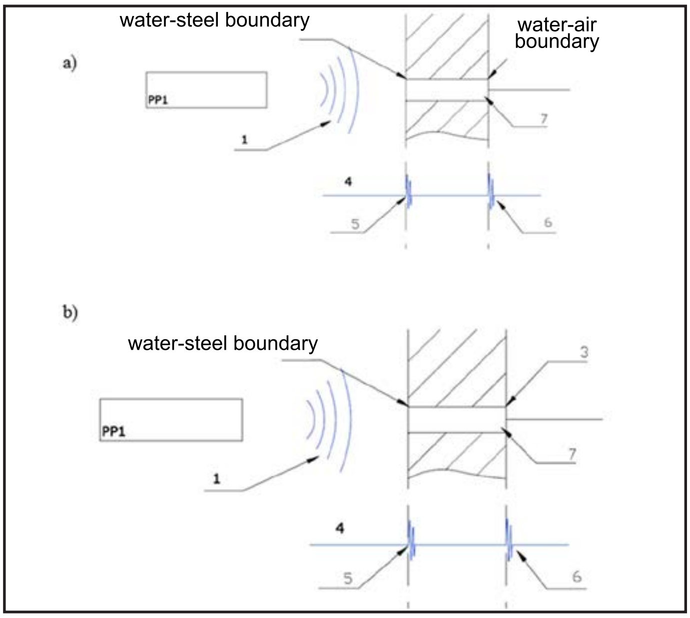

Fig. 5. Signals from the ultrasonic transducer positioned perpendicularly to the surface; signal for the case without (a) and with (b) an imperfection

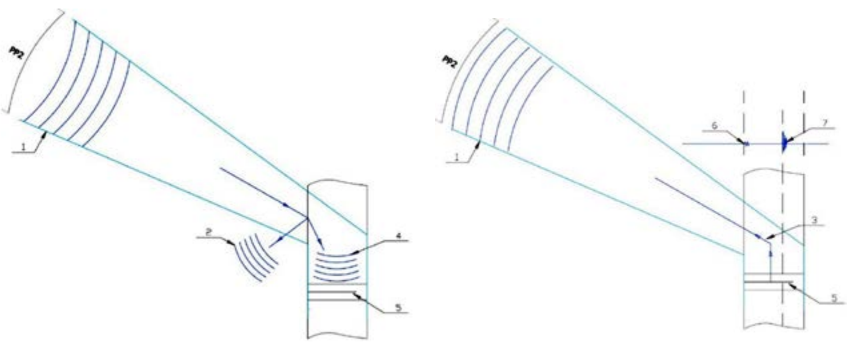

Fig. 6. Scheme of ultrasonic measurements involving transducers oriented at an angle in relation to the weld plane; the trajectory of transmitted (a) and recurrent (b) waves

whereas Figure 6b presents that of a wave received by the ultrasonic transducer.

The focused ultrasonic wave (1) transmitted by the transducer positioned at an angle (PP2) strikes the wall of an element being measured outside the joint area. Part of the transmitted wave (2) is reflected against the external surface of the wall, yet part penetrates the material, where it becomes refracted (4) and propagates as a wave led in the material, i.e. the so-called lateral wave. The adjustment of angles at which transducers are fixed enables the extensive observation of the weld area (significantly exceeding the weld width) and the most efficient use of the transformation of longitudinal waves into lateral waves (4). If a weld contains an imperfection (5), as a result of reflection, the imperfection will cause the generation of an additional echo (7), which, using the same route as the one described above, will return to the measurement transducer.

Testing of Shock Absorber Friction Welded Elements

The *opStrut* measurement system for post-friction weld immersive ultrasonic tests of friction welds in strut roads (shock absorber components) is a one-station device for assessing the quality of components. The machine is a modern system featuring fully automatic quality control based on non-destructive (ultrasonic) tests performed in a production cycle. The system recognises an element being tested and automatically "retools" the machine in terms of measurement software programme required in a given case. In addition, the system is provided with the so-called *error proof*, i.e. a marker of elements containing welding imperfections and a module drying the element after the performance of a test.

Measurement results concerning every tested element are saved in the device memory for the further development of statistical data obtained during production. The detection of an element containing welding imperfections is signalled by red light and appropriate information displayed on the operator panel. In addition, defective elements are marked mechanically. In such cases, the operation of the device is stopped until an element containing an imperfection is placed in the so-called separator of rejects. The system performs the continuous statistics of properly made and defective components, containing, apart from measurement results, information about the time of the measurement and the operator performing it. On the basis of experience related to similar equipment and initial measurements, the device supports software provided with criteria enabling the identification of properly made and defective elements. If need be, the assessment criteria can be changed by users at any time. The developed control system enables the testing of elements without removing flash.

The complete system of quality control related to friction welds in shock absorber elements (Fig. 7) is composed of the following elements:

- module automatically detecting an element being measured, retooling and checking the proper orientation of the element subjected to the test,
- module detecting the presence of an element,
- module detecting, stopping and manipulating during the measurement of an element being measured,

Fig 7. Device for the ultrasonic testing of welds (named opStrut) made by PBP Optel Sp. z o.o for BWI Krosno. Front panel view (a) and the shelf with standard samples (b)

- module refilling and checking the purity of measurement liquid in the measurement pool,
- shelf with standard samples.

The closed cycle of measurement liquid utilises two built-in containers enabling the replacement of liquid without the removal of containers. The containers are provided with an inlet and a drain outlet secured during normal operation. The inlet is equipped with a filter preventing particulates from entering the container as such particulates could affect test results.

Software

The device has two operating modes, i.e.
- with the automatic recognition of an element being measured and the application of appropriate software programme,
- with the permanent software programme (corresponding to the presently used production line) with the simultaneous verification of the compatibility of the element with the previously selected software programme.

The module of test statistics enables the generation of measurement reports for end users of manufactured components and makes it possible to create company standards. The full configurability of settings enables the optimum adaptation of criteria for the analysis and interpretation of ultrasonic tests.

Tests

The placement of the object being tested in the work opening is tantamount to introducing the object in the zone of measurement. The container into which the element is introduced is provided with fixtures and equipment necessary for tests. Measurements are performed on an element oriented vertically with the weld directed downwards. The proper placement of the element in the measurement field is secured by guides preventing its improper positioning or damage to the measurement probe, provided with sensors of proximity and of the proper position of an element in the measurement zone. The fixtures and equipment necessary for performing measurements include a self-centring gripping jaw, ultrasonic measurement probe and an ultrasonic probe identifying the type of an element being measured. The self-positioning system of the probe along with the function of adapting to the type of an element prevent any accidental change in a required position. In addition, the rig checks the level and condition of measurement liquid. Operators are informed about the compatibility of an element by green light and related information displayed on the operator panel. The detection of elements containing welding imperfections is signalled by red light. In such cases, the operation of the device is stopped until the element is placed in a container designated for rejects. After a test, measurement liquid residues are removed from the element by the stream of compressed air.

Interpretation of Results

Figure 8 presents actual results of the ultrasonic measurement (so-called A-scan) of friction welded pipes using a transducer oriented at an angle of 0° in relation to the weld; the A-scan is concerned with the weld free from imperfections.

Figure 9 contains the A-scan presentation for the transducer oriented at an angle of 31° when two welding imperfections were detected on the weld circumference.

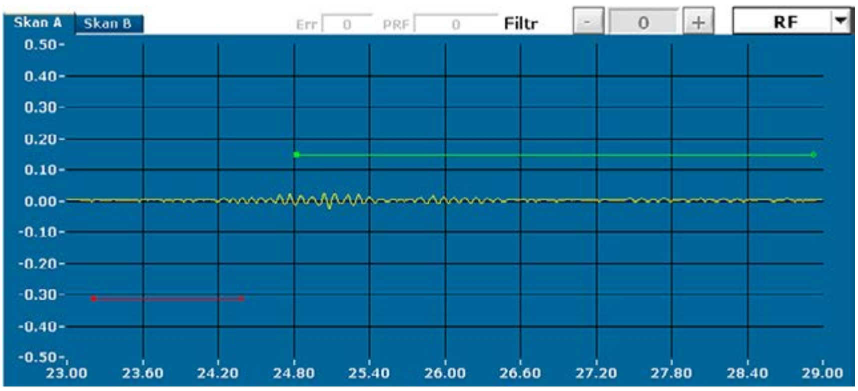

Fig. 8. A-scan presentation of the ultrasonic signal using the transducer oriented at an angle of 0o in relation to the weld free from imperfections

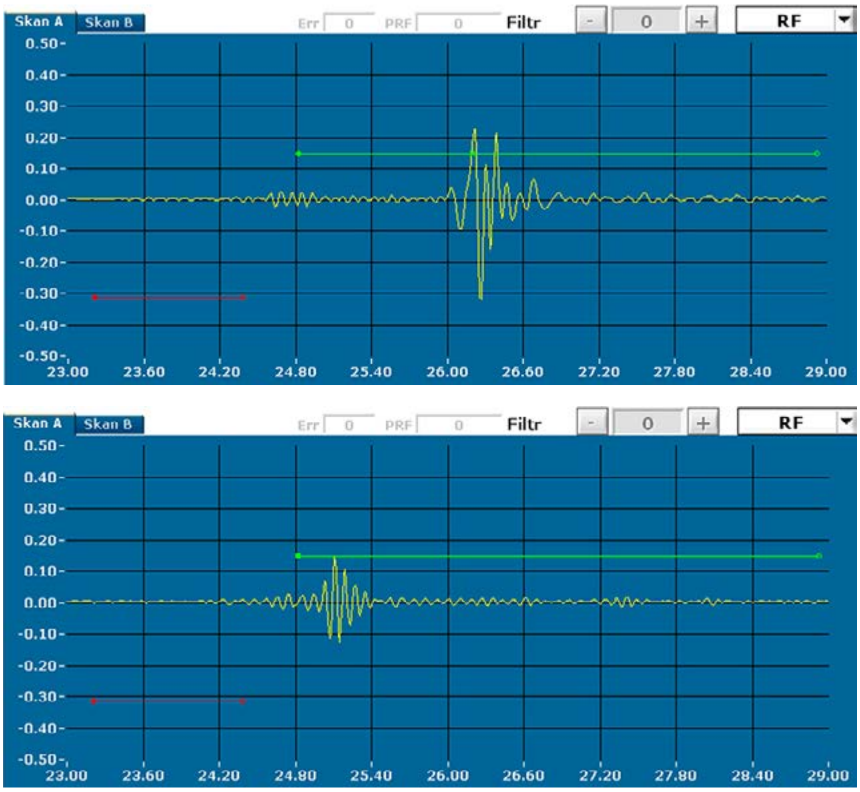

Fig. 9. A-scan presentation of the ultrasonic signal using the transducer oriented at an angle of 31° and detecting 2 imperfections (a and b) on the weld circumference

Figure 10 contains the B-scan presentation of an ultrasonic signal obtained by rotating the pipe by an angle of 360°. Unlike the A-scan presentation, the B-scan presentation enables the analysis of test results on the entire circumference in one two-dimensional image.

When testing the quality of shock absorbers on the production line, the analysis of A-scan and B-scan presentations can pose a problem for unskilled operators. To this end, an interface facilitating the identification of imperfection location was developed. The operator panel in the polar system with measurement results concerning a friction weld is presented in Figure 11. Areas marked red contain imperfections detected by the device.

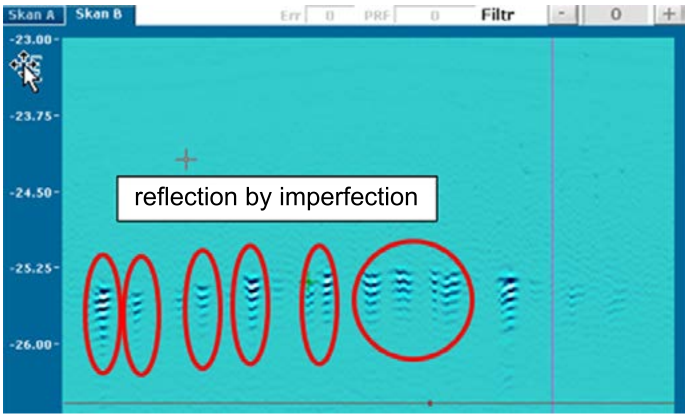

Fig. 10. B-scan visualisation of imperfections located on the friction weld circumference and detected using the transducer oriented at an angle of 31°

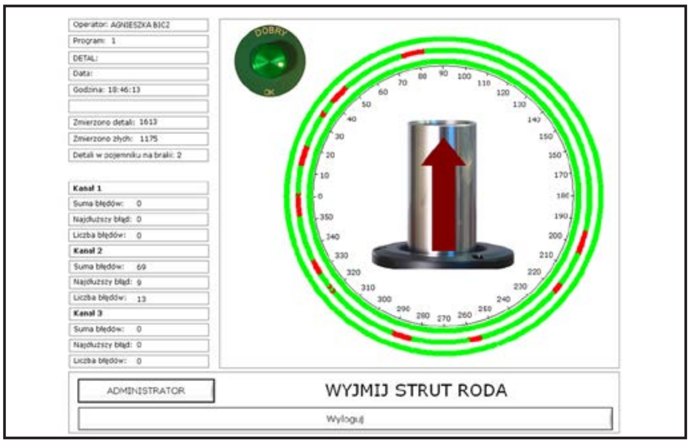

Fig. 11. Visualisation of imperfections for the operator of the opStrut device

Tests of MIAB Welded Elements

The quality tests concerning the welds made using the MIAB method, present in drive transmission elements (drive shafts and axle shafts), were performed using a laboratory test rig provided with a universal ultrasonic scanner equipped with a focusing transducer having frequency f=10 MHz , focus F=21 mm, focus diameter B_D≈0.4 mm and focus length F_Z≈6.1 mm. When scanning the elements subjected to the tests, the transducer was positioned at angle α=31.6°, which ensured the generation of a lateral wave in the tested element. The ultrasonic beam was focused on the surface of the pipe, at distance h≈4 mm away from the flash area. After passing through the focus, the wave was dispersed and refracted on the water-steel boundary, and next moved inside the steel, along the axle shaft surface, in parallel to the axis of rotation. As the system is in the test phase, in order to examine the possibility of detecting welding imperfections, artificial imperfections (incisions) were made on elements provided for the tests. Figure 12

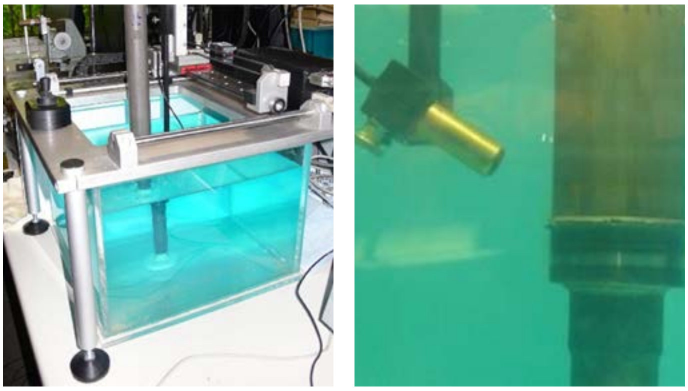

Fig. 12. Laboratory test rig. Ultrasonic scanner (a) and orientation of the transducer in relation to the weld being tested (b)

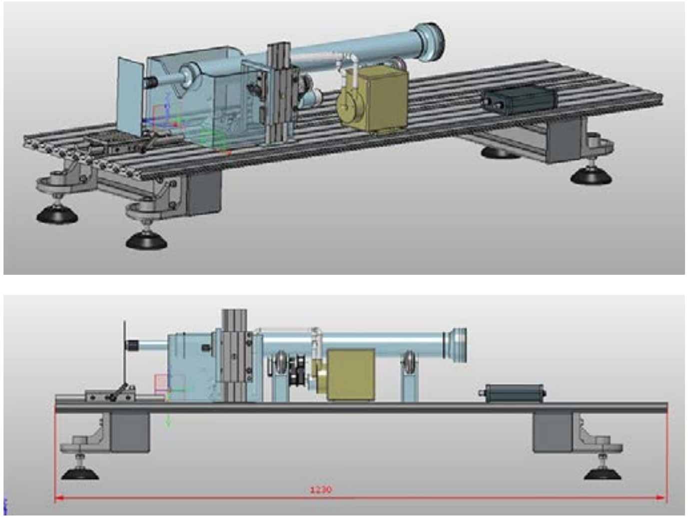

Fig. 13. Preliminary design of a demonstration rig for testing MIAB welded components

presents the laboratory test rig for testing Miab welded axle shafts.

Figure 13 presents the preliminary design of a specialist test rig for the ultrasonic inspection of Miab welded joints. By contrast with tests concerning shock absorber elements, the axle shaft is oriented horizontally. In order to provide the acoustic feedback, the ultrasonic wave was brought to the test area via the water film.

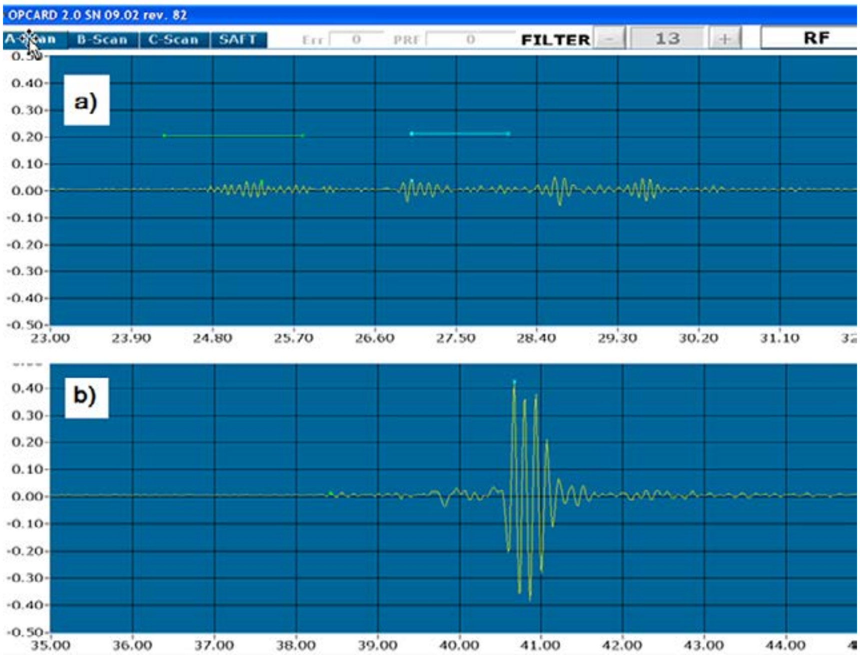

Fig. 14. A-scan presentation of the ultrasonic signal for the weld free from imperfections and with the artificial imperfection (1 mm wide incision) made using the MIAB technology

Each tested axle shaft has two welds made using the Miab welding method, from the side of the so-called stub shaft and from the side of the joint provided with approximately 1 mm wide gaps and an opening having a diameter of 0.4 mm. After locating the gap on the A-scan presentation (Fig. 14a), the selected joint was subjected to B-scan (Fig. 14b). Signals of non-zero amplitudes visible in the A-scan presentation for the welds free from imperfections (Fig. 14a) result from the reflection of the ultrasonic wave against the flash. Their amplitude is significantly lower than the signal reflected from the gap, and their position is different.

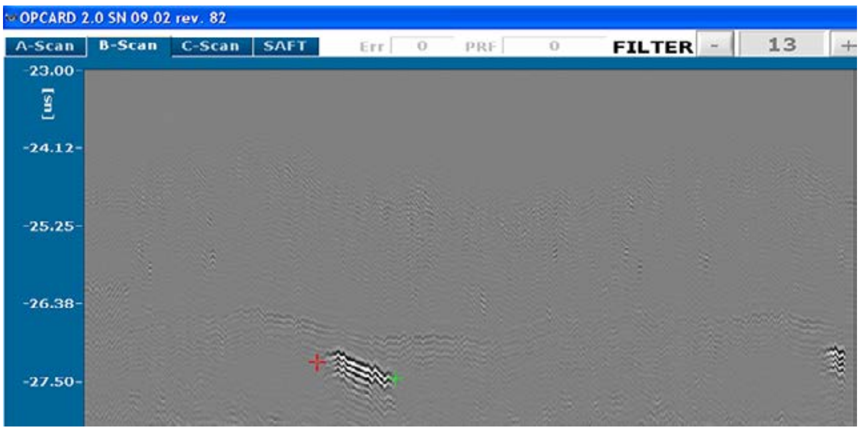

Fig. 15. Two-dimensional visualisation of an artificial imperfection presented as B-scan

The B-scan presentation (Fig. 15) was made by rotating the element until the repetition of the signal reflected against the gap. In order to verify the possibility of detecting small-sized imperfections it was necessary to make a cuboidal opening (ϕ 0.4 mm) in the weld. The element prepared in this manner was subjected to ultrasonic tests, the results of which are presented in Figure 16 in the form of A-scan and B-scan.

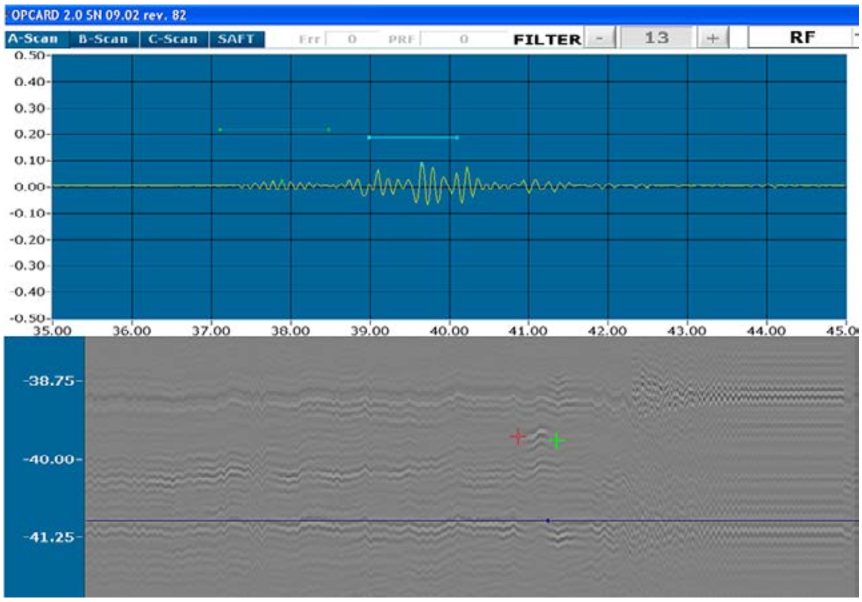

Fig. 16. Result of the ultrasonic test (A-scan and B-scan) of the weld made using the MIAB method provided with the artificial imperfection (ϕ 0.4 mm)

Summary

The ultrasonic tests of the thin-walled tubular elements of shock absorbers, axle shafts and drive shafts pose a significant challenge for designers, constructors and researchers. The results of individual tests and design solutions considerably supplement this narrow area of technique. The results of the individual research presented above enabled the formulation of the following conclusions:

- use of the lateral wave in tubular elements enables the detection of welding imperfections in friction welds and those made using MIAB welding,
- orientation of the ultrasonic transducer at an angle of 31° enables the transformation of longitudinal waves into lateral waves, thus providing the possibility of performing tests in friction welds and welds made using the MIAB method without removing the flash,
- in addition to detecting welding imperfections, ultrasonic tests can be used for the precise identification and positioning of elements subjected to tests,
- developed test station enables the detection of welding imperfections in MIAB welded elements.

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