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Defectoscopic Tests of Railway Rails

Abstract: Non-destructive tests are of key importance as regards ensuring the safe operation of the railway track. Such tests enable the detection of discontinuities formed both during production and operation. However, due to their nature, non-destructive tests are characterised by certain limitations. Non-destructive tests are mostly indirect and the presence of discontinuities is inferred on the basis of specific physical phenomena. Through the detection and assessment of the nature of discontinuities, non-destructive testing methods provide information about the properties of objects subjected to examination. The article presents some of the methods (visual and ultrasonic tests) used in the examination of railway rails. The article also discusses unconventional testing methods, i.e. the method of magnetic flux leakage (MFL) and the measurement of the alternating current field.

Keywords: VT, MFL method, MPM method, AFCM method, UT method, PA technique

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Defectoscopy plays a major role as regards the detection of cracks in rails. The proper maintenance of track structure requires the consistence performance of tests. Rails are joined using resistance welding or thermite welding methods. The above-named methods entail the possible formation of discontinuities, detectable using diagnostic methods such as visual tests, magnetic-particle tests or ultrasonic tests. The performance of the aforesaid examinations constitutes the basis for the safe operation of railway networks. The principle governing the assessment of discontinuities in defectoscopic tests consists in the comparison of sizes of discontinuities with their related standards. Parameters taken into account during such a comparison include the length and the area of discontinuities. The maintenance of railway tracks will always require the removal of some rails because of cracks or damage triggered during their production or operation. It is important to monitor the behaviour of rails on the track so that both users and manufacturers could intensify efforts to improve the quality of rails and their operating conditions [1]. Inspection methods include both surface and volume-oriented tests.

Surface tests

The primary tools applied in the visual inspection of rail quality are high-speed cameras [2]. The passage of an inspection vehicle is accompanied by the recording of images which are next subjected to analysis involving the use of dedicated software. Visual inspection systems are used to measure the rail head profile as well

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as gaps in rail joints. However, visual inspection does not provide complete information nor does it detect internal discontinuities (detectable using ultrasonic tests). On the other hand, visual systems make it possible to inspect the entire surface of the rails as well as provide information on missing bolts, the quality of sleepers or lacks of ballast. Figure 1 presents exemplary high-speed camera-based inspection of a railway track [2].

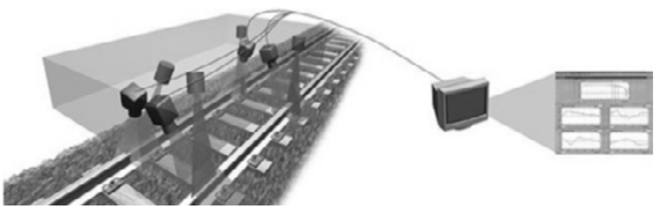

Fig. 1. High-speed camera-based inspection of a railway track [2]

Non-destructive tests also include magnetic methods used in the mobile diagnostics of railway rails. The above-named methods include the magnetic flux leakage method (MFL) and measurements of the alternating current field performed using the potential drop method [3]. The magnetic flux leakage method (MFL) is used to detect discontinuities in containers, wire ropes and elements subjected to continuous operation. The aforesaid method, applied to examine ferromagnetic materials, involves appropriate saturation with the magnetic field in the area of material being tested [3]. The area neighbouring a discontinuity is characterised by growing resistance enabling the induction of the magnetic field. After reaching a sufficiently high value, the magnetic field propagates around material discontinuities. The scatter of the magnetic field is measured using magnetic sensors located near a surface subjected to examination. The height of the sensors influences the MFL signal gain. In terms of result interpretation, the MFL method is significantly simpler in comparison with other electromagnetic methods. In addition to the signal of amplitude, it is possible to identify the location of a signal originating from a discontinuity. The number of sensors affect the accuracy of measurements. The performance of MFL-based tests requires appropriate equipment calibration, whereas the interpretation of signals originating from discontinuities could be encumbered with errors resulting from the condition of the surface and the thickness of the coating. The advantages of the MFL method include the performance of the non-contact testing of rails (maintaining an 8 mm to 10 mm gap from the surface of the rail subjected to the test), the high speed of a diagnostic vehicle as well as high reliability within a wide temperature range. Defectograms contain images of track structural elements such as sleepers and crossings [4].

The magnetic metal memory method (MMM) is based on the recording of local scatter fields located on the surface of an element subjected to examination. The method aims to identify stress concentration zones and metal structure homogeneity. The MMM technique does not require the application of special magnetising equipment or the initial preparation of the element surface, yet tests must be performed using small-sized and independently-powered devices [5]. The MMM method enables the initial diagnosis of fatigue wear and makes it possible to forecast the reliability of a given element. A significant disadvantage of the method is the poor repeatability of results. The magnetic metal memory method is used both in the manual and automatic testing (performed using a diagnostic vehicle) of railway rails. [6].

The Alternating Current Field Measurement method (AFCM) first found application in the 1980s as the method of the non-contact potential measurements of alternating current drops. The AFCM technique is also referred to as the potential drop method [1, 7]. This electromagnetic method makes it possible to measure the depth of cracks in metals. The method consists in providing the flow of alternating current near the surface of a conductor and does not depend on the geometry of a given element. In elements which do not contain discontinuities, the flow of current is uninterrupted. The flow of current becomes interrupted after coming across a discontinuity, when it starts flowing around the ends of the crack and downwards. The current-related magnetic field above the metal surface also becomes interrupted. The AFCM-based tests do not require the electric or magnetic contact of the sensors and can be applied without the removal of the protective coating (pain, oil, rust). After removing the sensors, current drops proportionally to the square of the distance. The signal weakens slowly even if the distance from the surface exceeds 5 mm [3]. Surface roughness or thicker protective layers create fewer problems than those experienced during tests involving the use of eddy current sensors, located at a shorter distance from the surface than during the ACFM-based tests. The method is used in the examination of rails; primary attention is paid to the dimensioning of fatigue cracks in rails, where it is not possible to use ultrasonic or visual tests. The ACFM-based tests involved the use of pencil-type sensors and multi-element array sensors. The detection of discontinuities is possible in every direction, yet the best results are achieved if faults are located at an angle restricted within the range of 0°to 30° and 60° to 90° in relation to the transducer. Figure 2 presents ACFM equipment and imaging [3,7].

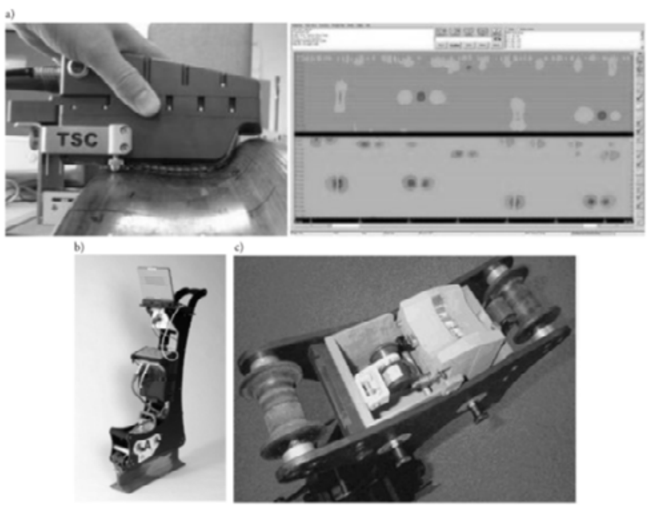

Fig. 2. Alternating Current Field Measurement technique [7]

Volumetric tests

Ultrasonic tests enable the detection and assessment of internal discontinuities. Similar to visual tests, ultrasonic examination makes it possible to monitor the development of discontinuities and compare them with results obtained in previously performed tests [8, 9]. One of the first applications of ultrasonic tests was the detection of defects in railways rails. Defectoscopic systems used in testing stations in steel works and track gauges are technologically advanced. The use of an appropriate number of transducers enables the examination of the nearly entire cross-section of the rail (except for a part of the rail foot). Discontinuities undetectable during ultrasonic tests are those which are formed under the surface and develop in the form of horizontal cracks. Transverse fatigue cracks are particularly dangerous. Transducers used in ultrasonic tests are single or double transducers of longitudinal waves and shear waves, with a beam introduction angle of 45° and that of 70° [8]. Figures 3 and 4 present how ultrasonic transducers are placed during ultrasonic tests.

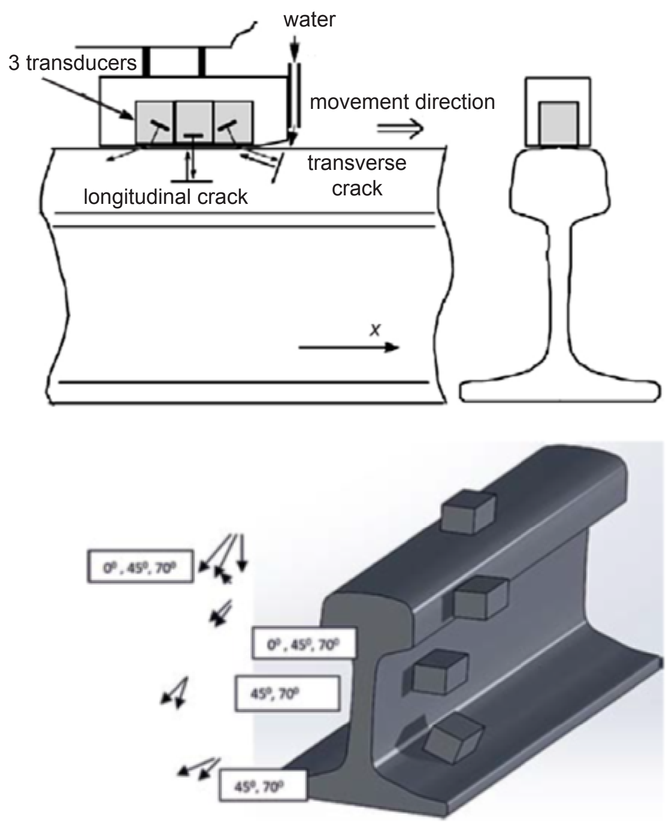

Fig 3. Movement of transducers during tests of rails [8]

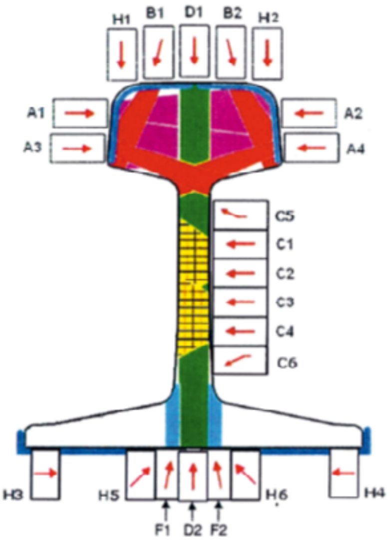

Fig. 4. System of transducers used in tests of rails at the final manufacturing stage [8]

The testing of track rails involves the introduction of ultrasonic waves from the rail head surface through the layer of liquid providing contact with the surface subjected to examination. As access from the rail foot surface is impossible, so is the detection of cracks developing in the rail foot. Transverse railway cracks are usually initiated on the outside edges of the rail foot. Undetected, often lead to the damage of the rail beyond repair. The sets of transducers featuring the liquid coupling do not provide appropriate results as regards the detection of vertical cracks in the rail head, usually initiated in its central part. The unfavourable orientation and longitudinal and transverse development of cracks are very dangerous. The purpose of testing railway joints is the detection of discontinuities present in the entire cross-section of the joint. The tests involve welds made during track structure repairs and, if need be, other welds as well [2]. The echo technique involves the use of one transducer, which, initially is used as the transmitter of impulses and, next, is "switched over" to work as a receiver. The signal transmitted by the transducer towards the material is reflected against a discontinuity (or the opposite surface) and returns to the transducer. Knowing the speed of the ultrasonic wave in the material and measuring the time between the transmission of the signal and its return to the transducer it is possible to determine the distance between the transducer and the obstacle. Based on the height of the echo of a discontinuity on the defectoscope screen it is possible to identify the approximate size of the discontinuity. Figure 5 presents an exemplary test involving the use of the ultrasonic echo technique.

The tandem technique involves the use of two angle transducers (i.e. transmitting and receiving ones), which, during scanning, are located at a constant distance from each other. The examination of the entire volume of the joint requires the repeated movement of the transducers along the weld. It is also necessary to change the distance between the transducers so that, each time, a different weld area could be scanned [9]. The positioning of the transducers in the tandem technique and the location of indications illustrated with an example of reference specimens are presented in Figure 6. In turn, Figure 7 presents a tandem rail tester, where transducers (2T45°) are mounted on

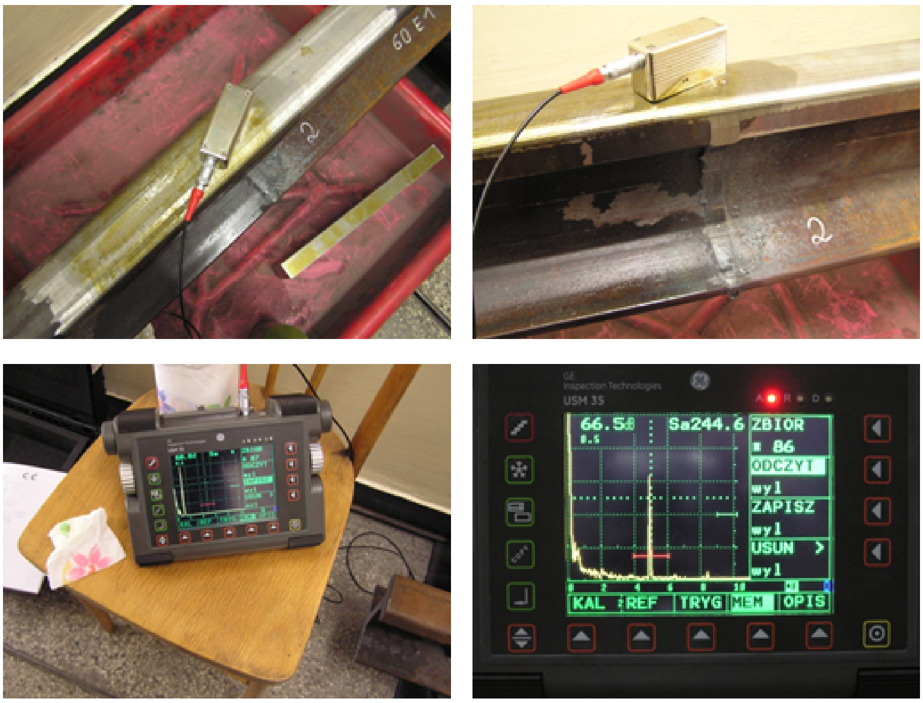

Fig 5. Exemplary application of the echo technique [10]

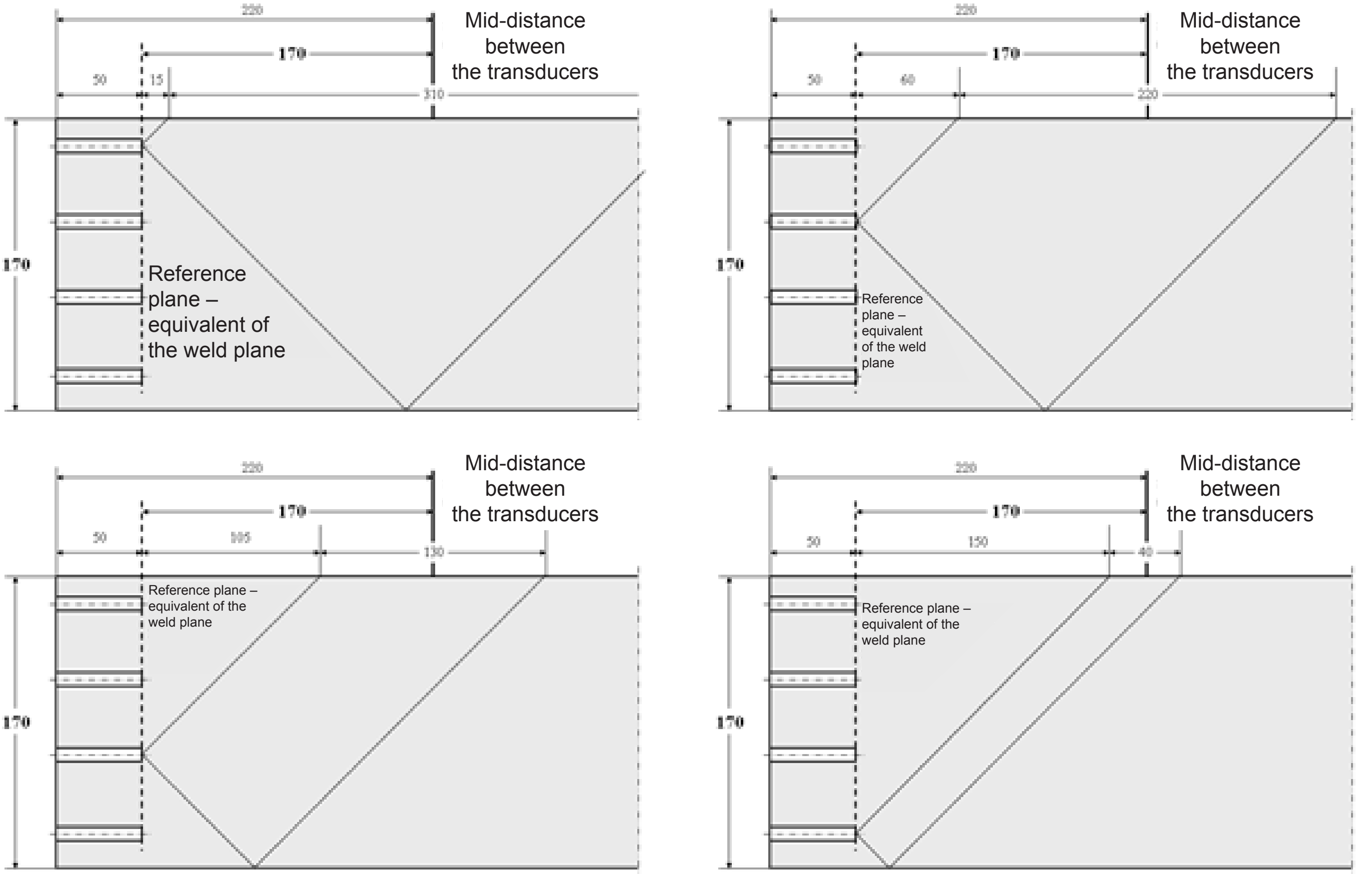

Fig 6. Location of reference mirrors illustrated with an example of reference specimens [10]

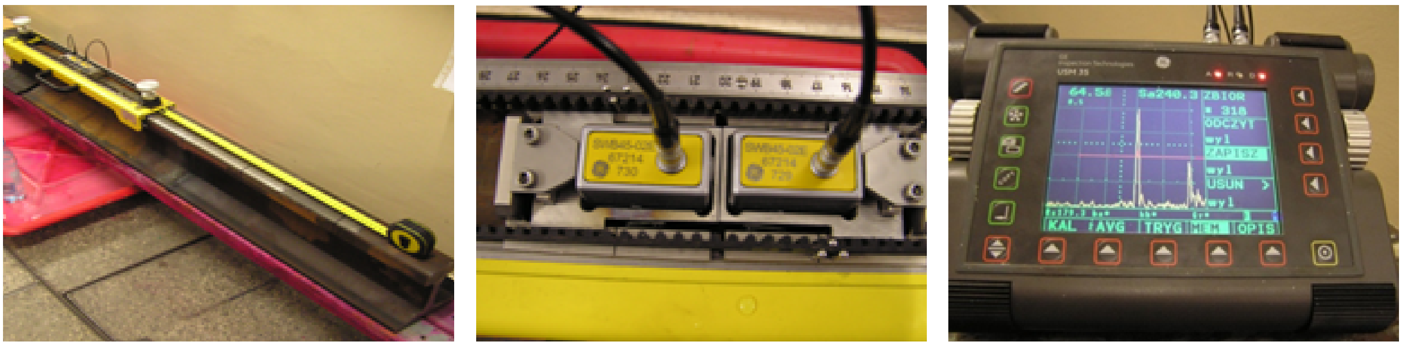

Fig 7. Tandem technique tester [10]

special guides. The millimetre scale facilitates the appropriate positioning of the transducers in relation to each other. The fact that the power supply leads are connected at the top makes it easier to move the transducers in relation to each other as well as facilitates their stable attachment [10, 11].

Tests performed from the rail running surface enable the application of multi-channel defectoscopes featuring single and double ultrasonic transducers having various beam introduction angles (see Fig. 8). The speed at which diagnostic vehicles travel amounts to approximately 50 km/h. The performance of tests requires ensuring contact between the transducer and the rail running surface. This, in turn, entails the necessity of applying a coupling medium, i.e. water.

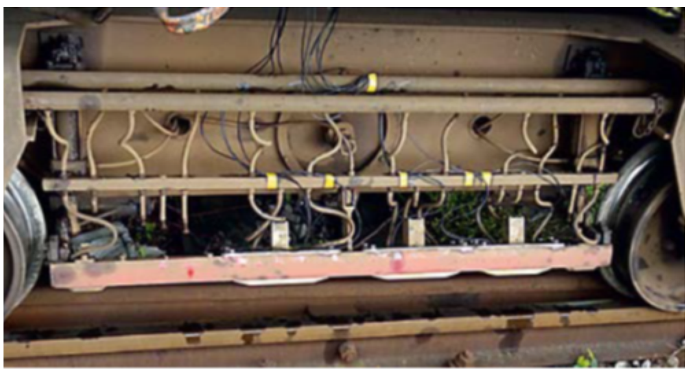

Fig 8. Bogie skid with UT transducers [8]

Images viewed on monitors enable the appropriate categorisation of discontinuities. Bogies are used for the local testing of rails. The tests involve the application of transducers of longitudinal and shear waves, having ultrasonic beam introduction angles of 0°, 45° and 70°. Test results are recorded using a computer system making it possible to view the results at any time. The joints of rails with turnout crossings require the performance of manual tests. The straight sectors of rails can be tested using manual track gauges or inspection track gauges (see Figure 9).

A breakthrough in ultrasonic tests was the invention of the Phased Array technique (PA), constituting the development of conventional ultrasonic echo technique tests. The Phased Array method involves the use of mosaic transducers containing a certain number of small and independently controlled converters (usually between 16 and 64) [12]. The use of the mosaic transducer enables the introduction of a series of ultrasonic beams, the processing of signals and their analysis in a graphic form. An S-scan obtained in the aforesaid manner, imaging the location of indications against the background of the weld groove, significantly facilitates the subsequent assessment and identification of detected indications [12].

Fig 9. Track gauge (model RDM-12) [8]

The Phased Array technique enables the control of an angle, at which the ultrasonic beam is introduced to a given element. As a result, it is possible to obtain various beam angles of incidence (or of refraction) by exciting selected transducer converters in previously programmed sequences. One transducer enables the performance of scans at various angles. Another advantage of the PA technique is the reduced duration of tests, resulting, among other things, from the unnecessity of exchanging the transducer and, consequently, the recalibration of equipment [13]. Figure 10a presents an example of a calibration block and a transducer used in the PA tests. The imaging of imperfections as well as a semiautomatic PA testing system are presented in Figure 10b. In the PA technique, when scanning the volume of a given material,

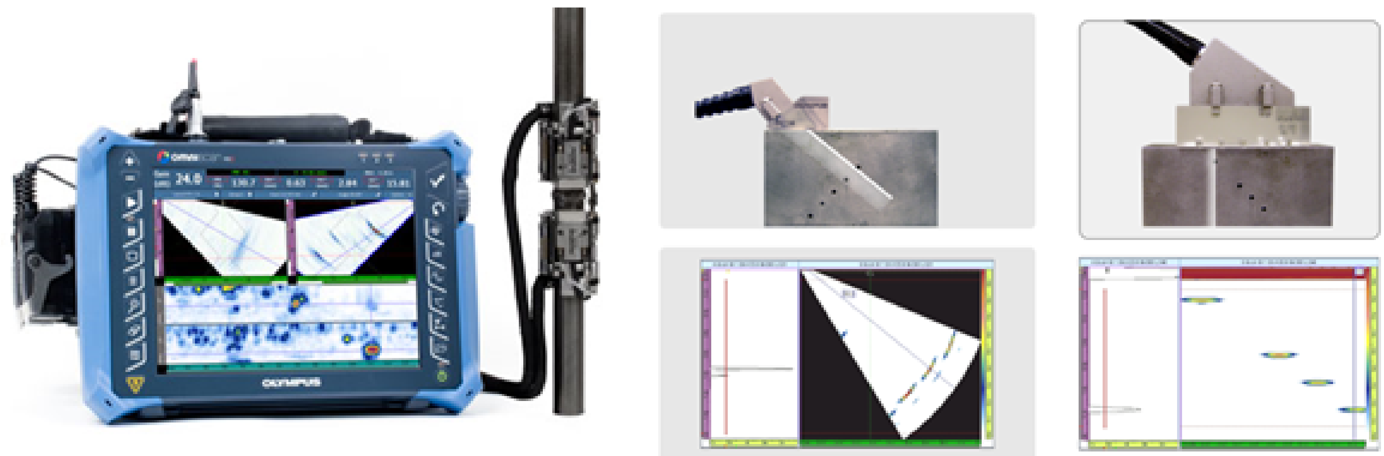

Fig. 10. Equipment used in PA technique-based tests: a) defectoscope and scanner, b) angle transducer and tests results obtained using sectoral scanning and c) straight transducer and tests results obtained using linear scanning [12]

an ultrasonic beam is introduced to an object using shear waves. Applied frequencies, ranges of converters and characteristics of ultrasonic beams do not differ from those used in conventional ultrasonic tests. The testing principle is very similar to that of the conventional ultrasonic method. The acceptance of an indication consists in the measurement of the maximum amplitude of echo in relation to the identified echo of a master reflector [14]. Figure 10a presents a defectoscope along with a scanner enabling the performance of PA tests. Illustrations b and c contain examples of linear and sectoral scan images.

The ultrasonic method is also used in the tests of railway rails, where it utilises the correlation between the displacement of ultrasonic waves and stresses. When measuring stresses it is necessary to determine the wave propagation rate with an accuracy of fractions of a meter per second [16]. The rate depends on material density, temperature and the presence of stresses. The Debro meter can also be used to examine continuous rails. The system is equipped with transducers making it possible to measure the time of ultrasonic wave passage as well as subsurface stresses around the rail perimeter. Measurements performed using the Debro meter also include rail internal stresses generated during the production of rails and their straightening using a roll flattener as well as stresses generated during transport and unloading. Importantly, internal stresses remain even after external factors (external forces, temperature, etc.) cease to affect the rail. The stresses counteract one another within the volume of a given element and may reach a yield point. Internal stresses result from technological processes affecting the element or from its operation. They may reduce the strength of a structure, which could lead to the formation of cracks in the material. Figures 11 and 12 present a measurement device enabling the performance of fast measurements in specific areas of the rail side surface. The measurement device is composed of a transmitting-receiving transducer of longitudinal and shear waves and an electronic unit tasked with the excitation of the transducers, the analysis of received signals and the calculation of stresses in accordance with a pre-set algorithm. The transducer systems allow for the influence of temperature changes on the rate of ultrasonic wave propagation [17]. The transducer is provided a temperature sensor enabling the automating compensation of the wave propagation rate along with temperature changes. Owing to an appropriate distance between the transducers, the measurement on the rail surface makes it possible to identify the ultrasonic propagation rate in the rail head, foot and web. The quadruple measurement of the time of passage enables the calculation of its average value; displayed results allow for temperature correction. A measurement cycle consists of 1–8 primary cycles and, as a result, provides the possibility of measuring stresses in relation to several positions of transducers [17].

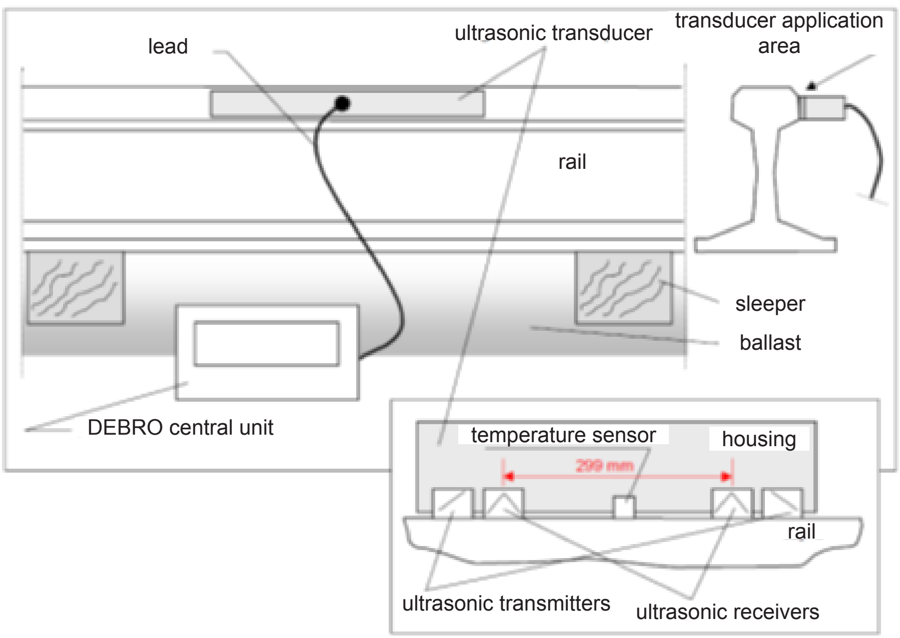

Fig. 11. Measurement elements in the Debro meter [16]

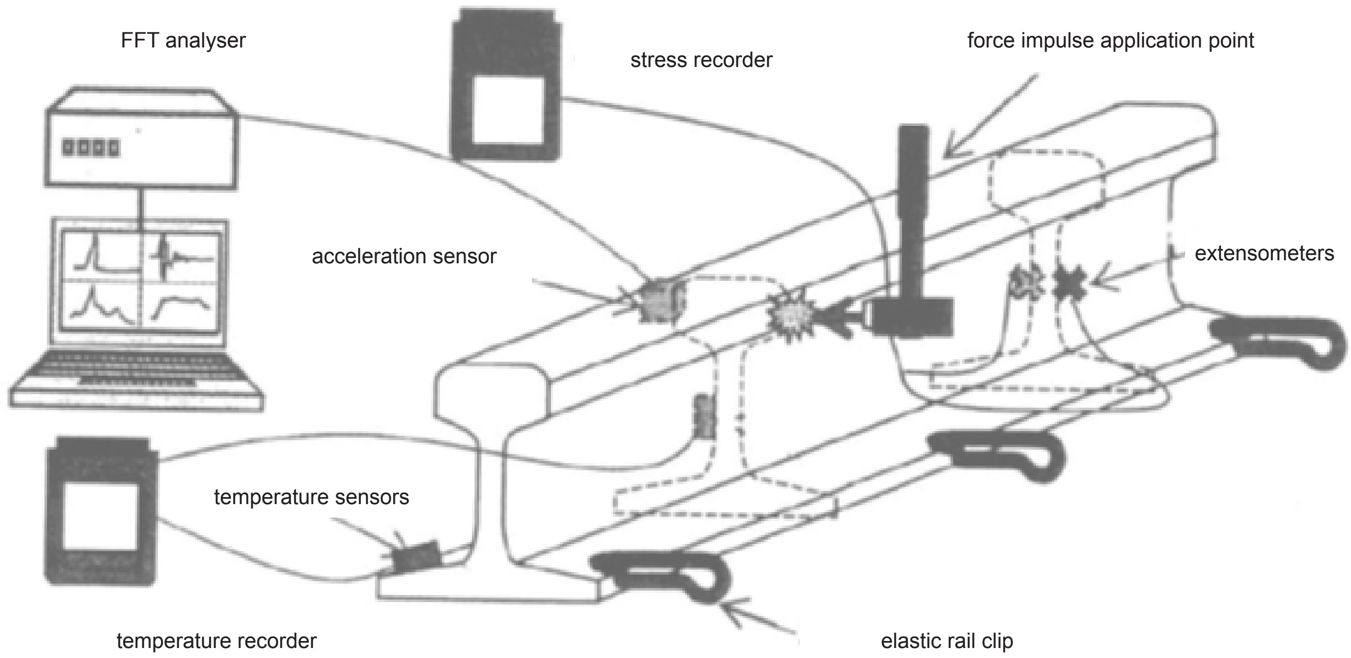

Fig. 12. Testing the correlation between stresses in continuous rails and internal stresses of the track structure [16]

Methods used to test internal stresses also include:

- destructive extensormetric method consisting in measurements of internal stresses; the method involves the use of an attached extensometer measuring stresses during the cutting of a given element. After stresses have been released, the length and the cross-section of the object change, whereas electric resistance changes proportionally to the deformation of the extensometer [17],
- X-ray radiographic method based on the diffraction of X-rays on atomic planes and on measurements between crystallographic planes. The deflection of X-rays only takes place in relation to certain angles (see Figure 13), depending on distances of these planes and radiation wavelength. Information about internal stresses is obtained from a depth of tens of microns [17],
- magnetoelastic method involving the use of the Barkhausen effect and the measurement of correlations between magnetic properties and stress. In the aforesaid method, a coil located near the surface enables the recording of magnetic noise from the subsurface area. Magnetisation and demagnetisation cycles are measured using dedicated counters. In industrial conditions, the measurement of the Barkhausen signal is possible using a U-shaped electromagnet, where the signal is detected by an induction coil. The method requires the calibration of a measurement device different for each steel grade. Information about internal stresses is obtained from a depth of fractions of millimetres,
- comparison of defective rails with stress-free rails. The method consists in making cuts in the rail web, driving the wedge into a given cut and comparing a newly formed crack with standard specimens of stress-free rails or in cutting the rail web and measuring the width of the gap formed as a result of the release of internal stresses,
- computer simulation involving the creation of the FEM mesh of a model subjected to tests, the use of actually applied loads, the calculation of stress condition and the graphic presentation of stresses present in a given element.

The above-presented method is currently the most advanced technique enabling the identification of internal stresses. Numerical calculations can be applied in experiments and provide information about the distribution of stresses and strains present both on the surface and inside elements subjected to examination [18].

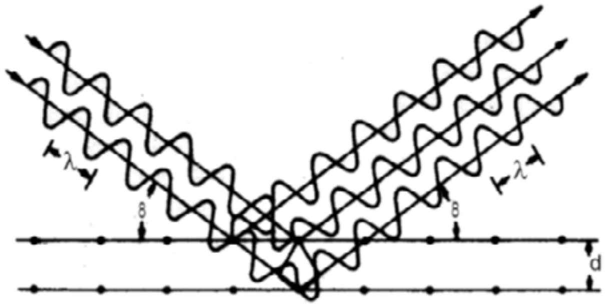

Fig. 13. Reflection of X-rays; d – distance between X-rays [17]

The above-presented overview discusses various methods used to detect discontinuities in railway rails. The study presents both surface methods, enabling the detection of surface discontinuities as well as volumetric methods, enabling the identification of imperfections located inside the material. Non-destructive tests are very important in terms of the proper functioning of the track structure. The improper performance of non-destructive diagnostic tests could lead to the formation of serious defects (e.g. cracks).

References:

[1] Makuch J.: Prezentacja. Diagnostyka szyn, wady w szynach. Katedra Mostów i Kolei. Politechnika Wrocławska. Wrocław 2015.

[2] Lesiak P., Wlazło M.: Badania wad Head Checking w szynach kolejowych metodą optyczną. Prace naukowe Politechniki Warszawskiej, Transport, 2014, vol. 104.

[3] Nichoha V., Shkliarskyi V.: Metoda strumienia rozproszenia pola magnetycznego w diagnostyce szyn kolejowych oraz jej miejsce wśród mobilnych środków badania nieniszczącego. Problemy kolejnictwa, September 2018, vol. 180, pp. 23–27.

[4] Costain J., Pearson N.R.: Możliwości współczesnych skanerów den zbiorników działających w oparciu o metodę strumienia rozproszenia pola magnetycznego. Badania Nieniszczące i Diagnostyka, 2017, no. 1–2, pp. 20–23.

[5] Roskosz M., Witoś M., Żurek Z.H., Fryczkowski K.: Porównanie możliwości diagnostycznych metod magnetycznej pamięci metalu, szumu Barkhausena i niskoczęstotliwościowej impedancji. Przegląd Spawalnictwa, 2016, no. 10, pp. 57–62.

[6] Sikora R., Chady T.: Badania nieniszczące metodami elektromagnetycznymi. Przegląd Elektrotechniczny, 2016, no. 9, pp. 1–7.

[7] Cost H.: Pomiar głębokości pęknięć – aktualna technika pomiarowa. Tech Control.

[8] Kowalczyk D., Antolik Ł., Mikłaszewicz I.: Wady szyn kolejowych, a badania ultradźwiękowe. Badania nieniszczące i diagnostyka, 2019, no. 4, pp. 9–13.

[9] Deputat J.: Nowe Techniki Badań Ultradźwiękowych. Pracownia Ultradźwiękowych badań materiałów. IPPT PAN, Warszawa.

[10] Hottowy G.: materials of the Ekstplast company

[11] Wytyczne PKP Polskie Linie Kolejowe S.A. Id-17:2005.: Wytyczne ultradźwiękowych badań złączy szynowych, zgrzewanych i spawanych. Warszawa 2005.

[12] Kaczmarek K.: Prezentacja. Nowoczesne techniki badań ultradźwiękowych oraz ich zastosowanie. Gliwice 2017.

[13] Mackiewicz S.: Badania złączy spawanych techniką Phased Array w świetle wymagań PN-EN ISO 13588. Przegląd Spawalnictwa 2015, no. 12, pp. 101–106.

[14] Mackiewicz S.: Ultradźwiękowe badania złączy spawanych techniką Phased Array. XXI Nieniszczące Badania Materiałów. Zakopane 18–20 March 2015.

[15] Mikłaszewicz I., Siwiec J.: Badanie naprężeń własnych w szynach kolejowych. Problemy kolejnictwa, 2017, no. 177, pp. 45–50.

[16] Towpik K.: Właściwości oceny stanu naprężeń w szynach toru bezstykowego.

Archiwum Instytutu Inżynierii Lądowej, 2017, no. 25, pp. 407–417.

[17] Kukulski J.: Metody badań naprężeń własnych w szynach, rozjazdach i kołach monoblokowych. Centrum Naukowo-Techniczne Kolejnictwa, pp. 97–115.

[18] Stolarczyk Ł., Kardas-Cinal E.: Wybrane metody pomiaru sił podłużnych w szynach toru bezstykowego. Prace naukowe Politechniki Warszawskiej, Wydział Transportu, 2018, vol. 121, pp. 373–380.