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Improving the Efficiency of Ultrasonic Testing of Solid-Rolled Wheel Rims During Repair of Car Wheelsets

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ABSTRACT

Increasing the efficiency of ultrasonic testing in railway transport is possible due to improvement and modification of the existing technology. One of the main tasks of increasing efficiency is to improve reliability and information content of ultrasonic testing of wheel rims during repair of wheelsets.

The contact method of ultrasound input for wheel rims is still predominant at the enterprises of the wagon and locomotive facilities of railways.

The article covers the techniques of ultrasonic flaw detection of the rim of solid-rolled wheels during repair of wagon wheelsets in accordance with the existing regulatory technical documents. The problems of detecting defects by piezoelectric transducers with input angles of 0°, 40°, 50° when testing the rim from the lateral inner surface and 90 ° from the side of the tread area are described.

A version of a new method for testing the wheel rim from the side of the tread area using piezoelectric transducers with input angles of 65°–74° is proposed. A comparative analysis was conducted to simultaneously identify eight reflectors in a test sample using 2.5R65°69°74°, P121–2.5–70° RDM and P121–0.4–90° transducers.

Keywords: solid-rolled wheels, Rayleigh waves, ultrasonic testing, tread, wheel rim, growing efficiency.

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INTRODUCTION

Today, ultrasonic testing in railway transport occupies a special place due to the need to ensure safety of cargo and passenger transportation. It is the basis for identifying internal defects, surface cracks revealed by the depth in various parts of wheelset axles, as well as in rims and disks of solid-rolled wheels[1].

To check the rims of solid-rolled wheels for defects, the main method is ultrasound (US) input from the inner edge of the wheel with piezoelectric transducer (PET) input angles of 0°, 40°, 50°. However, in practice, when US is input from the inner edge, there is a «dead» zone in which a defect may occur. For example, the standardised «dead» zone for PET for input angles of 40°, 50° is ≈6 mm, and for an input angle of 0° – 10 … 15 mm. At the same time, the contact method of US input may not provide the required sensitivity of the method in places of scoring and chips, which may be on the inner edge of the wheel [1]. The wheel rim thickness also affects the detection of defects in the case of a fixed position of PET in the USK-5A wheel scanning device. In the regulatory technical documentation, the main attention is paid to the detection of reflectors of certain sizes in different parts of the wheel, but the fact that defects can be located at different angles relative to PET and be in other zones is not considered. Natural defects (pores, cracks, delamination, etc.) differ from artificial reflectors (holes, drilling, cuts, etc.) by abnormality of the shape. For example, inside the defects there may be oxides and various substances, which, during US testing, as a rule, contribute to a decrease in the amplitude of the reflected signal. Voluminous defects such as pores, slag inclusions of various types provide scattering of the incident wave almost the same in all directions. However, for planar defects (cracks, delamination, etc.), the scattering has an obvious direction. The direction of the plane of such defects in relation to the plane in which US wave propagates can differ dramatically and directly depends on the manufacturing technology, conditions and modes of further operation of the wheels. Cracks that come out from one point or have a spider-like appearance are of interest for detection.

High-amplitude echo signals from planar defects are observed only under favourable conditions (specular reflection). With non-specular reflection, diffraction waves appear from the edges of the defect. Their amplitude is significantly smaller than the amplitude with specular reflection and is determined by the shape of the defect, the direction of emission and reception relative to the plane of the defect, and the type of emitted and received waves [2–4].

In practice, it is noted that when testing products with surface irregularities from mechanical processing with straight PET, a Rayleigh surface wave can be excited, which propagates perpendicular to the directions of irregularities [5]. Such an effect leads to appearance of false echo signals on the flaw detector scan and affects the correctness of assessment of the quality of wheel rims (tires). For example, when introducing US from the lateral inner surface of the wheel, a false signal can appear from the dihedral angle of the edge of the rim (tire) opposite the flange.

It should be noted that when testing with an inclined combined PET, the amplitude of the echo signal of the diffraction wave from the edge of the vertical half-plane with a small cross-sectional area is approximately equivalent to the amplitude of the reflected signal from a lateral cylindrical hole with a diameter of ≈4 mm for a longitudinal wave and 2 mm for a transverse wave (for calculating $d = \lambda/2\pi$, where λ is the wavelength at a PET frequency of 2,5 MHz).

Scattering is also observed on the uneven surface of the defect. The scattering is greater, the greater is the Rayleigh parameter ($R = 2k\sigma\times\cos\times\varepsilon$, where k is the wave number, σ is the root-mean-square value of the unevenness height, ε is the angle of incidence of the wave on the defect) [6].

Based on the above, it is clear that there are technological constraints that reduce the efficiency of contact US testing.

Currently, ongoing work is underway to develop directions for improving existing methods of ultrasonic testing of rolling stock wheelsets, including technical means of testing [7; 8].

The objective of the work is to improve the US testing of solid-rolled wheel rims for the presence of differently oriented crack-like defects.

CONTROL OBJECTS. APPROACHES USED

In accordance with the regulatory document[1], ultrasound testing of solid-rolled wheels is performed using the echo-pulse method to

[1] PR NK V.2. Rules for non-destructive testing of parts and components of wagon wheelsets during repair. Special requirements. Moscow, JSC Kodeks, 2013, 88 p.

Table 1

Options for methods of inputting US from the inner edge of the wheel rim[1]

✓ **DR2.1** (*input angle 0°*) control of the wheel rim circumference using longitudinal waves when PET is installed below the level of the tread ✓ **DR2.2** (*input angle 0°*) control of the wheel rim circumference with longitudinal waves at a distance of 30 mm from the lower edge of the rim (for wheels with increased hardness)	✓ **DR3.1** (*input angle 40°*) control of the wheel rim circumference using transverse waves when PET is installed below the level of the tread	✓ **DR3.3** (*input angle 50°*) control of the wheel rim circumference using transverse waves when PET is installed above the level of the tread
Detection of longitudinal fatigue cracks in the main section of the rim, developing predominantly perpendicular to the rolling surface, delamination, non-metallic inclusions and other internal discontinuities	Detection of transverse fatigue cracks on the outer sidewall of the rim in the mating zone with the tread	Detection of transverse cracks and internal discontinuities in the rim flange

identify internal and surface defects that are located in the rims and have characteristics that exceed the rejection values.

Table 1 shows the mandatory options for the method of testing a solid-rolled wheel from the inner side surface of the rim.

One of the methods of US testing of the surface of cylindrical parts is the echo method using Rayleigh waves. The advantages of this testing method are related to high productivity due to the installation of PET at one or several points, allowing to assess the condition of the entire surface of the tested object [9]. In this case, scanning over the entire surface is not required. Since the surface wave has a high sensitivity to detecting surface defects, the requirements for the condition of the surface of the part are high.

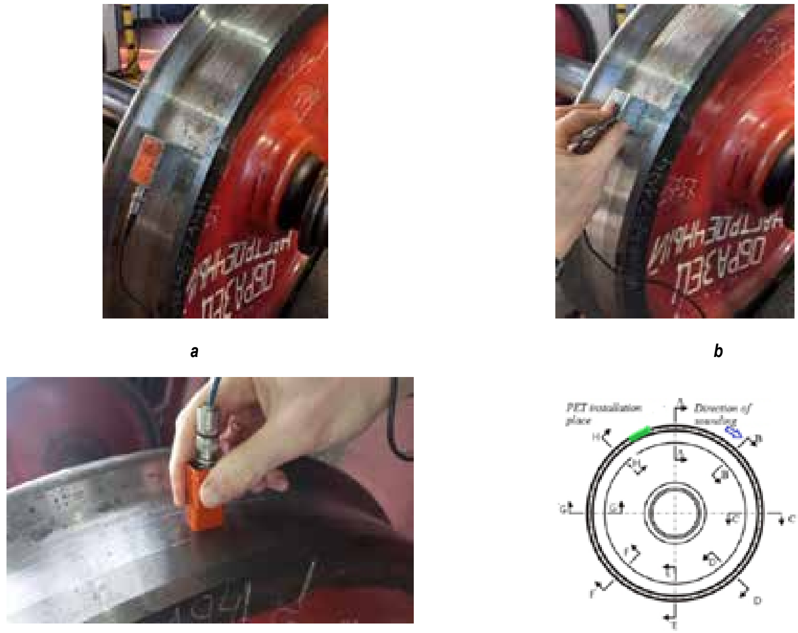
In the railway industry, the method has found the widest application for testing solid-rolled wheels and tires after turning with a wheel lathe. Testing with surface waves is carried out in two directions by moving PET at a distance of ¼ of the wheel circumference (usually at least one move). Various defects on the rolling surface and in the near-surface layer of the rim at a depth of up to 1 … 2 mm (DR4) are subject to detection.

It is known that according to Snell's law, after the US beam falls in PET prism at an angle of 55–57° in the medium, the refracted wave exists only in the form of a surface wave. This angle of incidence of the beam in the prism is used in PET for railway purposes, marked as P121–0.4–90°.

However, the use of this PET in practice is complicated by the influence of such factors on the results as: contamination, residues or excess of contact fluid, the presence of burrs left after turning the wheel, etc. It should be considered that in the process of working with this type of PET, it is quite difficult to find a defect due to its ability to receive waves with a minor «rear» lobe of the directional pattern. Also, the amplitude of the echo signal from the defect changes unevenly due to such phenomena as multiple re-reflection of waves from the boundaries (rim chamfer, fillet transition to the flange) and their subsequent interference [10].

Wheel inspection by surface wave according to the DR4 method variant (90°) from the tread side is insufficient, since defects can be located at different depths and will not always be detected from the inner side of the rim by transverse wave with inclined PET according to the DR3.1 variant (40°) and longitudinal wave with direct PET according to DR2.1 (0°).

To conduct experimental studies, a tuning sample (TS) was selected in the form of a formed wheelset with eight artificial reflectors on a solid-rolled wheel with a diameter of 903 mm. The US testing was carried out on TS from the tread side at a distance of 70 mm from the inner edge of the rim at one point of the wheel using the UD2–102VD ultrasonic flaw detector and a set of transducers: P121–0.4–90° (RF), P121–2.5–70° RDM (RF), P121–2.5–65° RDM (RF), 2.5R65°69°74° (China). Industrial oil I-20 was used as a contact fluid. When testing the wheel rim with P121–0.4–90º, the standard setting of the manufacturer was set (US speed s = 2999 m/s, high probing pulse amplitude, time selection zones $TZ1_{init}$, $TZ1_{fin}$, $TZ2_{init}$, $TZ2_{fin}$ are adjusted automatically, the PET frequency is 0,4 MHz, the input angle is 90°), and for all the other PET, testing parameters were set independently in accordance with the wheel circumference and the PET characteristics ($TZ1_{init,}$ = 133.6R, $TZ1_{fin}$ = 3000R, US speed s = 3260 m/s, high probing pulse amplitude, PET frequency is 2,5 MHz, the input angle is 65°, 69°, 70°, 74°).



a b

c d

Pic. 1. An example of identifying reference reflectors in TS [photo by the authors].
a– PET P211–0,4–90° (with built-in magnets); b – PET 2,5R65°69°74°;
c – PET P121–2,5–70-RDM; d – arrangement of reflectors in TS by sectors.

RESEARCH RESULTS AND DISCUSSION

It was of interest to study the features of detecting reflectors from the wheel tread using the traditional P121–0.4–90° PET (using a surface wave) and inclined PET with large input angles (using a transverse wave) 2.5R65°69°74° (a three-element PET in one housing), P121–2.5–70° RDM, P121–2.5–65° RDM (Pic. 1).

The use of such large angles of 65°–74° when inspecting wheelsets in the rolling stock division is not envisaged. However, these PET are widely used in rail flaw detection both as part of a flaw detection trolley and in manual confirmation testing (70° – rail head testing from the tread side, 65° – testing of welded joint zones in the head area from the tread side)[2,3]. It is worth noting that such input angles are used in testing welded joints, which ensures a low level of parasitic (false) signals and high detection of defects located at different depths [11–13].

The control of the tread with P121–0.4–90° PET (Pic. 2) showed that in TZ1 zone, reflectors were detected with a direct beam (by distance from the front face of PET) in the section C–C, D–D, and in TZ2 zone with a «rear» lobe (by distance from the rear face of PET) – in the section F–F, G–G. Outside TZ1 zone, a reflector was detected with a direct beam (by distance from the front face of PET) in the section A–A.

It is difficult to identify the remaining signals, and in some cases, it is impossible for the reasons described above. At the same time, the additional signals appearing in TZ2 zone can duplicate the signals of TZ1 zone, but with the recalculation of the distance of the artificially created flaw detector setting.

Testing the tread surface with the 2.5R650690740 PET (Pic. 3) showed excellent results in identifying all reflectors sequentially one after another.

Obviously, such high sensitivity is related to the design of PET, when one piezoelectric element can emit an US wave, and the other (located in the most favourable place for reception) can receive it. Large input angles, a frequency of 2.5 MHz and a wide directional pattern of PET contribute to the fact that defects of different geometric dimensions and shapes can be classified by the signal.

When creating a setting, an angle of 69° was entered into the flaw detector memory, one of three indicated in PET marking.

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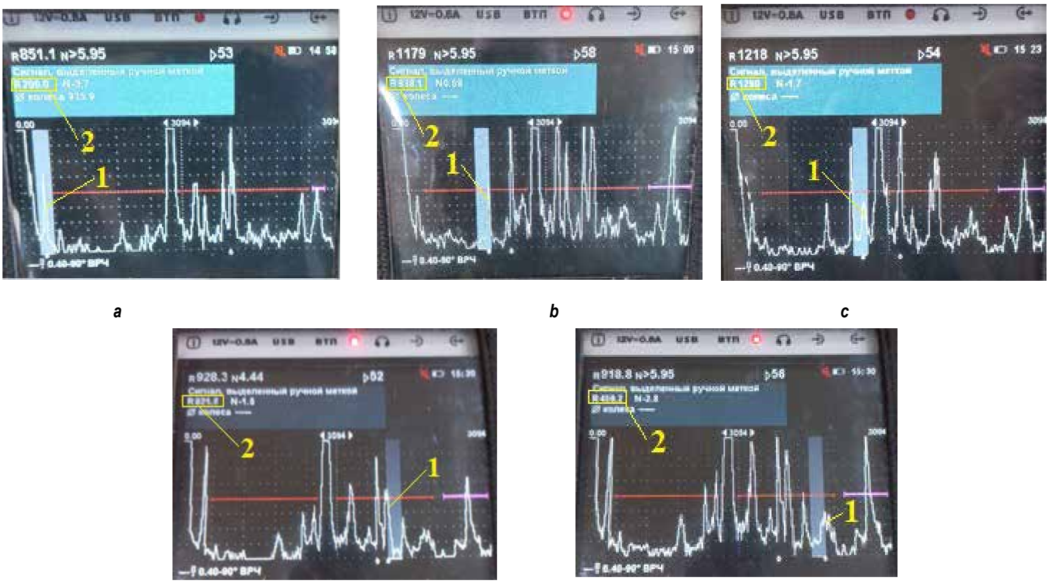
[2] STP BCh [standard of the Belarusian Railway] 38.427–2021. Non-destructive testing of rails and welded joints. Organisation standard (approved by the order of the head of the Belarusian Railway, dated 18.06.2021, No. 532NZ), 2021, 127 p.

[3] STP BCh 38.343–2016. Ultrasonic testing of rails on the way with the UDS2-RDM-22 flaw detector. Organisation standard (approved by the order of the head of the Belarusian Railway, dated 15.07.2016, No. 665NZ), 2016, 81 p.



a b c

d e

Pic. 2. Screenshots made while detecting reflectors in TS with PET P121–0.4–900:
1 – signal from the reflector; 2 – distance along the beam to the reflector, mm; a – horizontal drilling with a diameter of 5 mm at a depth of 10 mm from the wheel tread (outside the time selection control zone TZ1); b – vertical drilling of 5 mm in the flange at a distance of 17.5 mm from the inner edge of the wheel; c – vertical drilling of 5 mm on the tread surface at a distance of 70 mm from the inner edge of the wheel; d – detection of a cut on the chamfer 3 mm deep and 1 mm wide by the «rear» petal; e – detection of a 4 mm drill hole 5 mm deep on the inner edge of the wheel at a distance of 50 mm from the top of the flange by the «rear» petal [photos by the authors].

The wheel sounding scheme is shown in Pic. 4.

Due to multiple reflections of US beam from the tread surface, testing becomes effective along the entire length of the wheel circumference. Depending on the wheel diameter and the input angle of PET, the area of US beam re-reflection will vary in length and is within the range of 160 … 260 mm. It can be noted that such control from the side of the tread surface will allow to detect defects not only in the near-surface layer of the rim, but also at a depth of up to 35 mm from the tread surface. With such a scanning scheme, the efficiency of detecting defects: non-metallic inclusions, transverse cracks, cavities, delamination and other discontinuities only increases.

Scanning must be performed at several points, deflecting PET beam in both directions by 10–15°. When a signal appears in the control zone, it is necessary to find a position at which its amplitude will be maximum.

To confirm that the control is effective, and the setting is created correctly, a wheel pair was selected after turning the wheel at a wheel lathe with a similar diameter of 903 mm. As can be seen in Pic. 5, there are no false indications.

When using the R121–2.5–70° PET (Pic. 6), high control sensitivity is also achieved when detecting all reflectors.

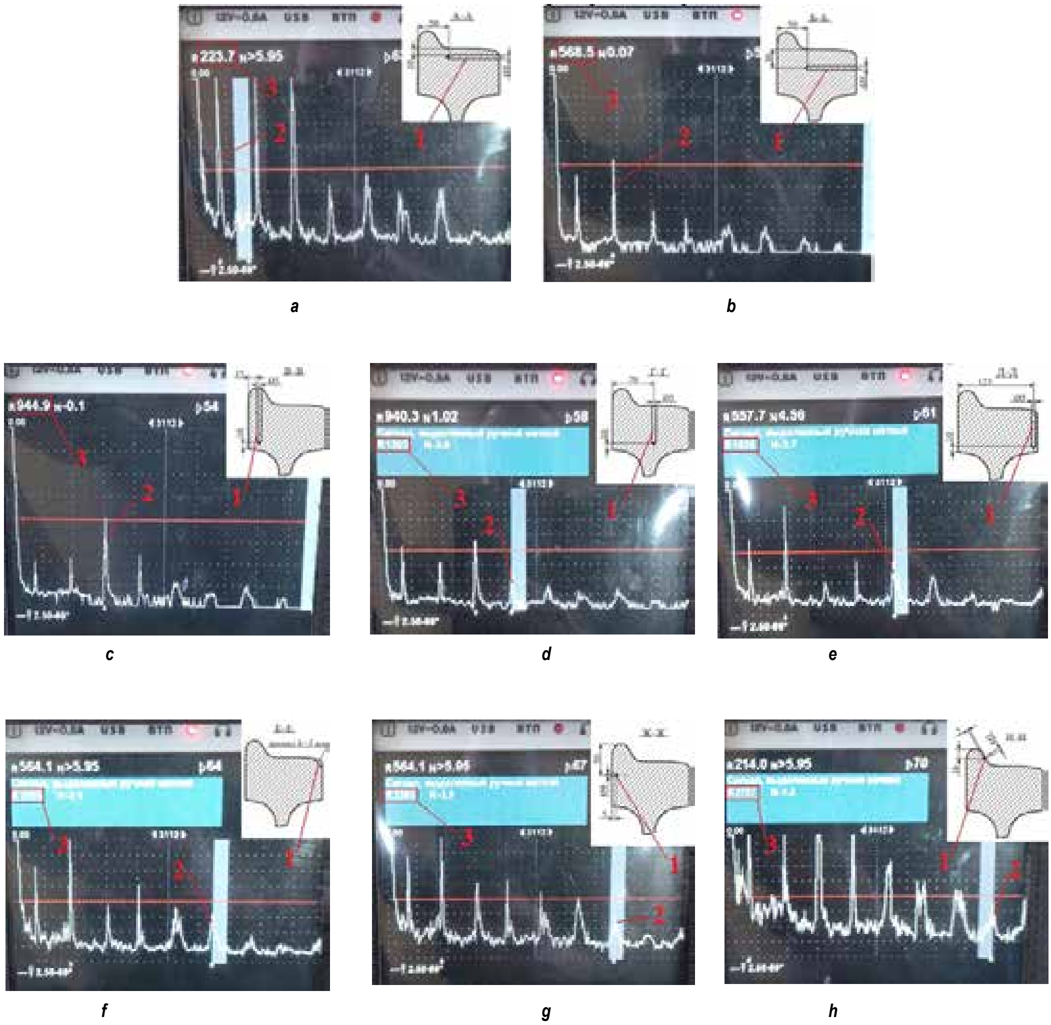
However, control with P121–2.5–70° RDM, due to its geometric dimensions and small contact area, is still inferior in sensitivity to the 3-element PET in terms of the spread of signal readings by amplitude, since one and the same piezoelectric element serves as emitter and receiver.

Ultrasonic testing of the wheel rim with this sounding scheme involves dividing the wheel into sections (point-by-point control) or scanning the tread surface at a distance of 300–400 mm in two directions by moving PET in the middle of the tread surface, deflecting PET beam in both directions by 10–15° every 5 cm of the path.

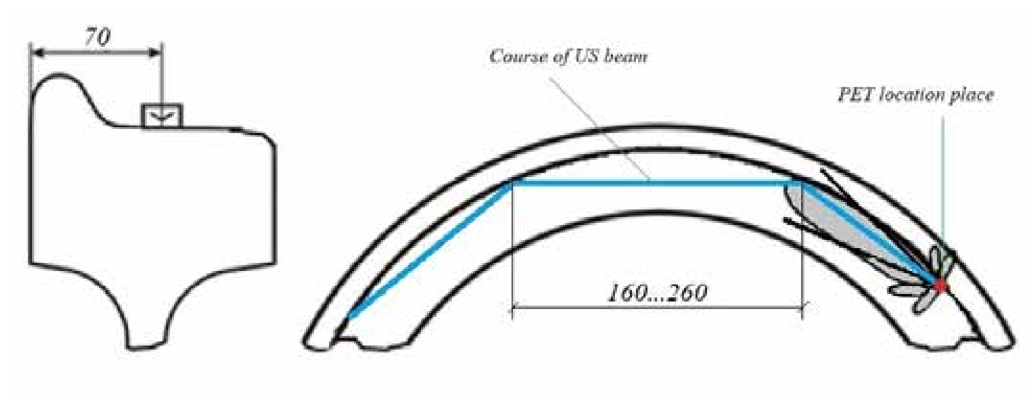
CONCLUSIONS

The results of the studies confirmed the high sensitivity of the new version of the testing method from the side of the tread surface at a distance of 70 mm from the inner side surface of the rim.

When PET is installed at one point and the beam is deflected in both directions by 10–15°, defects are detected using artificial reflectors in TS of different sizes, orientations and shapes. The high productivity of such testing does not reduce the reliability of the obtained results of ultrasonic flaw detection, and, due to the wide directional diagram, the efficiency of defect detection increases in comparison with the introduction of



Pic. 3. Screenshots made while detecting reflectors in TS with PET 2,5R65°69°74°:
1 – artificial reflector; 2 – signal from reflector, mm; 3 – distance along the beam to the reflector; a – horizontal drilling with a diameter of 5 mm at a depth of 10 mm from the wheel tread surface; b – horizontal drilling of 5 mm at a depth of 30 mm from the wheel tread surface; c – vertical drilling of 5 mm in the flange at a distance of 17.5 mm from the inner edge of the wheel; d – vertical drilling of 5 mm on the tread surface at a distance of 70 mm from the inner edge of the wheel; d – vertical drilling of 5 mm in the chamfer area of the tread surface at a distance of 125 mm from the inner edge; e – cut on the chamfer 3 mm deep and 1 mm wide; g – pre-drilling of 4 mm, 5 mm deep on the inner edge of the wheel at a distance of 50 mm from the crest; h – pre-drilling of 3 mm, 2 mm deep at a distance of 16 mm from the crest of the wheel [photos by the authors].



Pic. 4. Scanning scheme and direction of sounding [proposed by the authors].

a *b*

Pic. 5. Screenshots of a serviceable wheel of a wheelset after turning it at a wheel lathe, obtained with PEP 2.5R65°69°74° a – before installing PET; b – after installing PET on the tread surface [photos by the authors].

ultrasound from the side of the inner side surface of the rim. Due to possible re-reflection from the rim zone and considering that the testing is effective at a depth of up to 35 mm, it is advisable to use the proposed version of the method for wheels with a rim thickness of up to 40 mm.

The works [14; 15] provides information that assessment of admissibility of discontinuities using reference reflectors in TS can only be performed with a significant error, which is introduced by the difference in attenuation in the wheel (material St. 2, St. 2G, St. 1, St. T) and

Pic. 6. Screenshot while detecting reflectors with TS PET P121–2.5–70-RDM:
1 – horizontal drilling with a diameter of 5 mm at a depth of 10 mm from the wheel tread surface; 2 – horizontal drilling of 5 mm at a depth of 30 mm from the wheel tread surface; 3 – vertical drilling of 5 mm in the flange at a distance of 17,5 mm from the inner edge of the wheel; 4 – vertical drilling of 5 mm on the tread surface at a distance of 70 mm from the inner edge of the wheel; 5 – vertical drilling of 5 mm in the chamfer area of the tread surface at a distance of 125 mm from the inner edge; 6 – a cut on the chamfer with a depth of 3 mm and a width of 1 mm; 7 – a 4 mm drill hole with a depth of 5 mm on the inner edge of the wheel at a distance of 50 mm from the top of the flange; 8 – a 3 mm drill hole with a depth of 2 mm at a distance of 16 mm from the top of the wheel flange [photo by the authors].

TS. Therefore, the use of the proposed version of testing using PET with input angles of 65°–74° from the wheel rolling surface provides for the possibility of changing the technology of ultrasonic testing of solid-rolled wheel rims in terms of using it as the main method together with DR3.1 (40°), DR3.3 (50°), DR 2.1 (0°), DR2.2 (0°), DR4 (90º) complex or as an additional testing (for confirmation in controversial situations).

The approach we propose of ultrasonic flaw detection of rims of solid-rolled wheels of wheelsets during repair will improve the efficiency of non-destructive testing and operational reliability of railway rolling stock.

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