Influence of speed of rail flaw detection on the reliability of its results

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Abstract. The system of non-destructive testing of rails during their operation on the railroad network of the Russian Federation is based on the use of removable and mobile means of flaw detection. The increase in the volume of control by mobile means in recent years is explained by their higher productivity due to the higher speed of control. But the increase in the speed of control inevitably leads to the loss of acoustic contact and missing defects. **Keywords:** non-destructive testing, railway transport, reliability of monitoring results, rail defectoscopy tools

1 Introduction

Traffic safety in railroad transport depends on a huge number of factors, but the technical condition of the railroad track has the decisive influence on it. Any internal and external defects of rail reduce its strength characteristics [1-6], so the use of non-destructive testing to monitor and diagnose the railroad track is a means of ensuring traffic safety. Since 2013, mobile rail defectoscopy facilities in the track (defectoscope cars) have become the main means of non-destructive testing of rails. If in 2012 there were 81 mobile defectoscopy facilities in operation on the Russian railroad network, then in 2021 we had 143 units already.

The main features in the organization of a modern system of non-destructive testing of rails [7]:

- dependence of the frequency of control on the class and group (specialization) of the track;
- reduction of the maximum inspection frequency to 4 times a month, and the minimum frequency was reduced to 2 times a year;
- reduction of the maximum frequency of control with removable flaw detectors to once a month;
- possibility to perform continuous non-destructive testing of rails in the main track only by mobile flaw detection equipment while maintaining the total (removable and mobile) number of inspections of rails per year;
- observance of equal inspection intervals of rails separately for mobile means of inspection and separately for removable means of continuous inspection.

The quality of continuous ultrasonic testing of rails depends primarily on the presence of a stable acoustic contact [8], as well as on the design of the acoustic system (piezoelectric

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transducers), their settings, the condition of the rail rolling surface, ambient temperature, monitoring speed, etc. [9]. In turn, the main sign, which is the easiest to judge the quality of acoustic contact, and therefore the effectiveness of the ultrasonic control of rails, is the presence of the echo-signal from the bottom surface of the rail base in the channel with the input angle 0^0 and structural reflectors in the rail (rail face, bolt holes) in the control channels with input angles 45^0, 55^0 and 70^0. Also, the characteristic of the state of the acoustic contact can be the conditional length of these structural reflectors (with the loss of acoustic contact the conditional length will decrease). In the absence of acoustic contact workers of mobile defectoscopy are required to give these uninspected sections of track, bolted joints for rechecking by removable flaw detectors in due time.

In order to establish the influence of the speed of control on the quality of acoustic contact and the conditional length of structural reflectors it is necessary to analyze the defectograms of mobile defectoscopy of the test track section with artificial defects and track sections at different control speeds. Evaluation of the obtained measurement results in the absence of the actual value of the measured value is carried out by assessing their repeatability and reproducibility in accordance with ISO 5725-2 [10].

During the certification of uninspected track sections and bolted joints by mobile defectoscopy equipment (diagnostic complex ERA+ manufactured by JSC Radioavionika, four defectoscope cars manufactured by JSC Firma TVEMA, defectoscope cars produced by LLC NPO VIGOR and two defectoscope autotrucks ADE-1 produced by JSC Firma TVEMA) on Kuibyshevskaya Railways it was found that by reducing speed of rail check it is possible to record quality defectograms on 50% of uninspected track sections and 80% of uninspected bolted joints. A number of inconsistencies of the current track maintenance, violating the acoustic contact of the transducer with the rolling surface of the rail head were revealed in the remaining uncontrolled sections of track and bolted joints. Naturally, one of the ways to improve the reliability of control of rails is to replace distortion systems with piezoelectric transducers, requiring the presence of acoustic contact, to non-contact [11], but such systems during the ultrasonic control of rails in the track are not currently used.

Also, some cases of lack of echo-signals from defects even with satisfactory quality of defectograms recording on the defective section of the track were found in the course of defectograms interpretation of detected acutely defective rails. It should be noted that various methods of signal and image processing are used when transcribing defectograms [12, 13], but the results of measurements of the conventional dimensions of defects are obtained in manual mode. Despite the fact that the sensitivity of the corresponding channels of flaw detection equipment is set in advance and in some cases can exceed the sensitivity of acceptance control [14], the decrease in the conditional dimensions of defects to be detected will lead to a decrease in the reliability of ultrasonic testing.

In this regard, the choice of the most effective speed of rails control by mobile means of flaw detection is relevant. In this choice it is necessary to know the reliability indicators of ultrasonic rails control by mobile flaw detection means. Reliability is understood as the ability of NC methods (or the system as a whole) with the help of certain means and under certain conditions to detect in the object and evaluate unacceptable defects in accordance with its actual state. The ultrasonic testing techniques are characterized by such reliability indexes, as probability of correct detection P_{11}, probability of rejection P_{01}, symbolizing reliability $D=1-(P_{10}+P_{01})$, where P_{10} is probability of missing a defect [15].

Methods of experimental determination of the reliability of ultrasonic testing of rails rather time-consuming, because it requires complete information about the actual defective situation of the rail, which in reality can only be determined by complete destruction of the rail, which is too costly way to gather information, and in operating conditions is impossible.

ISO 5725-2 [10] provides the possibility, in the absence of information about the real value of the measured quantities to give an assessment of the precision - the degree of closeness to each other of independent measurement results obtained in specific conditions, not related to the true or conditionally true value (in the case of NC - the real defect situation). Since, during ultrasonic testing of rails in the track there is a possibility of measuring the conditional dimensions (by the length of the echo signals in the defectogram), and another characteristic of the reliability of the results of ultrasonic testing, as indicated above, can be the stability of the acoustic contact, then the evaluation of the results of measurement of conditional dimensions of structural reflectors and length of the acoustic contact loss zone with the indicators of precision (reproducibility and repeatability) is an important task, which allows to evaluate the accuracy of the results of ultrasonic testing.

The purpose of this work is to analyze the effect of the speed of control on the stability of the acoustic contact, and, therefore, the reliability of the results in ultrasonic testing by mobile means.

2 Materials and methods

All rail flaw detection tools are used to detect defects such as continuity defects and measure the coordinates of their occurrence with the contact method of ultrasonic vibration input. Applied means of defectoscopy differ by schemes of sounding and value of a number of basic parameters. In figure 1, as an example, the scheme of sounding, used in mobile means, equipped with a flaw detector "ECHO-COMPLEX", realizing both echo and mirror-shadow methods, is given.

The conditional length of the minimally detectable defect is determined from the conditions of the minimum required number of signals reflected from the defect K from N radiated, providing a confident decoding of the record and is calculated:

- for complexes with track and speed sensor synchronization, the conditional length of the minimum detectable defect is calculated by the formula 1:

$$\Delta L = N * \Delta S \tag{1}$$

Where ΔS is the discreteness of emission of ultrasonic vibrations;

N is the number of emitted signals.

- for the case when the emission frequency of ultrasonic oscillations is constant, the minimum conditional length of the registered defect is calculated for the maximum speed of control and determined by the formula 2:

$$\Delta L = (Vmax/f) * N \tag{2}$$

Where Vmax is the maximum control speed;

f is the emission frequency of ultrasonic oscillations.

The minimum required number of registered signals reflected from the defect K is calculated by the formula3:

$$K = 1{,}5 * \sqrt{N} \tag{3}$$

As noted above, rail sounding schemes differ depending on the types of manufacturers and generation of flaw detectors, so it is not correct to compare the results of measurements of conditional lengths of structural reflectors when using different types of flaw detectors. Also, the study of technical documentation of defectoscope cars allowed to establish that the defectoscope cars equipped with multichannel defectoscope "ECHO-COMPLEX" provide registration of minimum values of conditional length, so the results of control with the above defectoscope were used in the research.

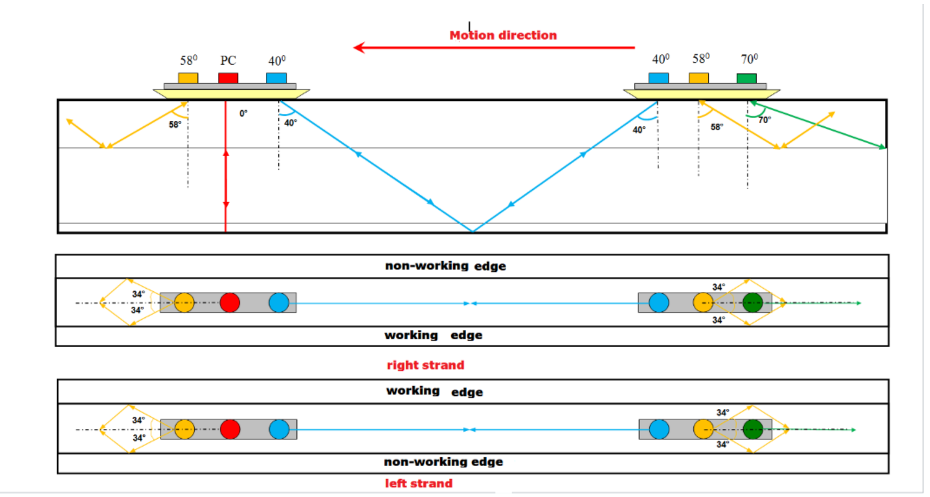

Fig. 1. Schematic diagram of the "ECHO-COMPLEX" flaw detector.

The need to consider precision arises because measurements performed on supposedly identical materials under supposedly identical circumstances do not generally yield identical results. This is due to the inevitable random errors inherent in every measurement procedure, and the factors affecting the measurement result are not fully controllable. Precision depends only on random errors and has nothing to do with the true or ascertained value of the quantity being measured. The measure of precision is usually expressed in terms of imprecision and calculated as the standard (standard deviation) of the measurement results. A smaller precision corresponds to a larger standard deviation. The quantitative values of precision measures depend considerably on the given conditions. Limiting cases of such conditions are repeatability conditions and reproducibility conditions [10].

Repeatability - precision under repeatability conditions (Figure 2). Repeatability conditions are conditions under which independent measurement results are obtained by the same method on identical test objects, in the same laboratory, by the same operator, using the same equipment, within a short period of time. ISO 5725-2 [10] uses the standard deviation as a measure of repeatability.

Reproducibility - precision under reproducibility conditions (Figure 2). Reproducibility conditions are conditions under which measurement results are obtained by the same method, on identical test objects, in different laboratories, by different operators, using different equipment.

ISO 5725-2 [10] establishes the rules for the presentation of the standard deviations of repeatability and reproducibility and their limits as well as the systematic error of the method. The value of the standard deviations of repeatability and reproducibility is presented with the indication of the experimental conditions, as a result of which they were obtained (number of participating laboratories, controlled values of the measured value in the measuring range of the method, the presence of outliers in the data of individual laboratories).

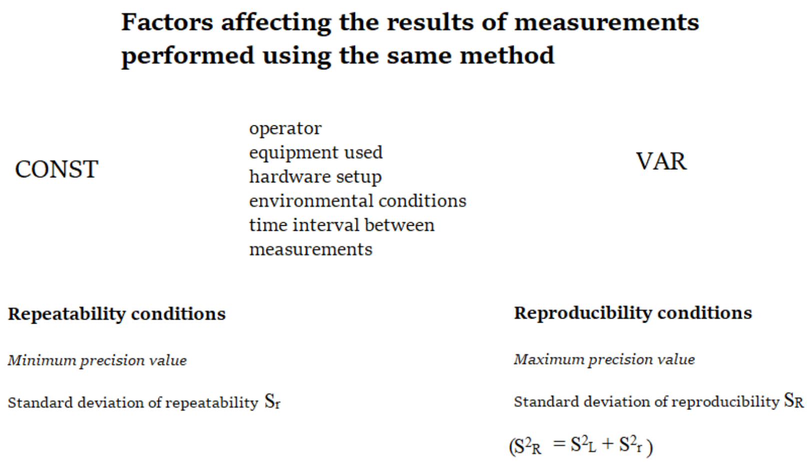

Fig. 2. Repeatability and reproducibility conditions.

Calculation of repeatability and reproducibility variance of measurement of conditional dimensions of bolt holes in rails and areas of bottom signal loss by two removable flaw detectors and one mobile defectoscopy tool, which implement the same sounding schemes, is performed according to the procedure given in ISO 5725-2 [10]. Repeatability conditions for each control means of a certain type are multiple passes over the same area or the results of measurement of conditional dimensions of the same design reflectors on the areas with the same characteristics. Repeatability conditions are realized by using different means of flaw detection.

As part of the study 30 passes defectoscope carriages [1] 002, 023, equipped defectoscope complex "ECHO-COMPLEX" at speeds from 15 to 35 km / h on the test section of the track of the Kuibyshev railroad were analyzed. Test section of the track is two railroad strands with 11 artificial defects. Their description, dimensions and relevant control parameters (input angle) are given in the table 1.

Table 1. Characteristics of artificial defects in the test section and entry angles.

Description of the artificial defect and its size	Input angle. deg.
oblique (triangular) cut in the rail neck from the side of the working face at an angle of 45º from the wall of the first bolt hole down from the end of the rail (dimensions 10 by 10 mm);	45
6 mm diameter hole from the working face of the rail head at a height of 20 mm and a depth of 50 mm;	70
oblique (triangular) cut in the rail neck from the side of the working face at an angle of 45º from the wall of the third bolt hole up from the end of the rail (dimensions 10 by 10 mm);	45
horizontal slot in the neck on the side of the working face above the first bolt hole (8 mm into the neck. length 50 mm)	0
oblique (triangular) cut in the rail neck from the side of the working face at an angle of 45º from the wall of the second bolt hole down to the end of the rail (dimensions 10 by 10 mm);	45
crosscut in the rail head from the rolling surface to a depth of 15 mm in the form of a segment with a radius of 75 mm;	70

horizontal kerf in the rail neck to a depth of 8 mm from the side of the working face in the form of a segment with a radius of 75 mm;	0
crosscut in the bottom of the rail to a depth of 7 mm in the form of a segment centered on the longitudinal axis of the rail with a radius of 75 mm;	45
horizontal groove in the head on the side of the working face to a depth of 40 mm in the form of a segment with a radius of 75 mm;	0
4 mm diameter hole from the working face of the rail head at a height of 20 mm and a depth of 50 mm	70
oblique (triangular) slot on the side of the working face in the neck at an angle of 45° from the wall of the third bolt hole up to the end of the rail (size 8 by 5 mm).	45

To increase the number of measurements we analyzed 6 passes by the defectoscopic autotrain ADE-1 № 040, also equipped with the defectoscopic complex "ECHO-COMPLEX", on the Ulyanovsk - Tsilna section of the way at the speeds from 15 to 40 km/h. In the course of the study an analysis of the conditional length of bolt holes on the control channels with the entry angles of 45^0 and 0^0.

Measurements of the conditional extent of artificial defects on the test section of the track and structural reflectors (bolt holes) on the section of track are made in the program for defectograms interpretation "KRUZ-M" on B-version, by measuring the extent of the echo signals in millimeters with the function of area selection.

The results of conditional extent measurements separately for each range of inspection rates were recorded as Form An according to ISO 5725-2 [10], with each defectoscopy tool considered as a laboratory (i), and each artificial defect or bolt hole - as a corresponding level in the specified form (j). The results of the calculation of the mean values in the basic elements (formula 2 of ISO 5725-2 [10]) and the scatter (variance) values in the basic elements (formula 3 of ISO 5725-2 [10]) were recorded in Forms B and C of ISO 5725-2 [10], respectively. Then, according to formulas 19 - 22 of ISO 5725-2 [10], the total average values were calculated separately for each level (artificial defect or bolt hole) three dispersions: repeatability, interlaboratory and reproducibility.

3 Results

To interpret the results obtained, it is advisable to use a graphical representation of the dependence of precision on the overall mean value. All the calculation procedures outlined in ISO 5725-2 [10] apply to the standard deviations of both repeatability and reproducibility, but given the identity of the dependencies obtained, they will be presented only for reproducibility. As an example, figures 3, 4 show relations between the standard deviation of reproducibility and the general mean value of the conditional length of an artificial reflector when it is detected by the transducer with the input angle of 45° at the control speeds of 15-20, 25-30, 30-35 km/h (figure 3) and between the standard deviation of reproducibility and the general mean value of the conditional length for a bolt hole when detected with the input angle of 0° with the control speed of 15-20, 25-30, 30-35 km/h (figure 4).

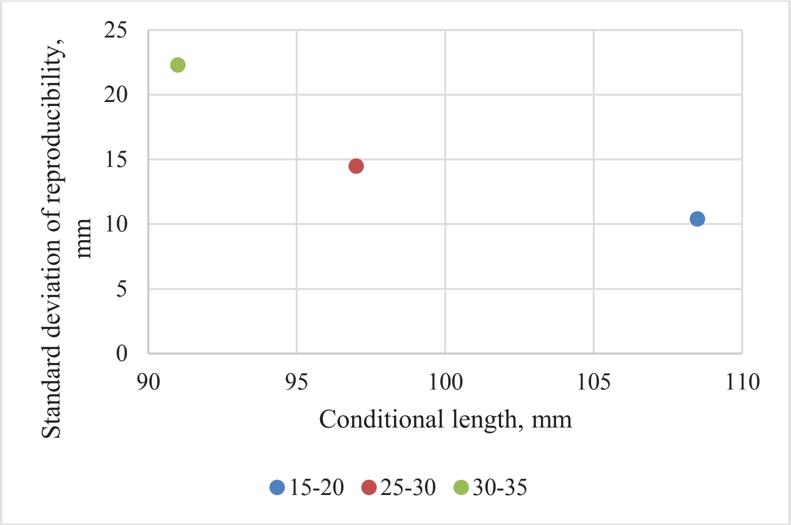

Fig. 3. Dependence of the standard deviation of reproducibility on the total mean value of the conditional length of the artificial reflector (input angle 45°).

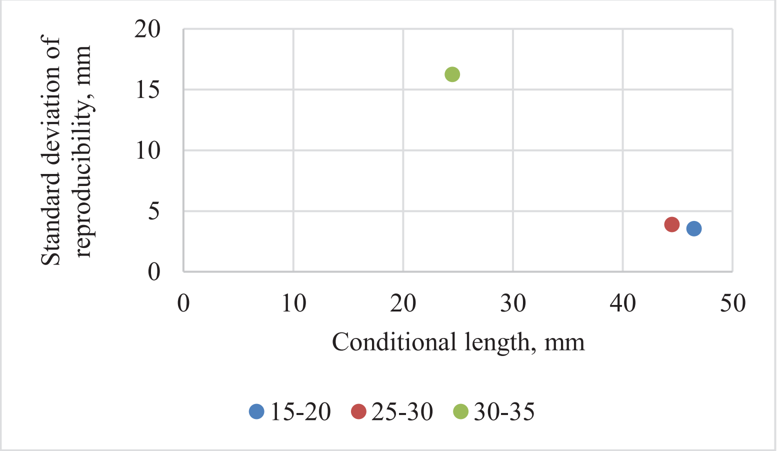

Fig. 4. Dependence of the standard deviation of reproducibility on the total mean value of the conditional length of the bolt hole (entry angle 0°).

4 Analysis of results

As indicated in section 1, the increase in the speed of control of rails affects the measured value of the conditional extent of artificial defects and structural reflectors (Figures 3 and 4). At the same time, as also follows from figures 3 and 4, the precision of measurement results decreases (the scatter of measured values increases), which, taking into account the capabilities of mobile registration systems and decoding programs, can lead to missing defects. However, the obtained results should not be interpreted as an unambiguous recommendation to reduce the speed of control, because the efficiency of control consists not only of its reliability, but also of productivity. Therefore, when adjusting the flaw detection complexes and checking their performance on the test sites it is necessary to perform the specified procedures at the speeds corresponding to the real speed of control. In addition, when analyzing the conditional lengths of structural reflectors, when deciphering the results of control, it is reasonable to evaluate the reproducibility of the results of measurements, for a correct assessment of the obtained lower value of conditional lengths. When comparing this value with the value specified in the technological documentation, you can make a statistically reliable conclusion about the presence or absence (stability) of acoustic contact, and, therefore, about the presence of uncontrolled rail sections. This information can be the basis for the development of risk-oriented approach in the operation of rail defectoscopy tools.

5 Conclusion

Assessment of repeatability and reproducibility of the measurements results of conditional lengths of artificial defects on the track test section and structural reflectors in rails (bolt holes) showed that the values of reproducibility dispersion at control speed from 30 to 40 km/h exceed the corresponding values at lower control speeds of rails, which is associated with a deterioration of acoustic contact of the transducer with the surface of the rails with an increase in control speed. Thus, an increase in speed can lead to non-reproducibility of measurement results of conditional lengths of artificial defects in the test section of the track when testing the serviceability of flaw detection equipment of mobile defectoscopy facilities and real defects during the control of rails. In turn, the loss of acoustic contact, the evidence of which is a decrease in the values of conditional length, will lead to the appearance of uninspected sections. It is reasonable to consider not only the values of conditional extent of structural reflectors, but also the reproducibility of its measurement results when deciphering the results of control to assess the stability of acoustic contact.

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