Analysis of the technique for controlling the eccentricity of wheel sets of rolling stock

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Abstract. The paper deals with the problem of insufficient resource of wheelsets. Existing solutions to the identified problem are considered. The influence of the geometric characteristics of wheelsets on the operating life of the rolling stock and railway track is shown. The control procedure of tread eccentricity of wheels used in the world practice is given. The theoretical study included calculations of components uncertainty of the known control procedure. The analysis of computational data shows that the largest values possess uncorrected deviation uncertainties of position and form of the datum and measured surfaces evaluated by type A. The control of geometric characteristics of wheelsets is proved to be made with low certainty because the uncertainty of measurement exceeds the permissible uncertainty several-fold. The findings of the theoretical studies confirm the need for further scientific and applied works to ensure the control accuracy of geometric characteristics for wheelsets.

1. Introduction
A wheelset is the main element of interaction of a rolling stock and railway track. Its operating life, reliability and other parameters largely determine the quality of carriage by rail. Currently, the main problem is insufficient resource of wheelsets, since this problem directly affects the economic aspects of the rail traffic. The problem of increasing the wheelset operating life is solved simultaneously in different ways: dynamics of the “wheel-rail” interaction [1]; increase of wheels and rails hardness [2]; optimization of wheels and rails profile [3]; lubrication [4] and many others. Among the studies of Russian and international researchers, studies on the influence of geometric characteristics of wheelsets on the operating life of the rolling stock and railway track can be emphasized [5]. It is proposed to analyze the geometric characteristics of wheelsets in terms of the functional purpose in order to assess the degree of influence of these characteristics on the operating life. In addition, it is posed to assess the measurement routine of the wheel eccentricity of wheelsets in terms of unaccounted component uncertainty of measurement.

2. Formatting the title, authors and affiliations
Rail wheelsets in the global rail industry have the same configuration and in general represent the body of rotation with two wheels pressed on one axis (Figure 1). To process the elements of wheelsets at the ends of journals, the center holes that are the technological datums of wheelsets are specified. The main design datums are the wheel threads with the tread diameters of d1 and d2. Treads are phantom sections of conical treads at a distance of 70 mm from the inner edges. The next set of design datums is the axle journals for axle box bearings E and J. The inner edges create the set of measurement datums for the tread surface.

When assessing the accuracy characteristics for the datum surfaces of wheelsets it is revealed that the tread surfaces have the form and position tolerances of the 13th-14th accuracy degree. The journals for...
the axle box bearings are made in the 7th accuracy degree using the principle of datum inversion. The journals for axle box bearings are selected as the main datums for measurements. Reliable control of the form and position of the tread surfaces relative to the journals for axle box bearings is an important component for the reliability of wheelsets during operation. An important task is the analysis of uncertainties arising from the control procedure of wheel eccentricity of wheelsets.

![Figure 1. Rail wheelset.](image1)

3. Theoretical studies

The eccentricity of the wheel $EE$ (Figure 2) is the radial offset of the wheel tread surface axis relative to the axis of the nearest wheelset journal.

The tolerance of eccentricity is regulated by Russian and international standards and industry documents such as Railway Group Standard GM/RT2466.

A measuring device is a control device. It has the form of rack 1 with its prismatic base being rested on the generator of the wheelset journal, and stop 2 contacts the measuring datum which is the inner edge of the wheel.

![Figure 2. Eccentricity measurement.](image2)

Measuring force is caused manually and equals to 1...3 N. The measurement is performed with the readout unit 3 in the form of a scale on the rod with a division value of 1 mm and nonius. Instrumental measurement uncertainty of the device equals to $U_{dev}=0.1$ mm. The measuring pin of the rod is located in the plane of the wheel tread at a distance of 70±0.1 mm from the inner edge.

When making measurements a wheelset is mounted on a rail track. The eccentricity of the tread is determined by the half-difference of maximum and minimum readings of the readout unit in one revolution of the wheelset at 10...20 points of the tread.
The first point on the tread surface must be marked to ensure the last measurement to be made at the same point. If the difference between the first and the last readings is greater than 0.2 mm, then the measurement should be repeated.

### 3.1. Calculation of uncertainty caused by the selected scheme of measurement.

The first component of uncertainty related to the selected scheme of measurement depends on the skewing $\pm AE$ of the wheel tread surface (Figure 3). The tread surface has the axis being offset in the tread by the eccentricity $EE$ relative to the common axes of journals $Z4$ and angular skewing $\pm AE$. Therefore, the eccentricity is a variable within the length of the generator $l_{meas}$.

Taking measurements in the midsection, the mean value $EE_{mid}$ is found. It is necessary to find the maximum value of $EE_{max}$. Consequently, the first component of uncertainty related to the selected scheme of measurement, $U_{ch.1} = f(AE)$ will be equal to:

$$U_{ch.1} = EE_{mid} - EE_{max} = -AE \cdot 0.5 \cdot l_{meas} = -0.5EPA$$

As far as $EPA_d = 2EE_r$, then $U_{ch.1} = -EE_r = -0.5mm$.

The deviation from the parallel alignment of the wheel axes and the axis $EPA$ is not determined by the eccentricity measurement, therefore the uncertainty $U_{ch.1}$ has a random component $U_{ch.1} = 0.25 \pm 0.25$ mm.

![Figure 3. Calculation of uncertainty caused by the selected scheme of measurement.](image)

The second component of uncertainty $U_{ch.2}$ related to the selected scheme of measurement depends on the out-of-roundness of the tread $TFd$.

By definition, the eccentricity is defined in the radial expression, therefore the second component of uncertainty caused by selected scheme of measurement will be equal to half of $TFd$ tolerance for the diameter:

$$U_{ch.2} = 0.5 \cdot TFd = 0.5 \cdot 1.0 = 0.5mm$$

Since it is a random variable, then: $U_{ch.2} = 0.25 \pm 0.25mm$.

### 3.2. Measurement uncertainty caused by the device datum

Uncertainty of measurement caused by the device datum $U_{dat} = f(\Theta)$ arises from the skew angle $\Theta$ of the wheelset axle journal, which is the measuring datum (Figure 4) equipped with the device $U_{dat} = l\Theta$

$$\Theta = TPS / l_2,$$

where $TPS$ is the coaxiality tolerance;

$l$ is the distance between the planes of the tread and the center of the axle journal;

$l_2$ is the axle journal length

$$U_{dat} = TPS \cdot l / l_2 = 0.07 \cdot (250 / 150) = 0.1mm.$$

It is a random variable, so $U_{dat} = 0.05 \pm 0.05mm$. 

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3.3. Measurement uncertainty caused by the force deformation

The uncertainty $U_F$ is generated by the elastic deformation of the device rod from the effect of the measuring force $P_{\text{meas}}$, with which the measuring pin makes pressure on the wheel surface (Figure 5), $\Delta P_{\text{meas}} = \pm F$. The measuring force is generated by the operator's hand, so we admit that the difference in measuring force will be $\Delta P_{\text{meas}} = \pm 5H$.

The uncertainty resulting from the force deformation $U_F$ is calculated by the equation

$$U_F = f(\Delta P_{\text{meas}}) = \frac{F \cdot l^2}{E} \left( \frac{S}{J_S} + \frac{l}{3J_K} \right),$$

(1)

where

- $F$ is the frictional force (measuring pressure);
- $E$ is the modulus of elasticity of rack 1 and bracket 2;
- $J_S, J_K$ are moments of inertia of the rack cross-section 1 and bracket 2 of the measuring device.

The numerical value of uncertainty is:

$$U_F = \pm \frac{5 \cdot 250^2}{2 \cdot 10^5} \left( \frac{450}{3.2 \cdot 10^4} + \frac{250}{3 \cdot 1.3 \cdot 10^4} \right) = \pm 0.03 \text{mm}$$
The contact deformations in the contact zone of the measuring pin with the wheel surface and the elastic deformations of the wheelset under measuring pressure and weight of the device can be neglected due to their small quantities.

4. Research results

The measured quantity is the axis eccentricity of the wheel tread surface relative to the axle of the wheelset journal. The tolerance of eccentricity is equal to $TE = 0.5 \text{ mm}$. The permissible uncertainty of the measurement is $TEe = 30\%TE = 0.3 \cdot 0.5 = 0.15 \text{ mm}$.

The total measurement uncertainty evaluated by type A is calculated by the equation:

$$\bar{U} = \sqrt{U_{dev}^2 + U_{ch.1}^2 + U_{ch.2}^2 + U_{dat}^2 + U_{F}^2} = \sqrt{0.01 + 0.0625 + 0.0625 + 0.0025 + 0.0009} = 0.37 \text{ mm}$$

The total measurement uncertainty evaluated by type B is calculated by addition of the components:

$$\bar{U} = U_{ch.1} + U_{ch.2} + U_{dat} = -0.25 + 0.25 + 0.05 = +0.05 \text{ mm}$$

The limit uncertainty is calculated from the formula $\bar{U} = |\bar{U}| + |\bar{U}|$ and is 0.42 mm.

5. Results discussion

The analysis of the eccentricity control procedure of the wheels revealed that the limit measurement uncertainty of 0.45 mm exceeds the permissible quantity of 0.15 mm by the factor of 3. The main measurement uncertainty accounts for uncertainties evaluated by type A. The components of the measurement uncertainty are summarized in the table 1.

| Uncertainty | Numerical value of uncertainty, mm |
|-------------|-----------------------------------|
| Instrumental measurement uncertainty of device $U_{dev}$ | $\pm 0.10$ | $-$ |
| Uncertainty related to the selected scheme of measurement: $U_{ch.1}$ | $\pm 0.25$ | $-0.25$ |
| $U_{ch.2}$ | $\pm 0.25$ | $+0.25$ |
| Measurement uncertainty caused by the device datum $U_{dat}$ | $\pm 0.05$ | $+0.25$ |
| Measurement uncertainty caused by the force deformations $U_{F}$ | $\pm 0.03$ | $-$ |
| Total | $\pm 0.37$ | $+0.05$ |
| Limited | $0.42$ | |
| Permitted | $0.15$ | |

To eliminate the effect of random uncertainty components and to bring industry documents to international standards, the proposals for increasing the accuracy control of the form and position for the wheel tread surfaces relative to the wheelset journal have been developed:
substitution of the eccentricity tolerance (alignment) in the radial expression as being noninspectable for the radial runout tolerance which has a diametric expression and includes deviations from the roundness of the tread surface;

- modification of the measuring procedure and creation of a new device which allows using a common axle of the journals for axle box bearings as a datum and measuring the tread surface in the two extreme cross-sections.

6. Conclusion

As a result of studies it is verified that operating life of wheelsets is determined by many factors and at present we cannot assert that any of the factors dominates. The least examined area is the measurement assurance of the life cycle for wheelsets. The analysis of the control procedure for the wheel eccentricity of wheelsets demonstrates that the control of geometric characteristics of wheelsets is carried out with low accuracy, and the measurement uncertainty exceeds the permissible one several-fold. The uncorrected deviation uncertainties of the form and position of the datum and measured surfaces have the highest values. The results showed that to ensure the control accuracy of geometric characteristics of wheelsets, it is advisable to conduct research and development to develop measuring instruments and reference documentation satisfying current requirements of metrology.

References

[1] Moreau A.: Characteristics of wheel/rail contact, *Rail Engineering. International Edition*, 1992, 3 pp 15-22

[2] Paul Molyneux-Berry, Claire Davis, and Adam Bevan 2014 The Influence of Wheel/Rail Contact Conditions on the Microstructure and Hardness of Railway Wheels *The Scientific World Journal* Volume Article ID 209752 pp 16

[3] Waara P 2001 Lubricant influence on flange wear in sharp railroad curves *Industrial lubrication and tribology* 53 4 pp 161-168

[4] Lin F, Dong X and Wang Y 2015 Multiobjective optimization of CRH3 EMU wheel profile *Adv Mech Eng* 7 pp 1–8

[5] Asplund Matthias, Palo Mikael, Famurewa Stephen and Matti Rantatalo 2014 A study of railway wheel profile parameters used as indicators of an increased risk of wheel defects *Proceedings of the Institution of Mechanical Engineers. Part F: Journal of Rail and Rapid Transit published online* 230 2 pp 323-334