Article citation info:
Garczarek A, Woźniak K, Olejniczak T., Waśkowicz R, Stachowiak D. Determination of the reactance of rail vehicles wheelsets. Rail Vehicles/Pojazdy Szynowe. 0000;xx:xx-xx. https://doi.org/10.53502/RAIL-168083

Rail Vehicles/Pojazdy Szynowe

www.railvehicles.eu

Determination of the reactance of rail vehicles wheelsets

Adam **Garczarek** [a, *], Krystian **Woźniak** [a], Tomasz **Olejniczak** [a], Radosław **Waśkowicz** [a], Dorota **Stachowiak** [b]

[a] *Division of Rail Vehicle Testing, Łukasiewicz Research Network – Poznan Institute of Technology, Poznan, Poland*
[b] *Faculty of Control, Robotics, and Electrical Engineering, Poznan University of Technology, Poland*

ARTICLE INFO

Received: 23 April 2023
Revised: 16 Mai 2023
Accepted: 11 June 2023
Available online: 18 June 2023

KEYWORDS

Resistance
Impedance
Reactance
Traction vehicles
Measurement methodology
Wheelset

The article presents issues related to the determination of resistance, impedance, and reactance of rail vehicles wheelsets in relation to applicable standards and regulations. The methodology of conducting this type of test is discussed, and a configured test stand is presented to measure the resistance and impedance of the wheelsets. The uncertainty budget for this type of testing is discussed. Exemplary measurement results are presented and analyzed.

1. Introduction

One of the most frequently used track occupancy control systems in the Polish railway network is the so-called track circuits based on the control of rail track closure by the wheel set of the vehicle moving on it. It is usually a closed track circuit powered by alternating current, consisting of a transmitter (power source) and a receiver (track relay) installed on an insulated section (a part of the track limited by insulated connectors). When the track section is unoccupied, the signal current flows in the circuit from the transmitter through one of the rail lines to the receiver and returns to the transmitter via the other route. In the case of entering a rolling stock section, the rails are short-circuited through its wheelsets, which de-energizes the track relay, signaling that the section is occupied. Figure 1 shows a typical track layout.

Classic track circuits used in Poland operate at a frequency of 50 Hz, while jointless track circuits use frequencies from 1500 Hz to 36 kHz [1]. A detailed breakdown is presented in Table 1 based on [2].

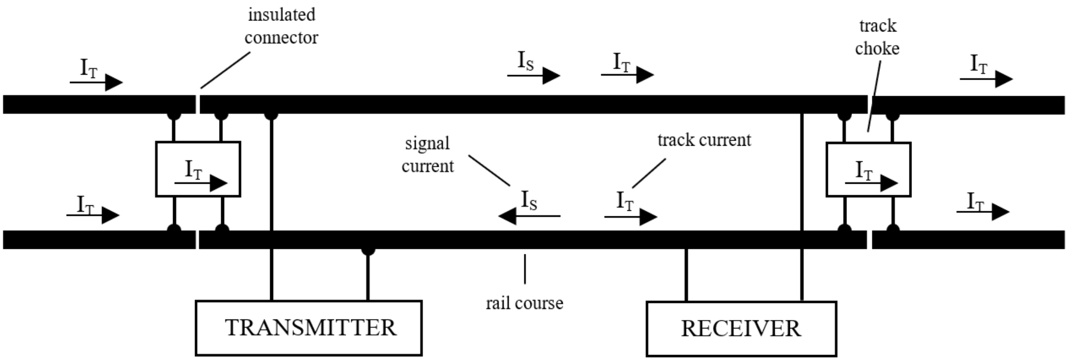

Fig. 1. Track circuit diagram

* Corresponding author: adam.garczarek@pit.lukasiewicz.gov.pl (A. Garczarek)

Table 1. Operating frequencies of RTC devices

Type of track circuit	Operating frequency [kHz]
Classic	0.05
Connectorless linear and station	1.58; 1.86; 2.17; 2.47; 2.8
Connectorless crossover	7; 8; 10; 12.15; 14.6; 16.8
Train sensor	10; 14.6; 19; 20.8; 23.4; 26.1; 28.7; 31.5; 34.6; 38.2

Based on the parameters of the track system, the sensitivity of the track circuit shunting system is determined. In order for the system to work properly, the reactance value (in some studies, the impedance is given) of the shunt is important and it should be at least one order lower than the system's own reactance.

It should be noted that the rail course is also used as a return conductor for the current supplying the rail vehicles, so the traction current must be isolated from the signal current.

Track chokes installed in insulated joints are used for this purpose. They allow the traction current to flow while stopping the signal current. Systems with similar functions are also used, such as open track circuit or electronic overlay circuit (EOC).

Wheelsets are one of the most important components of a rail vehicle and must meet several requirements. The determination of the resistance and impedance of wheelsets should be made according to the requirements of point 7.6.2.4. of the Annex to the Commission Regulation (EU) 2016/919 of 27 May, 2016 [3], as amended by the Commission Implementing Regulations (EU) 2019/776 of 16 May, 2019 [4]. Previously, such requirements were also included in Annex S-05 of the UTK President's letter [5]. The latest edition of the President's letter [6] does not contain these requirements.

Despite the existence of reference documents, the provisions contained therein are extremely general – "*The electrical resistance between the rolling surfaces of the opposite wheels of the wheelset does not exceed 0.05 ohm when measured with a voltage in the range of 1.8 VDC to 2.0 VDC (open circuit). In addition, the electrical reactance between the running surfaces of the opposite wheels of the wheelset shall not exceed f/100 milliohms, where f is in the range from 500 Hz to 40 kHz, with a measuring current of 10 A RMS and a voltage of 2 V RMS with an open circuit*" [3].

Such a record of requirements allows for some freedom in the method of carrying out this type of research, which depends in particular on the measurement equipment and the experience of the measurement team. This problem is quite often discussed in the available publications on this subject [7, 8]. However, much more attention is being paid to the problems associated with their damage [9] and the measurement of forces [10].

The lack of a specified acceptable measurement uncertainty the resistance and impedance of wheelsets may result in performing tests with a set of apparatus introducing a large measurement error. Therefore, this paper discusses the methodology for conducting resistance, impedance, and reactance tests on wheelsets.

2. Methodology for determining the resistance, impedance and reactance of wheelsets

The determination of reactance on the basis of resistance and impedance measurements of wheelsets consists of measuring the voltage drop and current flowing through the wheelset isolated from the rails using the technical method.

Wheelsets of rail vehicles such as: locomotives, traction units, special vehicles, trams, wagons and others can be test objects.

As a standard, the wheel set impedance is determined for 12 selected frequencies, at the beginning and end of the required measurement range resulting from documents [3, 4] and [5], and for the frequencies at which RTC devices operate: 0.5, 1, 1, 5, 2.5, 8, 10, 15, 20, 25, 30, 35, 40 kHz.

The general scheme of the measurement system is shown in Fig. 2, while Fig. 3 shows the actual wheelset during the measurements.

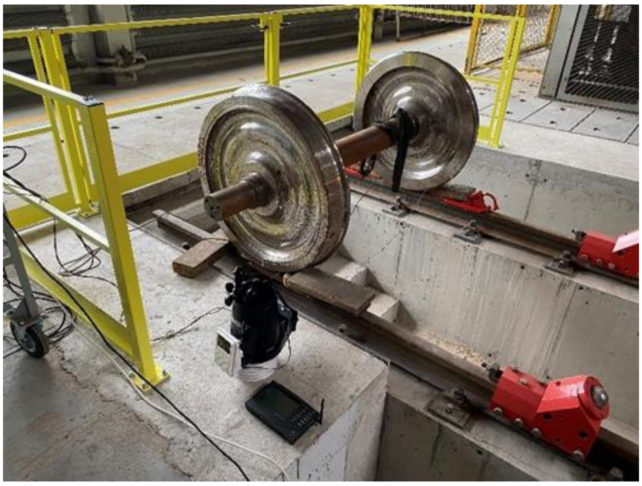

Fig. 2. Wheelset during comparative measurements

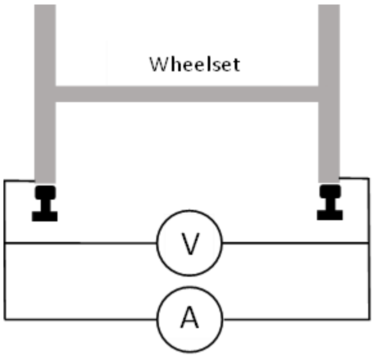

Fig. 3. Scheme of the measuring system

For impedance measurements, the test current is not less than 10 A RMS and the open-circuit voltage is 2 V RMS.

According to the standard requirements, the resistance of the wheelset should not exceed 0.05 Ω, while the reactance of the wheelset in the frequency range from 0.5 to 40 kHz should not exceed f/100 expressed in "mΩ", as shown in Fig. 4.

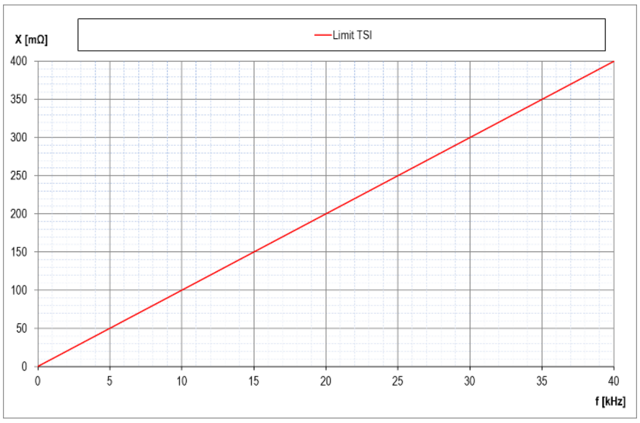

Fig. 4. Graphical interpretation of the TSI limit [2]

3. Measuring station

The tests shall be carried out in a place that allows safe lifting of the wheelsets. It is optimal to lift the wheelsets in halls industrial buildings equipped with stationary lifts with an appropriate lifting capacity, however, field test conditions often require the use of manual hydraulic jacks on properly hardened ground, while maintaining special safety conditions.

During the measurements related to the determination of resistance, impedance and reactance of wheelsets, environmental conditions related to the used measuring equipment are taken into account, therefore they are carried out at a temperature of 0–30°C. It is unacceptable to perform measurements in the open during precipitation and high humidity.

An exemplary set of equipment designed to perform measurements enabling the determination of resistance, impedance and reactance is presented below:

- DC power supply
- power amplifier
- multimeter
- signal generator
- oscilloscope
- current probe
- resistor.

Before the measurements, the rolling surfaces of the wheelsets are cleaned of rust and dirt. The places of contact of the measuring electrodes with the set wheels are thoroughly cleaned.

Figure 5 shows how to install the measuring probes on the wheelset. Figures 6 and 7 show, in turn, diagrams of the resistance and impedance measurement systems of the wheelsets, while Fig. 8 shows the measuring apparatus during the tests.

Fig. 5. Placement of the measuring probe

After preparing the test object and checking the measuring equipment, the value of the open circuit voltage is measured for the DC measurements and variables. Measurements of resistance and impedance of wheelsets are made with a current of not less than 10 A.

Impedance measurement is carried out for several frequencies, selected on the basis of sensitivity analyzes of railway traffic control devices to interference currents.

The dependence of impedance as a function of frequency in the absence of interference factors is linear. The lack of linearity on the basis of the measurements may indicate damage to the wheelset or disturbance of the measuring track.

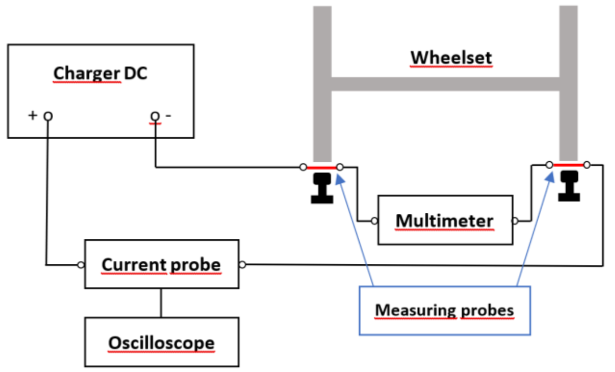

Fig. 6. Scheme of the resistance measurement system using the technical method

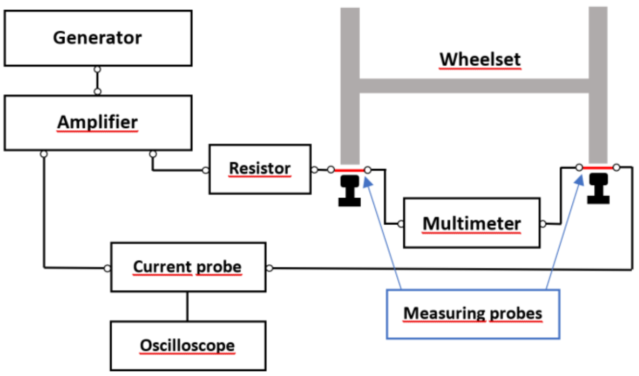

Fig. 7. Scheme of the impedance measurement system using the technical method

Fig. 8. A set of measuring equipment during tests

The resistance and impedance R(Z) are calculated from the relationship:

$$R(Z) = \frac{U_x}{I_x} \quad (1)$$

where: R(Z) – resistance (impedance) of the wheelset between the rolling surfaces of the wheels lying on the opposite side of the set, U_x – voltage drop between the measurement point on the running surfaces of the wheels on the opposite side of the set, I_x – test current intensity.

The reactance is calculated from the relationship:

$$X = \sqrt{Z^2 - R^2} \quad (2)$$

where: X – wheel set reactance between the running surfaces of the wheels on the opposite side of the set.

4. Uncertainty of measurement

The total uncertainty of determining the impedance of wheelsets is calculated according to the following relationship:

$$u(Z) = \sqrt{u(Z_A)^2 + u(Z_B)^2} \quad (3)$$

where: $u(Z_A)$ – type A statistical uncertainty, $u(Z_B)$ – type B uncertainty.

Type A statistical uncertainty is determined by fitting a straight line to the technically determined impedance values using linear regression in MS EXCEL. This value is determined using the LINEST function. The effect of using the function described above for exemplary results is presented in Table 2.

Table 2. Sample measurement values

f	I_{pom}	ΔU_{zest}	Z
[kHz]	[A]	[mV]	[mΩ]
0.5	11.2	57.994	5.18
1	11.2	100.493	8.97
1.5	11.2	139.59	12.46
2.5	11.3	199.99	17.70
8	11.7	703.47	60.13
10	10.2	775.37	76.02
15	10.9	1259.61	115.56
20	11.4	1750.3	153.54
25	11.7	2261.3	193.27
30	11.7	2729.3	233.27
35	11.1	3068.3	276.42
40	10.5	3347.1	318.77

a	7.8913	–1.3510	b
sea	0.0553	1.1452	seb
R^2	0.9995	2.5859	sey

The standard error of the impedance value $u(Z_A)$ for the data in the table above is 0.33 mΩ.

Type B uncertainty is determined on the basis of calibration certificates and technical documentation of the measuring devices.

The expanded uncertainty is determined with a confidence level of approximately 95% and a coverage factor of k = 2.

5. Measurements

According to the requirements of Commission Regulation (EU) 2016/919 of 27 May, 2016, in the field of special cases for Poland, tests were carried out to determine the resistance and impedance of the wheelsets. The presented results were realized with the set of measuring apparatus described above.

Figure 9 shows a summary of the test results for a six-axle diesel locomotive built on two types of bogies with evenly distributed load on individual wheels. The grouping of individual results divided into carts is clearly visible. The type 1 set clearly obtained lower values.

Figure 10 presents the results of the measurements presented in Table 3 in a graphical form. They show example measurements of six completely different railway vehicles. The highest values of reactance determined close to the limit were obtained by a heavy working vehicle, and the lowest by an electric locomotive.

According to Fig. 10, the values obtained depend not only on the mass of the vehicle, but also on the precision of the preparation of the measurement points, which is indicated by a clear division in Fig. 9.

Table 3. Examples of measurement values for different rail vehicles

f [kHz]		I_{pom} [A]	ΔU_{zest} [mV]	Z/R [mΩ]	X [mΩ]		I_{pom} [A]	ΔU_{zest} [mV]	Z/R [mΩ]	X [mΩ]		I_{pom} [A]	ΔU_{zest} [mV]	Z/R [mΩ]	X [mΩ]
DC	Diesel special vehicle	11.1	1.69	0.152	–	Diesel locomotive	10.7	0.434	0.041	–	Electric locomotive	11.0	5.925	0.539	–
0.5		11.3	35.4	3.1	3.1		10.6	51.1	4.8	4.8		11.3	33.8	3.0	3.0
1		10.2	52.1	5.1	5.1		10.8	96.3	8.9	8.9		10.2	48.0	4.7	4.7
1.5		10.2	70.6	6.9	6.9		10.3	126.7	12.3	12.3		10.2	62.5	6.1	6.1
2.5		11.2	117.0	10.4	10.4		10.6	191.0	18.0	18.0		10.1	89.9	8.9	8.9
8		10.6	302.5	28.5	28.5		10.8	598.4	55.4	55.4		10.6	247.2	23.3	23.3
10		10.3	358.6	34.8	34.8		10.9	734.0	67.3	67.3		10.4	290.0	27.9	27.9
15		11.1	563.0	50.7	50.7		11.2	1104.4	98.6	98.6		11.2	445.2	39.8	39.7
20		10.3	689.4	66.9	66.9		10.5	1405.7	133.9	133.9		10.5	540.8	51.5	51.5
25		10.6	893.7	84.3	84.3		10.8	1809.4	167.5	167.5		11.0	700.2	63.7	63.7
30		11.7	1159.7	99.1	99.1		11.8	2354.1	199.5	199.5		10.1	765.9	75.8	75.8
35		10.5	1219.1	116.1	116.1		10.5	2484.6	236.6	236.6		10.8	946.4	87.6	87.6
40		11.1	1482.2	133.5	133.5		11.4	3109.0	272.7	272.7		10.1	988.1	97.8	97.8

f [kHz]		I_{pom} [A]	ΔU_{zest} [mV]	Z/R [mΩ]	X [mΩ]		I_{pom} [A]	ΔU_{zest} [mV]	Z/R [mΩ]	X [mΩ]		I_{pom} [A]	ΔU_{zest} [mV]	Z/R [mΩ]	X [mΩ]
DC	Heavy working machine	10.5	0.627	0.060	–	Electric multiple unit	11.6	0.949	0.082	–	Passenger car	10.4	1.379	0.133	–
0.5		11.0	53.1	4.8	4.8		11.3	31.0	2.7	2.7		11.4	35.3	3.1	3.1
1		11.0	109.4	9.9	9.9		11.3	55.2	4.9	4.9		11.3	56.2	5.0	5.0
1.5		11.4	154.8	13.6	13.6		10.9	75.3	6.9	6.9		10.2	67.4	6.6	6.6
2.5		10.9	250.6	23.0	23.0		11.2	122.4	10.9	10.9		11.2	110.0	9.8	9.8
8		11.4	780.0	68.4	68.4		10.6	339.2	32.0	32.0		10.5	281.0	26.8	26.8
10		11.0	980.0	89.1	89.1		10.4	409.0	39.3	39.3		10.4	339.0	32.6	32.6
15		10.3	1376.0	133.6	133.6		10.6	613.7	57.9	57.9		11.2	531.0	47.4	47.4
20		10.9	2040.0	187.2	187.2		10.5	797.6	76.0	76.0		10.2	640.0	62.7	62.7
25		11.6	2700.0	232.8	232.8		11.1	1042.5	93.9	93.9		10.8	841.0	77.9	77.9
30		10.7	2976.0	278.1	278.1		10.2	1161.3	113.9	113.9		11.6	1084.0	93.4	93.4
35		10.1	3298.0	326.5	326.5		11.1	1443.9	130.1	130.1		10.3	1120.0	108.7	108.7
40		10.2	3794.0	372.0	372.0		10.1	1505.9	149.1	149.1		10.8	1359.0	125.8	125.8

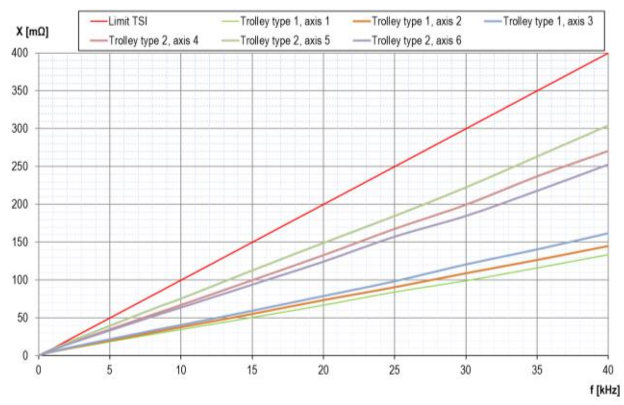

Fig. 9. Reactance of diesel locomotive wheelsets

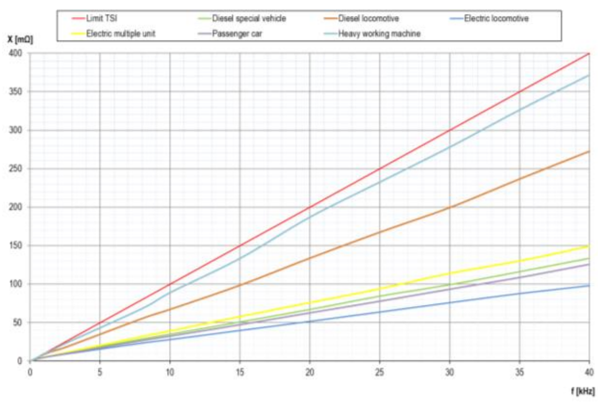

Fig. 10. Reactance of sets of various rail vehicles

6. Summary

One of the first problems encountered during the implementation of measurements is the question of what size is required as the final result of the research. On the basis of the presented results, it is easy to conclude that the value of the obtained resistances is at least one order lower than the impedance value at the beginning of the range, and the difference increases to two or three orders with increasing frequency. Therefore, the resistance value is negligibly small, however, its formal inclusion should oblige to provide the final results as the reactance of the wheelsets.

Based on many years of experience in conducting this type of research, it can be said that, in general, manufacturers of wheelsets have no problem meeting the normative requirements, however, to ensure the safety of railway traffic control, it is necessary to install track circuits with the highest reactance sensitivity. On the other hand, it is important that the wheelsets have the lowest resistance and transition impedance. In a comprehensive approach, it is also necessary to take into account the values of resistance and impedance of the transition between the contact surface of the wheel with the rail course, which is particularly affected by the lubrication of the wheel flanges and the appropriate condition of the rails.

Nomenclature

RTC	Railway Traffic Control
RMS	root mean square
DC	direct current
R	resistane
Z	impedance
X	reactance
EU	European Union
EOC	electronic overlay circuit

Bibliography

[1] UNE EN 50617-1:2015 Railway applications - Technical parameters of train detection systems for the interoperability of the trans-European railway system – Part 1: Track circuits.

[2] Białoń A, Furman J, Kazimierczak A, Zawadka Ł. Impedancja osi zestawu kołowego a bezpieczeństwo ruchu kolejowego – cz. I. Infrastruktura Transportu. 2013;4:12-15.

[3] Commission Regulation (EU) 2016/919 of 27 May 2016 on the technical specification for interoperability relating to the 'control-command and signalling' subsystems of the rail system in the European Union.

[4] Commission Implementing Regulation (EU) 2019/776 of 16 May 2019 amending Commission Regulations (EU) No 321/2013, (EU) No 1299/2014, (EU) No 1301/2014, (EU) No 1302/2014, (EU) No 1303/2014 and (EU) 2016/919 and Commission Implementing Decision 2011/665/EU as regards the alignment with Directive (EU) 2016/797 of the European Parliament and of the Council and the implementation of specific objectives set out in Commission Delegated Decision (EU) 2017/1474.

[5] Lista Prezesa Urzędu Transportu Kolejowego w sprawie właściwych krajowych specyfikacji technicznych i dokumentów normalizacyjnych, których zastosowanie umożliwia spełnienie zasadniczych wymagań dotyczących interoperacyjności systemu kolei z dnia 19 stycznia 2017 r.

[6] Lista Prezesa Urzędu Transportu Kolejowego w sprawie właściwych krajowych specyfikacji technicznych i dokumentów normalizacyjnych, których zastosowanie umożliwia spełnienie zasadniczych wymagań dotyczących interoperacyjności systemu kolei z dnia 05 listopada 2021 r.

[7] Białoń A. Rolling stock wheel set axle impedance and its influence on the work of traffic control devices. Technika Transportu Szynowego. 2018,12:34-37.

[8] Hardwick C, Lewis S, Lewis R. The effect of friction modifiers on wheel/rail isolation at low axle loads. P I Mech Eng F-J Rai. 2014;228(7):768-783. https://doi.org/10.1177/0954409713488102

[9] Kowalski S, Lachowski P. Selected damage and wear of wheelsets of rail vehicles. Autobusy: technika, eksploatacja, systemy transportowe. 2018;12:480-485. https://doi.org/10.24136/atest.2018.437

[10] Wu P, Zhang F, Wang J, Wei L, Huo W. Review of wheel-rail forces measuring technology for railway vehicles. Adv Mech Eng. 2023;15(3). https://doi.org/10.1177/16878132231158991