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Maciej GRZYWNA[1], **Maciej SZKODA**[2*]

EXAMINATION OF SELECTED GEOMETRICAL PARAMETERS OF WHEELSETS OF ELECTRIC MULTIPLE UNIT

Summary. The aim of the work is to investigate changes in the values of selected geometrical parameters of electric multiple unit (EMU) wheelsets as a function of mileage. Based on the conducted analysis of the literature, it was found that the problem of proper diagnostics and maintenance of wheelsets, as an element that directly affects the level of safety of railway vehicle traffic, is very up-to-date and justified. This work presents the characteristics of the geometrical parameters of the wheelset that were subjected to the tests. According to the terminology of EN 13715:2020-12, the geometrical parameters of the wheelset subjected to tests were characterized. As part of the research work, data from measurements of the values of the main geometrical parameters of the outer contour of the wheelsets were collected and systematized from 204 measurement sheets of vehicles. Data were collected from specially developed registers and databases. The research and analyses confirm the existence of a correlation between changes in the values of diagnostic characteristics of flange thickness and height and flange steepness as a function of kilometrage. The intensity of wheel rim wear changes depending on the conditions under which the vehicle is operated. The wheelsets' diagnostic characteristics were not fully predictable, which makes it difficult to forecast their future values. Based on the obtained results, actions that increase the durability of the wheels were proposed. For example, it is reasonable to assign vehicles to different routes so that the wheel rims wear evenly, eliminating the need for the subsequent accumulation of repairs and wheelset replacements before repair at the P4 level. Moreover, it is advisable to undertake work on the change of identification of basic individual primary characteristics of the wheel's external contour into primary characteristics of a collective nature. As a result of such action, it is possible to indicate the probability of occurrence of non-uniformity of values of diagnostic characteristics on the wheel circumference could be limited and the phenomenon of occurrence of measurement errors could be minimized.

1. INTRODUCTION

A wheelset is an essential component of a railway vehicle whose durability and reliability determine the safety of railway traffic. Therefore, it is important to continuously examine its value in use, which depends on the technological quality and the physic-mechanical properties of the materials used, as well as the conditions under which the rail vehicle is operated. In general, the service life of a wheelset is determined mainly by the intensity of the wear process. The appropriate design of running wheels, which are rigidly connected by an axle, enables the rail vehicle to interact correctly with the railway track. The characteristics of the wheelset load during driving influence the occurrence of many kinds of damage, resulting from, among other factors, fatigue and friction wear, primarily in the contact area between the

[1] Cracow University of Technology, Doctoral School; Jana Pawla II Str. 37, 31-864 Cracow, Poland; email: maciej.grzywna@doktorant.pk.edu.pl; orcid.org/0000-0002-0735-3349
[2] Cracow University of Technology, Department of Rail Vehicles and Transport; Jana Pawla II Str. 37, 31-864 Cracow, Poland, email: maciej.szkoda@pk.edu.pl; orcid.org/0000-0002-9511-2253
* Corresponding author. E-mail: maciej.szkoda@pk.edu.pl

tread and flange of the wheel and the rail head surface (Fig. 1) [10]. The wear of the wheelset components is influenced by processes that occur even before the operation phase, such as the design, construction, and production of the means of transport concerned. Increased damage intensity during operation may be a direct result of errors occurring during the aforementioned phases [15].

The issues of wheel rim wear intensity, research, and forecasting of wheel wear in rail vehicles are addressed in numerous scientific papers [8, 12, 19 21, 26]. In some papers [4, 27, 29], the authors described the mechanism of the initiation and development of polygonal wear of rail vehicle wheels. Based on operation research and analyses, it was found that the polygonal wear of wheels increases the wheel-rail interaction force drastically and adversely affects the safety and comfort of the train [29]. In another paper [27], the bending resonance of a wheelset was considered an important cause of polygonal wear. In addition, in [4], the authors used a long-term wear iteration and concluded that the growth progress of the typical polygonal wear on China's high-speed trains was reproduced. Parametric studies have shown that the dominant order of the polygonal wear largely depends on the vehicle's speed and wheelbase. A previous paper [1] presents the simulation process for predicting wheel wear evolution and its validation by comparing simulated results with in-service wheel profile measurements. The generality of the method has been verified by applying it to two different operational cases with very different track characteristics. In another study [28], the effect of passing trains on wheel wear was analyzed for the whole train, different cars, and different axles. The proposed method can provide an accurate basis for prediction of wheel wear. The semi-Hertzian theory and Kalker's simplified theory were used to solve wheel and rail contact problems.

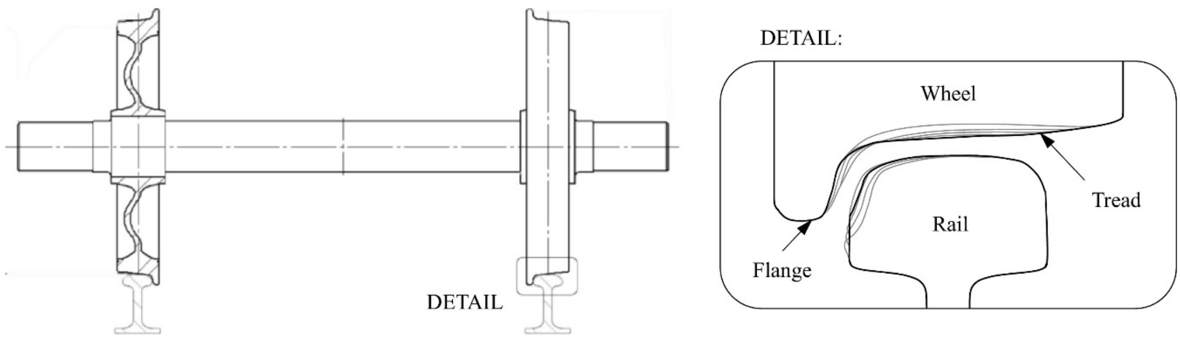

Fig. 1. Wheelset and rail head detailing changes in the geometry of the contact areas [2]

This publication presents the results of a study on changes in the geometrical parameters of wheelsets of electric trains as a function of kilometrage. These geometrical parameters occur in the diagnostics of wheel rolling profiles. The geometry of the wheel profile influences the dynamics of the movement of the rail vehicle on the track through the equivalent conicity, which induces a centering force that ensures stable vehicle movement when traversing straight sections and track curves. The correct profile of the wheel also has an influence on the derailment criterion (fulfilling the so-called Nadal's criterion). In particular, this is important when passing through switch rails and when running the wheel over a crossing when it is damaged or not sufficiently protected by the check rail. The third key property is the relevant physical-mechanical properties of the wheel material [9, 23]. Research on increasing the reliability and durability of rail vehicle wheels as a result of the use of new materials and technologies for wheelsets has been the subject of many papers. For example, in [11], the results of research on the fretting wear process in the wheelsets of rail vehicles are presented, while [22] provides a general data on present research in the field of tribotechnical systems and offers alternative variants of development of domestic tribotechnical systems for railway transportation.

The technical condition of the wheelset plays an important role in the assessment of the reliability and operational safety of railway vehicles. In the classification of a wheelset as an element of the railway safety system, it should be assigned the rank of a critical element, which was confirmed in previous research [20]. This study showed that defects related to wheels, such as cracks and the movement of the wheel in the axle seat, are failures with severe consequences. The consequences of a risk associated with the failure of a wheelset can be very serious and lead to events classified as major train accidents, resulting in significant material damage and loss of life [13]. These consequences result from the analysis presented in [7], which showed that the highest total costs related to the occurrence of serious railway accidents arise in events where the malfunction of the wheelset was indicated as the direct cause.

2. ASSESSMENT OF THE TECHNICAL CONDITION OF THE WHEELSET

Regular assessments of the wheelset's technical condition are needed to ensure appropriate reliability and to limit the risk of wheelset damage between scheduled maintenance and, thus, the occurrence of the abovementioned adverse events. The frequency and scope of this assessment are defined for each type of unit design in the relevant maintenance system documentation.

Directive 2008/110/EC of the European Parliament and of the Council of December 16, 2008, defined the entity in charge of maintenance (ECM) for the first time. The idea of putting an entity in charge of maintenance was developed in the Directive of the European Parliament and of the Council (EU) 2016/798 of May 11, 2016, on railway safety. The introduction of this concept was aimed to unambiguously assign the responsibility for servicing the vehicle to a specific entity and not (as was the case so far) to a number of different entities coexisting on the rail transport market. The ECM is assigned to each unit before it is put into service. This entity is recorded in the vehicle register in accordance with Art. 47 of Directive (EU) 2016/797. By applying an appropriate vehicle maintenance system, this entity ensures the safe use of vehicles.

In the context of the assessment of the wheelset condition, in addition to the maintenance system documentation applicable to the structural type of the railway vehicle, there may be parallel internal ECM manuals (e.g. [5, 16, 17]). These documents define the technical requirements for the wheelsets, the maintenance of which is the responsibility of the entity. They usually specify the geometrical parameters of the wheelsets to be assessed, the rules for this assessment, the methods for repairing the rolling profile, and the documents required for the wheelset maintenance process.

All instructions adopted for defining the requirements for the assessment of the technical condition of a wheelset with wheels having rolling circle diameters equal to or greater than 330 mm in the context of the assessment of the geometry of the wheel rolling profile must be in accordance with EN 13715:2020-12 [18]. This standard applies to vehicles complying with Directive 2016/797 on the interoperability of the rail system within the European Union [6] and which introduced and defined the Technical Specifications for Interoperability (TSI) – for wheels and wheelsets, it is the TSI LOC & PAS and TSI WAG). The standard defines three basic wheel rolling profiles:

- 1/40 (with an external bevel of 15%)
- S1002 (with an external bevel of 6.7%)
- EPS (with an external bevel of 10%)

These profiles are valid for new, free-standing wheelsets, as well as for wheels that have been fitted on a vehicle and have been classified during maintenance as requiring reprofiling (i.e., the restoration of the permissible wheel profile). The S1002 profile—the so-called European profile–is valid in the EU. An outline of this rolling profile, along with its characteristic points, is presented in Fig. 2.

The markings used in Fig. 2 are summarized in column 1 of Table 1 and the explanations in column 3. According to EN 13715:2020-12, the rolling profile S1002 complies with the UIC/ORE profile for wheels with diameters between 760 mm and 1000 mm (flange height = 28 mm), which is specified in UIC Leaflet 510-2 [25].

A proper assessment of the technical condition of a wheelset requires the creation of a set of characteristics of the internal structure, as shown in Fig. 3, which, according to the classification developed in [24], includes measurable and non-measurable characteristics.

In principle, non-measurable features should be classified as binary values (e.g., metallic or non-metallic wheel sound). Measurable features are represented as the numerical values.. These features are divided into primary and secondary, with the former being predominant. Primary measurable characteristics can be determined by direct or indirect measurements using appropriate physical quantity transducers (e.g., the wheel diameter in the rolling circle). Specialized equipment is required to measure some of these (e.g., an ultrasonic defectoscope is needed for axle testing). The primary measurable features are divided into individual and collective features. Individual features are assessed by a single measurement (e.g., the resistance of a wheelset), while the assessment of collective features is based on the average value of several measurements (e.g., the ring thickness of a rimless wheel at three points on the circumference of the wheel, approximately every 120°).

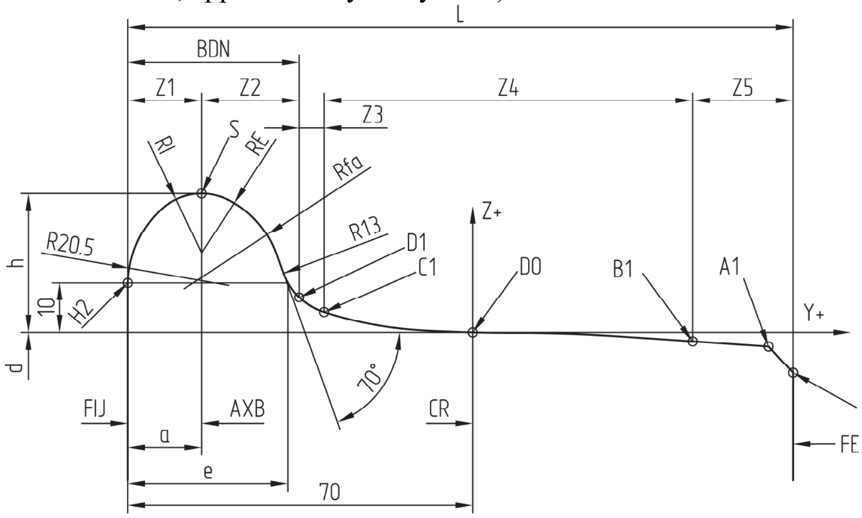

Fig. 2. Outline of the rolling profile according to PN-EN 13715:2020-12

Secondary characteristics result directly from relationships between the primary characteristics. They can be classified as intrinsic–relating only to the tested wheelset (e.g., the diameter difference in the rolling circle of the wheelset)–and extrinsic–relating to the tested bogie or vehicle (e.g., the diameter difference in the rolling circle of the bogie) [24].

The following basic geometrical parameters of the internal structure, which were used to assess the condition of the wheel rolling profile, were taken into account when carrying out the tests:

- rim thickness (*O*) or the ring thickness of a rimless wheel (*W*),
- flange thickness (O_g, designation according to EN-13715 – *e*, according to UIC 510-2 – *b*),
- flange height (O_w, designation according to EN-13715 – *h*, according to UIC 510-2 – *a*),
- flange steepness (q_r – according to UIC 510-2).

Fig. 4 presents the locations on the wheel rim cross-section where the listed geometrical parameters of the wheel rolling profile are to be measured.

3. INPUT DATA ANALYSIS

3.1. Identification data of the vehicle test sample

Two five-member electric trains used in commuter and regional transport operations with the axle configuration *Bo'2'2'2'2'Bo'* were selected for the study. The running gear of each of the vehicles consists of two extreme two-axle motor bogies (axles 1-2, 11-12) and four trailing Jacobs bogies (axles 3-10) with mono-block wheelsets (Fig. 5).

Both the motor and trailing bogies were fitted with a swivel castor guide with primary suspension in the form of coaxial helical compression spring sets. The secondary spring suspension consisted of pneumatic springs. The maximum wheelset load on the track was 180 kN. Each wheelset was decelerated by means of a disc brake with brake discs fixed to all the running wheels. Hence, there was no contact between the brake pads and the wheel treads as in conventional braking systems. The vehicles in question were equipped with a flange oil lubrication system, limiting the rate of increase in wheel rim wear.

Table 1

Designations used to describe the rolling profile in accordance with EN 13715:2020-12 and the ECM manual

Marking		Description
EN 13715:2020-12	**ECM Manual**	
1	**2**	**3**
Z1	Z1	Internal zone of flange (H2 – S)
Z2	Z2	External zone of flange (S – D1)
Z3	Z3	Connection zone, flange to wheel tread (D1 – C1)
Z4	Z4	Wheel tread zone (C1– B1)
Z5	Z5	Zone between the wheel tread (reverse slope) and chamfer (B1– I)
a	–	Position of the axis intersecting the tip of the flange relative to the internal face of the wheel
d	D	Wheel diameter
e	Og	Flange thickness
de	–	Difference between the reference value for flange thickness (32,5 mm) and the new value of "e"
h	Ow	Flange height
A1; B1; C1; D1; H2; I	–	Characteristic points (explained in the standard [18])
D0	–	Location of the wheel tread, 70 mm from its internal face. Origin of the coordinate axes
L	b	Rim nominal width, 135 mm lub 140 mm
Rfa; RE; RI; R13	–	Rounding radii of the periphery profile (explained in the standard [18])
S	S	Connection at the tip of the flange
AXB	–	Connection axis at the tip of the flange
BDN	–	Flange
CR	CR	Wheel tread plane
FEJ	–	External wheel rim face
FIJ	–	Internal wheel rim face
–	O[3]	Ring thickness (only for the rimmed wheel), the value of which depends on the rolling circle diameter
–	W[4]	Ring thickness of rimless wheel (only applies to rimless wheel), the value of which depends on the rolling circle diameter
–	q_r	Flange steepness (for a new profile defined in [25])

[3] It is assumed that the rim thickness test can be carried out using a calculation method when the diameter of the bare wheel is known by measuring the diameter of the rolling circle determined in accordance with EN 13715.

[4] It is permissible to test the ring thickness of a rimless wheel by an indirect method by subtracting from the known ring thickness of the new wheel half the difference between the rolling circle diameter (determined according to EN 13715:2020-12) of the new wheel and the actual rolling circle diameter (determined according to EN 13715:2020-12) measured on the wheel.

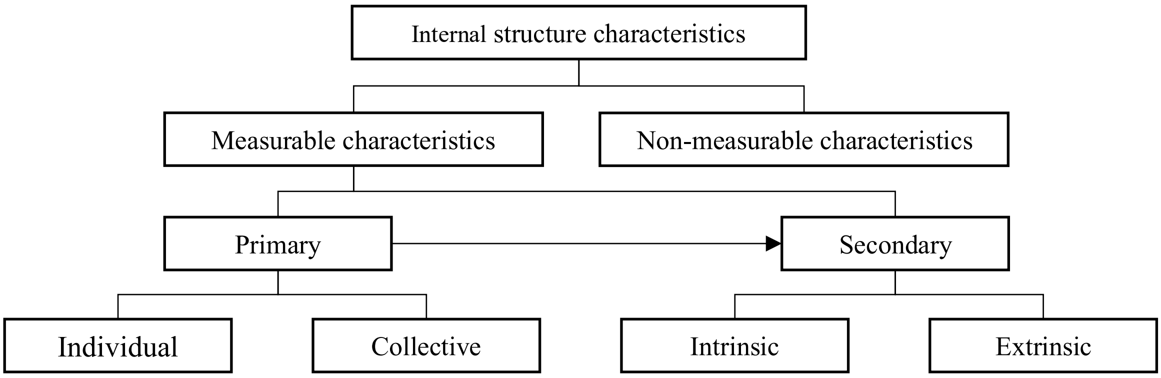

Fig. 3. Classification of geometrical parameters to be assessed

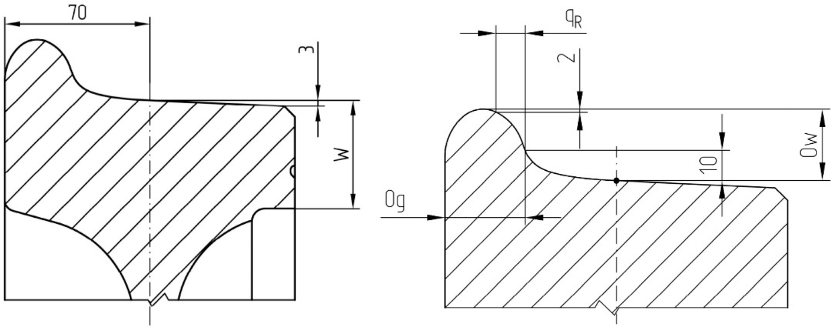

Fig. 4. Measurement locations for selected geometrical parameters of the wheel rolling profile

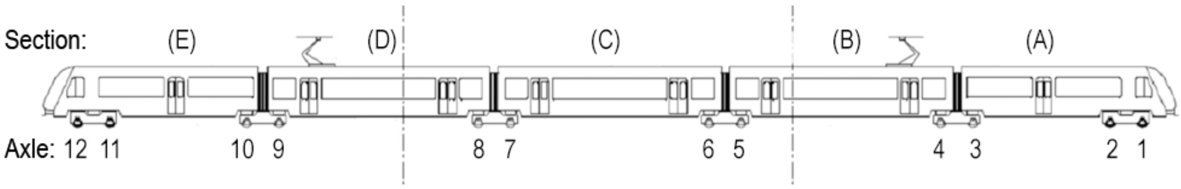

Fig. 5. Diagram of the examined vehicle with the designation of sections and wheelsets (axles)

3.2. Geometrical parameters to be assessed

According to the maintenance system documentation of the examined electric trains, the following characteristics of the internal structure (primary characteristics) of the wheelset must be measured during the inspection at the P2 maintenance level:

– wheel diameter in the wheel tread D
– solid rolled wheel thickness W
– flange height O_w
– flange thickness O_g
– flange steepness q_r
– size of the flat spot or deposit (accretion) on the tread

The characteristics resulting directly from the links between the primary characteristics are the secondary characteristics:

– difference of diameters of the wheel treads $|D\text{-}D'|$
– sum of the thicknesses of two flanges $OgL + OgP$.

It is also necessary to calculate the maximum difference in the wheel diameter between the wheelset, the bogie, and the entire traction vehicle. These values of the measurement characteristics must not exceed the limit values adopted for the type of vehicle concerned. A full assessment of the technical condition of a specific vehicle is carried out by measuring 21 measurable characteristics and two non-measurable characteristics, which are tested visually by assigning binary values to them.

Four basic measurable characteristics were selected for analysis:

- solid wheel rim thickness W
- flange height O_w
- flange thickness O_g
- flange steepness q_r

The diameter of the wheel on the tread depends directly on the wheel rim thickness, whereas the size of the flat spot or accretion on the rolling surface describes the failure of the wheel-rail head contact surface (rolling surface). Therefore, it cannot be compared with the geometrical parameters adopted for the study according to the established criteria.

3.3. Data collection methodology

As part of this research, data from measurements of the values of the main geometrical parameters of the profile of the wheelsets were collected and systematized from 204 measurement sheets of both vehicles prepared in accordance with the maintenance system documentation. The ECM did not have a digital information system in place to support the recording of data concerning the process of operation of the traction rolling stock. Therefore, data were collected passively based on specially developed registers and a database. Reporting data collected in this way is difficult and labor-intensive, especially when numerous vehicle samples are tested.

3.4. Analysis of changes in the values of the wheelsets' geometrical parameters

The geometrical parameters of the wheel profile were systematized so that they could be assessed. Table 2 lists the tests performed with the assigned values of the vehicle's total kilometrage, kilometrage from the last scheduled maintenance at the P2 level, and the number of days since the last measurement. For Vehicle No. 1, data were collected from nine feature measurements, while for Vehicle No. 2, data were collected from eight measurements.

An analysis of the data presented in the table suggests that the data are not complete. For Vehicle No. 1, the number of days and kilometrage since the last inspection at the P2 level between the fourth and fifth measurements of the geometrical parameters is 119 days and 45 458 km, respectively. These values are approximately twice as high as the other values shown in the corresponding rows and columns. A similar relationship can be observed for the same data collected for Vehicle No. 2 between the first and second measurements and between the fifth and the sixth measurements. These values do not meet the requirements of the inspection-repair cycle contained in the maintenance system documentation for such vehicles–it is stipulated that an inspection at the P2 maintenance level should be performed at a maximum of every two months (± three days) or every 30 000 km, whichever comes first. Therefore, according to the maintenance system documentation, there must have been measurements between these recorded ones from which no data were obtained for testing (in Table 2, the relevant rows are marked in grey). While the period between the maintenance activities at the P2 level may be longer than two months ± three days (this refers to an additional out-of-service period, which can occur, for example, as a result of high volumes of work at the rolling stock maintenance point and waiting for the vehicle to be serviced or other logistic delays). The kilometrage between inspections may not be exceeded, which supports the thesis.

3.5. Assessment of the changes in the wheelsets' geometrical parameters

Changes in the values of the basic geometrical parameters of the wheel, especially primary measurable features, may result of a number of processes. Such processes include the wear process, machining (which restores the acceptable rim contour), and a number of minor factors–such as the chemical composition and physical and mechanical properties of the material used, precision and workmanship, load variation (e.g., due to hunting), the temporary presence of material (e.g., sand) in the contact between the wheel rolling surface and the rail head surface, temperature, humidity, or air pollution [12]. Figs. 6-9 present the characteristics of changes in the values of tested geometrical parameters, the selection of which was justified in Section 3.2. The figures show the values of the features averaged for each measurement.

Table 2

List of measurements of geometrical parameters of the wheelsets of vehicles No. 1 and No. 2

Vehicle No. 1				Vehicle No. 2			
Measurement No.	Total kilometrage [km]	Kilometrage from last P2 [km]	Number of days since last measurement	Measurement No.	Total kilometrage [km]	Kilometrage from last P2 [km]	Number of days since last measurement
1	23 995	–	–	1	≅24 000[b]	–	–
2	47 799	23 804	65	–[a]			
3	66 070	18 271	58	2	68 044	≅44 000[b]	123
4	86 444	20 374	57	3	95 879	27 835	61
–[a]				4	118 337	22 458	48
5	131 902	45 458	119	5	145 034	26 697	61
6	157 000	25 098	60	–[a]			
7	185 018	28 018	59	6	182 701	37 667	101
8	209 734	24 716	63	7	209 195	26 494	62
9	235 527	25 793	62	8	238 354	29 159	63

[a] No maintenance logs.
[b] Approximate value due to lack of data on total kilometrage of Vehicle No. 2 at measurement No. 1.

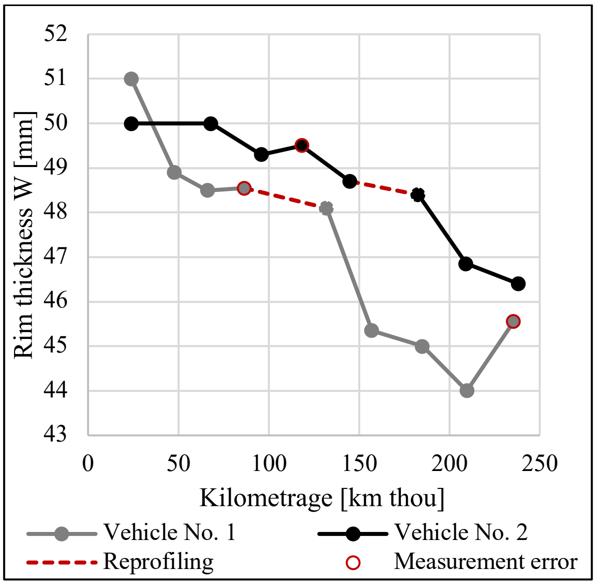

Fig. 6. Characteristics of changes in wheel rim thickness for Vehicles No. 1 and No. 2

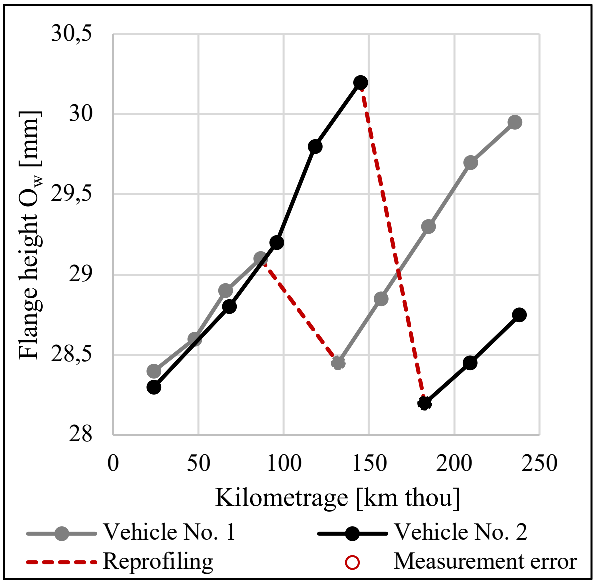

Fig. 7. Characteristics of changes in wheel flange height for Vehicles No. 1 and No. 2

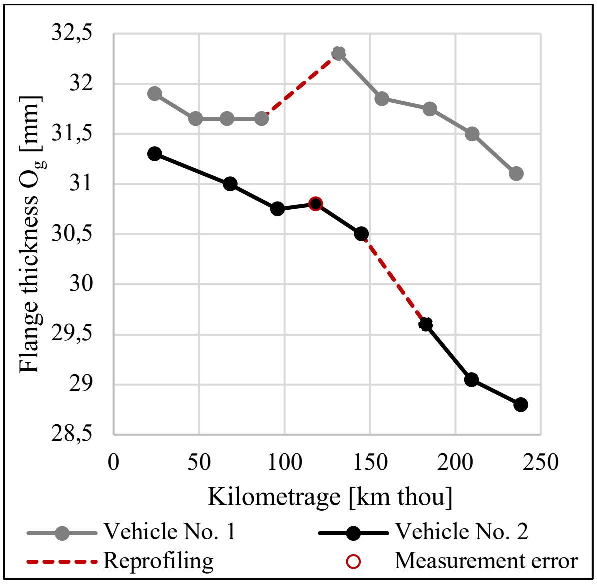

Fig. 8. Characteristics of changes in wheel flange thickness for Vehicles No. 1 and No. 2

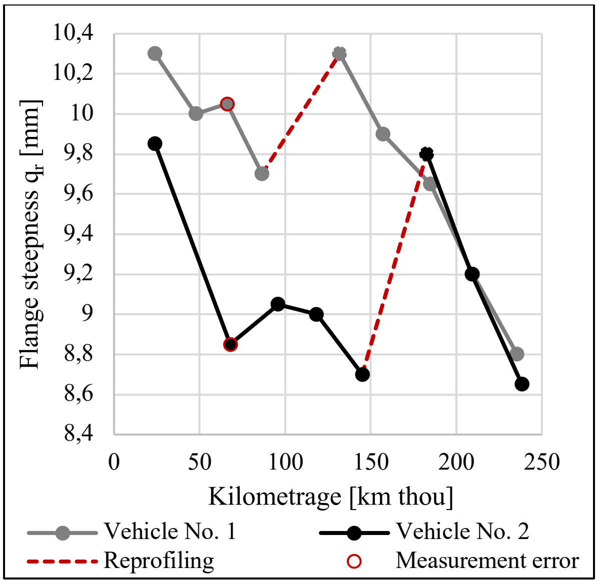

Fig. 9. Characteristics of changes in wheel flange steepness for Vehicles No. 1 and No. 2

An analysis of the nature of changes in the measured values reveals that each of the electric traction sets performed transport work under varying operating conditions. This is evidenced by the variation in the dynamics of changes in values of geometrical parameters in successive measurements. The use of a vehicle on main lines with a predominant ratio of straight track sections to curves has a lesser impact on the changes in the values of geometrical parameters than the use of a vehicle on mountain lines with many curves. As shown previously [3], the observation of strong relationships between the changes in the values of main geometrical parameters of railway vehicle wheels is confirmed as follows:

– A reduction in flange thickness O_g correlates with an increase in flange height O_w.
– A reduction in flange steepness q_r accompanies an increase in flange height O_w.

Table 3

Unreasonable values of the geometrical parameters of the wheel profile

Geometrical parameters	Vehicle No. 1	Vehicle No. 2
	Measurement No.	Measurement No.
Rim thickness W	4, 9	4
Flange height O_w	–	–
Rim thickness O_g	–	4
Flange steepness q_r	3	2

Regarding irregularities, it should be pointed out that the values of geometrical parameters for rim thickness W, flange thickness O_g, and flange steepness q_r show a non-unidirectionally decreasing trend, while for the flange height O_w, a non-unidirectionally increasing trend emerged. This dependence results from the theory of tribological wear, which shows that in two cooperating objects under conditions of dry or mixed friction, there is a change in the mass, structure, and physical properties of the surface layers of the contact areas. Locally occurring unreasonable values of geometrical parameters may be due to measurement errors resulting from the improper use and calibration of the measuring instruments, inadequate care in taking measurements, and errors in identifying a particular vehicle wheel. Such values could also occur if the result of the rim thickness measurement is not the average of three measurements on the wheel circumference. Another possible source of irregularity is wheel ovalization. This type of damage occurs on vehicles equipped with disc brakes when there is no contact between the brake blocks and the surfaces of the running wheels of the wheelsets.

Large differences are noticeable in the following values:

- flange height:
  - Vehicle No. 1, between measurements 4 and 5
  - Vehicle No. 2, between measurements 5 and 6
- flange thickness:
  - Vehicle No. 1, between measurements 4 and 5
- flange steepness:
  - Vehicle No. 1, between measurements 4 and 5
  - Vehicle No. 2, between measurements 5 and 6

In Figs. 6-9, the line segments of the data series between these measurements are highlighted in red and marked with a dashed line. It should be noted that they show a different trend than the other measurements. This indicates that the profile of the wheel rims of the tested vehicles has been reprofiled. As the values of the geometrical parameters are not preserved immediately after the contour renewal operation, the section of the graph between the measurements within which the wheelsets were turned runs diagonally instead of vertically. The constructional and limit values of the tested geometrical parameters are presented in Table 3.

The analysis of the course of changes in the values of the geometrical parameters in Figs. 6-9, considering the limit values presented in Table 4, leads to the conclusion that the decision criterion for the renewal of the profile of the wheels of both vehicles was probably a non-analyzed parameter, such as the difference in diameters in the tape circles of the wheels in a bogie or a vehicle. A decisive criterion for the renewal of the wheel profile could also be damage to the tread surfaces (e.g., flat spots or chipping on the tread surfaces). It should be noted that a large loss in flange thickness was observed during the operating period immediately after reprofiling. Subsequent measurements confirmed the formation of the so-called stabilized profile, which is characterized by the occurrence of material hardening between the final positions of the contact point with the rail head and reduces the intensity of the wheel rim wear process W in the operating phase until reprofiling.

Table 4

Limit values of geometrical parameters of wheelsets

Geometrical parameters	Constructional feature	Limit feature
Rim thickness W	$51^{+2}_{+0,5}$	20.5 mm
Flange height O_w	$28^{+0,5}_{-0,5}$	27.5 ÷ 36.0 mm
Flange thickness O_g	$32.5^{+0,5}$	22.0 mm
Flange steepness q_r	$10.8^{+0,2}_{-0,3}$	6.5 mm

3.6. Models of regression of the examined geometrical parameters

For the averaged vehicle operating conditions, after discarding the unreasonable values, it is possible to determine the curvilinear regression defining the changes of individual primary features as a function of the vehicle kilometrage. In the analyzed case, there was lack of data on the vehicle kilometrages at the time of the wheelset reprofiling and the non-observance of the values of the geometrical parameters immediately after the rolling profile reprofiling. For this reason the regression curves were determined exclusively based on the data obtained from the measurements taken during the operation period before the first rolling of the wheelsets. Figs. 10 to 13 show the trend curves of change:

– rim wear W_{wear}, calculated as the difference between the design value of that feature and the value obtained for that measurement due to lack of restoration of the design value by reprofiling
– flange height O_w
– flange thickness O_g
– flange steepness q_r

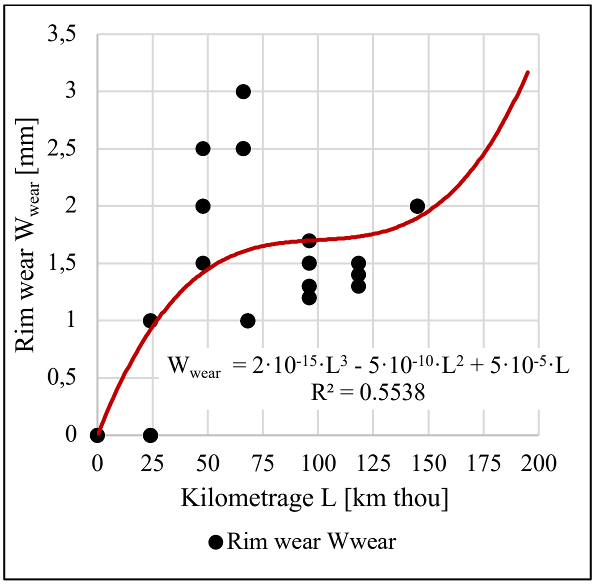

Fig. 10. Regression curve for the changes in wheel rim wear for Vehicles No. 1 and No. 2

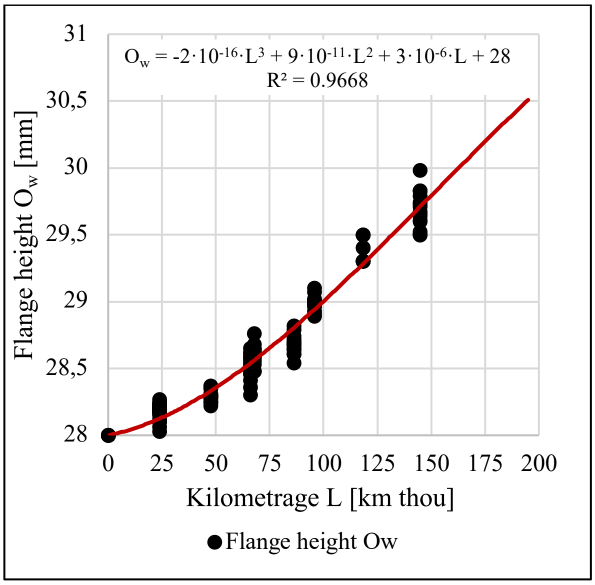

Fig. 11. Regression curve for the changes in wheel flange height for Vehicles No. 1 and No. 2

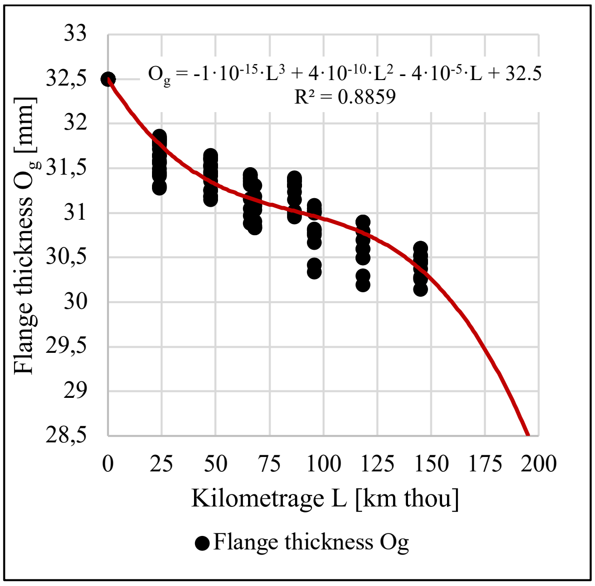

Fig. 12. Regression curve for the changes in wheel flange thickness for Vehicles No. 1 and No. 2

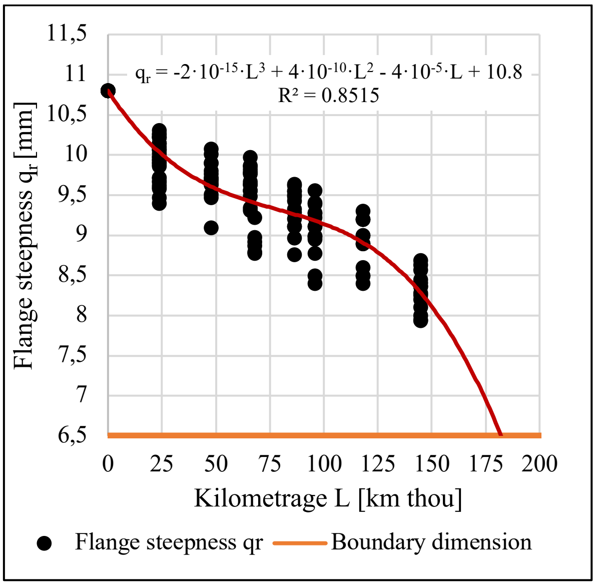

Fig. 13. Regression curve for the changes in the wheel flange steepness for Vehicles No. 1 and No. 2

For the analyzed data, a certain spread of the values of the geometrical parameters can be found regardless of the vehicle's kilometrage. For the assessment of rim wear, the coefficient of determination R^2 obtained defined the fit as poor, limiting the usefulness of the regression curve determined in this way. The coefficients of determination set for the other characteristics allowed the regression curves to be determined as having good fit. The obtained curve patterns may support the prediction of future reprofiling dates of wheelsets. However, considering the great variety of operating conditions of the analyzed traction vehicles, this prediction may be difficult. Therefore, such a prediction should be treated as auxiliary and not as a key criterion when making decisions about the renewal of the rolling wheels' profile.

4. CONCLUSIONS

The analysis confirmed the existence of a correlation between the changes in values of geometrical parameters such as flange thickness and height and flange steepness as a function of kilometrage, thus supporting the hypotheses formulated in specialist literature, for example, [3]. The intensity of wheel rim wear changes depending on the conditions under which the vehicle is operated. Main lines with many more straight track sections than curves exert lesser impacts on the wear of the wheel rim than mountain lines with many curves. It is reasonable to assign the vehicles to different routes so that the wheel rims wear out evenly, eliminating the subsequent accumulation of repairs and replacements of wheelsets before repair at the P4 level.

The values of the geometrical parameters of wheelsets are not fully predictable, which makes it difficult to forecast their future values. However, the usefulness of the determined regression curves in the decision-making process concerning the renewal of the profile of the running wheels cannot be ruled out.

Numerous measurement errors were revealed by the tests carried out in this study, which limits the usefulness of the collected data. This situation justifies the need to introduce a system identifying irregularities (e.g., by comparing the measured value of the geometric dimension with the values and trends determined by previous archival measurements). The authors of this publication feel it is also reasonable to undertake work to change the identification of primary individual characteristics of the wheel's profile (i.e., flange height, flange thickness, and flange steepness) to primary characteristics of a collective nature by calculating the average value from several measurements. Such a methodology could influence the limitation of the probability of non-uniform values occurring for geometrical parameters on the wheel circumference. This kind of methodology would also make it possible, at least in some cases, to eliminate measurement errors that cause unacceptable situations. An additional, helpful solution could be the development of an information system for collecting operating data. Such a system would make subsequent reporting and processing steps less labor-intensive.

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