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The influence of the reliability of wheelsets of innovative wagons in operation on the need for new wheels

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Abstract. The article considers one of the most important wagon units - wheelsets. An analysis was made of the growing number of uncoupled wagons of Russian railways for unplanned repairs and it was revealed that the most common reasons for this are the faulty condition of the wheelsets and axle boxes. It was determined that the factors influencing the nature of the malfunctions are the inappropriate quality of the repair of bogies, the admission to operation of secondary wheels with a rib thickness of less than 26 mm. One of the measures taken is the lubrication of rails and sleepers. The introduction of innovative wagons with wear-resistant wheelsets may also have an impact on reducing the growth in the number of uncoupled wagons requiring repair. The features of newly produced innovative wagons with a higher axle load and an increased turnaround time are considered. To assess the impact of an increase in the share of innovative wagons on the need for wheels, the reliability indicators of wheelsets of innovative gondola and hopper wagons were considered. Reliability was evaluated by indicators of the probability of nonfailure operation, the failure rate parameter and the time between failures. An assessment was carried out for each type of identified malfunctions. The most common were a thin rib and a shelled tread. Results of the calculations showed the dependences of the number of uncoupled wagons on faults from the run of wagons to uncoupling were defined. The probability of nonfailure operation of the wheels of the studied wagons was determined. It has been determined that the average mileage before a malfunction occurs for innovative gondola wagons is 3.5 times greater than for traditional wagons.

1 Introduction

In recent years, the number of railcars requiring current repair (CR) has been continuously increasing on 1520 mm gauge railways. The main share of the reasons for uncoupling freight wagons for repair is caused by wheelset malfunctions, as a result of which there is a periodic shortage of them.

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Objective of the work is to determine the reliability indicators of wheelsets of innovative and conventional wagons, taking into account the rate of wear of the wheel ribs and possibility of the appearance of ribs and shelled treads, and their impact on the need for new wheels.

In the works of scientists from different countries, the main provisions and factors affecting the life of the wheel, the reliability indicators of rolling stock and methods of their calculation were considered, the main directions for increasing the life of wheels and reducing the wear of profiles were indicated. However, an approach to determining the need for wheels, taking into account the probability of their decommissioning after reaching the maximum thickness of the rib and the frequency of occurrence of sliders and shelled treads, is not considered.

The object of the study is a wheelset of freight rolling stock of railways, the subject is methods of long-term planning of transport resources, in particular, wheelsets of freight wagons.

The demand for wheelsets and the increase in their prices indicate the need to improve long-term planning of the need for wheelsets, taking into account their resource and consumption of rim thickness.

One of the main tasks for determining the correct direction of solving the problem of shortage is to determine the balance of wheels and axles for the long term in order to minimize risks for all participants in the transportation process with the practical use of the proposed methodology in the railway carriage industry.

2 Assessment of the reliability of wheelsets of freight wagons

Wheelsets are among the most important assemblies of wagons, which are designed to transfer dynamic and static loads to the railway track and the direction of movement along the rail track [1-3]. The reliability of the rolling stock as a whole depends significantly on the serviceability of running parts. According to statistical data, wheelsets are subjected to the greatest wear and malfunctions in railway transport [4-6].

Reducing operating costs (fuel, repair of wheelsets and, accordingly, inactivity of wagon, noise reduction during train movement) associated with wheelset malfunctions, provided that traffic safety is ensured, is a very urgent task for the railway carriage industry.

The rolling stock fleet of Russian Railways is being replenished with new generation wagons. Currently, the age (average) of the freight wagon fleet working on the railway is 13 years old and is relatively young in Europe [7].

Despite this, the number of wagons requiring uncoupling for unplanned repairs is increasing (Figure 1). Intensive use of freight wagons requires maintenance and repair with the use of high-tech equipment by specialists of a high category. In 2018, the number of wagons requiring ongoing uncoupling repairs increased and amounted to more than 1.3 million wagons. According to statistics, the percentage of uncoupling in 2018 by 2017 was 0.9%. In 2019, this situation has not changed.

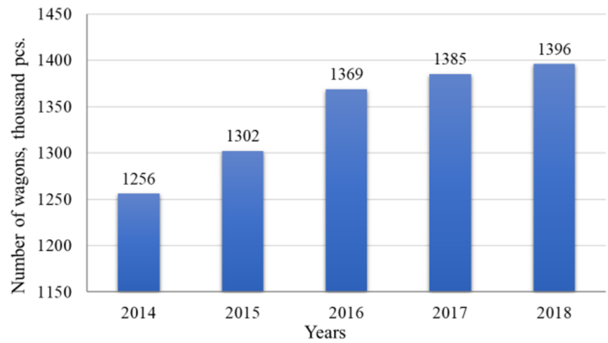

Fig. 1. Number of uncoupled wagons of JSC "Russian Railways" for unplanned repairs for the period 2014-2018

Many wagons are uncoupled many times a year during the current repairs of CR-1 and CR-2 several times between scheduled repairs. The main reason for uncoupling in the current repair for a long time are malfunctions of wheelsets and axle box units of wagons. Raise of uncoupling of freight wagons for current unplanned repair causes an increase in repair costs and train delays due to uncoupling of faulty wagons from formed trains or transit trains [8]. The structure of uncoupling for CUR of freight wagons in 2018 due to malfunctions of wagon assemblies and wheelsets is shown in Figure 2.

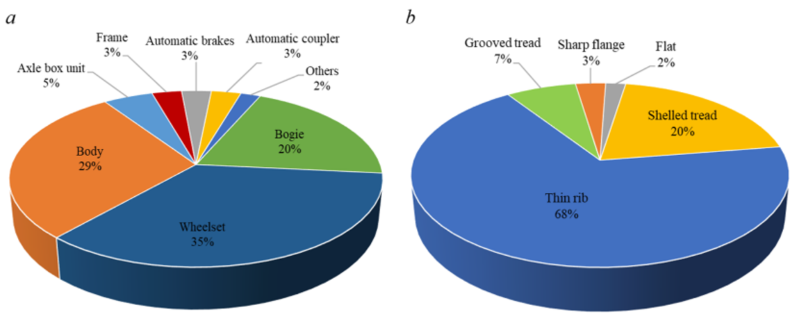

Fig. 2. The structure of uncoupling for CUR of freight wagons in 2018 due to malfunctions of wagon components (a) and wheelsets (b)

As the analysis showed, the increase in uncoupling of wagons is not caused by increased control over the thickness of the rib of wheelsets (JSC "Russian Railways" has begun widespread use of an automated diagnostic system for monitoring the parameters of wheelsets of wagons), but primarily:

- low-quality repair of bogies, which contributes to the wear of the ribs during train movement;
- operation of wagons whose rib thickness is less than 26 mm;
- due to the tightening of the control of the thickness of the rib with the use of CTM devices;
- by turning the wheels during repair work on the thickness of the rib up to 28 and 30 mm;
- the use of secondary wheels [9-11].

In order to reduce uncoupling by Order of the Ministry of Transport of the Russian Federation No. 349 dated 05.10.2018, a change was made to the TOR (technical operation rules) (Ministry of Transport of Russia, 2022), which allows to reduce the permissible thickness of the wheel rib of wagons to 24 mm. To minimize wheel defects, Russian Railways is increasing the volume of wheel and rail lubrication. In addition, it is planned to replenish the available number of wheels through purchase in China. However, some sources indicate that these measures do not guarantee the possibility of avoiding a shortage of wheelsets [12-13].

Currently, the Russian Federation produces new innovative wagons on wheels made of steel grade “T”, which have a number of advantages such as increased stiffness in the axial direction, low stiffness in the radial direction and an increased margin of fatigue resistance of the disk [14-15]. A certain number of traditional wagons are also produced with wheels made of steel of the “T” brand, which, according to specialists of UMC (United Metallurgical Company), allows to reduce the repair and maintenance costs of the wagon by a third compared to wheels made of steel of other brands. The increased resource of such wheels is due to the increased resistance of new wheels to wear and is confirmed by the results of a number of researches [16]. The number of innovative and traditional wagons with wheels of the “T” brand produced by the factories of the Russian Federation is constantly growing, which should help reduce the need for wheels in the future.

Innovative wagons differ from traditional wagons with a higher axle load of 25 tf, increased inter-repair mileage up to 500 thousand km, and increased reliability of wagons.

To assess the impact of an increase in the share of innovative wagons on the need for wheels, the reliability indicators of wheelsets of innovative wagons were considered based on the results of supervised operation.

Two types of innovative wagons were selected as the object under consideration for the research. These are gondola wagons of model 12-9853 (Figure 3, a), built in 2013, and hopper wagons of model 19-9870-01 (Figure 3, b), built in 2014, manufactured by Tikhvin Wagon Building Plant. These wagons (Table 1) are operated on new bogies of model 18-9855 (25 tf) with RV2SH-957-G wheelsets, the wheels of which are made of steel grade “T” with improved technical characteristics [17]. The number of wagons in supervised operation amounted to 400 units for each type of wagons.

Fig. 3. General view of the innovative gondola wagon model 12-9853 (a) and the innovative hopper wagon for grain transportation model 19-9870-01 (b)

Table 1. The main technical and economic parameters of the considered innovative freight wagons

Parameters	Gondola wagon model 12-9853	Hopper wagon model 19-9870-01
Tare weight, t	24.5±0.5	23.0±0.5
Load capacity, t	75	76.5
Body volume, m^3	92	101
Permissible load from the wheelset on the rails, kN (tf)	245 (25)	
Regulatory inter-repair period	up to 1 million km (8 years)	
Bogie model	18-9855	
Service life, years	32	

The current regulatory documents do not establish separate reliability indicators for both wheelsets and wheels. Therefore, the reliability indicators of wheelsets were determined in accordance with GOST 27.002-2015 (GOST, 2016).

Traditionally, the reliability of the objects being restored is assessed by the following indicators: the probability of nonfailure operation – $P(t)$, the failure flow parameter – $w(t)$ and the time to failure – L_0. To calculate the main statistical indicators of the reliability of wheelsets in the formulas, it is necessary to take into account not time, but mileage in km.

Probability of nonfailure operation:

$$P(L) = \frac{N(L)}{N} = 1 - \frac{r(L)}{N}, \tag{1}$$

where $N(L)$ – the number of wagons that are operational for mileage L; N – the total number of supervised wagons of this type; $r(L)$ – total number of failures per mileage L.

Distribution density of operating time to failure:

$$f(L) = \frac{r(\Delta L_i)}{N \Delta L_i}, \tag{2}$$

where $r(\Delta L_i)$ – number of failures during the interval ΔL_i; ΔL_i – length of the mileage interval (i=1, k). The mileage interval was assumed to be 25 thousand km.

Failure intensity:

$$w(L) = \frac{r'(\Delta L_i)}{N \Delta L_i}, \tag{3}$$

where N – number of wagons under observation; $r'(\Delta L_i)$ – the total number of failures in the interval ΔL_i ($r'(\Delta L_i) \neq N\Delta L_i$), since the wagons may fail several times during the observation period.

Operating time to failure (average mileage):

$$L_0 = \frac{\sum_{i=1}^{N} L_i}{r(L)}, \tag{4}$$

In addition, the railcar industry uses an indicator of the average number of failures per 1 million km of mileage:

$$K_{1mln} = 10^6 \frac{r(L)}{L_\Sigma}, \tag{5}$$

where L_Σ – total mileage of wagons for the period under review.

To calculate the need for wheels, an indicator such as the wear rate of the wheel rib is used. It is usually measured in mm per 10 thousand km of mileage:

$$t = \sum_{i=1}^{N} \left(\left(\sum_{1}^{8} \sigma_{ij} \right) \frac{1}{L_i} \right), \tag{6}$$

where σ_{ij} – the amount of wear of the rib in mm of the wheel j of the wagon number i; L_i – mileage of wagon number i in km.

Additionally, an assessment was carried out for each type of malfunction. The calculations took into account all cases of uncoupling of gondola wagons and hopper wagons for current repairs for the following malfunctions, which are considered the most common types of wheelset malfunctions:

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— thin rib (fault code 102);
— shelled tread of wheel rim (fault code 107).

Table 2 shows the results of calculations to determine the average mileage (operating time to failure) and the average number of failures per 1 million km along a thin rib and a shelled tread of wheel for the wagons in question and the rate of wear of the wheel ribs.

Table 2. Indicators of wheelset reliability based on the results of supervised operation

Type of wagon	Failure code	Operating time to failure, thousand km	Average number of failures per 1 million km	The rate of wear of the ribs, mm 10^{-4}
Gondola wagon 12-9853	102	348	3.6	0.23
	107	423	2.8	
Hopper wagon 19-9870-01	102	139	7.7	0.49
	107	164	7.3	
Gondola wagon 12-132	102	101	7.9	0.8
	107	109	7.5	

Based on the results of the calculations, graphs (Figures 4 and 5) of the dependencies of the number of uncoupled wagons according to the fault code 102 and 107 on the mileage of the wagons before uncoupling are constructed. As can be seen from Figure 4, the decoupling of gondola wagons according to the above malfunctions was carried out when running from 150-600 thousand km. The maximum number of decoupling gondola wagons is at runs from 300-350 thousand km.

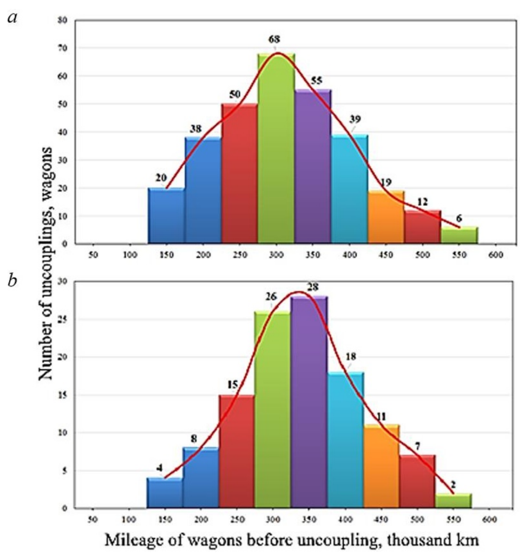

Fig. 4. Dependence of the number of uncoupled gondola wagons of the model 12-9853 on the fault of the thin rib (a) and the shelled tread of the wheel (b) on the mileage of the wagons before uncoupling on CR-2

According to Figure 5, the uncoupling of hopper wagons for wheel defects was carried out in runs from 50-225 thousand km. Moreover, the uncoupling of hopper wagons of the model 19-9870-01 on the shelled treads reached a maximum earlier than the wear of the rib.

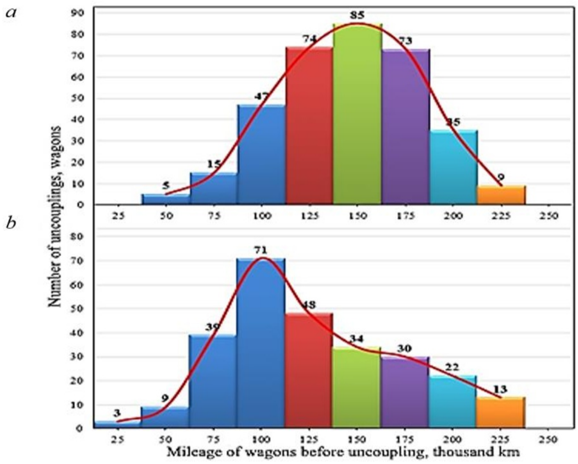

Fig. 5. Dependence of the number of uncoupled hoppers of the model 19-9870-01 on the fault of the thin rib (a) and the shelled tread of the wheel (b) on the mileage of the wagons before uncoupling on CR-2

In practice, methods of direct calculation of probabilities are usually used to determine the probability of nonfailure operation $P(L)$ from statistical data on object failures. The obtained results are shown in Tables 3-5.

Table 3. Results on determining the probability of nonfailure operation of the wheels of gondola wagons of model 12-9853 built by TVSZ from 2013

Indicators	Mileage, thousand km								
	150	200	250	300	350	400	450	500	550
by “thin rib”									
Number of uncouples	20	38	50	68	55	39	19	12	6
Probability of nonfailure operation	0.93	0.87	0.83	0.77	0.65	0.57	0.26	0.19	0.11
by “shelled tread”									
Number of uncouples	4	8	15	26	28	18	11	7	2
Probability of nonfailure operation	0.96	0.93	0.87	0.78	0.76	0.65	0.58	0.46	0.35

Table 4. Results on determining the probability of nonfailure operation of the wheels of hopper wagons model 19-9870-01 built by TVSZ from 2014

Indicators	Mileage, thousand km								
	50	75	100	125	150	175	200	225	250
by “thin rib”									
Number of uncouples	0	5	15	47	74	85	73	35	9
Probability of nonfailure operation	1	0.98	0.95	0.83	0.64	0.43	0.25	0.12	0.05
by “shelled tread”									
Number of uncouples	3	9	39	71	48	34	30	22	13
Probability of nonfailure operation	0.99	0.97	0.88	0.70	0.58	0.49	0.42	0.25	0.11

Table 5. Results on determining the probability of nonfailure operation of the wheels of gondola wagons of model 12-132 built by UVZ from 2014

Indicators	Mileage, thousand km								
	25	50	75	100	125	150	175	200	225
by “thin rib”									
Number of uncouples	2	15	56	95	78	42	20	5	1

Probability of nonfailure operation	0.99	0.96	0.86	0.74	0.62	0.43	0.25	0.18	0.09
by “shelled tread”									
Number of uncouples	7	16	31	62	99	83	65	14	3
Probability of nonfailure operation	0.98	0.96	0.89	0.81	0.73	0.69	0.55	0.28	0.15

Analysis of the results of researches to determine the probability of nonfailure operation of wheelsets of freight wagons shows that the considered wheelsets of innovative gondola wagons of model 12-9853 built by TVSZ from 2013 due to malfunctions of the “thin rib” and “shelled tread” began to detach unplanned repairs after a run of over 150 thousand km.

Hopper wagons of the model 19-9870-01 built by TVSZ from 2014 due to malfunctions of the “thin rib” and “shelled tread” were the first to be uncoupled for unplanned repairs after a run of 50 thousand km.

For comparison, it should be noted that gondola wagons of model 12-132 built by UVZ from 2014 on bogies 18-100 with standard wheelsets for the above malfunctions began to uncouple at a run of 35 thousand km.

Based on the results of operational observations of gondola wagons 12-9853 and 12-132, a graph of the probability of nonfailure operation from the mileage of wagons to uncoupling due to malfunctions of wheelsets of wagons with standard wheelsets is constructed (Figure 6). It can be seen from the graph that the wheelsets of innovative gondola wagons can run up to 600 thousand km and at the same time not detach into the current uncoupling repair due to malfunctions of a thin rib and a shelled tread.

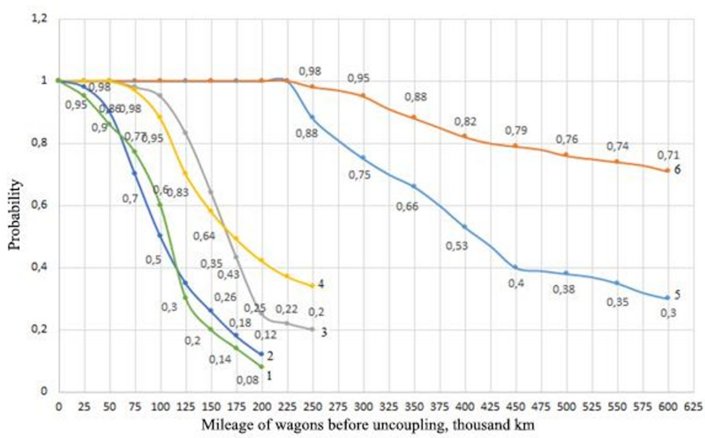

Fig. 6. Graph of the probability of nonfailure operation from the mileage of gondola wagons of models 12-9853, 12-132 and hopper wagons of model 19-9870-01 to uncoupling for CR: 1 – uncoupling by thin rib 12-132; 2 – uncoupling by shelled tread 12-132; 3 – uncoupling by thin rib 19-9870-01; 4 – uncoupling by shelled tread 19-9870-01; 5 – uncoupling by thin rib 12-9853; 6 – uncoupling by shelled tread 12-9853

Based on the results of the research, a graph is constructed (Figure 7), which shows the runs of traditional and innovative wagons before uncoupling for the current uncoupling repair and the number of uncoupled wagons as a percentage. At the same time, it was determined that the average mileage before the malfunction of innovative gondola wagons is 3.5 times greater than traditional wagons.

The average wear rate of the wheels of freight wagons in the fleet of freight wagons is $0.53 \cdot 10^{-4}$ mm/km. But the wheels in the bogie don't wear out the same way, one wheel usually wears out faster than the other.

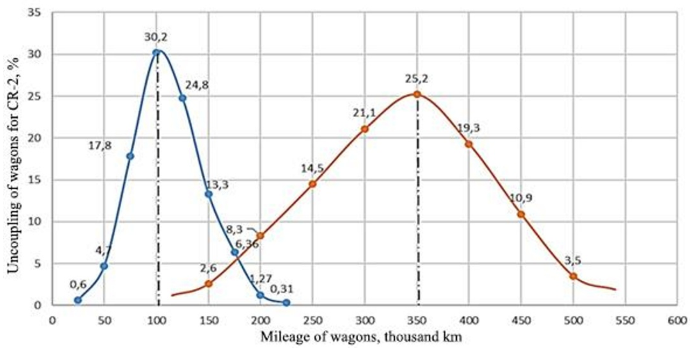

Fig. 7. Mileage of gondola wagons built in 2013 before uncoupling by thin rib during the overhaul period (2013-2018): 1 – traditional wagons; 2 – innovative wagons

Therefore, when calculating the need for wheels, in our opinion, it is necessary to take not the average rate, but the maximum rate of wheel wear of the wheelset, since when turning the wheel diameter is restored the same for both wheels. Based on the data on the uncoupling of gondola wagons 12-132, the maximum rate of wheel wear is 0.8 mm per 10 thousand km of mileage.

For gondola wagons of model 12-9893, the maximum rate of wheel wear is 0.27 mm per 10 thousand km, which is almost 3 times less. For hopper wagons of model 19-9870-01, this indicator is 0.46 mm, which is almost 1.7 times less than traditional gondola wagons.

The results obtained show that as the number of uncoupling in the current repair increases in the fleet of innovative wagons, the need for wheels should begin to decrease, and the need for wheels will decrease.

3 Conclusion

According to the results obtained, it was found that wheelsets of innovative TVSZ wagons (bogie model 18-9855, 25 tf) with an increased axial load compared to wheelsets of traditional wagons (bogie model 18-100, 23.5 tf) run before uncoupling due to wheelset malfunctions, namely along a thin rib and shelled treads by 1.7-3 times greater distance:

- in gondola wagons of model 12-9853, the wear period of the wheel rib to the maximum value is achieved with an average mileage of 359 thousand km, and shelled tread of the wheel rim is achieved with an average mileage of 397 thousand km;
- in the hopper wagons of the model 19-9870-01, the wear period of the wheel rib to the maximum value is reached with an average mileage of 175 thousand km, and shelled tread of the wheel rim appears with an average mileage of 153 thousand km;

The resource of the wheels depends both on the selected material of the wheels and the chassis as a whole, and on the design of the wagon and the intensity of its use. The resource of wheels of the same type when used in identical bogies turned out to be significantly lower for hopper wagons, unlike gondola wagons.

When calculating the need for wheels for the future, it should be taken into account that as the number of innovative wagons in the fleet increases, the need for wheels will decrease.

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