Reduction of freight car wheel wear of 1520 mm gauge railways

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Abstract. A brief description is given of the comprehensive modernization of standard freight car trucks through the use of devices of American companies adapted for railways with a 1520 mm gauge and wheels with ITM-73 specially developed wear-resistant profile, which allows several times to increase the resource of problematic running gears. An approximate method is proposed for solving the wheel–rail interaction problem with determining the position and size of non-elliptic contact patches, including with conformal contact. Using this method, new profiles have been developed for turning worn wheels (ITM-73-01), as well as new wheels for cars with an axial load on rails of 23.5 tf (ITM-73-02) and 25 tf (ITM-73-03). The data of experimental studies showed that the average wear rate of the wheel flanges of freight cars with complex modernized trucks equipped with wheels with ITM-73-01 profile is 3.5-5 times lower than that of a standard car with a standard wheel profile. According to forecast estimates, the use of wheels with profiles ITM-73-02, ITM-73-03 will allow to achieve even greater increase in the resource indicators of wheelsets for wear of the flanges.

In the 90s of the twentieth century on the railways of Ukraine and the CIS countries, excess wear of the wheel flanges of locomotives and freight cars began [1]. The wear rate has increased so much that on some railways the failure of the wear of the wheelsets disrupted the operation of the rolling stock. In addition, the wear rate of the side faces of the rail heads has increased significantly, especially in curved sections of a small radius track ($R \leq 650$ m) [2-4]. Since that time, this problem has been given increased attention [5-7].

Since the shape of the wheel profile directly affects not only the service life of the wheelsets and rails, but also the driving performance of the rolling stock, studies on the creation of new wheel profiles do not lose their relevance to this day [8-10].

In Ukraine, the solution of the problem of increasing the life cycle of wheelsets is carried out in several directions, including by improving the design of the truck to improve the dynamics of cars and reduce the forces of interaction of wheels and rails, as well as by changing the profiles of the contact surfaces of wheels and rails.

In freight cars of Ukraine and the CIS countries, three-element trucks of 18-100 model are widely used. These trucks have significant drawbacks: the tendency to self-excitation of yaw vibrations in straight sections of the track, poor performance when fitting into curved sections of the track, significant wear of wheels and rails. At the same time, violations of the safety conditions for train traffic, derailments are possible.
The result of theoretical and experimental studies to improve the design of these trucks was the development at the Institute of Technical Mechanics of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine (ITM NASU and SSAU) together with A. Stucki (USA) a comprehensive modernization of freight car trucks of 18-100 model and its implementation on the railway network of Ukraine [11]. This modernization consists in replacing standard rigid side bearings with clearances by constant contact elasto-dissipative bearings; installing wedges from high-strength iron (instead of steel) and replacing friction plates with wear-resistant; laying in the center plate of the polymer layer; the use of a specially designed wear-resistant ITM-73 wheel profile instead of the standard wheel profile. As a result, along with an increase in the resource of the most problematic elements of the truck, the life cycle of the wheelsets in the wear of the flanges and the tread of the wheels was increased by more than 2-2.5 times [11, 12]. To date, 1520 mm gauge railways have comprehensively modernized trucks of more than 25 thousand freight cars.

All elements of a comprehensive modernization, including the wear-resistant ITM-73 wheel profile, were used to create a promising model 18-7020 truck [13] at the Kryukovsky Car-Building Plant, which was adopted as one of the basic models for updating the freight fleet of Ukrainian railways.

The use of constant contact side bearings in improved designs of trucks without changing the profile of standard wheels leads to increased wear of wheels and rails when curving a car, therefore the above-mentioned non-linear ITM-73 profile was developed for wheels with a flange thickness of 32 mm.

To carry out theoretical research, appropriate mathematical software has been created that allows you to take into account a sufficient number of factors affecting the performance of the interaction of wheels and rails. Design schemes and mathematical models have been developed that allow one to take into account the design features of different types of cars and modernized carriage units, as well as to investigate the spatial random vibrations of vehicles when moving along a track of an arbitrary outline. To carry out the calculations, disturbances were generated that act on the moving car from the track and consist of four components: symmetric and skew-symmetric vertical irregularities, defined respectively as half-sum and half-difference of vertical irregularities of the right and left rails, as well as horizontal irregularities of the right and left rails. The components of the disturbances are based on the processing and analysis of real irregularities in the sections of the main line of the Dnieper Railway.

The design of the wheel profile was carried out taking into account a number of requirements: the angle of inclination of the flange working face should be large enough to prevent the vehicle derailment due to the rolling of the wheel onto the rail; the wheel tread should ensure the stability of the movement of the vehicle; the shape of the fillet at the base of the wheel flange should provide favorable conditions for the vehicle to fit into curved sections of the track and at the same time not lead to excessive contact stresses on the working face of the rail head.

The experimental dependences of wheel flange wear on the mileage of cars (standard and with comprehensively modernized trucks), obtained from long-term operational tests of cars on the most difficult route in Ukraine, Krivyi Rih – Uzhgorod through the Carpathian Pass, are shown in Figure 1. As you can see, with a mileage of 280 thousand km, not a single wheelset (whs) with a wear-resistant ITM-73 profile of the rim came into the regrind, while all wheelsets with a standard profile were regrinded, some several times.

In recent years, in many countries of the world, special attention has been paid to the development and implementation of optimal profiles of the wheel-rail contact pair. Two approaches are usually used in calculating the interaction parameters: the contact patch is reduced to a point and the resultant normal and tangential forces applied in it are calculated, or the shape and dimensions of the patch are determined and the acting forces distributed over it are calculated.

The point representation of the interaction of wheels and rails [14, 15] is used when the dimensions of the contact patches are relatively small, which is typical mainly for unworn surfaces of the bodies under consideration that do not have the property of conformal contact.
Figure 1. Experimental dependences of wear of wheel flanges on the mileage of cars.

However, conformal contact of wheels and rails is considered the most promising from the point of view of optimizing interaction processes [16]. In this case, the contact patch cannot be represented by one point and most often it has a non-elliptical shape. Therefore, it is necessary to determine its shape and size, as well as the distribution of acting forces on it. For example, the work [17] is devoted to solving the problem of non-hertz contact. It gives a mathematical model of the interaction of a wheel and a rail with a non-elliptical contact spot. The wheel and rail are represented by elastic semi-infinite bodies under pressure distributed over the contact area. The rail is adopted by a massless element, which is a cylindrical surface, and the influence of its vibrations is not taken into account. To determine the contact patch and the distribution of normal stresses at a geometrically found point of contact, the bodies are introduced one into another by a certain unknown value $\delta$, which is found by solving a rather complex system of equations by the iteration method.

The paper [18] presents a spatial mathematical model of the interaction between the railway vehicle and the inertial elastic-dissipative track, which takes into account the size of the contact patches and the distribution of normal and tangential forces along them and proposes a less laborious way to solve the contact problem, which nevertheless gives quite acceptable results.

The contact problem is solved under the assumption of continuous motion of the wheel along the rail. The input parameters are the angles of side rolling and yaw of the wheelset, the mutual lateral displacement of the wheel and rail. The distribution of the interaction forces over the surface of the found contact patch is performed. For this, it is divided into small finite elements, in each of which the contact is assumed to be single-point and elementary forces are calculated.

Tangent elemental forces are considered creep forces. The total longitudinal and lateral components of the distributed creep force are equal to the sum of the corresponding elementary forces. The elementary vertical forces of interaction are calculated by distributing the total vertical force between the elements of the contact patch in proportion to the amount of penetration of the wheel into the rail in each element.

Using the constructed interaction model, studies were carried out to create a new wear-resistant profile of wheels with conformal contact for P65 rails, taking into account wear of their heads.
The development of the wheel profile was carried out while analyzing two functions of the target: the dynamic performance of a freight car with comprehensively modernized trucks and the wear of its wheels. From the family of constructed wheel profiles, a profile was selected, when set in the calculations, the minimum values of these functions were achieved. As a result, the ITM-73-01 repair profile was obtained for wheels with a flange thickness of 29 mm.

The operational test data of a batch of experimental gondola cars with comprehensively modernized trucks whose wheels were turned according to the ITM-73-01 profile are shown in Figure 2. As you can see, the average intensity of wear of the wheel flanges of these cars in the range up to 100 thousand kilometers is 3.5-5 times lower than that of a typical car with a standard wheel profile.

![Wheel flange wear, mm](image)

- average wear values of eight wheels of each of the twenty-three experimental cars

**Figure 2.** Test data of a batch of experimental gondola cars with comprehensively modernized trucks.

With such a significant reduction in the wear of the flanges, it can be assumed that the wear of the rails along which the cars with the ITM-73-01 wheel profile will run will also noticeably decrease, which promises the railroads significant financial savings. In addition, the use of the ITM-73-01 profile allows one to increase the number of possible regrindings due to surface defects, which also significantly increases the life of the wheelset. The ITM-73-01 repair profile was implemented on the all Ukrainian railway network for regrinding worn wheels.

An ITM-73-02 profile with a flange thickness of 32 mm has been developed for turning new wheels with a similar effect on flange wear. When using this profile in the new-generation trucks of the 18-7020 model (with an axial load of 23.5 tf), according to forecast estimates, the wear intensity of the wheel flanges will decrease by more than 5 times, which will allow satisfying the requirements for wheel wear for promising freight cars. The technical council of Ukrzaliznytsya JSC decided to introduce the ITM-73-02 wheel profile in the design documentation for the new generation truck of 18-7020 model and to test cars with such wheels.

Currently, in Ukraine, as the base trucks of promising freight cars, in addition to the aforementioned trucks of 18-7020 model, new three-element 18-9817 trucks with an axle load of up to 25 tf are accepted. Trucks of 18-9817 model – a joint development of the American company ASF Keystone and the Ukrainian Industrial and Investment Group InterCarGroup. Their design has a number of distinctive features [19]: constant contact side bearings with spring elastic elements (Preload Plus type), the characteristics of which can be selected depending on the type of car; elastic adapters in axle boxes; friction wedge with spaced inclined contact surfaces, etc. ITM took an active part in choosing the inertial and elastic characteristics of these trucks. As the calculation results showed, the use of the ITM-73-02
profile for turning the wheels of these trucks leads to a significant increase (compared with the comprehensively modernized truck of 18-100 model and truck of 18-7020 model) the wear of the wheel flanges, which in operation can cause their undercutting. This deterioration in the conditions of contact between wheels and rails is mainly due to a change in the design of new trucks: due to the increased connection of the side frames by means of adapters, the frame of the truck becomes stiffer, which significantly increases the stability of the car motion, but at the same time makes it difficult to fit into curved sections of the track.

Studies have been carried out to improve the wheel profile for 18-9817 truck in order to improve its interaction and conditions of contact with the rail track. For this, on the basis of the ITM-73-02 profile, a family (more than 20) of wheel profiles with a flange thickness of 32 mm was built. For each profile version, the spatial contact problem of wheels and rails was solved, interaction parameters were analyzed, including the size and location of contact patches, and calculations were made of fitting a gondola car with 18-9817 trucks into a small radius circular curve (300 m) with different degrees of rail wear and its movement along straight sections of the track.

Based on the analysis of two conflicting criteria – the minimum flange wear of the wheels and the maximum stability margin of the vehicle – ITM-73-03 wheel profile was chosen [20]. As calculations showed, the use of this profile of the wheels significantly improves the process of interaction of a freight car with increased axial load and track and significantly reduces flange wear of the wheels, while ensuring high dynamic performance of the vehicle.

The dependences of the maximum values of the flange wear factor $A_{\text{max}}$ of the wheels on the motion speed of a loaded car equipped with 18-9817 trucks with ITM-73-02 and ITM-73-03 wheel profiles are shown in Figure 3. P65 rails with different degrees of wear were considered: unworn and slightly worn (lateral wear of the outer rail 3.5 mm). For comparison, the results obtained when installing wheelsets with standard wheel profiles in these trucks are also plotted. The term “flange wear” hereinafter denotes the wear of the fillet and wheel flange.

![Dependences of the maximum values of the flange wear indicator of the wheels on the speed of motion of a loaded car.](image)

If the rails in the curve are not worn (see Figure 3, a), then the wear rate of wheels with an ITM-73-03 profile is 5-8 times less than the wheels with an ITM-73-02 profile, and 10-11 times smaller than standard profile wheels. When driving on worn rails (see Figure 3, b)), the values $A_{\text{max}}$ of wheels with ITM series profiles are close and less than the wear of standard wheels by 7-8 times.

The Figure 4 shows examples of the distribution of vertical pressure $P$ across the contact patches transmitted from the wheels to the slightly worn rails, and the sizes of these patches. It is seen that the
contact conditions of the wheels with the ITM-73-03 profile are better than standard: the patch has extensive dimensions (conformal contact) and is located completely outside the working surface of the flange (on fillet and tread). Wheels with a standard profile with flange contact cause small patches and high pressure, i.e., such wheels wear out intensively and so-called flange cutting occurs. The level of vertical pressure on wheels with an ITM-73-03 profile is much lower.

**Figure 4.** Distribution of vertical pressure on the contact patches transmitted from the wheels to the rails, and the dimensions of these patches.

As additional studies have shown, the ITM-73-03 profile according to the criteria for wear of wheel flanges and the dynamic performance of vehicles can be used in cars equipped with promising trucks with a normal axial load on rails of 23.5 tf.

**Conclusions**

1. A non-linear wear-resistant ITM-73 wheel profile was developed, the use of which in freight cars with comprehensively modernized trucks of 18-100 model made it possible to increase the life cycle of wheelsets by wear of wheel flanges by more than 2-2.5 times.

2. An approximate method is proposed for solving the wheel–rail interaction problem with determining the position and size of non-elliptic contact patches, including those with conformal contact, and the distribution of normal and tangential interaction forces over them.

3. Using the proposed method ITM-73-01 (for turning worn wheels) and ITM-73-02 (for turning unworn wheels) wear-resistant wheel profiles developed, taking into account the form of wear of the heads of rails P65. According to experimental data, the average wear rate of wheel flanges of freight cars with comprehensively modernized trucks equipped with wheels with ITM-73-01 profile is 3.5-5 times lower than with the same mileage of a typical car with a standard wheel profile. The use of wheels with the ITM-73-02 profile when turning new wheels in cars with comprehensively modernized trucks and new trucks of 18-7020 model (with a normal axial load on rails of 23.5 tf) will allow to increase the life cycle of wheelsets by flange wear even more.

4. A wear-resistant wheel profile ITM-73-03 was developed for promising trucks of 18-9817 model with an axial load of up to 25 tf. Using a new profile of wheels will significantly improve the process of interaction of a freight car with these trucks and significantly reduce the flange wear of the wheels, while ensuring high dynamic performance of the vehicle. This wheel profile can also be used in cars equipped with promising trucks with a normal axial load on rails of 23.5 tf.
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