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Research paper

Study of the Effect of Adapter Design on the Load Distribution in the Bearing Units of Freight Cars

Martynov I. E.[1], Trufanova A.V.[1], Petukhov V.M.[1], Ischenco V.M.[2], Kladko N.S.[1*]

[1]Ukrainian State University of Railway Transport
[2]State University of Infrastructure and Technologies
**Corresponding author E-mail:kladkonadiia@gmail.com*

Abstract

The possibility of increasing the service life of 18-100 three-piece bogies by using taper bearing units with different types of adapters is considered in the article. The main task is the need to increase the longevity of the running parts of freight cars by reducing their dynamic loading. The solution of this problem is possible by improving the axle boxes. To determine possible design solutions, an analysis was made of modern domestic and foreign designs of bogies using bearing assemblies with adapters and three types of adapters with the highest quality indicators, namely the half-box of the 18-7020 bogie, adapter with elastic packing and adapter of the 18-4129 bogie. Three models of adapters were investigated using the finite-elements method, which, in accordance with reported manufacturer's data, have high reliability index and can provide equal load distribution between bearing systems rollers. The results of mathematical simulation suggest that the forces applied to the bearing systems rollers largely depend on the adapter design. Furthermore, the studied adapter designs are not acceptable and require further designing.

Keywords: *Adapter, Bearing Unit, Bogie, Roller, Radial Loading, Service Life,*

1. Introduction

The main task of the railway transport is uninterrupted delivery of cargo and passengers with the maximum speed, minimal cost of transport and providing absolute safety in operation. Therefore, the railway stock which is used for transportation must have improved technical and economic parameters, considerable strength, minimum metal intensity, create a minimum impact on the track superstructure. But the crucial task is providing increased service life of both cars as a whole and their separated units.

Unfortunately, most of the car designs being used at the Ukrainian railways today are out-of-date and old. Last fundamentally new technical solution concerning design features of freight cars were taken back in 1970s. The inadequate financing resulted in delivering extremely small number of newly constructed cars. As a result, the service life of the cars in operation was prolonged repeatedly. The middle age of a multipurpose gondola car is 24 years, the normative lifetime being 22 years. It leads to the situation when every car of Ukrzalyiznytsya rolling stock on average 3.5 times a year is sent for current (unplanned) repair with uncoupling, that leads to failure of about 720 cars every day.

One of the most important elements of the freight car design is axle boxes with roller bearings. As the long experience of operating freight cars proves, it is the inadequate reliability of axle boxes that led to 2066 car uncoupling accidents with moving trains in 1995-2017.

2. The Analysis of Researches and Publications

The design of a three-piece bogie of model 18-100, which has been used in the freight cars since 1950s, had unsatisfactory dynamical characteristic (especially in empty cars.) The constructive arrangement of interaction between the bogie solebar and the bearing boxes of the wheel pair is extremely unsuccessful. The reason of it is the fact that a large not spring-suspended weight rests directly on the axle box housing and rigidly transfers all kinds of static and dynamic loads to the axle bearings. Therefore wearing of axle box housing, pedestal jaw opening of the bogie solebar and the appearance of large gaps are unavoidable during the operation. When the car moves, it causes additional vibration of bogies, lozenging of bogie solebars, overloading of a box, which can lead to an irregular load on the axle box body, skewing of axle bearing rings and other malfunctions [1].

Accordingly, in case of operational skewing of the rings, the contact pressure is distributed along the raceways unevenly [2]. The combined (radial and axial) loads of the axle box influence significantly the kinematics and dynamics of its elements: along the contact line of the rollers with the raceways of the bearing rings, the radial load concentration appears due to the non-alignment of the rings, and along the ends of the rollers which contact the sides of the rings appear significant axial friction forces [3-5]. It leads to the uneven distribution of the load both between the rollers in bearings and along generatric lines of rollers. At such conditions of this load perception the largest voltage values appear at the ends of generatric lines of a roller [6]. As a result, the premature rolling body destruction happens followed by significant decrease of the service life of axle bearings.

The existing method of determination of equivalent load which is applied to the axle box does not take into account the specific features of load transmission and distribution, operation conditions of freight cars, as well as the freight car type and the specific features of its construction. For example, the fundamentals of the life prediction theory for rolling bearing were proposed by W. Weibull [7] in 1939 and were further developed in A. Palmgren`s and G. Lundberg`s [8] researches. However, the results of using this theory for cylindrical axle box bearings for railway vehicles differ significantly from the operation data. For instance, according to [9], the average service life of bearings must exceed 40 years, but in fact it is not more than 10 years [10]. The service life of rolling bearings depends on the size of contact stress, which appear in the contact area of rollers and bearing race calculates by the following formula:

$$L_{10} = \left(\frac{C}{P}\right)^{p} \qquad (1)$$

Where C – dynamic load capacity, kN, P – equivalent dynamic load, kN, p –index which is chosen depending on the bearing type.

It is worth mentioning that considering issues of increasing the service life of axle bearings, the main attention has been paid directly to improvement of the bearing design and production technology. The issues of optimization of the axle box housing design for providing of equal load distribution have not been given sufficient attention.

3. Problem Statement

Many car producers have developed a number of new generation bogies which are characterized with specific design and reliability to improve the reliability of driving gears of freight cars in general, and axle boxes with rolling bearings [11-13].
The bearing unit is one of the key units which are upgraded in new generation bogies. Using the double-row bearings with taper rollers of cassette model is considered to be promising.
The specific feature of a cassette bearing unit is using an adapter which acts as a transmission medium between the bogie solebar and bearings and is used instead of the axle box housing in 18-100 bogies.
The leading world manufacturers producing taper bearing units offer a great number of adapters, for example, the adapter with an elastic medium which is used in 18-194-1 bogies. The specific feature of this adapter is using the polyurethane elastic insert, which installed into the adapter and functions as a support for the bogie solebar [14].
An adapter with herringbone plates which are multi-layer V-shaped elastic elements through which the solebar is supported on the bearing unit adapter is used in the 18-4129 bogie [15].
Azovgazmash PJSC proposed a bogie [16] in which the wheel pair and solebar are connected with polyurethane and metal spring sets consisting of two parallelogram-shaped shock absorbers.
However, in spite of variety of adapter designs, the question is still to be considered: what adapter design would be the most favorable for providing equal load distribution between rollers in the axle bearings.

4. The purpose of the Study

The purpose of the study is building simulation models of axle box adapter of freight cars, analysis of the stress strain behavior of the latter to find the optimal designs.

5. Study of the Effect of Adapter Design on the Load Distribution in the Bearing Units

High labour intensity and prime cost of full-scale experiment, as well as the necessity to introduce sophisticated technology in the maximum tight schedule led to creating design-automation system (CAD).
It is noteworthy that any calculation is based on the calculation model, which combines the geometry of structure and loads to which this structure is exposed. When a calculation model of complex structure is created, its shape is somewhat idealized, while the degree of idealization influence on the reliability of calculation results. In our case it was important to define the load distribution between bearing unit rollers to determine service the life of bearings.
The finite elements method (FEM) was used to solve the problem.
In order to investigate the load distribution between the bearing unit rollers, three adapters from the construction rank were chosen, namely adapter of (half-box) 18-7020 bogie (Fig. 1) adapter with an AdapterPlus elastic packing (Fig. 2) and adapter with herringbone plates of 18-4129 bogie (Fig. 3)

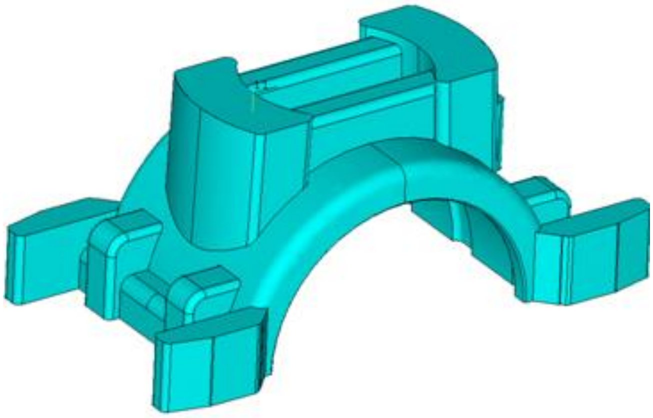

Fig. 1: Half-box of the 18-7020 bogie

Fig. 2: AdapterPlus adapter with elastic packing

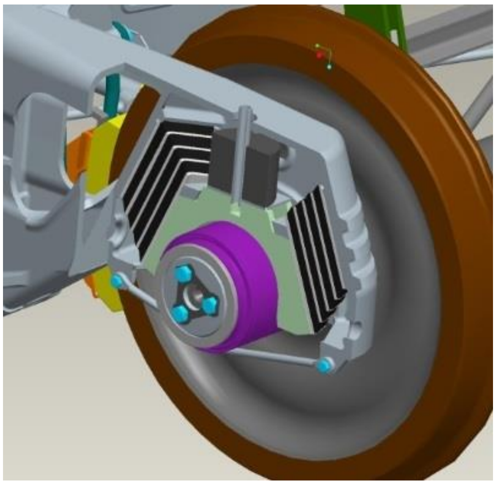

Fig.3 : Adapter of the 18-4129 bogie

At the first stage of the study, a geometric model of the adapter was constructed using the ANSYS preprocessor according to the dimensions of real adapters, taking into account the main features of the construction, namely:

– recesses in the middle part and along the edges (places where rollers in the bearing are missing)

– geometric lugs in the upper part of the frame, designed to absorb the vertical load and to provide its distribution between the rollers;

– fins in the side of the adapter, designed to fix it between the side jaws of the solebar and provide the accommodation of horizontal loads.

The constructed model is divided into finite elements of rather simple shape. Solid92 10-piece finite elements of the tetrahedral type were used to model the volumes of solid adapter bodies. The element is defined by ten nodes that have three degrees of freedom in each node: moving in the direction of the X, Y, Z axes in the coordinate system of the node. Such elements are most appropriate for modeling of machine-building constructions of relatively small dimensions, but complicated shapes.

The developed finite element model of the half-box consists of 41,957 finite elements and 121,728 nodes, for AdapterPlus adapter - 37952 finite elements and 112,579 nodes, for adapter with herringbone plates – 49,871 finite elements and 149,613 units. Finite element adapter models are shown on Fig. 4.

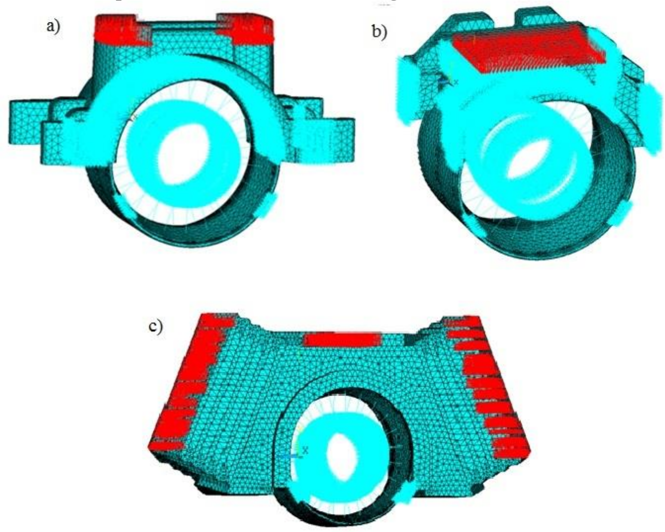

Fig. 4 : Finite element adapter models: a– half-box of the 18-7020 bogi; b– AdapterPlus adapter with elastic packing; c– adapter of the 18-4129 bogie.

Conta174 final elements were used for the contact surface of the outer and inner bearing rings. The contact elements have the same geometric dimensions and a common set of geometric characteristics as the real volume elements associated with them.

The elastic elements which model rollers were installed radially. The rigidity of the element is equal to the rigidity of the roller. The number of elements corresponds to the number of rollers in the bearing.

The finite elements Combin37 were used for rollers modeling. Combin37 elements were placed between the adapter and the outer bearing ring. The element arrangement is shown in Fig. 5, at the example of a half-box. Contact elements for all three types of adapters were designed similarly.

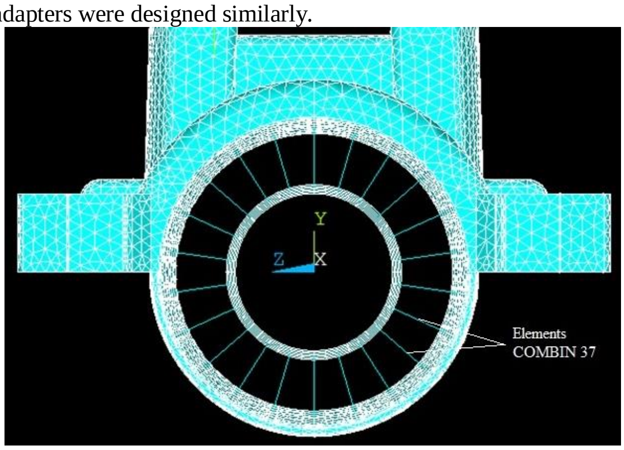

Fig. 5: The arrangement of elastic elements

Simulation of the stress-strain behavior of a bearing unit, which was made on the basis of the developed 3D models for all three adapters, enabled to study the radial load distribution the between rollers in these constructions. The bearings in the adapters were loaded with radial load, taking into account the vertical movement coefficient. The value of the normal force applied from the axis to the rails was assumed to be 23.5 tf/axis for the half-box of 18-7020 bogie, and 25 tf/axis for the adapter with an AdapterPlus elastic packing and the adapter which is used in 18-4129 bogies.

The following assumptions have been taken into account in the calculations:

– influence of longitudinal and lateral loads was ignored;

– the inner bearing ring was assumed to be completely rigid;

– the rigidity of the roller was taken constant;

– there was no friction between the adapter and the outer bearing ring;

– the adapter material worked in the elastic stage of deformation and had constant characteristics - the modulus of elasticity of steel from which the adapter is made, is taken $2.1 \cdot 10^{11}$ Pa, the Poisson's coefficient is 0.3.

– the materials of the contacting bodies are homogeneous, isotropic and ideally elastic.

During solving the set tasks, radial stress diagrams in the bearing units for every selected adapter model have been obtained (fig. 6).

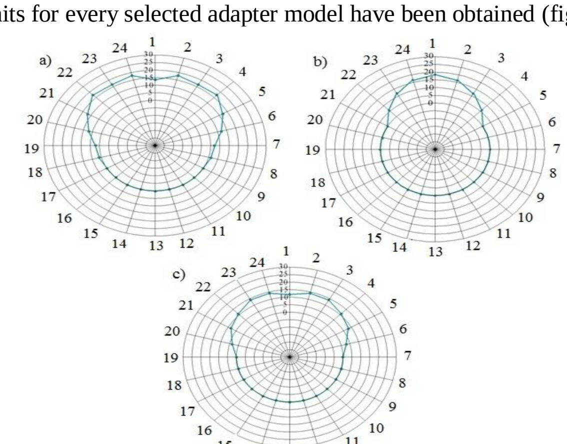

Fig. 6 : The diagrams of the load distribution between the rollers for all three types of adapters: a– half-box of the 18-7020 bogi; b– AdapterPlus adapter with elastic packing; c– adapter of the 18-4129 bogie.

Thus, the following force distribution between bearing boxes rollers, which are located in the loaded area, have been obtained for all three types of adapters. Readings have been made from the central rolling element, situated on the axis of symmetry of the rolling elements.

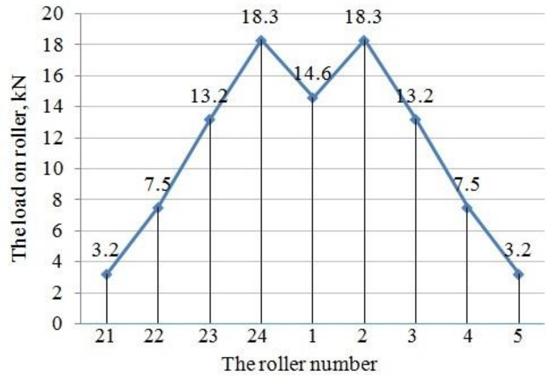

Fig. 7 : Radial loading distribution between the rollers of the bearing unit which is used together with the half-box of the 18-7020 bogie.

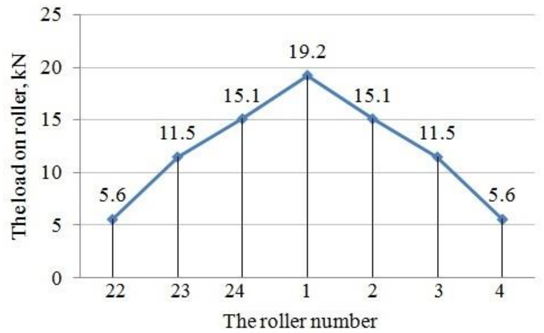

Fig. 8 : Radial loading distribution between the rollers of the bearing unit which is used together with adapter AdapterPlus with elastic packing.

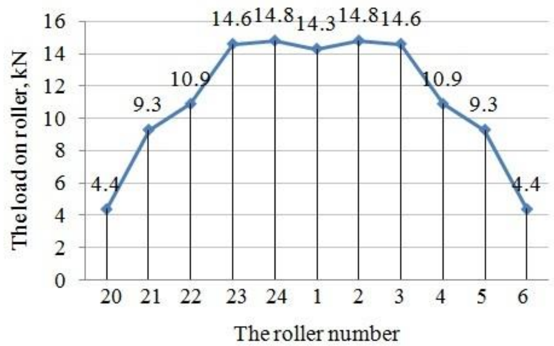

Fig. 9 : Radial loading distribution between the rollers of the bearing unit which is used together with adapter of the 18-4129 bogie.

According to the calculation results for a half-box, the second and the second to last rollers are exposed to maximum load value of average 13.3 kN. Thus, bearing box, in which half-box is used, takes several load peaks, and it negatively influences on its durability.

Only seven rollers are in the loaded area for the bearing box, which is used with AdapterPlus adapter, it is far fewer than in the other studied constructions, therefore the rollers are exposed to too heavy loads. Maximum load on the roller in this bearing box is 19.2 kN.

Table 1: Calculation results

	Normal force value, tf/axis	Number of rollers in a one row of bearing	Number of radial load “peaks” per rotation	Number of loaded rollers in a row	Maximum radial force perceptible by roller
Half-box of 18-7020 bogie	23.5	18	2	9	18.3
AdapterPlus Adapter	25	24	1	7	19.2
Adapter of 18-4129 bogie	25	24	2	11	14.8

The load diagram between rollers of the bearing unit which is installed with an adapter used at 18-4129 bogies, has the most favourable load distribution. It should be noted that the rollers in this construction have also two load peaks of about 14.8 kN.

6. Conclusion

In Following the results of the study, it may be concluded that

– installation of adapters between the bearing unit and the bogie frame has positive effect on the load distribution between rollers, which suggests the expediency of using it;

– a half-box and an adapter with elastic packing have worse performance than the adapter with herringbone plates. The main drawback of an adapter with herringbone latches is its rather complicated design.

– the manufacturability of the adapter design and the possibility of its integration with the typical 18-100 bogie would be an additional criterion in choosing the optimal adapter design.

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