METHODS TO INCREASE FREIGHT CARS' DISTANCE RUN BETWEEN REPAIRS BY UPGRADING CAR'S BOGIE

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ABSTRACT

The authors participated in MIIT University's researches aimed at refining mathematical and computer models of cars were refined, describing a motion along railway lines with normalized irregularities in plan and profile. The models consider spatial oscillations of each node, details of solid body, structure, material properties, as well as predict abrasive wear of critical parts and components of a bogie. The article justifies a possibility to increase overhaul life of a car by a simple upgrade of a bogie model 18-100 from 160 to 250 thousand km, and by a comprehensive modernization – up to 500 thousand km.

Keywords: *railway, freight cars, bogie model 18-100, computer model of car motion, upgrading, modernization, distance run between repairs, overhaul life, performance indicators of a car, wear reduction.*

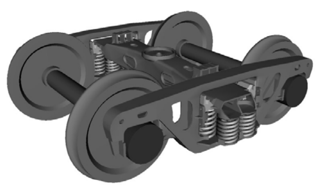
Background. *Freight cars in Russia are mainly operated on bogies model 18-100, which were originally designed for much smaller axial load than it is now. With an increase in the axial load working modes of a bogie differ from initially designed modes. A number of design flaws arises thus leading to the emergence of large dynamic forces, especially in the contact area of wheel and rail, as well as to intensive and uneven wear of friction pairs, inadequate damped oscillations of the car in motion. In our opinion, for a substantial increase in the overhaul life of cars on such bogies it is necessary first to improve their dynamic qualities and vibration load of running gears, i.e. to reduce dynamic forces and vibrations, which will result in reduced wear of cast bearing parts and assemblies, friction pairs in the bogie.*

Research regarding those tasks is carried out in order to identify effective and inexpensive ways to reduce vibration load and wear of parts and assemblies of running gears. It is carried out at the MIIT University's department of cars and cars facilities, using developed refined computer models describing the movement of different types of cars and bogies. These models were created under a software environment for computer complexes «DIONiS» (MIIT), «Universal Mechanism» (BSTU) and «MSC.ADAMS / Rail» (Mechanical Dynamics Inc.). The models represent basically a system of rigid bodies interconnected by joints and force elements, and include a solid or a nonrigid body (or boiler) and two two-axle bogies. Each bogie has its solids: two wheel sets, two side frames, four axle adapters and friction wedges, bolster, suspension strength elements, gaskets and vibration absorbers (Pic. 1). A special feature of a bogie's model is that it accounts for a spatial movement of friction wedges as individual solids with six degrees of freedom and the use of refined contact and friction interactions [1-3].

Objective. *The objective of the authors is to investigate ways to increase distance run between repairs, or overhaul life of freight cars.*

Methods. *The authors use general engineering methods, computer simulation, analysis, comparative method.*

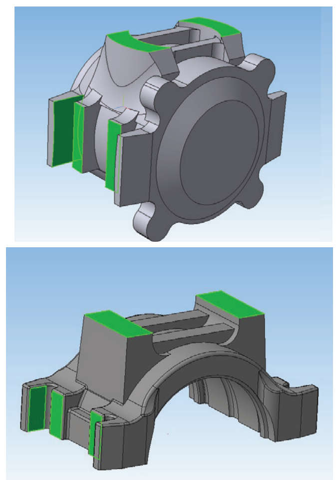
Results. *To simulate different types of axle boxes of bogies (body axle boxes, adapters and vibration absorbers), they were included in the computer model as individual solid bodies with complex relationship. For example, relation of wheel set with axle boxes is implemented as rotational joints with a degree of freedom. Due to the fact that radial and axial*



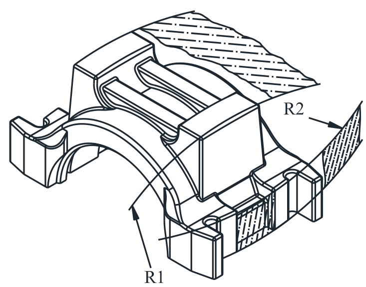
Pic. 1. Adjusted basic computer model of a bogie model 18-100.

a)

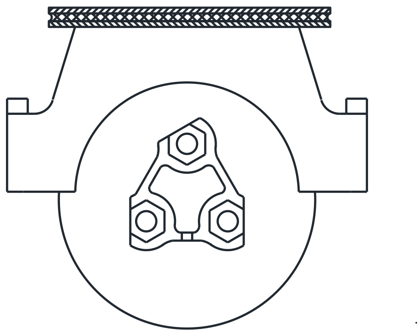
b)



Pic. 2. Contact supporting and thrust surfaces on the body of axle box and axle box adapter:
a) – a standard axle box body;
b) – a standard axle box adapter (semi-axle box).



Pic. 3. Option of axle box adapter with a modified transmission scheme of supporting and thrust loads.



Pic. 4. Axle box adapter in conjunction with a vibration absorber.

clearances between bearing assemblies are very small as compared to clearances in the pedestal opening of a side frame in all directions, the accounting for each bearing's body will not change the nature of dynamic processes in the system car-track, but will only give an opportunity to evaluate dynamic processes in the bearing. The accounting for each roller as of a separate body leads to a significant increase in computer time of calculation.

The computer model implemented four options of axle boxes:

№ 1 – ordinary bodies of axle boxes, Pic. 2a;

№ 2 – adapters (semi-axle boxes), Pic. 2b;

№ 3 – adapter with modified support surface, Pic. 3;

№ 4 – axle box body or adapter coupled with wear-resistant vibration absorber, Pic. 4.

As noted, when changing the transmission scheme of vertical, longitudinal and angular loads from side frames on the adapter and bearing assemblies, which is to replace flat supporting and thrust surfaces of the adapter with a cylindrical surface with a large radius of curvature, loading conditions of bearings improve. In case of curved surface, the effect of edged bearing at angular oscillations of rolling motion and lozenging of side frames and adapter's jamming are eliminated. This eliminates the likelihood of uneven distribution of loads falling on front and rear bearings.

The durability of roller bearing means a number of revolutions, which makes one of the rings relative to the other ring until the first signs of fatigue of the material appear in one of them or in the rolling body. We will fulfill further on an assessment of the durability of bearing axle boxes using the known method of evaluating fatigue failure of bearings.

Pic. 5 shows graphs of the distribution of radial forces on bearing rollers when changing the transmission scheme of the vertical load.

Calculations to assess the durability of bearing assemblies of wheel sets axle boxes with constant loaded movement of the car and conditions of the distribution of equivalent strength showed that (see. Pic. 6):

– When driving the car in a curved section of a track and under symmetrical distribution of equivalent force between bearing assemblies minimum faultless operation is 50209 thousand km;

– When driving the car in a curved section of a track and under asymmetrical distribution of equivalent force between bearing assemblies minimum faultless operation is 4582 thousand km;

– When driving the car in a straight section of a track and under symmetrical distribution of equivalent force between the bearing assemblies minimum faultless operation is 64242 thousand km;

– When driving the car in a straight section of a track and under asymmetrical distribution of equivalent force between bearing assemblies minimum faultless operation is 5413 thousand km.

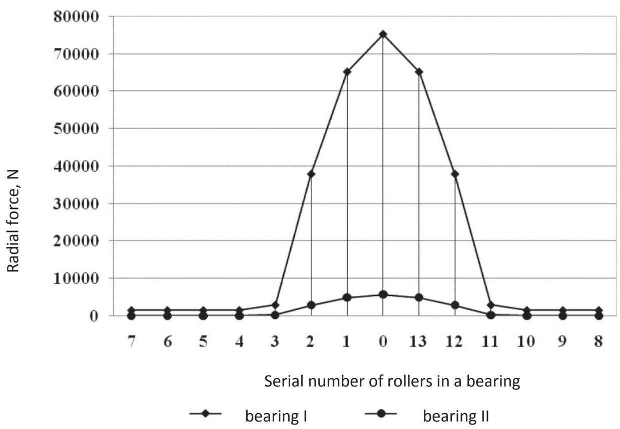
That is, using a scheme with a symmetrical distribution of equivalent force between bearings of axle assembly, it is possible to get the greatest probable faultless operation of bearings. This symmetrical scheme due to cylindrical supporting and thrust surfaces of an adapter developed in MIIT University gives an increase in the probable faultless operation of about 11 times (by 550%) as compared to the asymmetrical scheme used in standard axle assemblies and adapters with a flat supporting surface.

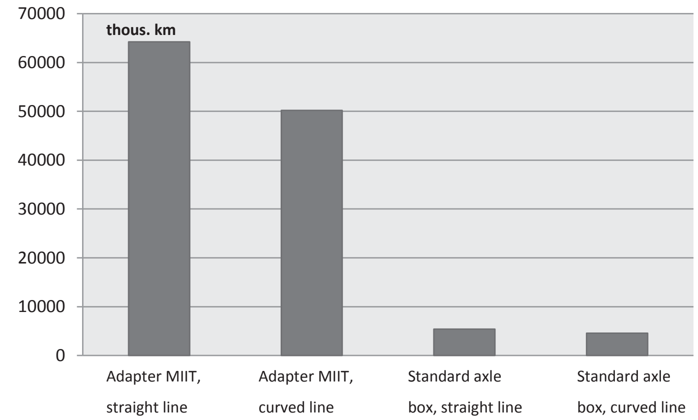
Wear-resistant vibration absorbers were simulated as a subsystem consisting of two steel layers and one polymeric elastomer layer (Pic. 4).

The polymer layer is realized using the Maxwell rheological model, so-called «Fancher spring» and non-linearity component (Pic. 7). A mathematical model is built at the condition of equality of elastic and elastic-dissipative forces due to inertia-free power element and includes a differential equation $d \cdot x_1 = c \cdot x_2$ where x_2 is difference between x and x_1; c, c_1 is stiffness of serial and parallel springs, respectively; d is parallel element dissipation.

Mathematical model of Fancher spring, which is some modification of the rheological model of parallel set of springs and dry friction damper, is constructed as follows:

Pic. 5. Graph of the distribution of radial forces on rollers in bearings of the axle box on the outside radius of a curved track section (asymmetric application of forces).





Pic. 6. Minimum faultless operation of a cassette bearing when moving a car in straight and curved track sections.

$$F_{fan,i} = F_{env,i} + (F_{fan,i-1} - F_{env,i-1})e^{-|\Delta x_i - \Delta x_{i-1}|/\beta};$$

$$F_{env,i} = -c_{fan} \cdot \Delta x_i - F_{mp} sign\{\Delta x_i - \Delta x_{i-1}\};$$

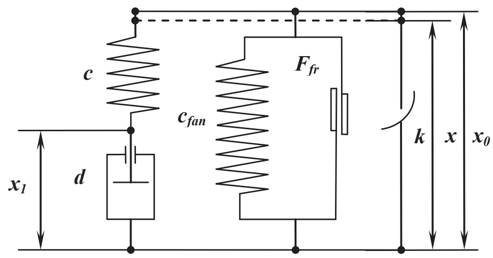
$$F_{env,i} = -c_{fan} \cdot \Delta x_i - F_{fr} sign\{\Delta x_i - \Delta x_{i-1}\});$$

$$F_{fr} = \mu \cdot c_{fan} \cdot \Delta x_i.$$

where F_i, F_{i-1} is force on current and previous steps of integration; x_i, x_{i-1} is deformation on current and previous steps of integration; $F_{env,\,i}$ is maximum value of the force with increasing x (minimum value with decreasing x) by x_i; μ is coefficient of friction; c_{fan} is rigidity of springs; F_{fr} is friction force; β is exponential parameter of suspension (delay). For the implementation of nonlinearity (change in the stiffness of the deformation) parallel to two, described above elements, an element is set, which is described by the dependence

$F_{nonlin} = \pm k(x - x_0)^3$,

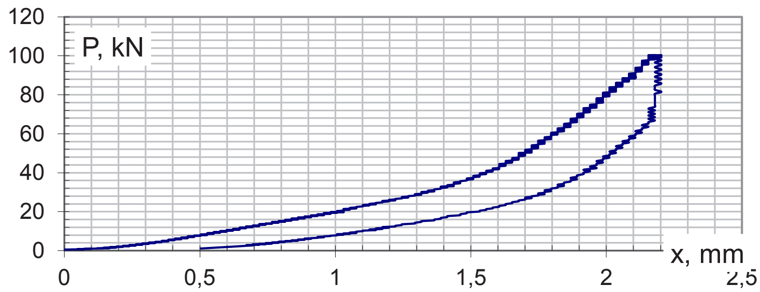
where k is a coefficient of non-linearity, «+» for soft, «–» for tough characteristics.



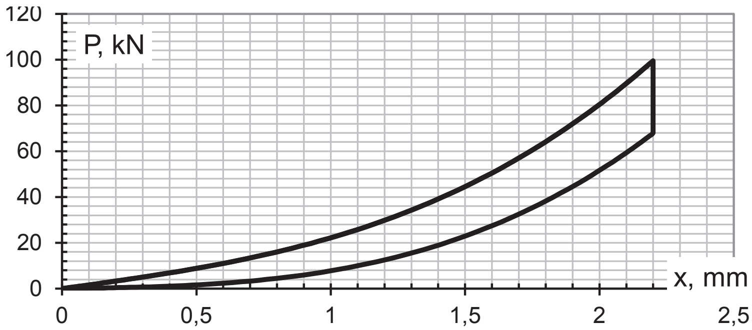
Pic. 7. The scheme for simulation of metal-polymer element of a vibration absorber.

Pic. 8 shows a hysteresis obtained in the tests of the of the rail pad of material TPK-5, and Pic. 9 shows a static hysteresis obtained by harmonic oscillations in the simulation for the following values of parameters: μ = 0,8; c_{fan} = c = 9 MN / m; β = 0,000002; k = $-6 \cdot 10^{12}$ N/m³; ν = 0,01 Hz.

Pic. 10 shows the dependence of strength from the deformation obtained by dynamic vibrations for received values: μ=0,8; c_{fan} = c = 9 MN/m; β = 0,000002; k = $-6 \cdot 10^{12}$ N/m³; d=4500 N s/m.



Pic. 8. Diagram of deformation of the polymer (full-scale experiment).

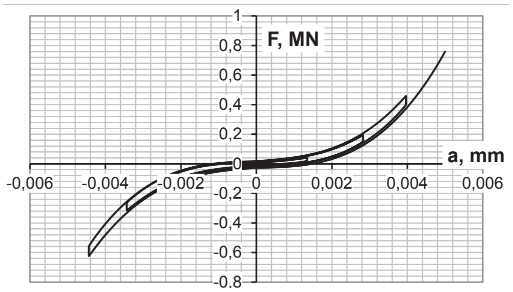


Pic. 9. Diagram of deformation of the polymer (computer simulation).

Table 1

Reduction in wear of bogie's components

Name of the friction assembly	Wear reduction in%:	
	MIIT adapter «B»	Vibration absorber «C»
Bearing surface of the axle box	4.05%	99.18%
Friction plate	1.41%	20.05%
Inclined surface of the wedge	3.62%	8.78%
Bearing surface of center plate	7.07%	17.88%
Wear of wheel's rim	27.42%	75.44%



Pic. 10. Dependence of force from deformation in dynamics.

A multivariate computer simulation was performed for motion of the tank with four options of the axle unit. The results are processed and average values are obtained in percent for curved and straight sections according to the loading of cars. The criteria for assessing the impact of selected options of axle assemblies are performance indicators, safety and wear in friction nodes. Table 1 and Pic. 11 and 12 show performance in percentage as compared to the standard axle assembly (where «–» – decrease in the index means improvement).

The analysis of average values of the dynamics and safety indicates that the greatest effect is obtained through a combination of adapter and wear-resistant vibration absorber. Here, a significant effect is achieved for lozenging of side frames and frame forces, i.e. 28% and 15% respectively. In terms of durability, maximum is reached on the bearing surface wear of the friction forces and wear in the wheel-rail contact, where the effect is 99% and 21%, respectively. For the upgraded adapter with a modified transmission scheme the effect in terms of dynamics is of 2-4%, and in terms of wear maximum effect is reached in contact area of wheel and rail and is of 17%. It should also be noted that for a standard adapter (semi-axle box) the maximum effect in terms of the dynamics is not more than 2,5%, while in terms of wear it is of 5,5%.

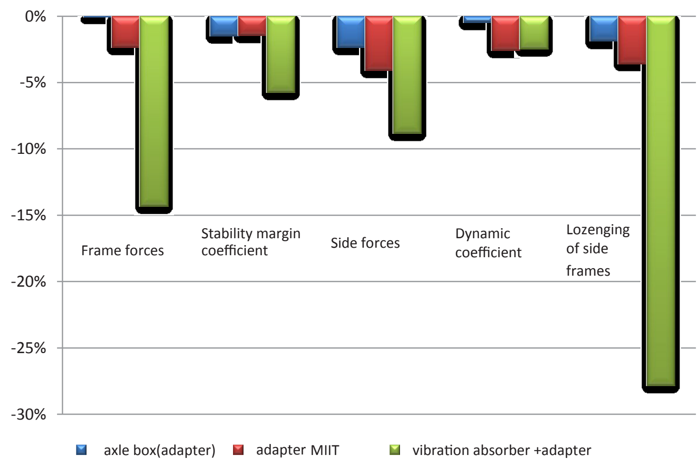
The proposed modernization of the adapter will make it possible to reduce dynamic forces and wear in the wheel-rail system and other friction nodes of a bogie. In particular, the use of an adapter with a modified transmission scheme will prevent edged bearing, thereby reducing the load on cassette bearings and increasing their durability by 11 times.

To determine the actual guaranteed overhaul life of a car and to calculate all quantitative parameters of wear of friction units of bogie a model was adopted based on the hypothesis of a linear relationship between volumetric wear and work of friction forces. Calculations were carried out for running of a typical 4-axle tank on a straight section in steep, with normal and flat circular and transient curved sections with irregularities in plan and profile of 2-3 degrees and with a total length of a section of 218 km. The calculations resulted in obtaining volumetric wear indicators and rates of their reduction for all wearable friction surfaces of the bogie 18-100 for upgrading options «B» and «C» of the axle unit, they are shown in Table 1.

Analysis of calculations was conducted to substantiate increase in a probable value of the guaranteed overhaul life of the tank taking into account weights, speeds, types of section and load of the car. It showed that regarding wear of the wheel rim design average increase in overhaul life is at least 75% for option «C» (wear-resistant vibration absorber) as compared to the option «A», and for option «B» (MIIT adapter) is of 27% as compared with the option A.

Currently, the base value of the overhaul life for a freight car without installing wear-resistant items

Pic. 11. The improvement in the dynamics indicators (in%).



Pic. 12. Wear reduction (in %).

in the bogie 18-100 is 110 thousand km. With the installation of wear-resistant elements in the friction units of the bogie according to the project M1698 PKB CV (option «A» is basis) overhaul life is of 160 thous. km. When the modernization is based on the option «B» (MIIT adapter), taking into account the value of increasing overhaul life regarding wear of wheels by 27%, a probable value of the guaranteed overhaul life is of 203,2 thous. km. Under option «C» (wear-resistant vibration absorber), basing on the value of increase in mileage by 75%, guaranteed overhaul life of the tank will be of 280 thousand km. With simultaneous modernization following the option «B» (27%) and the option «C» (75%) the total value of the increase in mileage will be of 102%, or 326,4 thous. km.

In other words, to provide a guaranteed overhaul life of a car equal to 250 thous. km, it is sufficient to establish a wear-resistant vibration absorber on the pedestal adapter, but more reliable solution is to install pedestal adapter (MIIT «B» option), that reduces wheels' wear by 27% and increases probability of faultless operation of cartridge bearings by 550%.

Conclusions. *As a result, in order to further increase the guaranteed overhaul life of the car up to 500 thousand km, it is proposed to make all wear-resistant and support components in friction pairs of the bogie as a wear-resistant vibration absorber, consisting of a three-layer metal-elastomeric gasket. Wear-resistant and support components should also include wearable plate of axle opening, movable friction strap, gasket-bowl in center plate node, slide cap, plate under a set of seven double row springs or a cap under a spring.*

Conceptual designs and drawings of a modernized adapter and wear-resistant vibration absorbers for all wearable components of a bogie have been developed and protected by Russian patents for inventions and utility models.

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