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Improvement of methods for assessing the reliability of axle boxes for freight cars

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Improvement of methods for assessing the reliability of axle boxes for freight cars

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Abstract. The box bearing unit of the freight car is a complex mechanical system, which is influenced by various factors. Under normal operation, the parameters characterizing the functional state of the components of the axle box should be within the prescribed limits throughout the standard service life. Mathematically, this corresponds to the placement of the axle box elements in the space of admissible states. The railroad model consists of a set of submodules: track and elastic ballast layer. The model allows simulate the microgeometry of the track, the characteristics of the inequalities, and the elasticity of the base under the track. Subsequently, the main parameters characterizing random processes were determined: the magnitude of the mathematical expectation, the variance, as well as the minimum and maximum values of the effort. The results indicate that random processes are distributed according to normal law. According to the results of the research, for each of the random loading processes of the axle boxes, appropriate correlation functions were constructed and the space of "admissible states" for different operating modes was con-structed.

1. Introduction

Railway transport is the main transport artery of Ukraine. It is the railway transport that performs overwhelming majority of cargo and passenger transportation both for Ukrainian and in the interstate connection.

Traffic safety is a priority for railways. Its provision depends on the well-coordinated work of all structural railway transport sub-divisions, but one of the key factors is the reliable operation of wagons. Failures of wagon structural elements may cause delays in the delivery of goods to consumers due to uncoupling of wagons along the route, as well as significant additional costs for restoring the railway infrastructure operability.

One of the most critical structural elements of a freight wagon is an axle box unit with roller bearings. As the long-term experience of rolling stock operating shows, during the period from 2009 to 2019 axle box units caused 2339 cases of wagons uncoupling along the route due to excessive heating. At the same time, up to 1000 cases of axle box unit failures were additionally detected annually by means of remote-control devices for wheelsets and by wagon inspectors basing on external signs.

Bearings constitute the main structural elements of the axle box unit. Ensuring bearing durability under dynamic radial and axial loading is challenging. When calculating the strength and reliability of structural elements of axle box units, simplified schemes are often used, but they don’t take into account the number of operating factors.

A freight wagon axle box unit is a complex mechanical system. It consists of an axle box housing (or adapter), in which the outer and inner bearing rings, rolling elements, a separator and sealing devices are located, preventing the dirt and moisture ingress into the unit inner cavity.

Random nature of the impact on the axle box unit is determined by random values of the load parameters, random distribution of loads in time and at different points of the system, random combination of loads and many other factors (overload, different track conditions, climatic conditions, level of running gears wear and tear, repair and technical service quality). *Literature review*

The fundamental principles of calculating the strength and reliability of bearings of all types are set out in [1]. It should be noted that, until recently, there was no unified methodological approach to both the choice of the bearing type and the methods of calculating the latter for strength and reliability in relation to railway axle box bearings. Only the study [2] of O.M. Savchuk, Professor of Ukrainian State University of Railway Transport named after Academician V. Lazaryan, proposed a unified method for calculating bearings with cylindrical rollers installed in resilient housings of bearing supports.

The issue of selection and standardization of reliability indicators of carriage cylindrical axle box bearings, taking into account the peculiarities of their operation, was considered in the article [3].

There is also a noteworthy work [4], in which an attempt to determine the theoretical and actual longevity of bearings was made. Research is devoted to the analysis of axle box bearing damage [5, 6, 7, 8].

Research of I. E. Martynov, Professor of Ukrainian State University of Railway Transport [9, 10, 11], is devoted to the substantiation of introduction of double-row tapered cassette bearings on the railways of Ukraine. He also determined the percentage of double row tapered bearings operation resource. But in his research, average loads were used to calculate the bearings operation life.

Among the many known methods, devoted to the determination of certain indicators of the technical systems reliability, it is necessary to outline the so-called theory of "emissions", the foundations of which were created by the American researcher S. Rice [12] and his followers [13, 14]. With regard to mechanical systems, this theory was developed further in the works of Professor V.V. Bolotin [15, 16] and his students [17]. However, the abovementioned works do not take into account the combined action of vertical and horizontal forces acting on the axle box unit. Therefore, the improvement of methods for calculating the axle box unit durability is an urgent task.

2. Development of a mathematical model of axle box unit operation

The axle box unit of a freight wagon is a complex mechanical system. Its parameters change during operation. These changes are associated with material ageing, accumulation of fatigue and corrosion damage, frictional wear and tear, strength characteristics deterioration, etc.

External loads q_i affect the axle box unit when the wheel pair passes the irregularities of the superstructure of the track. They are different in their origin and are random in nature. That is, the loads take random values $q_1, q_2, \ldots, q_i$ from a certain range of possible external loads *Q*. The change in these loads over time is a random process $\nu(t)$. Stochastic process of the axle box unit operation leads to a change in its elements condition. As a result, the axle box unit takes on the corresponding condition u_i from the range of possible conditions *U*. The range *U* is chosen in such a way that with its help, within the framework of the selected design scheme, the technical condition of the axle box unit is fully described.

Operator *L* connects each instantiation of elements from the volume of external loads with the instantiation of elements in the volume of possible conditions U

$$Lu = Q, \tag{1}$$

The random nature of the axle box unit behavior is due to the spread of its own properties as well as the acting loads. During normal operation, the parameters characterizing the axle box elements functional condition must be within the established limits during the entire standard service life. Mathematically, this corresponds to finding elements in the admissible volume Ω of the range of possible conditions U. Overrange of the random process $v(t)$ of the axle box unit operation outside permissible volume Ω leads to its failure.

At the initial moment of time (the moment when the wagon starts moving), the random process of the axle box unit operation $v(t)$ with a probability equal to 1 will be in the admissible volume Ω of the range of possible conditions U, i.e. $P(0)=1$. Since axle box units are highly reliable products, runouts from this volume in the time interval [0, t] are highly doubtful, i.e.

$$P(t) = P\left\{v(\tau) \in \Omega;\ \tau \in [0, t]\right\}. \tag{2}$$

As a result of the load action there may be contact bearing resistance in the volume between the rollers and the raceways during axle box bearings operation. They lead to subsequent destruction of the bearing.

Then the permissible volume Ω will be set by limiting the maximum contact bearing resistance $\sigma(t)$ that arise between the rolling elements in the bearing and depend on the bearing steel ultimate strenght

$$\sigma(t) < \sigma_{\text{CT}} , \tag{3}$$

where σ_{CT} is ultimate compressive strength of bearing steel.

The maximum contact bearing resistance $\sigma(t)$ will depend on the magnitude of the vertical and horizontal loads affecting the axle box bearing together. Then the range of possible conditions U will be two-dimensional, and, according to the theory of random processes, the main statistical characteristics of a random process of combined action of radial $P_{rad}$and axial loads P_{axial}take the following form

$$\overline{P} = \overline{P}_{rad} + \overline{P}_{axial} , \tag{4}$$

$$D_P = D\left(P_{rad}\right) + D\left(P_{axial}\right) + 2k_r \sqrt{D\left(P_{rad}\right) \cdot D\left(P_{axial}\right)} , \tag{5}$$

$$R_{(P)} = R\left(P_{rad}\right) + R\left(P_{axial}\right) + 2R\left[\left(P_{rad}\right)\left(P_{axial}\right)\right], \tag{6}$$

where $\overline{P}, \overline{P}_{\text{rad}}, \overline{P}_{axial}$ are mathematical expectations of random processes of total, radial and axial loading $PP_{rad}P_{axial}$ respectively ;

$D(P), D(P_{rad}), D(P_{axial})$ are variances of corresponding loading processes;

$R_{(P)}, R(P_{rad}), (P_{axial})$ are correlation functions of corresponding loading processes;

k_r is correlation coefficient of the corresponding loading processes;

$R\left[(P_{rad})(P_{axial})\right]$ is cross-correlation function of the processes that $P_{rad}P_{axial}$.

$$\overline{N} = \frac{1}{2\pi}\sqrt{-\frac{\ddot{R}_{(P)\,\tau=0}}{R_{(P)\,\tau=0}}} . \tag{7}$$

The mathematical expectation of random process runouts is determined by the formula. The distribution of the load vector will be a surface in the form of a hill (Figure 1).

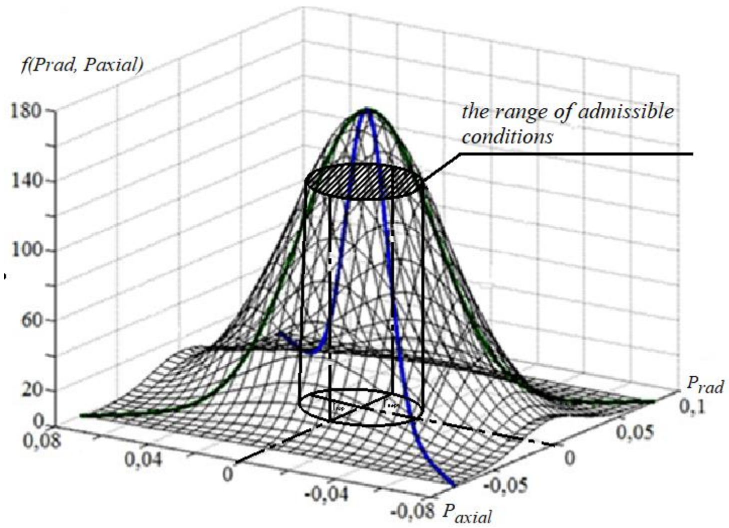

Figure. 1 General view of the volume of the axle box unit permissible conditions.

If you cut this surface with a plane parallel to the plane $P_{rad}oP_{axial}$ (horizontal plane), you will get an ellipse in the section. The equation of the ellipse projection on the plane will have the form $P_{rad}oP_{axial}$

$$\frac{\left(P_{rad}-P_{axial}\right)^2}{D_{P_{rad}}}-\frac{2\left(P_{rad}-\overline{P}_{\mathrm{rad}}\right)\left(P_{axial}-\overline{P}_{\mathrm{axial}}\right)}{\sqrt{D_{P_{rad}}\cdot D_{P_{axial}}}}+\frac{\left(P_{axial}-\overline{P}_{\mathrm{axial}}\right)^2}{D_{P_{axial}}}=const\ . \quad (8)$$

To determine the failure rate for two combinations of loads, it is advisable to represent the random values as a random vector on the plane. It is advisable to represent vector components $P_{rad}P_{axial}$ as random normal statistically dependent processes. To bring the equation to the canonical form, it is necessary to move the origin of coordinates to the point with coordinates $(\overline{P}_{rad}\,\overline{P}_{axial})$ and rotate the coordinate axes by angle φ. The form of the normal law on the plane will have the form, where $D\left(P'_{rad}\right),D\left(P'_{axial}\right)$ are the main standard deviations.

$$f\left(P'_{rad},P'_{axial}\right)=\frac{1}{2\pi\sqrt{D\left(P'_{rad}\right)\cdot D\left(P'_{axial}\right)}}\cdot exp-\left[\frac{(P'_{rad})^2}{D\left(P_{rad}\right)}-\frac{(P'_{axial})^2}{D\left(P_{axial}\right)}\right]. \quad (9)$$

To determine the density of the probability distribution, we will use the statement that for a stationary random process the correlation with its first derivative is equal to zero. Then

$$\begin{aligned}f\left(P'_{rad},P'_{axial},\dot{P}'_{rad},\dot{P}'_{axial}\right)&=\frac{1}{4\pi^2\sqrt{DP'_{rad}\cdot DP'_{axial}\cdot D\dot{P}'_{rad}\cdot D\dot{P}'_{axial}}}\times\\ &\times exp\left[-\frac{1}{2}\left(\frac{P'^{\,2}_{rad}}{DP'_{rad}}+\frac{P'^{\,2}_{axial}}{DP'_{axial}}+\frac{\dot{P}'^{\,2}_{rad}}{D\dot{P}'_{rad}}+\frac{\dot{P}'^{\,2}_{axial}}{D\dot{P}'_{axial}}\right)\right].\end{aligned} \quad (10)$$

The number of runouts of the total load change random process is the runout of combined action change vector of vertical and horizontal loads outside the volume, basing on ellipse. Dimensions are determined by the limits of the range of admissible conditions.

3. Formulation of the range of admissible conditions

To establish the limits of the range of admissible conditions, the maximum contact bearing resistance arising on the rollers under the action of radial P_{rad} and axial P_{axial} loads was obtained.

It was determined that the maximum contact bearing resistance in the contact zone of the rollers with the raceways occur at the point of transition from the moving line to the end of the roller and, at a load of 230 kN/axle is equal to 1198 MPa.

As a result, we have obtained the limiting values of radial P_{rad} and axial P_{axial} loads, which lead to contact bearing resistance in the bearing, causing its destruction. The value of this load is the radius r of the limit of the range of admissible conditions.

The random process of the loads change r affecting the axle box bearing during operation must be within the obtained range with a radius. Exceeding the obtained ultimate load in operation will result in bearing failure (Figure 2).

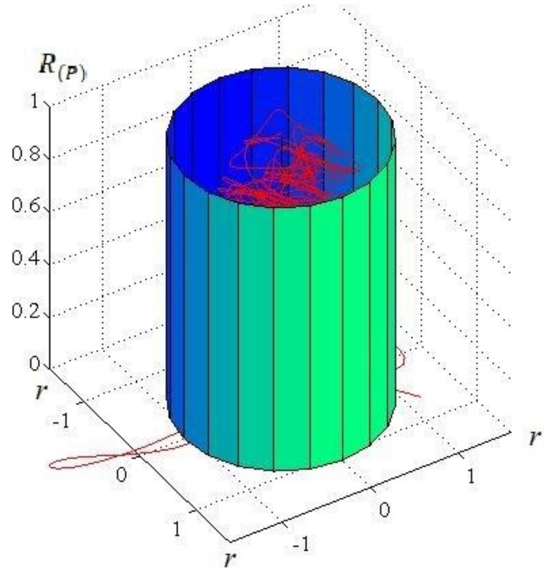

Figure. 2 Runout of the radial and axial loads action change vector beyond the range of permissible conditions.

The mathematical expectation of runout N of the total random process of changing the loads represents the runout of radial and axial loads action change vector beyond the cylinder. Having calculated the number of possible runouts beyond the permissible condition with a radius r, we will determine the axle box bearings reliability indicators for various wagon movement modes.

In the worst case, the lower bound for the probability of no-failure operation for a doubled cylindrical bearing is 0.9921.

4. Conclusions

- Method for determining the reliability indicators of freight wagon axle box bearing units has been presented, a feature of which is the probabilistic nature of the loads, and the failure is interpreted as the runout of combined bearing loading random process outside the "range of permissible conditions";
- Limits of the range of permissible conditions have been established for various loading options for freight wagon axle box unit;
- Indicators of probability of failure-free operation for freight wagon axle box bearings have been determined.

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