On condition evaluation of axle unit bearings of wheel pair

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Abstract. At present, axle units of freight cars undergo a complete checkup with disassembling and visual inspection of the bearing parts every five years. During an annual interim checkup, external inspection of an axle box with removed cap is carried out and the lubricant condition is checked. The state of the rolling surfaces of bearings during an interim checkup should be assessed using the known methods of nondestructive testing.

1. Introduction

At present, the automated systems for vibroacoustic diagnostics (ASVD) are being used more widely. They are intended to rapidly assess the technical condition of the machinery as such and its particular mechanisms. The ASVD assembled according to a modular principle consists of sub-systems for collecting and switching information on the vibration state of an object, primary analog processing subsystems, and secondary digital processing and control. The current state of microprocessor technology makes it possible to create small-size ASVD capable of not just making a decision on the operability of a diagnosed node but also recognizing the type of the defect and the degree of its danger to the mechanism.

The Railroad Car Service Department of the South-Eastern Railway jointly with LLC "Industrial Ecology and Safety" developed a device for testing bearings of wheel pairs of cars. It is called VMD-2001 (Vibration Measuring Device) and it measures the numerical characteristics of the vibroacoustic signal and stores the diagnostic results in memory. Reports on the results of diagnostics are transferred to a personal computer and stored in a database. The existing data transmission networks and the corresponding software allow collecting the diagnostic results in the single database quickly, both in the Car Depot and in the Car Service Department.

Availability of a large amount of information on the results of non-destructive quality control of the axle roller bearings of the wheel pairs, obtained using VMD-2001, makes it possible to apply known methods of probability-statistical analysis of data to find an objectively grounded conclusion about the quality of a wheel pair bearing.

The purpose of this work is to analyze the repair quality of the axle box bearings of a freight car wheel pair, to evaluate the current technical condition of the bearing park, and to analyze general tendency of the quality changing of the bearings.

The development of algorithms for the digital identification of defects is a particularly complex task, requiring a large number of full-scale tests conducted with various possible combinations of defects in the construction, which is being diagnosed. The amount of on-site tests and the costs of conducting such tests could be significantly reduced if digital mathematical modeling of signals...
generated by various combinations of defects is applied in the development of identification algorithms.

Figure 1 shows the section of a roller bearing consisting of an inner ring (hereinafter referred to as a “ring”) and an outer collar (hereinafter referred to as a “collar”) in-between of which the rolling bodies are “located-rollers”. Those are enclosed in a separator (not shown in the picture). The bearing collar is fixed in a stable case.

2. Methodologies
The results of the tests of the axle unit bearings at the stand of diagnostic unit VMD-85 with VMD-2001, obtained at the EletsCarDepot, and generalized work results of the Railroad Car Service Department of the South-Eastern Railway, given in the document "Analysis of the Railroad Car Service Department work in 2001", were taken as initial data for the analysis.

Instrumental measurements were made, the shock pulse registrations were taken \( x_i \) varying from 0 to 5V in increments of 0.33 was taken as a variable) for more than 6000 wheel pairs.

| \( x_i \) | 0  | 0.3 | 0.6 | 1  | 1.3 | 1.6 | 2  | 2.3 | 2.6 | 3   | 3.3 |
|-----------|----|-----|-----|----|-----|-----|----|-----|-----|-----|-----|
| \( p_i \) | 1290 | 576 | 658 | 709 | 687 | 742 | 556 | 428 | 389 | 76  | 50  |

where \( p_i \) is the occurrence frequency of event \( x_i \).

Figure 2 shows the histogram of the appearance of event \( x_i \). The ordinate axis represents the probability of occurrence of event \( x_i \), the shock pulse magnitudes are plotted along the abscissa.
A program was written with the calculation of the main characteristics and the construction of the necessary graphs in the frame of the unique system for working with MATHCAD formulas. The mathematical expectation $M_x = 1.322$ and the variance $D_x = 1.202$ were calculated for the universe.

Figure 3 shows the graph of the empirical distribution function. The values of the distribution function are plotted along the ordinate axis, and the shock pulse magnitudes are plotted along the abscissa [3]. It can be seen from the graph that the function does not increase monotonically, but has several angles of inclination, as indicated by tangents to the fracture points of the function. Let us assume that the function describes the four operating states of the wheel pair unit bearings.

Weibull distribution [2] of the following form can be an approximation of such distribution as:
\[ f_w(x) = \frac{m}{M} \left( \frac{x - u}{M} \right)^{m-1} \exp \left[ -\left( \frac{x - u}{M} \right)^m \right]. \tag{1} \]

where \( m \) is the form parameter, \( u \) is the position parameter, and \( M \) is the scale parameter.

With \( m < 1 \), Weibull distribution describes the phase of new equipment run-in; with \( m = 1 \), it describes the phase of maximum reliability, and with the further increase in \( m \) it describes the phase of aging or deterioration.

Let us assume that all the axle units can be divided for convenience into four groups according to the condition of the bearings: 1 - high quality, 2 - slightly worn out, 3 - heavily worn out and 4 - defective, Fig. 2.

Using the definition of a mixture of distributions, the authors obtained a probability density function that represents the sum of four probability density functions, each of which describes a certain process.

\[ f_w(x) = a_1 \cdot f_{w_1}(x) + a_2 \cdot f_{w_2}(x) + a_3 \cdot f_{w_3}(x) + a_4 \cdot f_{w_4}(x) \tag{2} \]

\[ f_{w_i}(x) = \frac{m_i}{M_i} \left( \frac{x - u_i}{M_i} \right)^{m_i-1} \exp \left[ -\left( \frac{x - u_i}{M_i} \right)^{m_i} \right] \tag{3} \]

where all summands have the form of expression (3) and its own set of parameters \( m_i, u_i \) and \( M_i \).

The resulting probability density function of Weibull distributions is described by the probabilistic-statistical model of bearing quality with an accuracy of 0.004. Coefficients \( a_i \) denote the relative proportion of each of the four groups in the total number of bearings that were diagnosed.

Fig. 4 represents the graph of the distribution function obtained using the probability density function of Weibull distributions. The graph shows the behavior of the four components of the probability density function, with respect to the bearing operation condition groups [4]. This graph interprets the condition of bearings according to the principle of deterioration: the better the quality of bearings, the higher the curve is. It allows estimating the quality of wheel pair bearings.

![Figure 4. The graph of Weibull distributions functions](image)
3. Conclusion
The following conclusions can be drawn from the analysis of distribution parameters:

1. Over the past 10 years, the overall condition of the bearing park has significantly deteriorated since the number of axle units to be rejected has increased from 4-4.5% in 1991 to 6-7% in 2001.

2. As of 2001, about 39% of the axle-bearing units that passed diagnostics can be attributed to the third group, which is characterized by a high degree of wear out of the rolling surfaces and a dangerous decrease in the contact fatigue strength of the metal.

In support of the conclusions mentioned above, it can be noted that the analysis into the causes of the failure of the axle units in 2001 showed a significant proportion of defects (up to 50%), directly related to the decrease in the contact fatigue strength of the metal: a high wear out of the separators’ centering surfaces, cracks of the thrust, outer and inner rings and the like.

Thus, the general set of qualitative condition of the axle unit bearings was obtained. The probability density function was described with the help of mixtures of Weibull distributions. On the basis of the results obtained, the authors quantified the bearings they used in the experiment. A classifier for evaluating the quality of wheel pair bearings was proposed. The probability-statistical model of mixtures of Weibull distributions was described taking into account the estimation of parameters by the method of mean-square error between the theoretical and empirical distributions.

Further development of the probabilistic-statistical model and implementation of the results will allow determining the quality of bearing repair in the Car Depot, to plan the funds for purchasing components by the Car Service Department.

References
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