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Predictive model of risks in railroad transport when diagnosing axle boxes of freight wagons

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Abstract

The research is aimed at developing a predictive model of the risks in railroad transport when using diagnostics of the axle boxes of freight wagons, which will allow assessing traffic safety during the operation of freight wagons. To develop a predictive model of the risks in railroad transport, the approaches of the probability theory were used. The constructed predictive model of the risks makes it possible to assess traffic safety during freight transportations; to determine further measures to reduce them; to evaluate the diagnostic method. The authors developed a predictive model of the risks in railroad transport when using the diagnostic methods of freight wagons' axle boxes during maintenance and repair of axle box. This model includes the probability of failure-free operation of the axle boxes of freight wagons, the probability of identifying of the technical condition of the axle boxes of freight wagons, the significance of the diagnostic parameter and its relative assessment after appropriate maintenance, repair or technical control.

Keywords

Railroad traffic safety, risks, axle box, diagnostics, freight wagons, railroad transport

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Introduction

Scientific and technical progress in railroad transport is associated with the creation of sophisticated modern rolling stock units with a constant increase in requirements for their quality under severe operating conditions. Complexity of modern technical systems, variety of operating modes, increase in the loading and movement speed of rolling stock require new approaches to solving the problems of their reliability to reduce the risks of failures. Fundamental solutions cannot be efficient without proper ensuring of the operation reliability of the rolling stock and its components under the real operating conditions and during repairs.[1-3]

The traffic safety analysis in the rolling stock industry of the Ukrainian railroad in recent years points to the need for modernization and improvement of the obsolete and worn-out technological equipment for maintenance and repair, which will, first of all, ensure a high level of reliability and, thereby, guarantee the traffic safety increase.[4,5]

Literature review and the problem statement

To decrease the operating costs and increase the economic efficiency of cargo transportations, as well as to increase the traffic safety, transition to new technological equipment for diagnosing the technical condition of freight wagons and their units during technical maintenance and repair is required.[6,7]

Ensuring an appropriate level of traffic safety in the railroad consists in maintaining the proper technical condition and reliability of freight wagons, and traffic safety can be assessed by the risks of possible failures of freight wagons after maintenance and repair.[8] Ensuring acceptable risk values can be achieved by a proper diagnosing of units and elements of freight wagons.

Failure analysis of units and elements of freight wagons in the rolling stock industry of Ukrainian railroads in recent years shows that a significant proportion of the failures accrue to the axle boxes. These are closed boxes: which have external and internal parts. The outer parts of the axle boxes include the housing, labyrinth ring, locking and inspection covers, and the inner parts include two cylindrical bearings and an end mount. During the operation of the axle box as part of a freight wagon, measures are taken to ensure its safe operation: inspection – without carrying out technical measures; maintenance - with the implementation of technical actions, including partial disassembly of the axle box assembly with the removal of the inspection hatch; repair – involves a complete disassembly and diagnostics of all components. Further failure analysis of the axle boxes of freight wagons indicates that almost all the failures are related to poor repair and maintenance, which is significantly affected by non-compliance with production technology,

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including the human factor.[9] To reduce the risks during repair and maintenance of freight wagons, it is necessary to use the methods of axle boxes diagnosing followed by the risk calculation to assess the traffic safety in the railroad transport.

Let us perform analysis of the latest works related to the risks and traffic safety in the railroad transport. Thus, the works[10,11] present the techniques of failure tree analysis to assess the traffic safety. Such techniques are used to improve the maintenance efficiency of railroad transport and reduce the risks. Several methods in[12,13] present improved techniques for failure tree analysis for decision-making.

The works[14–16] give the risk models to assess the traffic safety. The works[14, 15] are based on the accident scenarios, taking into account the human factor. In,[16] expert opinions were used to assess the risks. In works,[17,18] traffic safety is associated with the maintenance processes of the transport system elements. In,[19] a system for identifying the risks in railroad transport is presented. In,[20,21] the probability of rail failures is used to assess the safety. In,[22] the method of operational reliability is used to assess the traffic safety. In,[23] the power supply systems of the railroad are considered as critical for the safety of transport system. Risk analysis[24] made it possible to use the stochastic methods for assessing the traffic safety. In,[25] the methods for assessing the risks and opportunities for improving the traffic safety during the design, operation and maintenance of railroad vehicles are presented. Particular attention is paid to the designs of freight wagons and their influence on the traffic safety. In the works,[26,27] the traffic safety is described using risk matrices.

The paper[28] presents a research method for the efficiency of the maintenance and repair system of the axle box, which establishes the dependence of the number of maintenance services of the axle boxes on the number of their repairs during operation and allows increasing the level of traffic safety. The use of the risk models presented in the work in the railroad transport can reduce the risks when diagnosing the axle boxes of freight wagons in order to increase the local or general level of train traffic safety.

This work is aimed at developing the predictive model of the risks in railroad transport when using the diagnosing of the axle boxes of freight wagons, which will make it possible to assess the traffic safety during operation of the freight wagons.

Materials and methods of research

When using the diagnostic methods for the axle boxes of freight wagons, both during maintenance and repair, and during technical control, the following expression can be written to determine the probability of their failure-free operation:

$$P_{FP} \le \prod_{i,j,k=1}^{n,m,p} P_{ijk} + \sum_{i,j,k=1}^{n,m,p} \Delta P_{ijk}\xi_{ijk} \le 1 \qquad (1)$$

where P_{ijk} – the probability of failure-free operation of axle boxes of freight wagons after the i-th maintenance, the j-th repair or the k-th technical control, established when applying the diagnostic methods; ΔP_{ijk} – the probability of the diagnosing of the axle boxes of freight wagons after the i-th maintenance, the j-th repair or the k-th technical control, established when using the diagnostic methods within the diagnosis; ξ_{ijk} – the significance of the diagnostic parameter obtained using a specific diagnostic method for the axle boxes of freight wagons after the i-th maintenance, the j-th repair or the k-th technical control; n, m, p – the number of maintenance, repairs and technical controls, respectively.

If no diagnosing methods are used for the axle boxes of freight wagons, the second component in expression (1) will be equal to:

$$\sum_{i,j,k=1}^{n,m,p} \Delta P_{ijk}\xi_{ijk} = 0, \qquad (2)$$

in the case of taking into account the action of human factor during diagnosing the proper compliance of the technical condition of the axle box, and if we take into account the action, the expression will take the following form:

$$P_{FP} \le \prod_{i,j,k=1}^{n,m,p} \left(P_{ijk} - P_{hijk}\right) \le 1, \qquad (3)$$

where P_{hijk} – the error probability of the maintenance personnel when diagnosing the proper compliance of the technical condition of the axle box after the i-th maintenance, the j-th repair or the k-th technical control.

On the other hand, the probability of diagnosing the axle boxes of freight wagons after the i-th maintenance, the j-th repair or the k-th technical control, established when using the diagnostic methods within the diagnosis, can be written using a relative assessment of the diagnostic parameter in the following form:

$$\Delta P_{ijk} = \frac{\sum_{i,j,k=1}^{n,m,p} z_{ijk}\xi_{ijk}}{\sum_{i,j,k=1}^{n,m,p} z_{ijk}}, \qquad (4)$$

where z_{ijk} – the relative assessment of the diagnostic parameter when diagnosing the axle boxes of freight wagons after the i-th maintenance, the j-th repair or the k-th technical control.

Then expression (1) takes the following form:

$$P_{FP} \le \prod_{i,j,k=1}^{n,m,p} P_{ijk} + \frac{\sum_{i,j,k=1}^{n,m,p} z_{ijk}\xi_{ijk}^2}{\sum_{i,j,k=1}^{n,m,p} z_{ijk}} \le 1. \qquad (5)$$

Using the value of the failure-free operation of the axle boxes of freight wagons, we write down an expression for assessing the risk that may occur during operation:

$$R_{FP} = 1 - P_{FP} \qquad (6)$$

To provide assessment of the risks that may arise during the operation of freight wagons, after the i-th maintenance, the j-th repair or the k-th technical control, based on expressions (5) and (6), we write the following:

$$R_{FP} = 1 - \prod_{i,j,k=1}^{n,m,p} P_{ijk} - \frac{\sum_{i,j,k=1}^{n,m,p} z_{ijk}\xi_{ijk}^2}{\sum_{i,j,k=1}^{n,m,p} z_{ijk}}. \qquad (7)$$

Table 1. Technical parameters of Thermal and Vibroacoustic diagnostics methods.

	Visual control			Thermal method			Vibroacoustic		
	P	z	ξ	*P*	z	ξ	*P*	z	ξ
i	0.55	0.11	0.31	0.65	0.13	0.29	0.75	0.17	0.31
j	0.65	0.12	0.39	0.74	0.15	0.44	0.77	0.18	0.47
k	0.75	0.14	0.48	0.82	0.18	0.48	0.83	0.2	0.51

Table 2. Technical parameters of Magnetic-particle inspection and Eddy current testing.

	Visual control			Magnetic-particle inspection			Eddy current testing		
	P	z	ξ	*P*	z	ξ	*P*	z	ξ
i	0.55	0.12	0.29	0.63	0.17	0.34	0.67	0.15	0.33
j	0.59	0.13	0.38	0.75	0.19	0.49	0.76	0.17	0.47
k	0.67	0.14	0.47	0.81	0.21	0.51	0.82	0.19	0.49

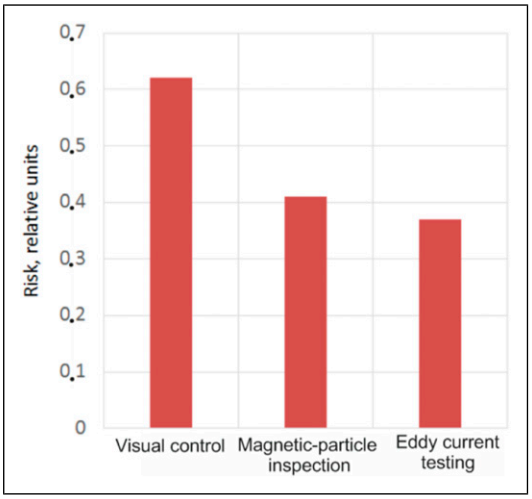

Figure 2. Risks that may arise during the operation of freight wagons after the depot repair of the axle box assembly using various diagnostic methods.

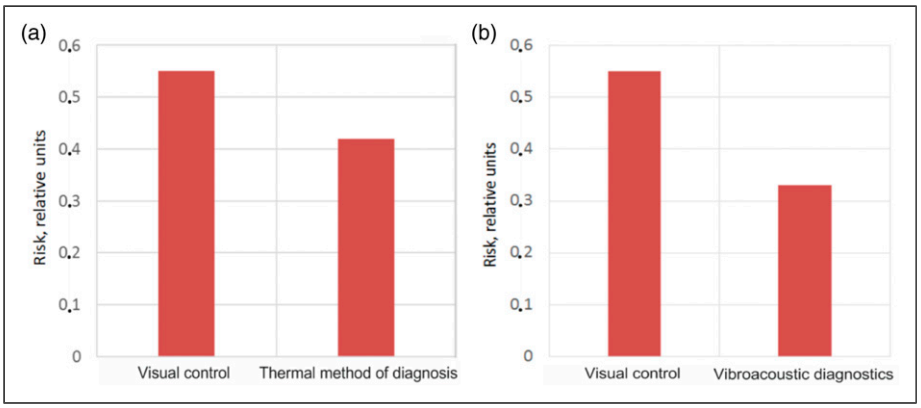

Figure 1. Risks that may arise at the stage of the life cycle – operation using various diagnostics methods of the axle box: a – during maintenance along the route; b – during maintenance and repair in a wagon shed.

The last expression represents the predictive model for assessing the risks in railroad transport when using diagnostics of the axle boxes of freight wagons, which will make it possible to assess the traffic safety during cargo transportations.

Results

To demonstrate the efficiency of a predictive model for assessing risks in railroad transport when using diagnostics of the axle boxes of freight wagons (7), we will give a graphic illustration for various diagnostic methods, and, accordingly, diagnosing parameters, risks that may arise during the operation of freight wagons.

Tables 1 and 2 show the results of observations of the technical parameters of the axle box during the diagnostics of one gondola wagon according to the data of the Baturynska wagon depot of the Prydniprovska railway.

The comparative results are given in Figure 1 and Figure 2. The average calculation results are presented in the graphs (Figure 1, Figure 2), which are constructed for a group of 18 gondola wagons. Data in Figure 2 are given for the case of control of the axle box parts subject to mandatory non-destructive testing.

In Figure 1 and Figure 2, we can see that the smallest risk that can arise during the operation of freight wagons, when performing maintenance and repairs of the axle box, occurs in the case of using the method of diagnosing according to the vibroacoustic parameters. Therefore, this diagnostic method was recommended for implementation in the wagon depot of Baturynska Station of the Prydniprovska Railway along with the widely used diagnostics methods (thermal, magnetic particle and eddy current). As a result, the risks of failure of the axle boxes of freight wagons in the wagon depot of Baturynska Station were reduced by 1.1…3.7 times during 2018–2020.

Conclusions

The authors of the work developed a predictive model of the risks in railroad transport when using the diagnostic methods of the axle boxes of freight wagons during technical maintenance and repair of the axle box, which includes the probability of failure-free operation of the axle

boxes of freight wagons, the probability of diagnosing of axle boxes of freight wagons, the significance of the diagnostic parameter and its relative assessment after appropriate maintenance, repair or technical control, which allows one to determine the risk level and, thereby, select a diagnosing method to improve the train traffic safety.

The paper constructs a predictive model of the risks in railroad transport when using diagnostics of axle boxes of freight wagons, which makes it possible to assess traffic safety during cargo transportations and determine further measures to reduce the risks. The practical value of the developed mathematical expression is to substantiate the feasibility of using the diagnostics method of axle box units of freight rolling stock – vibration-based diagnostics. The practical value of the developed predictive model of the risks in railroad transport when using diagnostics of the axle boxes of freight wagons lies in the possibility of choosing the best diagnostic method. In addition, the predictive model of the risks in railroad transport when using diagnostics of the axle boxes of freight wagons consists in the ability to assess the traffic safety during cargo transportations.

This model can be applied to assess the risks for the rolling stock of railroads, both 1520 mm gauge and for other gauges. The use of the vibroacoustic method in combination with other diagnostics methods that are widely used on the railway network (thermal during operation, magnetic particle and eddy current during repair) will significantly reduce the risk of axle box failure in operation. It is expedient to use this diagnostics method for any type of freight wagons throughout the entire stage of the life cycle of a freight wagon – operation. In addition, in the railroads of different countries, somewhat different methods for diagnosing the axle boxes have been developed. This is directly related to their design and maintainability, as well as to the development of non-destructive testing methods during operation and repair.

Declaration of Conflicting Interests

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