Statistical and optical approach to the analysis of brake equipment malfunctions in passenger cars

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ABSTRACT

Based on the analysis of the collected statistical material, the main trends and causes of malfunctions of the brake equipment components of passenger cars were identified. It was found that a significant part of transport accidents occurs due to malfunctions of pneumatic brake components, which directly affects the overall safety of railway transport. The obtained data were systematised using the specialised software package "STATISTIKA". The research results showed that the frequency of malfunctions largely depends on seasonal factors, including changes in temperature and humidity. This emphasises the importance of taking into account climatic conditions when operating brake equipment for passenger rolling stock. It was recommended to use a diagnostic system to monitor the state of brake equipment of passenger cars. It enables the construction of mathematical models that describe the performance of components and makes it possible to control key parameters, including air pressure in the brake main. This approach helps to improve brake reliability, reduce malfunction diagnostics time and extend inter-repair periods. The article provides a list of stages for the implementation of a diagnostic system that will make it possible to predict the residual life of components of pneumatic and electro-pneumatic systems, to prolong the service life of railway cars in accordance with their technical state and significantly improve the level of overall railway safety.

Keywords: diagnostic system, railway car, engineering, statistical processing, traffic safety, railway transport.

1. INTRODUCTION

The modern development of railway transport requires the implementation of high-technology control methods, among which optical approaches occupy a special place. The use of structured light, as well as correlation and singular optics, makes it possible to obtain highly accurate information on the condition of the brake equipment without its dismantling. Such methods provide non-destructive testing, enhance the reliability of diagnostics, and create the basis for more effective statistical analysis of malfunctions in passenger cars.

Automatic brakes are the most widely used on the world's railways. However, to increase the efficiency of braking, electropneumatic brakes are used, the advantage of which is associated with the almost instantaneous propagation of electrical brake control signals, which reduces longitudinal-dynamic forces and braking distance due to the simultaneous application of brakes in all train cars[1]. To improve the level of safety of passenger trains and the use of a brake diagnostic system, pneumatic and electrical signals that control the brakes of passenger rolling stock were analysed[2]. In the pneumatic method, the brakes are controlled by changing the air pressure in the main air duct of the train relative to the set charging pressure.

Braking of railway rolling stock is a complex, multifactorial process that plays a critical role in ensuring traffic safety. Its complexity is due to the interaction of mechanical, electrical, thermal, pneumatic and other brake systems during operation. A significant number of malfunctions in railway transport are associated with failures of brake equipment components, which becomes especially critical under dynamic loading conditions[3-5] and during the analysis of the strength of new vehicle designs[6], which requires improved control and diagnostic methods.

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Seventeenth International Conference on Correlation Optics, edited by Oleg V. Angelsky, Claudia Yu. Zenkova,
Proc. of SPIE Vol. 13813, 1381323 · © 2025 SPIE · 0277-786X · doi: 10.1117/12.3092460

Modern methods of mechanical systems diagnostics, in particular, brake equipment for railway cars, actively use optical and correlation approaches[7-10]. Structured light is used for non-destructive testing and detection of microdamages[11-14]. The introduction of digital signal processing along with artificial intelligence and fuzzy logic improves the accuracy of analysis, automates malfunction monitoring and predicts failures of mechanical components[15-17]. The integration of these methods with engineering modelling[18-19] improves diagnostics and increases the reliability of rolling stock operation[20-21], which is a key task for railway safety.

2. PROCESSING OF RESEARCH RESULTS

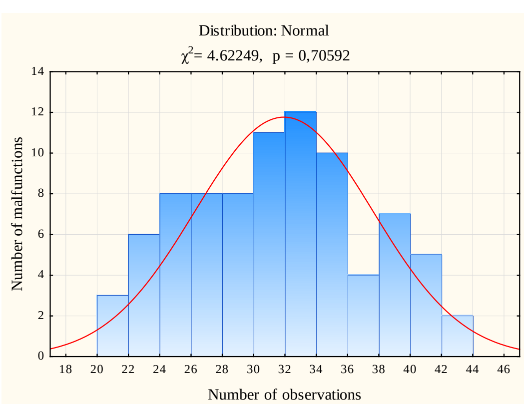
Based on the results of the collected statistical material for 2023 regarding the malfunctions of electric air distributors No. 305 of passenger cars during maintenance, it was systematised and processed in the specialised software package "STATISTIKA". The histogram (Figure 1, a) shows the experimental random variables of the malfunctions of electric air distributors described by the normal distribution law.

The sample variance is an unbiased estimate of the population variance. The standard deviation is an estimate of the root-mean-square deviation based on this unbiased variance. In descriptive statistics, the mean and sample variance are calculated using the following formulas:

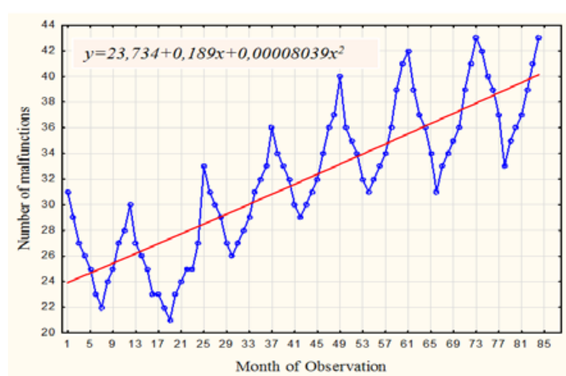
$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}; \qquad S^2 = \frac{\sum_{i=1}^{N} \left(x_i - \bar{x}\right)^2}{N-1}, \tag{1}$$

where N is the size of the given sample; x_i is the i-th element of the sample.
It was determined that the criterion χ^2 =4,62249, the variance S^2=32,44, and the arithmetic mean of malfunctions $\bar{x}$ = 31,94.

According to the results of the technical inspection of the distribution of malfunctions of brake equipment components for 2023, it was found that the largest percentage is represented by electric air distributors – 30 %. It was found that the increase in the number of malfunctions of electric air distributors No. 305 depends on seasonality and increases mainly during the period of reducing ambient air temperature, so their total number increases significantly (Figure 1, b). The decrease in temperature conditions and increase in humidity leads to a deterioration in the operating conditions of the elements of electric air distributors – a reduced quality of insulation, unsatisfactory state of the electrical contacts, destruction of solenoid valve coils, reduced quality of rubber cuffs and gaskets, damaged valve seats, reduced quality of lubrication, etc., which ultimately leads to failures of brake equipment components while the train is in operation. In addition, as a result of deterioration in the density of rubber cuffs, gaskets, and valve seats, the risk of air leaks and air leakage increases, which worsens both the operation of the components and the technical characteristics of the brake system of passenger cars as a whole



a)



b)

Figure 1. Results of statistical material processing on malfunctions of the elements of electric air distributors No. 305: *a*) histogram of the distribution of malfunctions; *b*) distribution of malfunctions by months.

The presented results of malfunctions and analytical studies of the operation process of electric air distributors No. 305 made it possible for the first time to identify a number of negative factors that affect the performance of their elements under operation. In addition, these malfunctions lead to an increase in operating costs and an increase in the time of the train's journey to its destination, as well as a decrease in the level of traffic safety[22-23].

3. DIAGNOSTIC SYSTEMS FOR BRAKE COMPONENTS OF PASSENGER CARS

In order to reduce the idle time of passenger trains at railway stations, it is advisable to use diagnostic systems that monitor the relevant pressure and voltage parameters in the brake system of the railway car with sensors (Figure 2)[24].

The use of a diagnostic system for the brake components of passenger cars is aimed at approaching the maximum compliance of the monitored parameters and should include the following steps:

- determination of the limit values of the criteria for malfunction grading;

- determination of the list of malfunctions of the brake system components of passenger cars that need to be diagnosed;

- development of a diagnostic model, which should provide information on the hazard level of the brake system components of passenger cars that are diagnosed, as well as information for the service personnel;

- development of diagnostic software, which at the user interface level should formalise the process of diagnosing the brake system components of passenger cars and provide the possibility of increasing its functionality;

- creation of the necessary measuring devices to control the brake system components of passenger cars and development of an information collection system for them;

- carrying out testing, which involves assessing the reliability according to the declared list of malfunctions of the brake system components of passenger cars, taking into account the statistical data of operation;

- development of regulatory and technological documents, programme and methodology for diagnosing brake system components of passenger cars and operational documentation for diagnostic equipment.

The technology for diagnosing the brake equipment components of passenger cars should take into account: the time required for measurements and diagnostics; complete information provided to the repair personnel; simple and accurate measurement methods; and the possibility of automated analysis of measurement results.

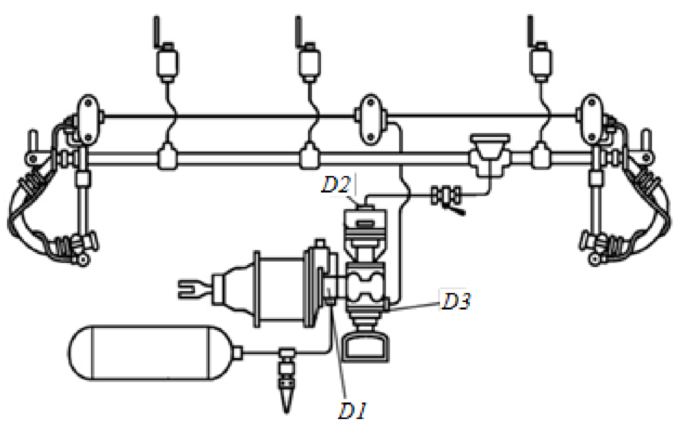


Figure 2. Diagnostic system of a passenger car: D1 – pressure sensor of the brake cylinder; D2 – pressure sensor of the brake main; D3 – voltage sensor.

CONCLUSION

A comprehensive inspection of the brake equipment components of passenger cars was carried out during scheduled maintenance. The research collected detailed statistical data on the frequency and nature of malfunctions of electric air distributors. It was found that the largest number of malfunctions is 30% of the total. The obtained results allow us to identify potentially problematic areas in the operation of individual elements of electric air distributors.

The collected statistical material on the malfunctions of electric air distributors No. 305 was processed and systematised in a specialised software package "STATISTIKA". It was established that random variables – malfunctions of electric air distributors – obey the normal distribution law. It was determined that the trends in the number of their growth or decline depend on the seasonal factors that affect them. A calculation was performed, which proves that the criterion χ^2=4.62249, the variance S^2=32,44, the arithmetic mean of malfunctions $\overline{x}$ =31,94.

The article proposes the introduction of the diagnostic system for brake equipment of passenger trains in order to increase the level of traffic safety. This system involves the construction and analysis of mathematical models that describe the serviceable state of components and mechanisms of brake equipment. The use of the diagnostic system enables the integration of data on the technical state of brake equipment, creating a comprehensive description of its functionality. This approach helps to optimise maintenance, increases the reliability of brake equipment and reduces the risk of malfunctions during the operation of passenger cars.

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