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Decision Making Based on the Results of Automatic Diagnostics of Parts and Assemblies of Rolling Stock

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ABSTRACT

The article reviews a preventive maintenance system for repairs, the main disadvantage of which is that it is essentially an open system of technical control that does not take into account objective assessment of rolling stock «as it is». The objective of the study was to review and summarize the existing researches and to word the proposals to develop the system of rolling stock maintenance. Based on the analysis of the researches in that field it is proposed to reduce material and labor costs for maintenance of cars by making the system of technical diagnostics closed. As a feedback, it is advisable to use an automatic test diagnostic control system that detects car defects while the train is running. It will significantly reduce the number of manual operations for inspecting rolling stock in the arrival parks of sorting stations and automate decision-making on possibility of subsequent operation of controlled rolling stock based on its actual condition.

A technique is proposed for evaluating the results of technical diagnostics of rolling stock in which probabilistic estimates are used, dividing the most significant defects of the controlled object into three classes according to the degree of their significance for operation safety. It has been established that Weibull distribution corresponds to fatigue defective phenomena, while Rayleigh distribution corresponds to wear phenomena with constant or periodic workload.

To identify defective car wheels and axle boxes, a dynamic system is proposed, which includes: the controlled object which is a wheel or axle box, automatic test diagnostic equipment and a resolver for deciding on further operation of the identified defective car. The optimal equation of the separating function of «false alarm» and «acceptance» is obtained on the basis of the Bayes criterion, which minimizes the average risk of making a wrong decision.

Keywords: railway, traffic safety, rolling stock, test diagnostics, classification of defects.

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Background. The intensification of the transportation process led to development of technical diagnostics, which is widely used in railway transport. At the same time, conditions have now developed when, without widespread introduction of objective methods and «digital means of monitoring the technical condition of locomotives and cars that meet the current level» [1, p. 9], it is difficult to count on a significant increase in efficiency of rolling stock operation and improving quality of its maintenance and repair [1].

«A variety of external and built-in, universal and specialized means of technical diagnostics of rolling stock have been created» [2, p.14] and extensive experience in their application has been accumulated. However, what has been done in this area still lags far behind the needs of practice.

Objective. The objective of the article is to review and summarize studies on decision making process based on the results of automatic diagnosis of parts and assemblies of rolling stock.

Methods. The author uses general scientific and engineering methods, comparative and content analysis methods.

Results. «To maintain the cars and locomotives in constant operational condition on the railways of the Russian Federation and Belarus, a preventive maintenance system is being used that is based on the following principles» [3, pp. 78–80]:

a) «frequency of repairs established in a planned manner, determining the amount of work to restore serviceability of a car (locomotive) according to the type of periodic repair;

b) organization of overhaul maintenance of cars, establishment of duration of an overhaul period in the repair cycle, depending on the type of car and its working conditions;

c) periodic inspection, certification and checking of the condition of units and assemblies of a car» [3, pp. 78–80].

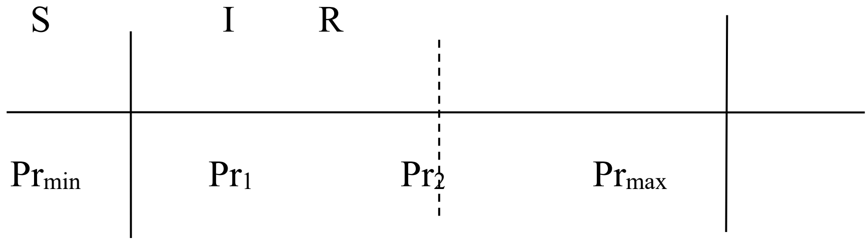
Along with the well-known advantages, this system also has disadvantages. The main one is that it is essentially an open system of technical control, providing for mandatory performance of a certain list of works and not taking into account objective assessment of rolling stock «as it is». The situation is aggravated by the fact that «a limited amount of time (within 20–30 minutes) is allotted for inspection of the train at maintenance points» [3, p. 96].

A significant reduction in material and labor costs for maintenance of cars and at the same time the increase in their technical condition can be achieved **if the technical diagnostic system is closed**. It is proposed to use a resolver as feedback, which will determine the conditions for subsequent operation of the controlled rolling stock based on its actual state and «will significantly reduce the number of manual operations for inspecting the rolling stock in the arrival parks of stations» [4, p. 44]. For this purpose, the use of automated non-destructive testing and diagnostics test systems that determine the defects of cars within the moving train while approaching the station is relevant. In this case, rejection of a unit or a part of a car «will be carried out automatically, without participation of an operator» [2; 5–9].

The interest in the technical test diagnosis of locomotives and cars is also related to the fact that «complexity of a design, intensity of operation and increasing requirements for reliability and safety do not allow intuitive and manual way to determine their technical condition» [4, p. 46]. «The use of specialized diagnostic tools makes it possible to reliably determine the technical condition of rolling stock» [10, p. 41].

«Automated diagnostic systems for monitoring the technical condition of cars and locomotives, while the train is running, should identify the following malfunctions of the most critical components of rolling stock: temperature monitoring of axle boxes and braked wheels; control of geometric dimensions and defects of wheels along the running surface; control of overall dimensions of cars; control of parameters of draw-and-buffer mechanism of automatic couplings; identification of dragging parts of the faulty brake system of cars, etc.» [2, p. 147].

To assess the results of technical diagnostics of locomotives, a probabilistic approach is proposed. In railway transport, there is a problem of assessing reliability of results of diagnostics of locomotives and cars



Pic. 1. Three-position assessment of the state of an object (node).

[4, p. 106]. «*Diagnostic reliability* means quantitative assessment of the degree of correspondence of diagnostic results to the actual technical condition of the object. This estimate is probabilistic and accumulation of statistical material is necessary to proceed with the estimate. The investigated unit of the controlled object following diagnostic analysis can be recognized as suitable or rejected (and accordingly designated S or R)» [4, pp. 106, 107]. The same author noted that «the quality of the diagnostic equipment can be assessed by the admissible probability of an error in diagnosing $P_{A.}$ This value can be determined experimentally from the reference sample by the method of repeated tests. If the number of tests is N, the number of correctly made decisions is N_M, the number of erroneous decisions is N_0, then P_A estimate for sufficiently large values of N will be determined from the expression» [4, p. 107]:

$$P_A \approx 1 - N_M/N = N_0/N = \alpha + \beta. \qquad (1)$$

Probabilistic assessment of reliability of locomotive diagnostics

Following the advice of the researchers, «let us turn to probabilistic estimates of reliability of diagnostics from the standpoint of operation of locomotives and cost-effectiveness of their maintenance. Missing a defect in the equipment of a locomotive can lead to a violation of traffic safety during the trip. In addition to losses from train stops, which can be quantified, more severe cases are possible, which are evaluated according to other criteria (for example, losses from rolling stock wrecks and accidents)» [4].

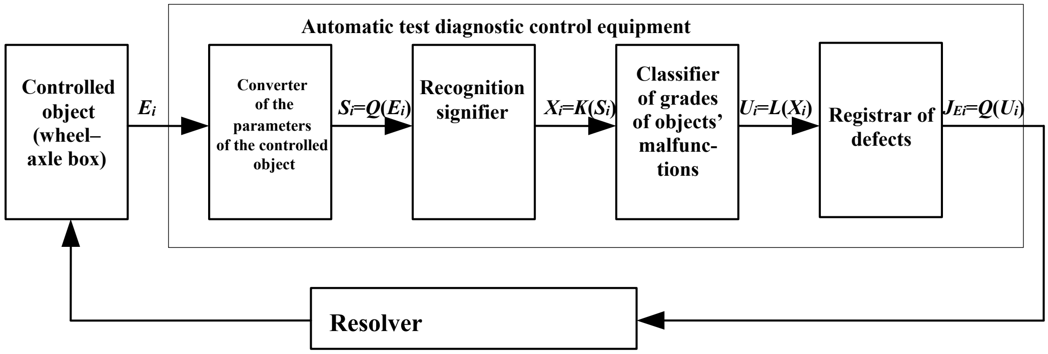
At the same time, erroneous recognition of a suitable object as malfunctioning one is associated with additional repair costs. Comparison and optimal selection of indicators are usually carried out empirically. «From a technical point of view, reduction in probability of errors is directly related to the quality of technological equipment and diagnostic algorithms» [4, p. 108].

«The parameter selected as evaluative for diagnostics is compared with the boundary value of this parameter. If the parameter value does not exceed the setting, the object is considered suitable, otherwise it is rejected» [4, p. 109]. «The conditions for making a diagnostic decision change over time, while the probability of error increases. The threshold values for decision making are different for each unit of the diagnosed product, as the result the specific value of the setting expands to the field of possible values, complicating thus the diagnosing process. A significant impact on the increase in the number of diagnostic errors is exerted by external conditions (humidity, temperature, interference, electromagnetic fields). This affects both operation of a diagnostic device and a tested object itself» [4, p. 109].

«For these reasons, a decision on the condition of an object will be more objective, if it will be made not by the threshold, but by the range of tolerance fields» (Pic. 1).

«Here Pr_{min} and Pr_{max} are the minimum and maximum values of the diagnosed parameter, Pr_1 and Pr_2 are the zone of the indefinite solution (in Pic. 1 this corresponds to the solution I). The decision algorithm is modified as follows:

- if the diagnosed parameter is in the range [Pr_{min}; Pr_1], then a decision is made on suitability of the object;
- if the parameter is within [Pr_2; Pr_{max}], then the object is considered faulty;
- with parameter values in the range [Pr_1; Pr_2] the decision on suitability is



Pic. 2. Structural diagram of a system of automatic test diagnostic control of axle boxes and wheels during train movement.

considered not made, and the diagnostic process should be repeated.

Moreover, to determine suitability, other additional criteria and methods for diagnosing or repeating the experiment are used» [4, p. 46; 15].

«We show that in the case of using the described solution algorithm, the probability of an error decreases. For this, a probabilistic approach is applied and one of two alternative cases is considered (the device is fault-free or faulty). With a working device, the probability distribution density of the controlled parameter is rather accurately approximated by the Rayleigh distribution» [4, p. 110]:

$$p(x) = (x/\sigma^2)\exp[-(x_2/\sigma)], \qquad (2)$$

where x – value of the controlled parameter;

σ – standard deviation;

$p(x)$ – probability distribution density.

«Distribution (2) has a clearly expressed asymmetric nature with a maximum and with a decrease in the characteristic to zero and is a special case of the Weibull distribution with density:

$$\xi(x) = \frac{\alpha}{\sigma}(X/\sigma)^{\alpha-1}\exp\left[-(X/\sigma)^{\alpha}\right], \qquad (3)$$

when α = 2 and a particular case of distribution of a random variable $S = \sqrt{x_n^2 / n}$ with density:

$$P(x) = \frac{\sqrt{2n}}{\sigma S(n/2)}\left(\frac{x\sqrt{n}}{\sigma\sqrt{2}}\right)^{n-2}\exp\left\{-\frac{n}{2}\left(\frac{x}{\sigma}\right)^2\right\}, \qquad (4)$$

when $n = 2$» [4, p. 111].

Fatigue phenomena lead to the Weibull distribution, and wear phenomena with constant or periodic workload with constant amplitude lead to the Rayleigh distribution. Thus, the Rayleigh distribution is, in a certain sense, universal in nature and can be used to study the corresponding failure flows.

«Wheel sets belong to the running parts and are one of the most critical car elements. Therefore, special, increased requirements of Gosstandart [state standard], the Rules for technical operation of railways, Instructions for inspection, repair and assembling of car wheel sets, as well as other regulatory documents in design, manufacture and maintenance are applied to them» [13, p. 46].

Particular attention should be paid to monitoring the condition of wheel sets during train movement, which allows to pre-identify defective wheel sets, transmit the information «to the nearest point of technical maintenance for the purpose of detailed inspection by technical personnel» [14–18].

«In a structural form, the system for automatic test diagnostics of axle box assemblies is a complex dynamic system, which includes: the controlled object which is a wheel or an axle box, test diagnostic control equipment and a resolver for determining the conditions for further operation of controlled rolling stock» [4, p. 138]. This device provides decision making (on the basis of the class assigned to the detected defect) about further operation of the defective car (for example, on operation without restrictions, taking it to the nearest repair depot for routine inspection and

Table 1

Distribution of digital indicators of wheel defects by fault classes

No.	Name of defect or controlled parameter	Digital indicators		
		Operation allowed	Conventional operation with stop at the nearest station	Immediate decommissioning
1	High flange, mm	0–3	3–7	7 and more
2	Adjustable slide on the running surface, mm	0–0,5	0,5–1,0	more than 1,0
3	Shelled treads or dents on the surface of the ridge, mm	0–1,0	1,0–4	more than 4
4	Local or general increase in the width of bandage or rim of a wrought wheel, mm	0–3	3–6	more than 6
5	Ring workings on the running surface at a distance of up to 40 mm from the outer end of the bandage, depth, mm	0–0,5	0,5–2	more than 2
6	Weld-on deposit on the running surface, height, mm	0–0,1	0,1–0,5	more than 0,5

repair, immediate decommissioning). The general functional diagram of the test hardware diagnostics is shown in Pic. 2.

«The parameter converter converts the conditions' space of the controlled object E into the space of electrical signals S to be further processed:

$S_i = Q(E_i)$, (5)

where Q is operator of transforming the conditions' space of an object into a signal space. The functioning algorithm of this operator corresponds to the action of an analog-to-digital converter used to measure continuous values of measured defects and issuing a digital equivalent in a form consistent with operation of a signifier» [12, p.145; 19].

«The signifier (forming object conditions' coding) converts the space of signals S into the space of signs X characterizing the state of the object:

$X_i = R(S_i)$, (6)

where R is operator of transforming the space of signals into the space of signs.

Based on the analysis of signs of the conditions of an object, the classifier performs the classification function, that is, it generates a signal indicating that the feature vector belongs to the corresponding class of states:

$\gamma = L(X_i)$, (7)

where L is algorithm of the classifier» [12, p. 146].

The registrar, guided by the decision γ_i, made by the classifier, provides information J_{Ei} that the state of the controlled object belongs to the corresponding class of states, that is,

$J_{Ei} = H(\gamma_i)$, (8)

where H is operator of transforming the classifier signal by an informant.

«Thus, a generalized analytical record of the process of hardware test fault detection, built on the basis of expressions (5), (6), (7) and (8), has a form:

$J_{Ei} = H(L(R(Q(E_i))))$» [12, p. 146]. (9)

The resolver, on the basis of defects in components and invalid parameter values of wheel sets given in Guidance document of VNIIZhT [13] and in the standard of the state association Belarusian Railway STP BCh 17.310-2015, determines the gradation of digital indicators of defects. The distribution of digital indicators of wheel defects by fault classes is presented in Table 1.

The allocation of wheel defects into three categories corresponds to the functioning algorithm of the «ASK PS automated rolling stock control system, which provides automatic classification of wheel set parameters into three groups: «Alarm 0» – normal operation of a moving unit; «Alarm 1» – conditionally permissible operation of a moving unit with further monitoring; «Alarm 2» – an immediate stop of a train and inspection of a defective moving unit» [18, p. 38].

The software of the ASK PS system provides for control of various diagnostic subsystems, starting from peripheral installations, workstations of automated workplaces ARM PTO and workers, to monitoring performance results. Here the advantages of digital technology are realized: «deterministic test data on the results of the control of each specific car and locomotive are collected into a single database for subsequent analysis and processing. This provides a stream of objective and accurate information that allows the digital complex to form control actions without participation of operators» [20, p. 154].

Conclusion. The use of test technical diagnostics will significantly increase reliability of assessing the technical condition of controlled rolling stock.

The classification of defects in rolling stock and its critical parts increases visibility of information and systematizes data about detected defects of the controlled rolling stock.

The use of automated diagnostic monitoring systems can simultaneously identify and eliminate malfunctions of the running parts of rolling stock that arise during operation, as well as significantly reduce the number of manual operations to inspect rolling stock at the receiving tracks and ensure full automation of the monitoring of such wagons during train movement.

The combination of pre-processed data on controlled trains at the approaches to maintenance points of the central stations will increase the efficiency of the integrated digital model of the car fleet within the ASK PS of the entire railway.

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