ЕКСПЛУАТАЦІЯ ТА РЕМОНТ ЗАСОБІВ ТРАНСПОРТУ

V. V. BURCHENKOV[1*]

[1*]Dep. «Cars», Belarusian State University of Transport, Kirova St., 34, Gomel, Republic of Belarus, 246653,
tel. +37 (529) 530 37 84, e-mail lenadva@tut.by, ORCID 0000-0002-3664-4655

Improving the Methodology of Placing Peripheral Devices for Monitoring the Technical Condition of Rolling Stock

Purpose. Based on the research work of units and parts of rolling stock undercarriage in transient modes of emergency situations it is proposed to optimize the sequential placing of peripheral contactless devices for technical control of locomotives and cars on railway lines. **Methodology.** Investigation of transient processes of temperature increase of faulty axle bearings of locomotives and cars during remote technical diagnosing allows one to organize theory and hardware construction of the peripheral systems for testing the rolling stock on the move. Automatic control of the technical state of the rolling stock on the move – the last and in some cases the only possible process step, which allows revealing unacceptable defects in rolling units and thereby prevent emergencies in railway transport. **Findings.** Based on the research it was proposed a solution to the optimization problem of placing peripheral control devices of rolling stock when moving according to the criteria of the linear and exponential nature of heating defective axle boxes of wheelsets and other units of undercarriage. The risks of train stop on the railway line because of the erroneous classification of normally heated axle boxes as overheated, as well as the consequences of classification of overheated axle box as normally heated axle boxes were evaluated. **Originality**. Optimization model of placing peripheral control devices based on probabilistic criteria for evaluating the degree of permissible risk that, at a minimum, should not be exceeded during the transition to control technical means. A functional block diagram of test hardware diagnostics for the wheelsets when determining the gradations of digital indicators of defects was proposed. **Practical value.** The value of the results obtained lies in the improvement of a method of placing technical control peripheral devices and diagnosing rolling stock when determining the distance between the control stations in the same direction and organizing tracking modes for railcars with developing defects. From a technical point, reduced error probability is directly related to traffic safety and diagnostic algorithms.

Keywords: rolling stock; axle boxes; temperature control; method of placing; unit diagnostics

Introduction

With the development of remote control of the train movement and an increase in the coverage areas of centralized dispatching systems, the possibilities of visual observation of the technical condition of the undercarriage of cars and locomotives of trains along the route are reduced. On the railways of the world, peripheral systems for contactless control of the undercarriage of cars and locomotives in motion are widely used.

Overheating of the axle boxes of cars is characterized by an unsteady heat exchange mode and a temperature increase of the wheelset axle neck and the axle-box body on the move. The rate of increase in the temperature of the axle neck depends on the nature of the axle box malfunction; to neutralize this tendency, the development and implementation of technical devices for controlling the temperature of axle boxes, brake discs and blocks is accelerated in order to prevent emergency situations.

At the same time, modern conditions impose on systems for diagnosing and control of undercarriage not only the requirements for detecting faulty elements, but also for early detection of emerging defects. This tendency actualizes the task of improving the methodology for determining the loca-

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tions of peripheral control devices for rolling stock, taking into account the option of tracking cars with heating axle boxes.

The basis of the strategy for optimizing the placement of peripheral diagnostic devices on railway lines is the recommendations developed based on statistical data and evaluation of the risks degree. The heating of the axle neck, at which the axle box should be considered emergency (overheated), is at the level above 100–140°C. For axle boxes with roller bearings, the temperature of the axle neck in the range of values up to 300°C changes at a speed of 2 to 15°C per minute, and in the range of values from 300 to 800°C (the approximate temperature of the axle neck fracture) reaches the values of 18–20°C/min. The maximum rates of increase (gradients) of the axle neck temperature are also characterized by its statistical data on fractures. Thus, according to foreign data, the fracture of the axle neck if there is no lubrication for axle boxes with rolling bearings occurs after 55–60 km. According to the statistics of All-Russian Scientific Research Institute of Railway Transport, the car mileage to the axle neck fracture is no more than 45–50 km. If an unacceptable heating of the axle box is not detected in time, its destruction occurs [5, 9, 14].

During the operation of the axle box, heat from the bearing is transferred to the axle box body. The value of the temperature rise of the axle box body ΔT_{abb} is determined by the temperature of the axle neck, the temperature of the outside air and the speed of the train. The heating of the axle box body due to solar radiation, its thermal resistance during heat transfer from the bearing to the body, the presence of moisture on the axle box surface, etc., have a great influence on the value ΔT_{abb}. Taking into account the influence of individual interfering factors, the distribution of the probability density of the real values of the temperature excess ΔT_{abb} of normal (curve 1) and overheated (curve 2) axle boxes with rolling bearings is shown in Fig. 1.

The sets of ΔT_{abb} values for normally operating and overheated axle boxes have an intersection zone. This indicates the impossibility of error-free recognition of overheated axle boxes by ΔT_{abb} value. Indeed, if we select a certain value of ΔT_{abb} as a recognition criterion, for example, 20°C, then a certain number of overheated axle boxes, ΔT_{abb} of

which is lower than this value, will not be detected, and vice versa, a certain number of normally operating axle boxes, ΔT_{abb} of which is higher than 20°C, will be taken as overheated. Tracking the rate of increase of axle box temperature at control points to a value exceeding the permissible one during operation indicates the statistical nature of these dependencies [3].
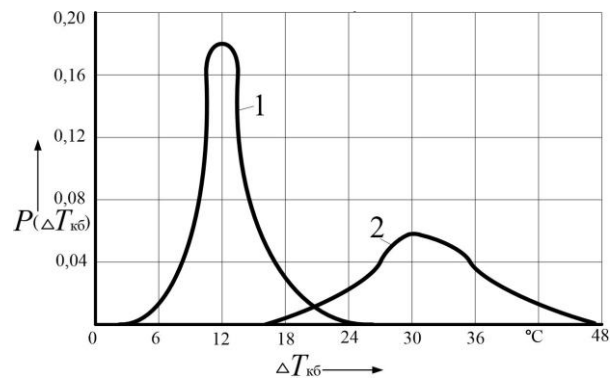

Fig. 1. Distribution of ΔT_{abb} values for axle boxes with rolling bearings

It follows from the above that the automation of the process of detecting overheated axle boxes will be successful only when using statistical methods for processing the measurement results.

Purpose

Based on the study of the operation of units and parts of the rolling stock undercarriage in transient modes of the development of emergency situations, the article provides optimizing the sequential placement of peripheral contactless devices for technical control of locomotives and cars on railway lines.

Methodology

The existing network of train observation points sets the degree of permissible risk, which, at a minimum, should not be exceeded during the transition to control by technical means. The dependencies identified during the analysis of the data make it possible to form a strategy for placing the control devices of heating axle boxes, focused on risks. In this case, the only and sufficient parameter of the axle box malfunction is its temperature, considered as an indicator of the risk of derailing.

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Probabilistic assessment of the reliability of remote technical control of car wheels during train movement. Let us turn to probabilistic estimates of the reliability of detecting overheated and normally heated axle boxes. An overheated axle box skipping may lead to a violation of traffic safety along the route. In addition to losses from train stops, which can be quantified, more severe cases are possible, which are evaluated by other criteria (for example, losses from rolling stock wrecks and accidents).

At the same time, the erroneous recognition of a normally heating axle box as faulty is associated with additional costs for stopping the train on the running line. Comparison and optimal choice of indicators among these components are made on the basis of statistical data. From a technical point of view, reducing the probability of errors is directly related to traffic safety and diagnostic algorithms.

The parameter selected as an estimate for diagnosing is compared with the setting – the boundary value of this parameter. If the value of the parameter does not exceed the setting, the object is considered suitable, otherwise it is rejected [4, 10].

The conditions for making a diagnostic decision change over time, and the probability of error increases. The boundary values for making a decision are different for each category of equipment for detecting overheated axle boxes (for example, the boundary value for running line multifunctional hardware components set (MHCS) is 120°C; for the devices placed before the service points it is equal to 100°C, etc.). Due to the above-mentioned the specific value of the set is expanded to the field of possible values, which complicates the diagnostic process. External conditions (influence of solar radiation, ambient temperature) have a significant impact on the increase in the number of diagnostic errors. Due to these reasons, making a decision on the state of the object will be more objective with three-position evaluation of the object state [8, 16]. Having supplemented the minimum and maximum values of the parameter being diagnosed with the zone of an indefinite decision, the decision-making algorithm is modified as follows:

– if the parameter being diagnosed does not exceed the minimum value, a decision is made on the suitability of the object;

– if the parameter exceeds the maximum value, then the object is considered faulty;

– when the parameter values are in a certain range between the minimum and maximum values, the object is subject to monitoring in the tracking mode. At the same time, to determine the suitability, fixation of the parameter under control is used for each diagnostic point [15].

Let us show that in the case of using the described decision formation, the error probability decreases. To do this, we apply a probabilistic approach and consider one of two alternative cases (axle boxes operate in normal mode or in an overheated state). With normally heating boxes, the distribution probability density of the controlled parameter is fairly accurately approximated by the Rayleigh distribution [10]:

$$p(x) = (x/\sigma^2)\exp\left[-(x^2/\sigma)\right], \qquad (1)$$

where x – the value of the parameter being controlled; σ – root-mean-square deviation; $p(x)$ – probability distribution density.

Distribution (1) has a pronounced asymmetric nature with a maximum and with a characteristic drop to zero and is a special case of the Weibull distribution with density

$$\xi(x) = \frac{\alpha}{\sigma}\left(X/\sigma\right)^{\alpha-1}\exp\left[-\left(X/\sigma\right)^{\alpha}\right] \quad (2)$$

with $\alpha = 2$ and a special case of the distribution of a random variable $\xi = \sqrt{x_n^2}/n$ with the density

$$P(x) = \frac{\sqrt{2n}}{\sigma\Gamma(n/2)}\left(\frac{x\sqrt{n}}{\sigma\sqrt{2}}\right)^{n-2}\exp\left\{-\frac{n}{2}\left(\frac{x}{\sigma}\right)^2\right\} \quad (3)$$

at $n = 2$.

A gradual temperature increase of the axle box leads to the Weibull distribution, and random temperature changes due to the influence of solar radiation or other factors lead to the Rayleigh distribution. Thus, the Rayleigh distribution is, in a certain sense, universal in nature and can be used when setting up threshold devices.

Wheelsets belong to the undercarriages and are one of the most important elements of the car. Therefore, they are subject to special, increased requirements of the State Standard, the Rules for the Technical Operation of Railways, Instructions

for the Inspection, Repair and Formation of Car Wheelsets, as well as other regulatory documents during the design, manufacture and maintenance [13].

Particular attention should be paid to monitoring the condition of wheelsets when the train is moving, which makes it possible to detect defective wheelsets in advance, transfer the information received to the nearest inspection station for detailed diagnostics by technical personnel [19].

Structurally, the system for automatic control of the technical condition of axle boxes is a complex dynamic system. It includes the object of control – a wheel or axle box, test diagnostic control equipment and a decisive device for determining the conditions for further operation of rolling stock under control. This device provides a decision (based on the class assigned to the detected defect) on the further movement of the defective car (for example, about moving without restrictions, moving to the nearest repair depot for preventive control and repair, about immediate exclusion from operation).

The converter of parameters converts the state space of the object under control (wheel – axle box) E into the space of electrical signals S, subject to further processing:

$$S_i = Q(E_i), \qquad (4)$$

where Q – space transformation operator of the object state into a signal space. The operation algorithm of this operator corresponds to the action of analog-to-digital converter used to measure continuous values of measured defects and issuing a digital equivalent in a form consistent with the operation of the attribute generator [1, 21].

The attribute generator (object state code) converts the signal space S into the attribute space X, which characterizes the state of the object:

$$X_i = R(S_i), \qquad (5)$$

where R – operator of transformation of signal space into attribute space.

The classifier, based on the analysis of the attributes of the object state, performs the function of classification, that is, it generates a signal indicating that the attribute vector belongs to the corresponding class of states:

$$\gamma = L(X_i), \qquad (6)$$

where L – classifier operation algorithm.

The algorithm for making a decision in favor of one of the state classes of recognition objects depends on the decision method. Two methods are possible: constant sample size decision and sequential decision.

In the first case, there are n attributes (n = const) $X_1, X_2, …, X_n,$ which belong to one of the classes of states Ω_i. The hypotheses that the sample values belong to the a priori known distributions $W_n(X_1, X_2, …, X_n / \Omega_i)$ and $W_n(X_1, X_2, …, X_n / \Omega_{\gamma j})$ we denote by H_i and $H_{\gamma j}$ and the decisions consisting in making appropriate hypotheses by γ_i and γ_j. Establishing a decision rule is reduced to dividing the n-dimensional attribute space ($X_1, X_2, …, X_n$) into two non-intersecting areas A_i and A_j, that is:

$$(X_1, X_2, …, X_n) \in A_i \to \gamma_i;$$
$$(X_1, X_2, …, X_n) \in A_j \to \gamma_j.$$

Since during classification it is necessary to delimit the intersecting areas of the attribute space into non-intersecting areas of state classes using the discriminant function, classification errors are inevitable. There are two kinds of errors: the probability of a «false alarm» (error of the first kind), that is, the probability of making a decision about a malfunction of an object at a time when it is actually working:

$$P_{\text{fa}} = P\left\{\frac{\gamma_j}{H_i}\right\} = P\left\{(X_1, X_2, …, X_n) \in \frac{A_j}{\Omega_i}\right\} =$$
$$= \int_{A_j} … \int W_n\left(\frac{(X_1, X_2, …, X_n)}{\Omega_i}\right) dX_1 dX_2 … dX_n; \quad (7)$$

and the probability of «missing» a faulty object (error of the second kind), that is, assigning the sample to the class Ω_i, although it reflects the Ω_j-th class of the state:

$$P_{\text{miss}} = P\left\{\frac{\gamma_j}{H_j}\right\} = P\left\{(X_1, X_2, …, X_n) \in \frac{A_i}{\Omega_j}\right\} =$$
$$= \int_{A_i} … \int W_n\left(\frac{(X_1, X_2, …, X_n)}{\Omega_j}\right) dX_1 dX_2 … dX_n. \quad (8)$$

Obviously, with a given (constant) sample size, it is impossible to simultaneously make the probabilities of «false alarm» and «missing» arbitrarily

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small. You can only change their ratio by moving the separating function. The optimal equation of the discriminant function can be obtained based on the Bayes criterion, which minimizes the average risk of making a wrong decision [16]. When using Bayes' criterion, the discriminant function will take the form:

$$D(X_1, X_2, ..., X_n) =$$

$$= \frac{P(\Omega_j)W_n\left(\dfrac{X_1, X_2, ..., X_n}{\Omega_j}\right)}{P(\Omega_i)W_n\left(\dfrac{X_1, X_2, ..., X_n}{\Omega_i}\right)} =$$

$$\frac{P(\Omega_j)W_n\left(\dfrac{X_1, X_2, ..., X_n}{\Omega_j}\right)}{P(\Omega_i)W_n\left(\dfrac{X_1, X_2, ..., X_n}{\Omega_i}\right)} =$$

$$= \frac{P(\Omega_j)W_n}{P(\Omega_i)W_n}\lambda(X_1, X_2, ..., X_n) = \frac{C_{ij} - C_{ii}}{C_{ji} - C_{jj}}, \quad (9)$$

where $P(\Omega_i)$, $P(\Omega_j)$, $\Omega\lambda$ − a priori the probabilities of the corresponding state classes; $\lambda(X_1, X_2, ..., X_n)$ − likelihood function;

$$\begin{vmatrix} C_{ij} & C_{ii} \\ C_{ji} & C_{jj} \end{vmatrix}$$ − loss cost matrix whose rows correspond to hypotheses H_i and H_j and columns correspond to solutions γ_i and γ_j.

The minimum value of the average risk:

$$R = P(\Omega_i)C_{ii} + P(\Omega_j)C_{ji} + P(\Omega_i)(C_{ij} - C_{ii})P_{fa} -$$

$$-P(\Omega_i)(C_{ji} - C_{jj})(1 - P_{miss}), \quad (10)$$

where P_{fa}, P_{miss} − «false alarm» and missing probabilities determined by the discriminant function.

At various stages of the implementation of equipment for detecting axle box malfunctions, when a priori information about the statistics of the parameters under control is still insufficient, other criteria for optimality of the decision can also be used, which are special cases of the Bayes criterion (the Neumann–Pearson criterion, Kotelnikov criterion, etc.) [2, 17].

However, regardless of the criterion used, classification by constant sample size is as follows:

− the likelihood ratio $\lambda(X_1, X_2, ..., X_n)$ is calculated with the measured attribute vector;

− the hypothesis H_i, depending on whether the found point is located above or below the discriminant function is accepted or rejected.

With the sequential classification method, the number of attributes (sample size) can vary. The decision-making procedure is reduced to the fulfillment of the condition $B < \lambda(X_1, X_2, ..., X_n) < A$.

The decision is made in favor of the hypothesis H_j, as soon as the inequality $\lambda(X_1, X_2, ..., X_n) \geq A$, is satisfied, and as well as in favor of the hypothesis H_j − if the inequality $\lambda(X_1, X_2, ..., X_n) \leq B$ is satisfied.

If the result of calculating the likelihood ratio for n attributes falls between the stopping boundaries A and B, then the next $(n+1)$-th attribute is being formed, and the calculation procedure is repeated.

It is proved [14] that the stopping boundaries providing the set probabilities of «false alarm» and «missing» are determined from the expression:

$$A = \frac{1 - P_{miss}}{P_{fa}}; B = \frac{P_{miss}}{1 - P_{fa}}. \quad (11)$$

The defect recorder, guided by the decision γ_i, adopted by the classifier, issues information J_{Ei} about the belonging of the state of the object under control to the corresponding class of states, that is:

$$J_{Ei} = H(\gamma_i), \quad (12)$$

where H − operator of the signal transformation of the classifier by the informatory.

Thus, the generalized analytical record of the hardware test fault detection process, constructed on the basis of expressions (5) − (7) and (10), has the form:

$$J_{Ei} = H(L(R(Q(E_i)))). \quad (13)$$

The general functional diagram of the test hardware diagnostics is shown in Fig. 2 [16].

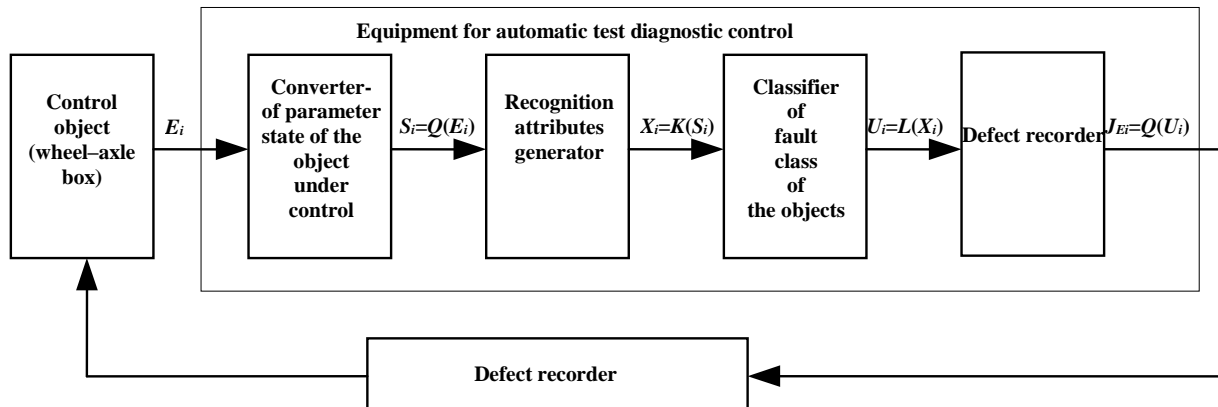ЕКСПЛУАТАЦІЯ ТА РЕМОНТ ЗАСОБІВ ТРАНСПОРТУ

Fig. 2. Block diagram of the system of automatic test diagnostic control
of axle boxes and wheels during the train movement

The decision-making device on the basis of component defects and unacceptable parameter values given in the Belarusian Railway Standard for wheelsets STP BCh 17.310–2015 [8] determines the gradation of digital indicators of defects.

For this purpose, the study of the heating nature of the axle boxes deserves attention. The statistical data of tracking at the control points of the axle box temperature rise to a value exceeding the permissible one during operation made it possible to identify heating of axle boxes of two fundamentally different types. They are: «2linear» – the axle boxes are characterized by a uniform, linear temperature rise at several control points until it reaches its limit value; «Exponential» – there is such a rapid temperature increase of the axle box between two points that at the next point its limit value has already been exceeded and an immediate train stop is required [11].

Axle boxes of the «linear» type. According to the statistical characteristics of the data of the «tracking» option (for the MHCS-02 equipment), it is possible to calculate the average increase in both the axle box temperature and the temperature difference between both axle boxes of the same axle (Fig. 3). Increase in each of these parameters can result in excess of its limit value and more often, the excess of the set temperature difference of the axle boxes is observed.

The influence of the section parameters, such as increased movement resistance in curves of a small radius or the maximum permissible speed, on the temperature rise of the axle boxes has not yet been revealed.

While the train stop at the stations, the cooling of the faulty axle box may occur, and, therefore, the increase in its temperature slows down, hence, when assessing the route, it is necessary to pay attention to the train movement time between two control points.
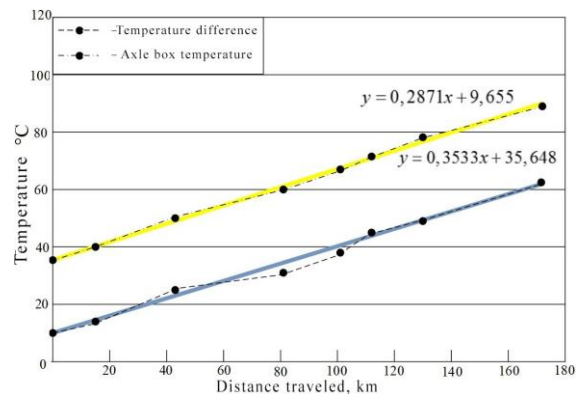

Fig. 3. Linear temperature change of the heating axle box $y = 0.2871x + 9.655$ and temperature difference of two axle-boxes $y = 3533x + 35.648$ of one axle

Based on the collected statistics, it is possible to calculate the limit values for the average temperature rise of the axle boxes (in degrees per kilometer), which are typical for the overwhelming majority of measurements that have already taken place (Table 1).

Numerous cases of the axle box temperature exceeding its limit value were considered. This allows, on the one hand, to check the correctness of the choice of this temperature value in operation, and on the other, to establish how long a train with a faulty axle box can still move without derailing [6, 14].

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Table 1

**Average temperature increase of axle boxes
(in degrees per kilometer)**

Parameter	Proportion of cases, %	
	95	100
Average increase in the absolute temperature of a faulty axle box	0.35	0.40
Average increase in temperature difference between axle boxes of one axle	0.33	0.38

Findings

The temperature value is taken as the value, at which the grease in the axle box loses its properties, the linear course of the temperature curve is no longer preserved, and then an exponential temperature increase occurs. Based on practical experience, it is possible to choose this value equal to about 120°C and, based on the linear temperature increase, calculate the distance that, after reaching its limit value, the train can pass without derailing for each specific case.

Thus, it seems possible to use the available data both on the maximum temperature rise and on its rise, determined online for a specific case.

These data are also of interest for the organization of operation, since they make it possible to determine the station most suitable for servicing a faulty car (check with a possible subsequent change in the movement order) [8].

Axle boxes of «exponential» type. As a result of the analysis of the identified heating axle boxes, it was found that in many cases the axle box temperature in the interval between two adjacent control points does not grow linearly, but so quickly that already at the next control point, an excess of its limit (the so-called alarm) value (in absolute terms or by the difference in temperature of the axle boxes of one axis) is observed.

It seems appropriate to mathematically describe the temperature change in these cases by an exponential function of the form $y = ae^b$ (see Fig. 4), the parameters a and b of which are determined empirically. In this case, it is also possible to distinguish between the temperature rise of the faulty axle box and the temperature difference between the axle boxes of one axle.

In order to correctly determine the distance between successively placed control points, at which the heating axle boxes are reliably detected, it is possible to combine both of these parameters, choosing their values for unfavorable situations. Of particular interest is the case when at one control point the measured temperature is approximately equal to the ambient temperature, for example, a – 25°C (Table 2), and at the next point its limit value has already been exceeded, as a result of which the damage to the axle box takes place [1, 7].

Thus, there are several scenarios for determining reasonable distances between two consecutive control devices, and the use of a combination of the worst parameters does not seem to be acceptable from the point of view of the necessary expenditures.
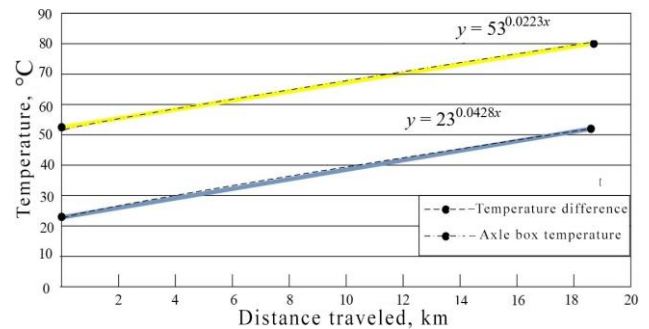

Fig. 4. Exponential temperature change of the heating axle box $y = 53^{0.0223x}$ and temperature difference of two axle-boxes $y = 23^{0.0428x}$ of one axle

Table 2

Values of parameters *a* and *b* for axle boxes of «exponential» type

Parameter determination method	Parameter value			
	a_1	b_1	a_{dt}	b_{dt}
Observation:				
– current	53.8	0.0196	18	0.056
– in a special case	25.0	0.037	–	–
– worst case	65.0	0.037	33	0.1351
Calculation	69.0	0.040	49	0.15

Especially unfavorable is the case when the temperature of the axle box at the control point is slightly lower than the alarm value «hot», and

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therefore the train can freely run to the adjacent section of the line. For this case, when determining the distance between the sensors of the heating axle boxes, one should use the value of the parameter *b* known from observations (it can be rounded up in the direction of increasing safety) and select the parameter *a* 1°C higher than the value «hot».

Optimization model for the placement of peripheral control devices. If we take as a basis the linear temperature increase of the axle box, then, knowing how much the temperature rises on average (see Fig. 5), one can choose an appropriate distance between two adjacent points for placing control devices based on the temperature limit values.

The data obtained using the model (Fig. 5) can be supplemented by the results of the inspection of the train at the station.
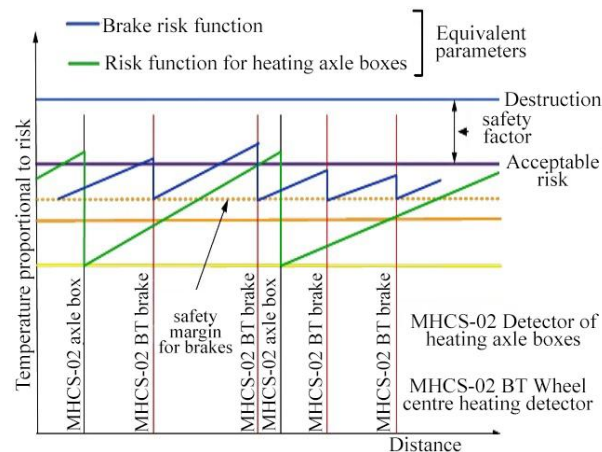

Fig. 5. Model for choosing the distances
between two adjacent control devices depending
on the degree of risk due to the temperature
increase of the axle box

A car building worker when inspecting by the contact method (by touching the axle box cover by the back of his hand), establishes that the temperature has been exceeded, or visually, according to the appearance of the axle box cover, when the axle box is overheated. Fig. 6 shows the temperature dependence of the axle box cover on the air temperature at different values of the temperature of the axle neck of the wheelset. The characteristic of this dependence indicates a low accuracy in the visual determination of the level of heating of the axle box body. When using measuring transducers – bolometers (MHCS-01D and MHCS-02

complexes) or photon sensors (MHCS-03) – it is possible to detect a heating axle box in advance, first of all it refers to axle boxes of the «linear» type.
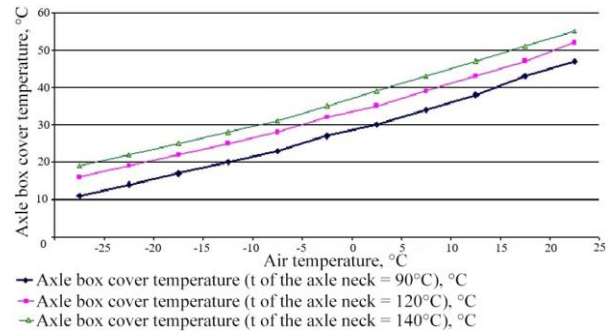

Fig. 6. Dependence of the temperature
of the axle box cover on the air temperature
at different values of the axle neck temperature

The existing automated rolling stock control system (ARS CS) sets the degree of acceptable risk, which, at least, should not be exceeded when switching to control by technical means. Early detection of the heating axle box of the «linear» type allows arguing for the increase in the distance between the points of the detector placement in comparison with the intervals between the available train observation points. In this case, it can be assumed that at the previous point, the temperature of the axle box (or the temperature difference between the two axle boxes) is 1°C lower than the set value. A linear temperature increase in the observed case allows one to get its rounded value, which can be used to determine the distance.

Originality and practical value

The model for optimizing the placement of peripheral control devices was developed based on probabilistic criteria to assess the degree of acceptable risks, which, at least, should not be exceeded when switching to control by technical means. A functional diagram of test instrumental diagnostics with a decider for wheelsets in determining the gradations of digital defect indicators is proposed.

The value of the results obtained consists in improving the methodology for placing peripheral devices for technical control and diagnostics of rolling stock when determining the distance between control points in the same direction and organizing tracking modes for cars with developing

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defects. From a technical point of view, the reduction in error probabilities is directly related to movement safety and diagnostic algorithms.

Conclusions

The dependencies revealed during the analysis of the calculated data make it possible to supplement the risk-oriented strategy for placing control devices for heating axle boxes with the results of practical observations. In this case, the only and sufficient parameter of the axle box malfunction is its temperature, which is considered as an indicator of the risk of train derailment. The operator of the data transmission system of line points (DTS LP), when optimizing the placement of control points can use the values measured in practice to calculate the economic efficiency of measures. Due to the technical means of temperature control distributed over the network, it is possible to detect a heating tendency in advance and coordinate the implementation of appropriate measures [18, 20].

To correctly determine the distance between the peripheral control points, at which the heating axle boxes are reliably detected, it is advisable to combine both of these parameters, choosing their values for unfavorable situations. The probability of detecting heating axle boxes on the road network depends on the density of the placing peripheral devices. The use of a linear model of the dynamics of heating process of axle box makes it possible to obtain a rounded value of the distance between successively placed control points. The temperature difference between the hottest axle box and the average temperature of the remaining axle boxes on the controlled side of the car is a more perfect criterion for determining the distances.

It was found that the highest confirmation of the readings is recorded when the dynamics of the axle box heating is above 1ºC per 1 km of the car run. At a train speed of 60 km/h, this corresponds to a heating rate of 1ºC/min.

Further data transfer to the road separation server using the options for tracking the «suspicious car» with its known route allows drawing conclusions about the increased damage probability or about the need for a denser placement of control points. Tracking these parameters along the entire train route using sequentially located control devices is promising for developing a strategy for optimizing the placement of such devices [12, 15].

With regard to other potential malfunctions of cars and locomotives (for example, to flats on the rolling surface of wheels), three gradations of defects have been established when determining their parameters to predict the development and optimize the placement of technical means of control, which ultimately can lead to more rational use of the MHCS. For example, on the railway lines of the Belarusian Railway, the interval for the MHCS installation in the same direction is 30–35 km, in some sections, this interval can be reduced to 20–25 km with the introduction of subsystems for detecting flats, dragging parts and control devices of rolling stock derailment. In order to increase the efficiency of using the information received by the maintenance points operator from the peripheral points, the MHCS complexes must be installed at a distance not exceeding 10 km from the railway junction.

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В. В. БУРЧЕНКОВ[1*]

[1*]Каф. «Вагони», Білоруський державний університет транспорту, вул. Кірова, 34, Гомель, Республіка Білорусь, 246653, тел. +37 (529) 530 37 84, ел. пошта lenadva@tut.by, ORCID 0000-0002-3664-4655

Удосконалення методики розміщення периферійних пристроїв контролю технічного стану рухомого складу

Мета. У статті передбачено на підставі дослідження роботи вузлів і деталей ходової частини рухомого складу в перехідних режимах розвитку аварійних ситуацій оптимізувати послідовне розміщення периферійних безконтактних пристроїв технічного контролю локомотивів і вагонів на залізничних лініях. **Методика.** Дослідження перехідних дефектних процесів підвищення температури несправних буксових підшипників локомотивів і вагонів за умови технічного дистанційного діагностування дозволяє систематизувати теорію й апаратну побудову периферійних систем перевірки рухомого складу піл час руху. Автоматичний контроль технічного стану рухомого складу під час руху – остання і в ряді випадків єдино можлива технологічна операція, що дозволяє виявити неприпустимі дефекти в рухомих одиницях і тим самим запобігти виникненню надзвичайних ситуацій на залізничному транспорті. **Результати.** На підставі дослідження запропоновано розв'язок задачі оптимізації розміщення периферійних засобів контролю рухомого складу

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під час його руху за критеріями лінійного й експоненціального характеру нагрівання дефектних букс коліс-них пар та інших вузлів ходової частини. Оцінено ризики зупинки поїздів на перегоні через помилкове від-несення букс, які нормально гріються, до класу перегрітих, а також наслідки віднесення перегрітих букс до класу тих, які нормально гріються. **Наукова новизна.** Модель оптимізації розміщення периферійних при-строїв контролю розроблена на підставі ймовірнісних критеріїв для оцінки ступеня допустимих ризиків, який, як мінімум, не повинен бути перевищений під час переходу до контроля технічними засобами. Запро-поновано функціональну схему тестового апаратурного діагностування з розв'язувальним пристроєм для колісних пар під ча визначення градацій цифрових показників дефектів. **Практична значимість.** Цінність отриманих результатів полягає в вдосконаленні методики розміщення периферійних пристроїв технічного контролю й діагностики рухомого складу під час визначення відстані між постами контролю в попутному напрямку та організації режимів стеження для вагонів з дефектами, що розвиваються. Із технічної точки зору, зниження вірогідності помилок прямо пов'язане з безпекою руху та алгоритмами діагностування.

Ключові слова: рухомий склад; буксові вузли; температурний контроль; методика розміщення; діагнос-тика вузлів

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