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ЕКСПЛУАТАЦІЯ ТА РЕМОНТ ЗАСОБІВ ТРАНСПОРТУ

UDC 629.46.027.1

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Influence Assessment of the Information Concerning the Bearing Type of Axle Box of Cars on the Automatic Classification Accuracy of Heated Boxes

Purpose. The main purpose of the work is to determine and classify the heated cars' boxes based on the probability of appearance of roller and cassette type boxes in the classes of heated and overheated boxes, as well as the laws of probability density distribution of the recognition signs of normally heated and overheated roller and cassette type boxes. **Methodology.** The operation features of freight cars with cassette type axle boxes with increased operating heating have been investigated. The methodology of assessing the probability of recognition errors was proposed, which takes into account the fact that sets of normally heated and overheated boxes consist of subsets of boxes with different types of bearings. A system of equations is obtained, the roots of which represent epy values that minimize the recognition probability of the errors of the heated boxes. **Findings.** It was found out that with some methods of determining the bearing type, for example, by the average value of the ranges of thermal image for each car, the probability of erroneous selection may depend on the probability density distribution of the sign for bearings of different types and the threshold value of this sign. The optimal thresholds for detecting the overheated roller boxes in comparison with the optimal thresholds for detecting overheated cassette boxes were determined. It has been established that the pass of an overheated cassette bearing, provided that the type of bearing is determined correctly, is less likely to lead to an accident than if the cassette box is classified as a roller box. The rejection criteria of axle boxes according to their heating temperature difference on one of the wheel set axis for three variants of settings of the alarm system according to an arrangement of multipurpose complexes of technical means (CTM) were formulated. The practical implementation of this method of adjusting the CTM settings for the Minsk branch of the Belarusian Railways was demonstrated. **Originality.** A system of equations is obtained, which allows finding the optimal values of temperature thresholds for the detection of overheated roller and cassette boxes under the assumption that the error probabilities in the selection of boxes by their types are known and constant. **Practical value.** The developed method of adjusting the alarm settings of CTM makes it possible to significantly reduce unjustified train delays and the number of car uncouplings.

Keywords: freight cars; cassette and roller boxes; overheating of boxes; heating boxes classification; threshold temperature criteria

Introduction

When the new generation of cars with cassette boxes and conical bearings was put into operation, unreasonable delays of trains with loaded and empty cars occurred, with increased operating heating of bodies and axle box covers.

The operation peculiarity of cassette boxes with conical bearings is determined by their design and is associated with relatively higher (approximately 1.5–2 times) normal operating temperatures of bearing heating, compared to the heating temperatures of serial axle boxes with standard cylindrical bearings [1, 3].

Increased heating of such bearings is manifested at low external air temperatures ($T_{e.a.}$) from November to March, when the average value of the levels of thermal signals, expressed in quanta, and the relative temperatures of the axle box bodies in-

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crease in 1.5–1, 7 times in comparison with summer values [1]. The annual graph of the average value of the thermal signals and temperature levels is shown in Fig. 1.

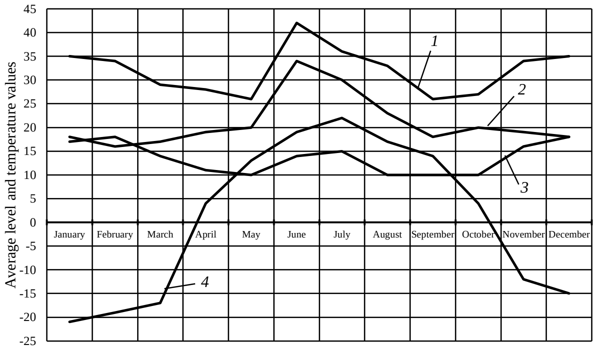

Fig. 1. Annual graph of the average values of the thermal signals and temperature levels:
1 – average level values; *2* – maximal level values;
3 – maximal values of temperature difference;
4 – external air temperature

The criterion of the overheated boxes was formed, taking into account the ratio of the heating level of the controlled box to the average value of the temperature levels of the remaining boxes on one side of the car. This was the thing that resulted in unreasonable delays of trains with operating heating of conical bearings.

Until now, the informativity of automatic control equipment for boxes according various recognition signs of heated boxes has been investigated as a whole without taking into account the type of bearing of the controlled axle boxes. The experience of operating the equipment for detecting overheated boxes shows that this leads to additional losses in the information capacity of the equipment, which are expressed in an increase in the probability of errors in recognizing heating boxes and, as a result, in unreasonable train stops (due to false readings of the equipment) and passing emergency heating axle boxes. This is because the permissible heating of cassette boxes with conical bearings is 1.5-1.8 times higher than the permissible heating of the roller boxes, and when setting the equipment for detecting overheated roller boxes, some of the functional cassette boxes with increased heating can be attributed to the class of the overheated boxes during automatic recognition.

Purpose

Taking into account the constantly growing number of cars with cassette boxes, as well as the emergence of automatic recognition (selection) devices of the boxes by bearing type [2, 17, 18], the author envisages assessing the influence of these devices on the probability of making an erroneous decision about the technical condition of the axle box, as well as on the choice of the threshold temperature value of the classification signs.

Methodology

According to the temperature criterion of the box bodies, their classification as normally heated (N) and overheated (O) axle boxes is possible. If the a priori probability of the appearance of a normally heated box (N class) is denoted $P(\text{N})$, the probability of an overheated box (O class) is $P(\text{O})$, the probability of correct classification of normally heated boxes as normally heated class $P(\text{N/N})$ and the overheated boxes as overheated class $P(\text{O/O})$, then the probability of correct box classification will be as follows:

$$P_{\text{CBC}} = P(\text{N})P(\text{N/N}) + P(\text{O})P(\text{O/O}). \quad (1)$$

However, in the practice of the box temperature control, the informativeness of a sign is usually characterized by the error probability in the box classification. If one assumes that the probabilities of correct and incorrect classification of normally heated (overheated) boxes to the class of normally heated (overheated) ones form a complete set of events, then the error probability in automatic recognition of heating boxes will be:

$$P_{\text{er}} = P(\text{N})\left[1 - P(\text{N/N})\right] + P(\text{O})\left[1 - P(\text{O/O})\right]. \quad (2)$$

The probability $\left[1 - P(\text{N/N})\right]$ is usually called the «false alarm» probability P_{FA}, i.e. the probability of erroneous classification of a normally heated box as the overheated class, and the probability $\left[1 - P(\text{O/O})\right]$ – the probability of passing an overheated box P_{pas}, or the probability of erroneous classification of an overheated box as a class of normally heated boxes [8]. In this case

$$P_{\text{er}} = P(\text{N})P_{\text{FA}} + P(\text{O})P_{\text{pas}}. \quad (3)$$

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According to this criterion, if the separable function has a threshold value of X_{i0}, then the probability of making an erroneous decision when recognizing the heated boxes on the basis of X_i sign is determined by the expression (3). But this expression does not take into account the varieties of types of controlled boxes, and taking them into account, each of the designated classes is divided into two subsets: roller and cassette boxes.

The continuous law of the probability density distribution of the sign of normally heated boxes in this case will take the form [12]:

$$W_{11}(X_i)=P(\mathrm{N_r})W_{11\mathrm{r}}(X_i)+P(\mathrm{N_c})W_{11\mathrm{c}}(X_i), \quad (4)$$

where $\left.\begin{matrix}P(\mathrm{N_r}),\\ P(\mathrm{N_c})\end{matrix}\right\}$ – the appearance probabilities of the roller and cassette boxes in the class of normally heated boxes; $\left.\begin{matrix}W_{11\mathrm{r}}(X_i),\\ W_{11\mathrm{c}}(X_i)\end{matrix}\right\}$ – the probability density distribution laws of the recognition sign (X_i) of normally heated roller and cassette boxes.

Accordingly, the continuous law of the probability density distribution of the recognition sign of overheated boxes will be as follows:

$$W_{12}(X_i)=P(\mathrm{O_r})W_{12\mathrm{r}}(X_i)+P(\mathrm{O_c})W_{12\mathrm{c}}(X_i), \quad (5)$$

where $\left.\begin{matrix}P(\mathrm{O_r}),\\ P(\mathrm{O_c})\end{matrix}\right\}$ – the appearance probabilities of the roller and cassette boxes in the class of overheated boxes; $\left.\begin{matrix}W_{12\mathrm{r}}(X_i),\\ W_{12\mathrm{c}}(X_i)\end{matrix}\right\}$ – the probability density distribution laws of the recognition sign (X_i) of overheated roller and cassette boxes.

Substituting expressions (4) and (5) into formula (3), we obtain the recognition errors probabilities, taking into account the fact that the sets of normally heated and overheated boxes consist of a subset of boxes with different types of bearings:

$$\begin{aligned}P_{\mathrm{er}}(X_i)=P(\mathrm{N})\left[P(\mathrm{N_r})\int_{X_{i0}}^{\infty}W_{11\mathrm{p}}(X_i)dX_i+P(\mathrm{N_c})\int_{X_{i0}}^{\infty}W_{11\mathrm{c}}(X_i)dX_i\right]+\\ +P(\mathrm{O})\left[P(\mathrm{O_c})\int_{-\infty}^{X_{i0}}W_{12\mathrm{c}}(X_i)dX_i+P(\mathrm{O}_r)\int_{-\infty}^{X_{i0}}W_{12\mathrm{r}}(X_i)dX_i\right].\end{aligned} \quad (6)$$

By taking a derivative of the resulting expression and equating it to zero, we have an equation:

$$\begin{aligned}&P(\mathrm{N})\left[P(\mathrm{N_r})W_{11\mathrm{r}}(X_i)+P(\mathrm{N_c})W_{11\mathrm{c}}(X_i)\right]-\\ &-P(\mathrm{O})\left[P(\mathrm{O_c})W_{12\mathrm{c}}(X_i)+P(\mathrm{O}_r)W_{12\mathrm{r}}(X_i)\right]=0,\end{aligned} \quad (7)$$

the root of which is the threshold value of X_{i0} sign, which minimizes the error probability, provided that the bearing type of the axle box is not recognized [13].

Let us consider how their selection by bearing type will affect the recognition error of the overheated boxes. Let us suppose that there is a device determining the axle box bearing type [4, 5, 17]. In general, such recognition can occur with some error, and the error may depend on the axle box state, for example, in the case of recognition of the box type by its thermal signals.

Let us designate: P_{ncr} is the probability that a normally heated roller box is classified as a cassette box; P_{nrc} – the probability that a normally heated cassette box is classified as a roller one; P_{orc} – the probability that the overheated cassette box is classified as a roller one; P_{ocr} – the probability that the overheated roller box is classified as a cassette one.

Suppose that for each type of boxes, the threshold value of the sign is set: X_{i01} – for roller boxes and X_{i02} – for cassette ones. In this case, the probability of a «false alarm» for roller boxes P_{far} and cassette P_{fac}:

$$P_{\mathrm{far}}(X_{i1},X_{i2})=$$
$$=P_{\mathrm{ocr}}\int_{X_{i01}}^{X_{i02}}W_{11\mathrm{r}}(X_i)dX_i+\int_{X_{i02}}^{\infty}W_{11\mathrm{r}}(X_i)dX_i; \quad (8)$$

$$P_{\mathrm{fac}}(X_{i1},X_{i2})=$$
$$(1-P_{\mathrm{nrc}})\int_{X_{i01}}^{X_{i02}}W_{11\mathrm{c}}(X_i)dX_i+\int_{X_{i02}}^{\infty}W_{11\mathrm{c}}(X_i)dX_i, \quad (9)$$

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and the probability of pass of the overheated roller P_{or} and a cassette box P_{orc}:

$$P_{\text{or}}(X_{i1}, X_{i2}) = \int_{-\infty}^{X_{i01}} W_{12\text{r}}(X_i)dX_i + P_{or}\int_{X_{i01}}^{X_{i02}} W_{12\text{r}}(X_i)dX_i; \quad (10)$$

$$P_{\text{orc}}(X_{i1}, X_{i2}) = \int_{-\infty}^{X_{i01}} W_{12\text{c}}(X_i)dX_i + (1-P_{orc})\int_{X_{i01}}^{X_{i02}} W_{12\text{c}}(X_i)dX_i. \quad (11)$$

Let us find the general probability of erroneous decision:

$$P_{\text{er}}(X_{i1}, X_{i2}) = P_{\text{r}}P(\text{H}_{\text{r}})P_{\text{far}}(X_{i1}, X_{i2}) + P_{\text{c}}P(\text{H}_{\text{c}})P_{\text{fac}}(X_{i1}, X_{i2}) + P_{\text{c}}P(\Pi_{\text{c}})P_{\text{orc}}(X_{i1}, X_{i2}) + P_{\text{r}}P(\Pi_{\text{r}})P_{\text{ocr}}(X_{i1}, X_{i2}). \quad (12)$$

Substituting (8) and (11) into (12) and taking from the resulting expression the partial derivatives X_{i1}, X_{i2}, we obtain a system of equations, the roots of which represent the values X_{i01} and X_{i02}, minimizing the probability of error in recognition of the heating boxes:

$$\left.\begin{array}{l} P_{\text{r}}P(\text{N}_{\text{r}})P_{\text{ncr}}W_{11\text{r}}(X_{i01}) + P_{\text{c}}P(\text{H}_{\text{c}})(1-P_{\text{orc}})W_{11\text{c}}(X_{i01}) - \\ -P_{\text{c}}P(\text{O}_{\text{c}})(1-P_{\text{orc}})W_{12\text{c}}(X_{i01}) - P_{\text{r}}P(\Pi_{\text{r}})P_{\text{ocr}}W_{12\text{r}}(X_{i01}); \\ P_{\text{r}}P(\text{N}_{\text{r}})(1-P_{\text{ncr}})W_{11\text{r}}(X_{i02}) + P_{\text{c}}P(\text{H}_{\text{c}})P_{\text{orc}}W_{11\text{c}}(X_{i02}) - \\ -P_{\text{c}}P(\text{O}_{\text{c}})P_{\text{orc}}W_{12\text{c}}(X_{i02}) - P_{\text{r}}P(\text{O}_{\text{r}})(1-P_{\text{ocr}})W_{12\text{r}}(X_{i02}) = 0 \end{array}\right\}. \quad (13)$$

The resulting equations system makes it possible to find the optimal thresholds for detecting overheated roller X_{i01} and cassette boxes X_{i02} under the assumption that the error probabilities in the selection of boxes by their types are known and constant.

However, with some methods for determining the type of bearing, for example, by the average value of thermal signal ranges for each car, the probability of erroneous selection may depend on the probability density distribution of a sign for bearings of different types and the threshold value of this sign X_{j03}.

In this case, the error probabilities in the selection of boxes by their types are as follows:

$$\left.\begin{array}{l} P_{\text{ncr}} = \int_{X_{j03}}^{\infty} W_{\text{nr}}(X_j)dX_j; \; P_{\text{nrc}} = \int_{-\infty}^{X_{j03}} W_{\text{nc}}(X_j)dX_j; \\ P_{\text{orc}} = \int_{-\infty}^{X_{j03}} W_{\text{oc}}(X_j)dX_j; \; P_{\text{ocr}} \int_{X_{j03}}^{\infty} W_{\text{or}}(X_j)dX_j, \end{array}\right\}, \quad (14)$$

where $\left.\begin{array}{l} W_{\text{nr}}(X_j), \\ W_{\text{or}}(X_j) \end{array}\right\}$ – are the probability density distributions of the selection sign of the bearing type for normally heated and overheated roller boxes, respectively; $\left.\begin{array}{l} W_{\text{nc}}(X_j), \\ W_{\text{oc}}(X_j) \end{array}\right\}$ – are the probability density distributions of the selection sign of the bearing type for normally heated and overheated cassette boxes, respectively.

Moreover, the criterion according to which it is assumed that the losses do not depend on the error type, in some cases cannot be considered satisfactory.

Findings

The pass of the overheated cassette box, provided that the bearing type is determined correctly, is less likely to result in an accident than if the cassette box is classified as the roller one [14]. The losses caused by the errors of each type can be repelled by the weight coefficients (K_1–K_8). Without dwelling on the method of determining the weight coefficients and repeating the substitution sequence, taking into account equations (8) – (14), we obtain the expression of the total recognition error, provided that the selection of the bearing type is performed by the probabilistic method according to the X_j sign:

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$$P_{\text{er}}(X_{i1}, X_{i2}, X_{i3}) = P_{\text{r}} P(\text{N}_{\text{r}}) \left[K_1 \int_{X_{j03}}^{\infty} W_{\text{nr}}(X_j) dX_j \times \int_{X_{i01}}^{X_{i02}} W_{11\text{r}}(X_i) dX_i + K_2 \int_{X_{i02}}^{\infty} W_{11\text{r}}(X_i) dX_i \right] +$$

$$+ P_{\text{c}} P(\text{N}_{\text{c}}) \left[K_3 \int_{X_{j03}}^{\infty} W_{\text{nc}}(X_j) dX_j \times \int_{X_{i01}}^{X_{i02}} W_{\text{nc}}(X_i) dX_i + K_4 \int_{X_{i02}}^{\infty} W_{11\text{c}}(X_i) dX_i \right] +$$

$$+ P_{\text{c}} P(\text{O}_{\text{c}}) \left\{ K_5 \int_{\infty}^{X_{i03}} W_{12\text{c}}(X_i) dX_i + K_6 \left[1 - \int_{X_{i03}}^{\infty} W_{\text{oc}}(X_j) dX_j \right] \times \int_{X_{i01}}^{X_{i02}} W_{12\text{c}}(X_i) dX_i \right\} +$$

$$+ P_{\text{r}} P(\text{O}_{\text{r}}) \left\{ K_7 \int_{\infty}^{X_{i01}} W_{12\text{r}}(X_i) dX_i + K_8 \left[1 - \int_{X_{j03}}^{\infty} W_{\text{or}}(X_j) dX_j \right] \times \int_{X_{i01}}^{X_{i02}} W_{12\text{r}}(X_i) dX_i \right\}. \quad (15)$$

Thus, we obtained an equation that makes it possible to find the optimal threshold values of sing simultaneously when detecting the overheated boxes and their selection by the bearing type.

Fig. 2 shows the dynamics of the optimal detection threshold for the overheated boxes calculated by formula (15) with an increase in the number of cassette boxes in trains and the absence of their recognition by type (curve *1*). One can see how, with the increase in the probability of appearance of the cassette box, the optimal recognition threshold shifts from the optimal detection threshold of the overheated roller boxes (curve *2*) to the optimal detection threshold of the overheated cassette boxes (curve 3), which do not depend on the change in the ratio of cassette and roller boxes in trains. Let us trace how the probability of the total recognition error of the heated axle boxes changes in this case.

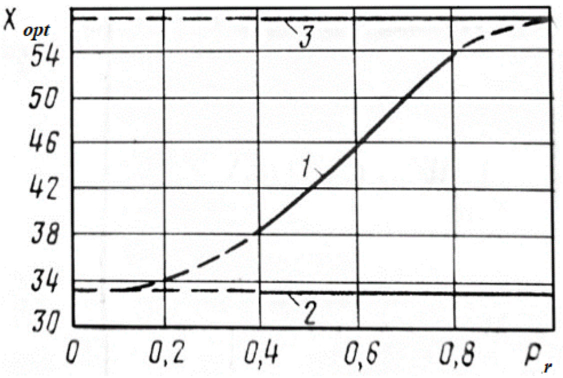

Fig. 2. Influence of the appearance probability of a cassette box on the detection threshold of the overheated boxes in the absence of information about the bearing type (*1*), the optimal detection threshold of the roller (*2*) and cassette boxes (*3*)

Fig. 3 shows the dependence curves $P_{\text{er}} = f(P_{\text{r}})$ calculated by formula (15). The calculations are performed for three cases: box selection by the types of bearings is not carried out (curve *1*); box selection is carried out faultlessly (curve *2*); box selection is carried out with some error (curve *3*).

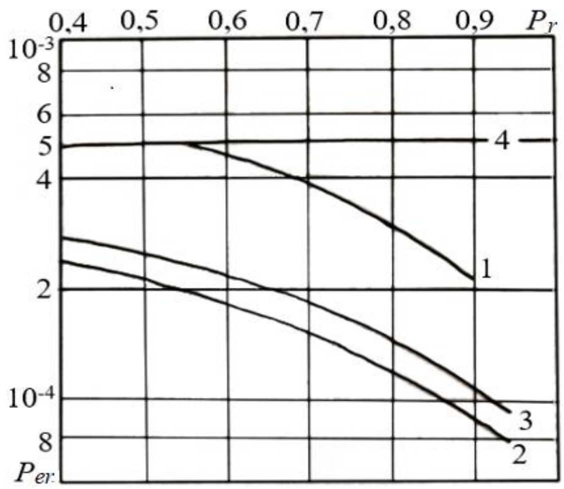

Fig. 3. Dependence of the error probability when detecting overheated boxes on the appearance probability of a roller box

In the latter case, the average temperature of the axle box bodies of one car was a sign for determining the bearing type [4]. The probability density distributions of this sign for boxes of various types are subject to logarithmic-normal laws with the parameters:

$$a_{\text{rn}} = 0.77; \quad a_{\text{cn}} = 3.2; \quad a_{\text{ro}} = 1.51; \quad a_{\text{co}} = 3.3;$$

$$\sigma_{\text{rn}} = 1.02; \quad \sigma_{\text{cn}} = 0.53; \quad \sigma_{\text{ro}} = 0.99; \quad \sigma_{\text{co}} = 0.51.$$

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The weight coefficients K_1–K_8 in the calculations are taken to be equal to one, i.e. it is assumed that the recognition is carried out in two classes.

The analysis of the curves shows that although with an increase in the percentage of cassette boxes in the rolling stock, the error in detecting the overheated boxes decreases, nevertheless, the introduction of error-free selection of boxes by type makes it possible to further reduce the probability of making an erroneous decision by an average of 2.2 times. Determining the type of bearing by the parameters of thermal pulses increases the probability of error in recognizing the heated boxes in comparison with their error-free selection by 10–15% [15, 16]. Changing the ratio of the weight coefficients, it is possible to significantly (more than an order of magnitude) reduce this error component with a certain (5–10%) increase in the total error in detecting the overheated boxes [7]. The last assumption is illustrated by the family of curves in Fig. 4. The coefficient K_6 in expression (15) was changed within one order.

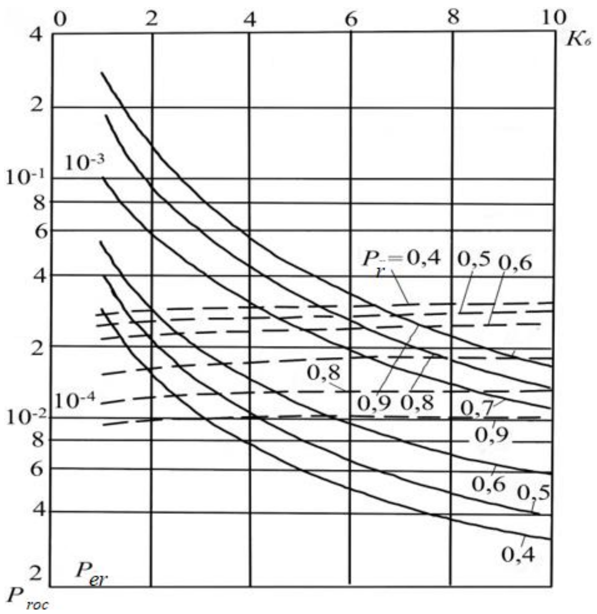

Fig. 4. Influence of the K_6 weight coefficient on the recognition error probability in the boxes by types (contour lines) and the detection of the overheated boxes (dashed)

Thus, the research results allow concluding that during automatic detection of the overheated boxes it is advisable to select them by the bearing type, since the accounting of information on the box type reduces the error probability when detecting the overheated boxes almost by 2 times. At the same time, one should note the low reliability of the existing systems for determining the box type in rolling stock under control. A more adequate assessment of the state of different types of bearings and axle boxes is possible with the combined use of rejection temperatures, in particular, used in the innovative promising complex CTM-03 [2, 6, 18].

In the software version 2.0.9.6 dated 02/18/2020 for the CTM-01D and CTM-02 operated on the Belarusian Railways, automatic correction of alarm thresholds is used [10]. Algorithms for the box rejection according to the new assessment criterion made it possible to abandon the insufficiently reliable method of car classification by the bearing type with an increase in correction of alarm thresholds for operating heating of the conical bearings in the cassette type axle boxes. Due to this solution complex, correction algorithms of alarm thresholds were excluded in the 2.0.9.6 software version.

Automatic correction of the settings dependence on the external air temperature and the location of the peripheral control devices significantly reduces the number of indications for the operating heating of the cassette boxes in winter and the risk of untimely detection of faulty boxes at high external air temperatures. With the degree software version CTM-02, the temperature difference between the lower sectors of the box bodies on one axle of the wheelset practically does not depend on the external air temperature and is not affected by the solar radiation [1, 14].

The new rejection criterion of axle boxes by the difference in their heating temperature on one axle of the wheelset is less susceptible to the influence of low temperatures of the external air, but its numerical value in CTM-01D increases in summer due to the influence of solar radiation. The difference between the temperature of the most heated box and the average temperature of the rest of the boxes on the controlled car side is a more advanced analogue of the «Alarm 0 {O}» criterion.

At low external air temperatures, when the levels of the thermal signals and the relative temperature of the box bodies increase in comparison with summer readings, the control of the CTM-01D equipment deteriorates. This is also influenced by the increase in the fleet of cars with cassette boxes.

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Therefore, new rejection criteria of axle boxes based on the difference in their heating levels on one axle of the wheelset in CTM-01D, similar to the CTM-02 algorithms, made it possible to significantly reduce unreasonable train delays.

The software provides several options for alarm settings in accordance with the considered criteria and the territorial location of the CTM. Practical implementation of this methodology for correcting the settings of the CTM equipment for the Minsk Branch of the Belarusian Railways is shown in Fig. 5.

Fig. 5. CTM location on railway lines of the Minsk Branch of the Belarusian Railways

In front of the junctions with check stations CS (Minsk, Molodechno, Orsha), CTM-02 with the «CS» setting are installed. On the approaches to large intermediate stations with a constant watch of car inspectors (Borisov, Negoreloye, Osinovka, Pukhovichi), CTM-02 was installed with «Intermediate, lowered» setting with a decrease in the thresholds by 3ºC. Here the car inspectors check the condition of the axle boxes more thoroughly [11]. The rest of the line stations are equipped with the CTM-02 and CTM-01D with «Intermediate, increased» setting with an increase in thresholds by 4ºC. The CTM settings in front of the «CS» junctions differ from the «Intermediate» settings only by a lower (by 10ºC) threshold «Alarm 0.» In this case, the temperature thresholds «Alarm 1» and «Alarm 2» remain the same.

Practical value

The developed methodology for correction of the alarm settings of the CTM can significantly reduce unreasonable train delays and the number of car uncoupling.

Conclusions

The proposed differentiation of settings ensures non-stop passage of transit trains, and faulty boxes with a relatively high temperature are detected in the conditions of a check station. This correction significantly reduces the number of CTM-01D readings for the operating heating of conical bearings of cassette boxes in winter and the risk of untimely detection of faulty boxes at high temperatures of the external air. As a result of the transfer of the CTM-02 to the degree version, the number of train delays monitored according to the indications at the intermediate stations has decreased. The number of freight cars uncouplings as a result of the axle box overheating decreased. Uncouplings have become more grounded. This indicator was also influenced by the improvement in the quality of inspection and repair of axle boxes in the «CS» and depots.

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Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту, 2021, № 3 (93)

Оцінка впливу інформації про тип підшипника буксового вузла вагонів на точність автоматичної класифікації букс, що гріються

Мета. Основною метою цієї роботи є визначення та класифікація букс вагонів, які гріються, на основі ймовірності появи роликових і касетних букс у класах букс, які гріються, і перегрітих, а також законів розподілу щільності ймовірності ознак розпізнавання роликових і касетних букс, які нормально гріються, та перегрітих. **Методика.** Досліджено особливості експлуатації вантажних вагонів із буксовими вузлами касетного типу, що мають підвищений робочий нагрів. Запропоновано методику оцінки ймовірності помилок розпізнавання з урахуванням того, що множини букс, які нормально гріються, та перегрітих складаються з підмножин букс із різного типу підшипниками. Отримано систему рівнянь, корені якої подають значення, що мінімізують імовірність помилки розпізнавання букс, які гріються. **Результати.** З'ясовано, що за деяких способів визначення типу підшипника, наприклад, за середнім значенням амплітуд теплових сигналів для кожного вагона, імовірність помилкової селекції може залежати від розподілу щільності ймовірності ознаки для підшипників різних типів і порогового значення цієї ознаки. Визначені оптимальні пороги виявлення перегрітих роликових букс порівняно з оптимальними порогами виявлення перегрітих касетних букс. Установлено, що пропуск перегрітої касетної букси за умови, що тип підшипника визначено правильно, з меншою імовірністю призведе до аварії, ніж за умови віднесення касетної букси до роликової. Сформульовано критерії бракування буксових вузлів за різниці температур їх нагрівання на одній осі колісної пари для трьох варіантів настроювань тривожної сигналізації відповідно до розташування багатофункціональних комплексів технічних засобів КТСМ. Показано практичну реалізацію цієї методики коригування настроювань апаратури КТСМ для Мінського відділення Білоруської залізниці. **Наукова новизна.** Отримано систему рівнянь, яка дозволяє знаходити оптимальні значення температурних порогів для виявлення перегрітих роликових і касетних букс у припущенні, що ймовірності помилок у селекції букс за їх типам відомі і постійні. **Практична значимість.** Розроблена методика коригування настроювань тривожної сигналізації комплексів КТСМ дозволяє суттєво знизити необґрунтовані затримки поїздів і кількість відчеплень вагонів.

Ключові слова: вантажні вагони; касетні та роликові букси; перегрівання букс; класифікація букс, які гріються; порогові температурні критерії

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