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# INVESTIGATION ON FEATURES AND TENDENCIES OF AXLE-BOX HEATING

**Summary.** Breakdown of rolling stock axle-boxes if not detected in due time may cause a rail accident or disaster. At present, a lot of advanced technologies, modern equipment and devices, which “recognizes” faulty axle-boxes when the train is in motion, have been implemented. However, the timely identification of breakdown of rolling stock axle-boxes still is an acute problem, the initial stage of damage emergence being especially problematic. Presently, rolling stock axle-box breakdown is determined according to the higher than permissible temperature of the axle-box body. The article provides statistical data of dangerously heated axle-boxes, determined train delay durations, the number of delayed trains by danger level, and dependence of damage on the season. After systematization of data on axle-box damage and heating temperatures of broken axle-boxes, heating tendencies of axle-boxes of freight wagons are described. Finally, basic conclusions are given.

# ИССЛЕДОВАНИЕ ОСОБЕННОСТЕЙ И ТЕНДЕНЦИЙ НАГРЕВАНИЯ БУКС

**Аннотация.** Своевременно не обнаруженная неисправность буксы может привести к аварии поезда или катастрофе. В настоящее время внедрено много передовых (прогрессивных) технологий, современного оборудования и приспособлений, которые «распознают» неисправную буксу во время движения поезда. Но, несмотря на это своевременное, обнаружение неисправности буксы остается острой проблемой, особенно в начальной стадии повреждения. В настоящее время повреждения букс подвижного состава определяются по температуре нагревания корпуса буксы. В статье предоставлены статистические данные о буксах, нагревающихся до опасного предела, установлена продолжительность задержек поездов, количество задержанных поездов по уровням (категориям) опасности и зависимость нагрева букс от времени года. Тенденции нагрева букс грузовых вагонов описаны на основе систематизации данных о неисправностях букс и температуры их нагрева. В конце предоставлены выводы.

## 1. INTRODUCTION

Temperature of rolling stock axle-box bodies is one of the most important parameters of diagnostics, upon exceeding thereof it is stated that the axle-box is in technical disorder [2]. The normal operation of the axle-box is characterized by heat exchange balance between axle-box elements, wheel-set and ambient air temperature, i.e. when the released amount of heat equals the amount of heat dissipated in the environment by the axle-box and wheel-set [5-7]. Axle journal temperature when the train is running at the uninterrupted regime depends on the type and dimensions of bearings, antifrictional and hydrodynamic properties of the lubricant, spaces between the bearing rollers and rings, static and dynamical loads of the bearing, train running speed, duration of travel without stops, and ambient air temperature, and the road curves [16]. Friction of axle-box node parts results in the heating of their surfaces. Upon reaching the limit values this heating may cause the structural changes in the upper surfaces of the bearing parts, due to which the rollers may become clogged [6]. Axle journal fracture may occur after 25 min (or if the train is moving, on the average, at 60 km/h after 25 km) from the moment when the inner ring of the bearing spins on the axle journal [17-19), therefore of special importance it is to locate the Hot Axle-Box Detectors (HABD) at a proper distance. With the inner bearing ring spinning on the axle journal (one of the most dangerous axle-box breakdowns), the temperature increase variation reaches from 8ºC/min to 38ºC/min. Therefore, after 25 min (or if the train is moving, on the average, at 60 km/h after 25 km) the temperature of the axle journal of the wheel-set at the place of ring spinning may reach from plus 266ºC to plus 800ºC. The article [8] provides an analysis of the causes of axle journal fractures of two freight wagons, whereby it was established that temperature of the axle journal at the moment of fracture was from plus 900ºC to1000ºC. For this reason, it is very important to locate HABD at a proper distance. It is set in modern requirements that a distance between two HABD should not exceed 35 km [15].

Modern HABD should ensure that axle-boxes of all impermissibly hot rolling stocks should be diagnosed. HABD danger levels are identified (Danger 1 and Danger 2), which with account taken of the axle journal heat flow temperature may be plus 100ºC, 120ºC or 140ºC. If HABD is regulated when axle journal temperature is plus 100ºC, less is a possibility that HABD will not fix the impermissibly hot axle-box, whereas the number of halted trains will increase and, on the contrary, after identifying HABD danger levels according to the axle journal temperature 140ºC, the number of halted trains will reduce considerably, and probability of not fixing an inadmissibly heated axle-box will increase.

Axle-box breakdowns may be subdivided into four main groups: poor lubrication, fatigue, not qualitative mounting and contamination (with metal admixtures, water). Bearing damage occurs due to improper lubrication, excessive load, excessive rotation speed, inadequate mechanical properties insufficient operating clearance, radial stress caused by an external heat source, obstructed run due to the breaking of the cage, initial damage of the bearing [1]. The damage of box-axle bearing mechanisms could be classified into two types: brinelling and spalling [11]. Brinelling consists of one or more indentations distributed over the entire raceway circumference that is subjected to static overloading [4]. Each indentation acts as a small fatigue site, producing sharp impacts with the passage of the rolling element, eventually leading to the development of spalling at the indentation sites as the bearing continues to operate. Under normal loading conditions, the bearing will form minute cracks due to material fatigue after certain duration of usage. With an increase in size during cyclic loading, the cracks progress to the surface and are manifested as spalling in the contact areas [3]. Considering different research works performed by scientist Harward [4] or completed by various companies in 2008 [10, 12, 14] axle-box bearing defects are summarized as a wear, spun cone, corrosion, flaking, spalling, brinelling, peeling, smearing, and chipping.

In general, bearing defects are associated with the speed of the train, wheel impact [1, 13], and poor lubricant handling [1]. Wheel impact can result in a loose fit bearing inner raceway. Consequently, it causes wear on the inner raceway circumference and can lead to a spun cone. In addition, wear on the race/roller cage and solid surface can also be caused by poor lubricant handling, excessive lubrication or lack of lubrication [1]. It is imperative that lubricant is clean, as it will help to prolong the bearing life cycle. If the lubricant is contaminated with water, this may lead to a water-etched surface.

Furthermore, as water is added to the bearing, rust can form inside the bearing roller or raceway. Subsequently, the wear will be magnified due to the fatigue on the contact surface between the roller and raceway, until the roller is broken. Typically, fatigue in the car body shell results from changes in the internal and external differential pressure on an airtight structural vehicle as trains passes each other in tunnels [9].

Upon having made a survey of scientific reports, it was stated that statistical data were lacking on the distribution of axle-box breakdowns and heating temperatures, characteristic of these breakdowns. This research work is targeted at identifying the correctness (validity) of the HABD fixed readings of hot axle-boxes, to determine most frequent breakdowns of axle-boxes and their distribution, to describe the axle-box heating tendencies.

## 2. INVESTIGATION OF AXLE-BOX HEATING AND RESULTS

Modern methods for calculation of rolling bearings are carried out most often in two directions: static bearing load, performed according to residual contact stresses, and longevity according to crumbling due to metal fatigue. Other methods used have not been finally elaborated as they are related to numerous random factors that are difficult to be calculated.

Breakdowns of the rolling stock axle-boxes may be identified in two ways: according to the increased temperature of the axle-box body and according to noise vibrations generated by the broken bearing. At the present time, the simplest and most reliable method for identification of rolling stock axle-box breakdowns is according to the increased axle-box body temperature; therefore it is used in the railways throughout the world.

Temperature change of the rolling stock axle-boxes when the train is moving was investigated according to the readings of the hot axle-box detection devices (temperature values) at the HABD.

HABD are mounted on the two side rails, as shown in Fig. 1, to detect the heat emitted by a vibrating bearing if the inner raceway is loosely fitted or defective.

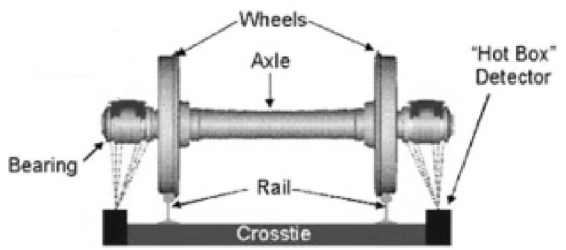



Fig. 1. Hot box detection system
Рис. 1. Система обнаружения горячых букс

The automatic rolling-stock control posts (HABD) are mainly designed to fix inadmissibly heated axle-boxes of rolling-stocks, clogged axle-wheels and wheel rolling surface defects and to ensure the safe train traffic, to timely determine hot axle-boxes. Axle-box heating measuring devices are installed in a special hollow sleeper and of the stopped wheels in the rail sole fastening chamber. This system is aimed to measure absolute temperature separately on both sides of the axle-wheel of the axle-box and axle journal zones (left and right, according to the train running direction).

HABDs are used to calculate the following parameters according to the measured values:

1) absolute and ambient temperature differences of axle-boxes and axle journals (differential);
2) absolute temperature difference of the left and right sides of axle-boxes and axle journals, located in one axle wheel.

Heating of axle-boxes is measured vertically from the bottom, and temperature of the rims of axle wheels is measured at an angle in respect of the rails. The operating principle of the axle-box heating system is based on measuring infra-red radiation intensity from the surfaces under control with the axle wheel moving through measurement zones.

Change of temperatures in wagon axle-boxes at the train moving was analyzed according to axle-box temperatures fixed in the HABD posts during the entire train movement route. Rolling-stock axle-boxes where heating temperatures exceeded the permissible limits were analyzed, and trains were stopped in a way-station because of traffic danger. Analysis is made of HABD of the first-level danger (due to the impermissibly heated axle-box, the train may travel to the nearest station, where technical workers must perform the axle-box review in more detail and determine the reason of heating) and of the second-level danger (due to the impermissibly heated axle-box, the train is stopped at once at a way-station, technical workers are called).

Primarily, it was by State Company “Lietuvos geležinkeliai“ (“Lithuanian Railways” – abbreviation is LG) explored how many trains were halted in 2011-2013 due to the impermissibly hot axle boxes. The obtained results are presented in Fig. 2.

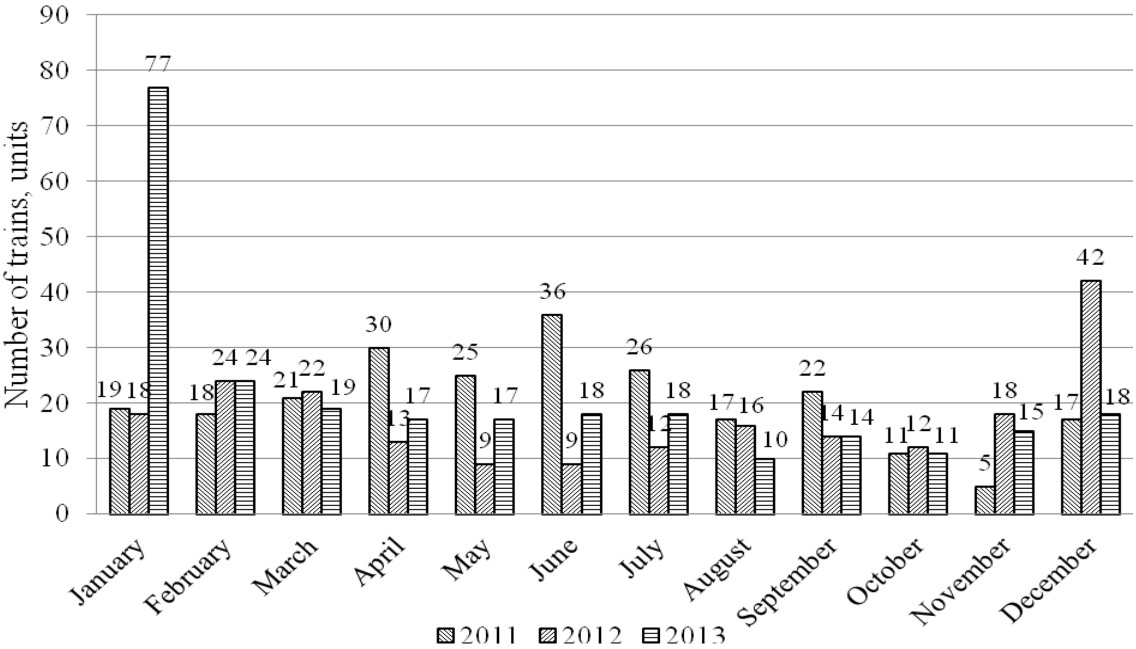



Fig. 2. Dynamics of HABD halted LG trains with impermissibly hot rolling stock axle-boxes

Рис. 2. Динамика остановленных поездов АО «Литовские железные дороги» до опасного предела нагревающимся буксами подвижного по показанию ПОНАБ

Fig. 2 shows that the number of trains halted in April-July 2011 was significantly higher than in 2012-2013 within the same period. After making an analysis it was established that the number of trains halted in 2011 was higher due to the sunlight access to the the scanning device.

In 2011, 248 trains were halted according to HABD; in 2012 – 209 trains, and in 2013 – 259 trains. It is shown in Fig. 2 that the number of trains, halted in 2012, was by almost 60% higher than in 2011, and in January 2013 even by 76 %. This phenomenon may be explained by the fact that the railways started operating the wagons where cartridge type bearings were mounted. The heat exhange processes of the said bearings differ from those of the axle-boxes, where standard bearings are mounted. Seeking to avoid the ungrounded halting of the trains, HABD increased the threshold danger temperature by 5 ºC.

In conducting an investigation it was determined that HABD fixed the increased axle-box body temperature in 123 freight trains of LG, but after a loco driver adopted a decision to drive at not higher speed than 50 km/h (set speed 90 km/h), the axle-box body temperature decreased to the permissible limit, and in other HABD the increased heating was not fixed. The total idle time of LG trains due to impermissibly heated axle-boxes fixed by HABD is given in Fig. 3. Each train halting case and idle time duration were established from train handling schedules.

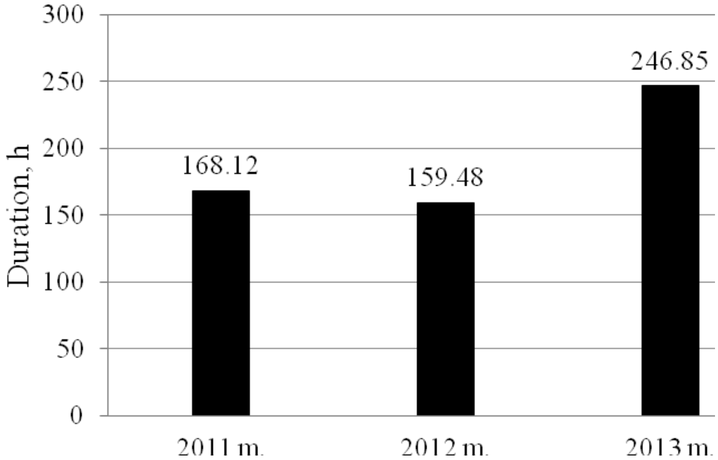



Fig. 3. Dynamics of the average idle time of LG trains halted by HABD in 2011-2013
Рис. 3. Динамика средней продолжительности задержек поездов остановленных по показанию ПОНАБ на АО «Литовские железные дороги» за 2011-2013 г

Fig. 3 shows that the average idle time per train in 2011 made 40 min, in 2012 – 45 min, in 2013 – 57 min. In 2013, the average train idle time increased by 50% due to the halted trains where cartridge bearings were mounted.

The number of HABD halted trains by danger is presented in Fig. 4.

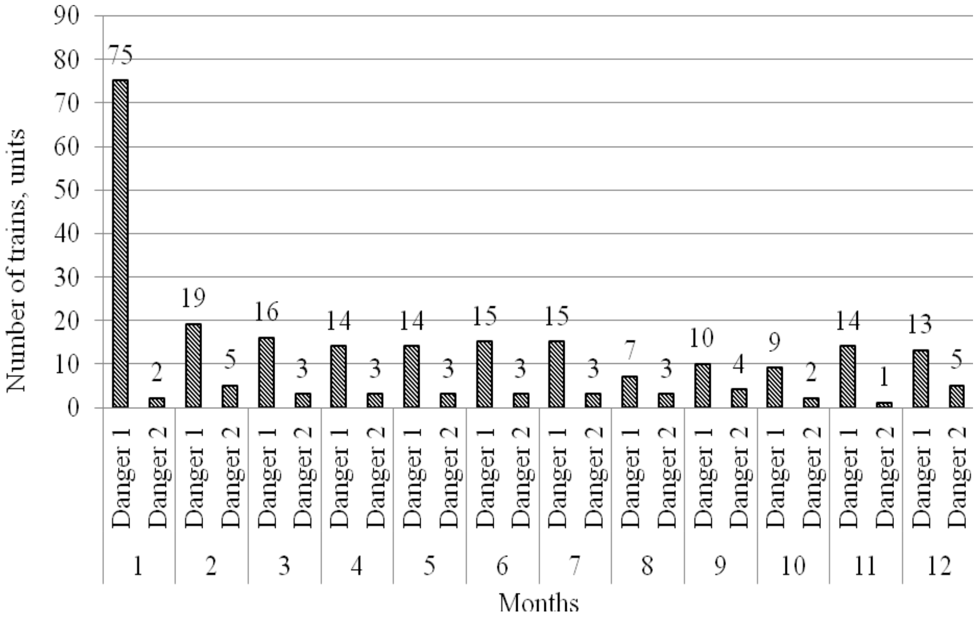



Fig. 4. Dynamics of LG trains halted in 2013 by danger levels
Рис. 4. Динамика остановленных поездов АО «Литовские железные дороги» по порогам тревожной сигнализации за 2013 г

Fig. 4 shows that the number of HABD halted trains by danger levels has almost the same tendency (except January). On the average, per month, the first level heating danger is fixed in the rolling stocks of 13 trains and the second level heating danger in wagons of 3 trains. The least heating of axle-boxes was fixed in August-October.

After conducting the investigation in LG, it was established that in 2011-2013 due to HABD readings 97 freight wagons were decoupled where axle-boxes got heated impermissibly. To identify the exact reason of the axle-box heating, 97 axle-boxes were dismantled, the fixed breakdown data thereof is given in Fig. 5.

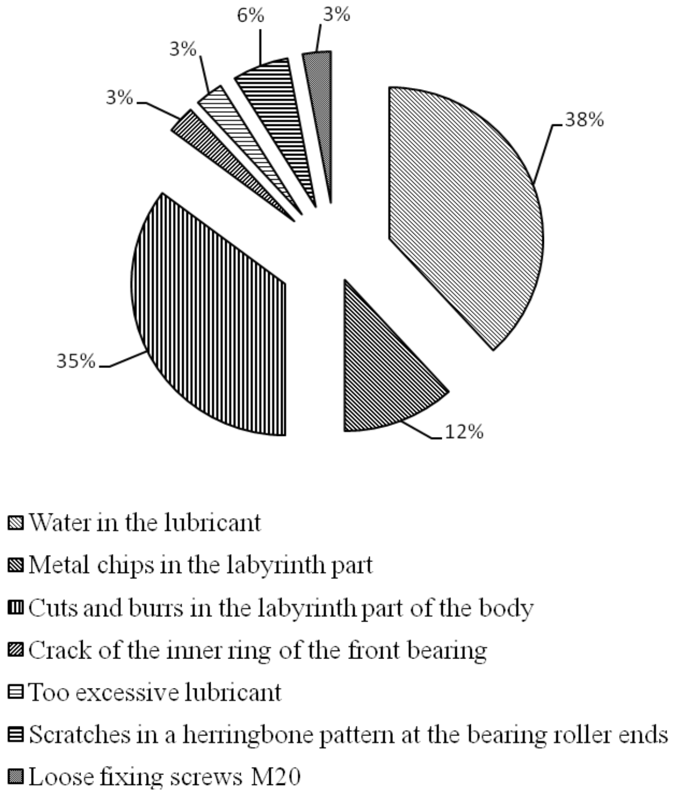



Fig. 5. Distribution of axle-box breakdowns of LG freight wagons
Рис. 5. Распределение неисправностей буксовых узлов грузовых вагонов АО «Литовские железные дороги»

Fig. 5 shows that most often axle-box heating (38%) occurred due to the lubricant contamination with water, cuts and burrs in the labyrinth part of the axle-box and metal chips in the labyrinth part.

The following data were processed in determining temperatures according to HABD readings:

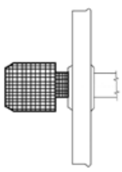
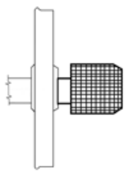
1) train passage date and time (evaluated year and day time);
2) name of the way-station where the train underwent control (distance from one HABD to another HABD);
3) train movement direction;
4) train number and serial number during the day in the specific HABD post;
5) the highest level of heating danger of axle-boxes;
6) ambient air temperature (during the train movement through HABD post);
7) train acceleration;
8) train weight;
9) absolute axle-box body and axle journal temperature;

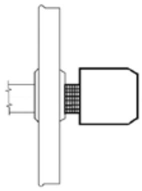
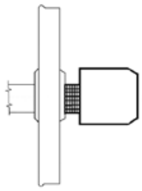
10) differential axle-box body and axle journal temperature (not evaluating the ambient temperature);
11) tempertuare differences of the left and right sides of the axle wheel of axle-boxes and axle journals.

In accordance with the distribution of breakdowns and according to temperatures fixed by HABD, the temperature distribution in the axle-box body and axle-box elements is provided in Table 1.

Table 1

Distribution of temperatures faulty axle-boxes of LG trains in 2011-2013

<table>
<tr><th>Breakdown</th><th colspan="2">Tendentious heating place of the technically serviceable axle-box</th><th colspan="2">Tendentious heating place of the faulty axle-box and temperature difference of heating places</th><th>Average difference of temperatures of serviceable and not serviceable axle-boxes, °C</th></tr>
<tr><td>Water in the lubricant</td><td rowspan="2"></td><td rowspan="5"></td><td rowspan="5"></td><td>Temperature of the body is, on the average, by 10°C higher than that of the axle journal</td><td>35</td></tr>
<tr><td>Cuts and burrs in the labyrinth part</td><td>Temperature of the body is, on the average, by 7°C higher than that of the axle journal</td><td>37</td></tr>
<tr><td>Crack of the inner ring of the front bearing</td><td rowspan="3">Temperature of the body is, on the average, by 1°C higher than that of the axle journal</td><td>Temperature of the body is, on the average, by 13°C higher than that of the axle journal</td><td>44</td></tr>
<tr><td>Too excessive lubricant in the axle-box</td><td>Temperature of the body is, on the average, by 16°C higher than that of the axle journal</td><td>39</td></tr>
<tr><td>Loose fixing screws M20</td><td>Temperature of the body is, on the average, by 15°C higher than that of the axle journal</td><td>35</td></tr>
</table>

| | | | | | |
|---|---|---|---|---|---|
| Metal chips in the labyrinth part | | |  | Temperature of the axle journal is, on the average, by 24°C higher than that of the body | 51 |
| Scratches in a herringbone pattern, formed at the bearing roller ends and in the inner part of the external ring edge | | |  | Temperature of the axle journal is, on the average, by 8°C higher than that of the body | 29 |

It is seen from Table 1 that heat exchange process of the normally operating axle-box is such that released temperature distributes evenly in axle-box body and the axle journal. Two breakdowns of the axle-box (metal chips in the labyrinth part and scratches in a herringbone pattern formed at the bearing roller ends and in the inner part of the external ring edge) have a typical temperature increase in the area of the axle journal. The highest heating temperature of the axle-box is monitored at the existence of metal chips in the labyrinth part, and the highest axle-box body temperature at the existence of the crack of the inner ring of the front bearing.

It would be possible to identify at HABD not only the faulty axle-box, but also the type of the specific breakdown of axle-box after conducting more comprehensive investigations of temperature distribution in the elements of the faulty axle-boxes and upon researching of typical temperature increase speeds at the existence of a specific breakdown.

## 3. CONCLUSIONS

1. Cartridge bearing heat exchange process is totally different from the heat exchange process of the cylindrical bearing; therefore, it is necessary to install the axle-box type recognition subsystem in Hot Axle-Box Detectors (HABD).
2. With a train running at a speed lower than 50 km/h, the body temperature of impermissibly hot axle-box body decreases to permissible limits, and further heat exchange process is adequate to the heat exchange process of the axle-box that is in technically good order.
3. According to HABD readings, the idle time duration of halted State Company “Lithuanian Railways” trains has been increasing tendentiously; therefore, it is expedient to take measures for more precise HABD readings.
4. According to HABD readings, the number of halted State Company “Lithuanian Railways” trains by danger level is steady, on the average, per month: in the rolling-stocks of 13 trains, the heating danger of Level 1 is fixed, and in the wagons of 3 trains, the danger of Level 2, on the average.
5. Axle-box breakdowns of two types (metal chips in the labyrinth part and at the bearing roller ends and scratches in a herringbone pattern in the inner part of the outer ring edge) have the specific increased axle journal temperature.
6. During investigation the authors revealed how the temperature of faulty axle-boxes is distributed in the axis and in the axle-box (Table 1).
7. The lowest number of axle-box heating at State Company “Lithuanian Railways” was fixed in August-October.
8. It is foreseen to proceed with research and data systematization, giving an evaluation of variable train movement modes (train speed change, short stops, acceleration, etc.) and their impact on heat exchange of axle-boxes; to examine in more detail the regularities of temperature alteration of faulty axle-boxes.

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