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Analysis of failures of bearings of axle box unit with polyamide cages and prospects of increasing their service life

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Abstract. The article analyzes failures of bearings of the axle box unit with polyamide cages and investigates the influence of climatic conditions on operational characteristics of cages. It is determined that the greatest number of defects during the operation of polyamide cages occurs in the following periods: summer-autumn, autumn, winter, winter-spring, spring. The revealed dependence of the operational properties of polyamide samples on weather and climatic conditions in different seasons of the year allows predicting the change in the operational characteristics of the cage and taking measures to restore and improve them. The authors proposed a method of restoration and improvement of operational properties of cages by processing them using a technique of high-frequency electrothermy. Full-scale tests showed the high efficiency of the proposed method, expressed in reducing the weight of the samples as a result of moisture removal, as well as in an ambiguous change in strength properties. Their ambiguity lies in the fact that cages differently restore their original hardness indicators after processing. And in the periods corresponding to winter and winter-spring, it was possible to restore strength indicators to a level even above the original one. For high-frequency processing of polyamide cages, a device has been developed that provides the required coverage of the workpiece electrodes on the upper, lower and inner side surfaces of the partitions. The test of the developed device made is possible to achieve the desired results, expressed in a significant decrease in the relative humidity of the cages and an increase in their strength characteristics by 7.6% of the initial level. All this confirms the practical importance and progressiveness of the developments presented in the work.

1. Introduction

Ensuring the safety of train traffic, high passenger and cargo turnover at a minimum cost is an important task of the railway transport company. Its solution in the conditions of instability of the domestic economy is based both on the introduction of new technical means and technologies, and on the improvement of existing ones. In this sense, it is important to raise the requirements for the reliability of components and parts of rolling stock, in particular, the increase in the durability of wagons, the service life of which has a great impact on the performance of the rolling stock and, in general, on the economic efficiency of rail transport. Hence it appears that one of the primary plans in the strategy for the development of the railway industry is to equip the rolling stock with modern, new and durable technical means to ensure high reliability [1].

2. The statistics of accidents in railway transport and analysis of failures of bearings of the axle box unit with polyamide cages

Accident statistics in recent years reflects positive achievements in the established strategy. So, as of 2015, in comparison with the previous year, the number of accidents in railway transport increased by 41% [2]. And in the first half of 2016 the number of equipment failures in the infrastructure of JSC "Russian Railways" decreased by 20% [3]. In 2017, in order to increase transportation efficiency, the management of JSC "Russian Railways" set the goal for the Administration office of the rolling stock of the Central Directorate of Infrastructure to reduce equipment failures by at least 15% for JSC "Russian Railways". As a result, for 10 months of 2017, this target indicator was exceeded (-26%) [4]. All this is indicative of the choice of the right strategy.

One of the examples of modern achievements is the renewal of the fleet of Russian wagons and equipping them with axle boxes with cassette type bearings. Historically, axle boxes of wagons “survived” two generations of bearings, and now due to the transition to the third generation, significant results have already been achieved. So, as of 2012, according to the Central Directorate for the Repair of Freight Wagons in the Russian Railways network, the number of rejects due to malfunctions in axle boxes was an absolute majority (95.2%) in the total number of detected rejects (Figure 1) [5].

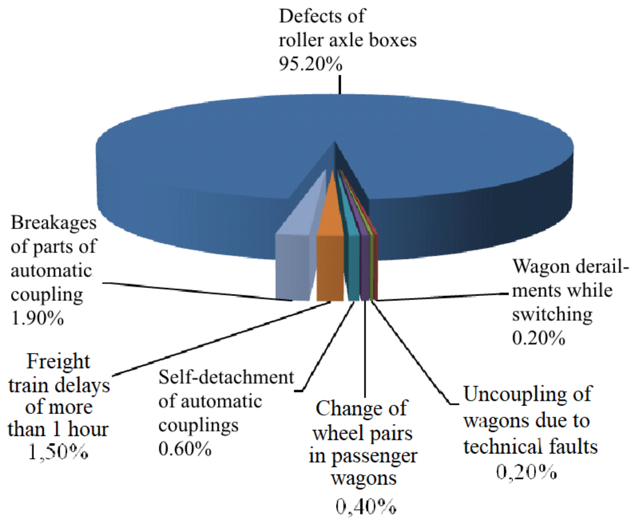


Figure 1. Number of cases of rejects in JSC "Russian Railways" as of 2012 and its types.

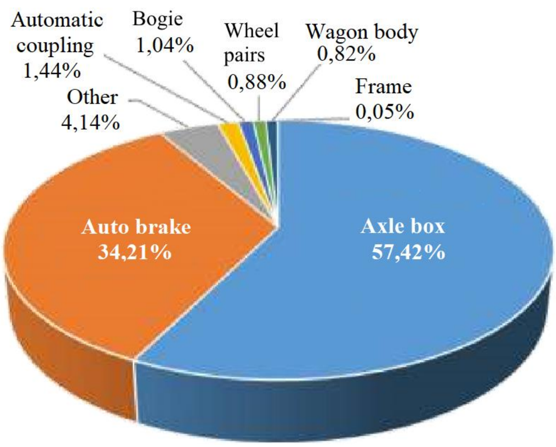


Figure 2. The number of equipment failures in the wagon system according to CAS ARE for 2015-2016.

For 2015 and 2016, according to the comprehensive automated system of accounting, control and analysis of the reliability of equipment failures (CAS ARE), the number of failures of the axle boxes was 57.42% of the total number of equipment failures in the wagon system (Figure 2). But along with the positive dynamics, the largest percentage of defects in the axle box can be attributed to its bearings (Figure 3).

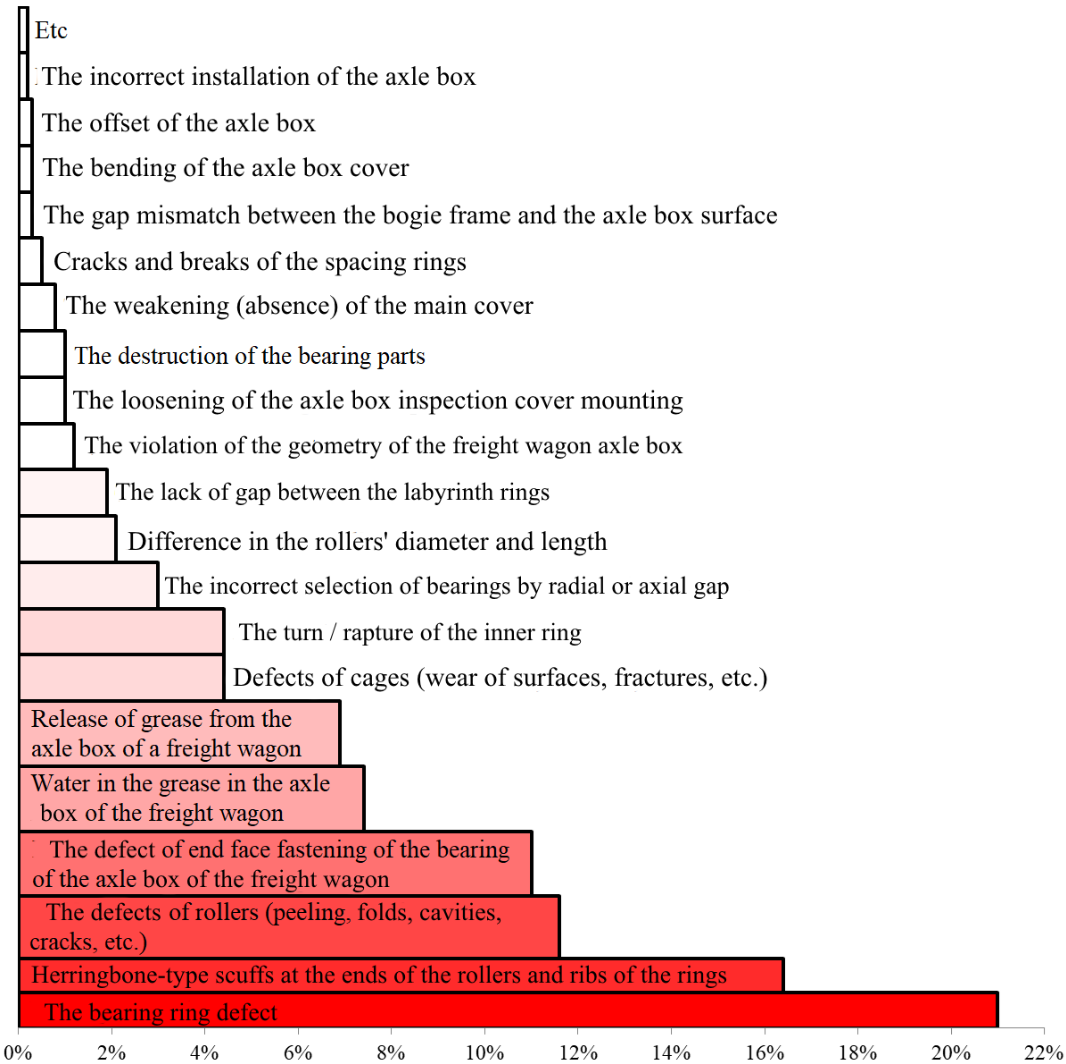


Figure 3. The failure distribution of axle unit for 2015-2016.

Today JSC "RZD" has introduced axle boxes with cassette-type bearings of the following companies: Brenco, Timken and SKF [6-8]. Manufacturers guarantee trouble-free operation of the cassette bearing for eight years of operation or 800 thousand kilometers, as well as provide service within the warranty period and thus exclude the intervention of repair units of JSC "Russian Railways" in their service. This results in an increase in the cost of introducing and maintaining new axle boxes. However, as noted by Sergey Goncharov, the chief engineer of JSC "PGK", "the overall economic effect of the introduction of new axle boxes can be estimated only in the long term" [9]. But today, to reduce the maintenance costs of wagons and reduce downtime of unprocurable rolling stock, work is underway to create service centers that work with cassette bearings. The plans also include the licensing of railway enterprises for a complete overhaul of axle boxes with cassette-type bearings, which includes assembly or disassembly, fault detection, repair or replacement of defective parts.

According to the diagram of the distribution of failures of the axle boxes (Figure 3), the majority of faults occur in bearings, which leads to a failure of the axle box with the ensuing consequences. The most important functional component of the bearing is the cage. Since 1995, Russia has been producing roller bearings with a polyamide cage (Figure 4a). In cassette-type bearings, to keep the tapered rollers at equal distances from each other and maintain their uniform rolling around the entire bearing circumference, a polyamide cage is used as well, but with an improved design (figure 4b) [10].

a b

Figure 4. The axle box bearings with polyamide cages: a – with cylindrical rollers; b – with tapered rollers.

The operating experience of bearings with polyamide cages in railway transport in the construction of running gears, both wagons and locomotives, has been fully justified for the past two decades and confirmed the prospects of using polymers instead of hard-to-find non-ferrous materials (brass cages). However, along with the advantages, the operating experience of such cages revealed a number of shortcomings that result in a reduction in the period of overhaul operation of the axle boxes. In work [5] it is mentioned that the most common defects of the polyamide cage are cracks (67% of the total number of reasons for rejection of cages, as of 2012), and the level of rejection of cages by "cracks" is not reduced, and in some cases there is an increase in their number. The reasons for the formation of such a defect include:

– the violation of the cage manufacturing technology, which entails the formation of casting defects;
– exceeding operating loads;
– the influence of climatic conditions on the operation of the rolling stock, in particular, on the operation of the axle box, including both water and grease contamination, and changes in the structure and properties of the polyamide cage.

3. Materials and methods

The absorption of moisture by the cage during operation should not exceed the permissible rate (0.4% of the mass fraction), but this is possible when operating the axle box only at temperatures close to 40 °C. For a detailed study of the influence of climatic conditions on the performance properties of the cage, samples were made (width is $4 \pm 0{,}2$ mm; height is $6 \pm 0{,}2$ mm; length is 50 ± 2 mm) in accordance with GOST 26277-84. Here it should be mentioned that during their manufacture in the batch of polyamide cages, a factory defect was found (Figure 5) formed by casting. It should also be noted that the manufacturers do not even control the occurrence of such defects, and products with this type of rejects are supplied to the operational and repair enterprises of JSC "Russian Railways".

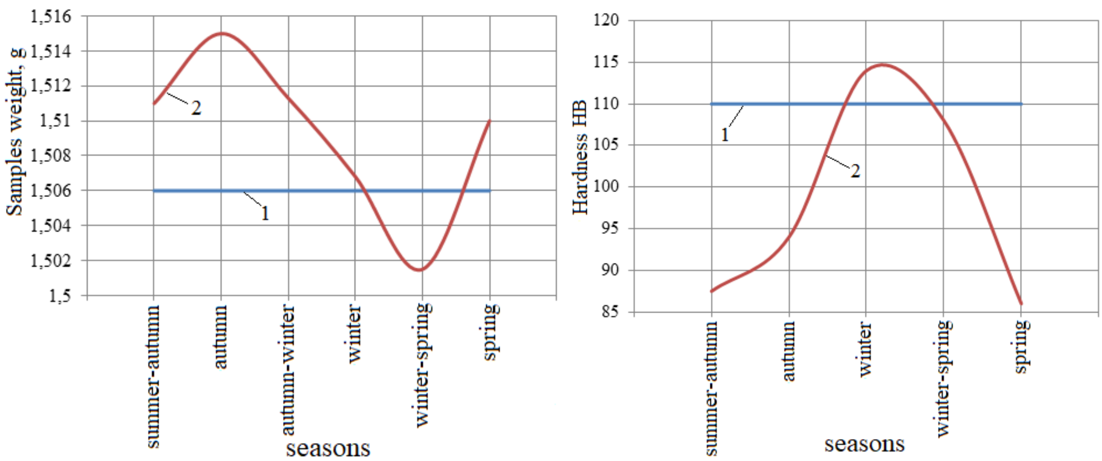
The manufactured samples were kept in simulated weather and climatic conditions corresponding to the operational seasons of the year, as well as weighed on the analytical balance of the model HTR–

120CE (accuracy is up to 0.0001 g) before and after exposure. Moreover, the duration of each experiment was chosen in accordance with GOST 12423-66 and was at least 24 hours. The study itself was conducted in winter, and Figure 6a presents a graphical display of its results.

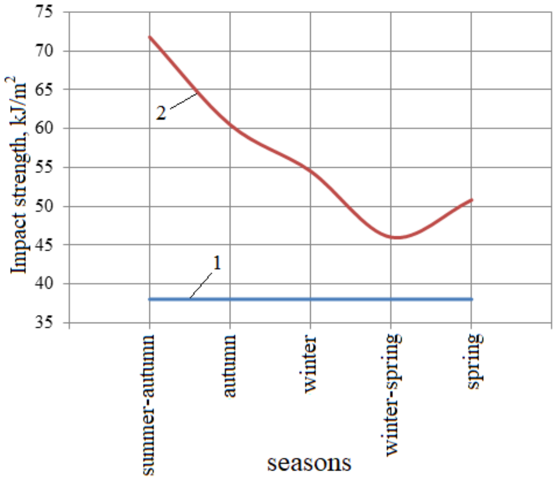
Figure 5. A factory casting defect in the polyamide cage of the axle box bearing

The next stage of this study was to determine the effect of different weather conditions on the strength characteristics of the samples from the cage. To this end, the samples were exposed to such simulated weather and climatic conditions that have the greatest impact on wear, cracking and damage. In accordance with the work [5], seasonal periods of operation of polyamide cages with the greatest number of rejects are: summer-autumn, autumn, winter, winter-spring, spring. After having been kept in simulated conditions, the samples were subjected to hardness and impact strength tests. Hardness measurement of each sample was made at least ten times at different points of its surface using the device TEMP-3. A graphical display of the average hardness values for the specified periods is shown in Figure 6b. Impact strength tests were performed by use of a pendulum impact testing machine 2083 KM-0.4 with an axe 2J by the Charpy method in accordance with GOST 4647-80.

The conducted researches make it possible to reveal dependence of physical and mechanical properties of samples from polyamide on weather and climatic conditions in different seasons of the year. The resulting picture (Figure 6) allows one to predict changes in the operating characteristics of the cage and take measures to restore and improve its operational properties..



a b



c

Figure 6. Dependence of the influence of weather and climatic conditions by seasons on: a – changes in the weight of polyamide samples; b – changes in the hardness of polyamide samples; c – changes in the hardness of polyamide samples; 1 – before the modeling of weather and climatic conditions; 2 – after the modeling of weather and climatic conditions

4. Method of recovery and increase of operational properties of cages

Within the framework of these studies, it was determined that it is possible to restore and improve the performance properties of a polyamide cage by treating it in the field of high-frequency currents (HFC), in other words, high-frequency (HF) electrothermy [5, 12-14, 20]. This method of processing has proved to be the most progressive, resource-and energy-saving method [11, 13, 15-20]. Its essence consists in placing a polyamide product (and any other polar thermoplastic polymer) between the capacitor plates. Then, high-voltage HF energy is supplied to the capacitor. The alternating electric field formed between the capacitor plates causes dipole polarization in the sample and the emergence of bias current, which leads to the heating of the polymer. It follows therefrom that the source of heat in this processing method is the polymer itself. At the same time, the heat is released evenly and with high intensity. Due to this, the process is practically non-inertial. The process flow diagram of high-frequency processing is shown in Figure 7.

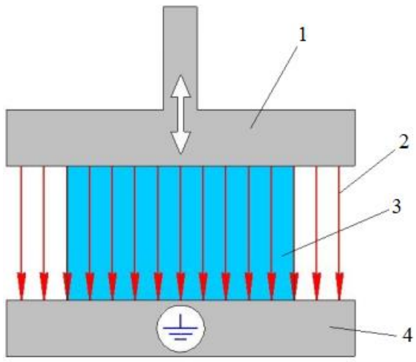


Figure 7. The process flow diagram of HF processing: 1 – the mobile high-potential plate of the working capacitor; 2 – the electromagnetic radiation flux; 3 – the heated polymer; 4 – the low-potential plate of the working capacitor.

To confirm the possibilities of restoring and improving the operational properties of the cage, an additional series of experiments with samples of the same dimensions was carried out (4 ± 0.2×6 ± 0.2×50 ± 2 mm). The experiment included the drying of polyamide samples with the high-frequency equipment of the UZP 2500 model [21] after modeling the above-described weather conditions. This allowed to achieve the results presented in Figure 8.

Analysis of the graphs (Figure 8) showed high efficiency of the HF drying process, expressed in reducing the weight of the samples as a result of moisture removal. As for the strength properties, it should be noted that the samples from the cage sufficiently restore their initial hardness values after HF treatment not in all seasonal periods. The hardness of samples used in periods corresponding to the winter and winter-spring was restored with a quality even higher than the initial one.

A device was developed for the high-frequency processing of polyamide cages (Figure 9). It consists of the upper high-potential and lower low-potential plates on which the upper and lower contact groups are installed. The complexity of the device is determined by the structural features of the cage, consisting of partitions, the upper rim and the lower rim. The resulting device provides the required coverage of the work piece by electrodes on the upper, lower and inner side surfaces of the partitions. The electrodes are simultaneously connected to a high-frequency generator. This design of the device under HF exposure forms a potentials difference between adjacent electrodes, between the upper high-potential plate with electrodes connected through the lower contact group to the lower grounded plate, and the lower grounded plate with electrodes connected through the upper contact group to the upper high-potential plate.

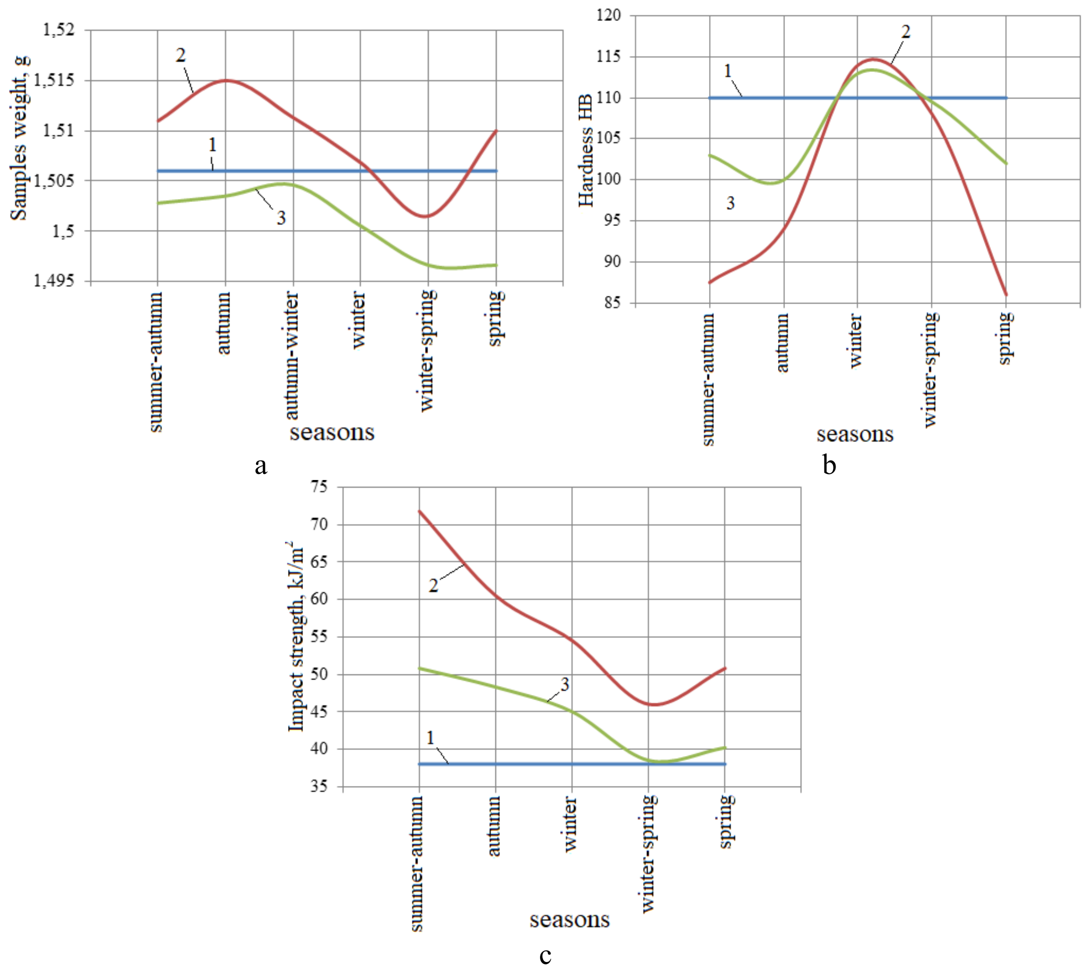


Figure 8. Dependence of influence of HF processing and weather-climatic conditions on seasons of year on: a – changes in the weight of polyamide samples; b – change in the hardness of polyamide

samples; c – change in the impact viscosity of polyamide samples; 1 – before the modeling of weather-climatic conditions; 2 – after the modeling of weather-climatic conditions; 3 – after HF drying.

Using the developed device on high-frequency equipment of the model UZP 2500, polymer cages made of Armamid PA PA 30-1ETM were dried. Table 1 presents the results of high-frequency drying.

Table 1. The results of drying cages on the UZP 2500 installation

Drying time, sec.	Relative humidity,%	Breaking strength, MPa
0	5,6	136,7
60	2,05	137,2
80	1,6	139,3
100	1,15	141,4
120	0,7	144,3

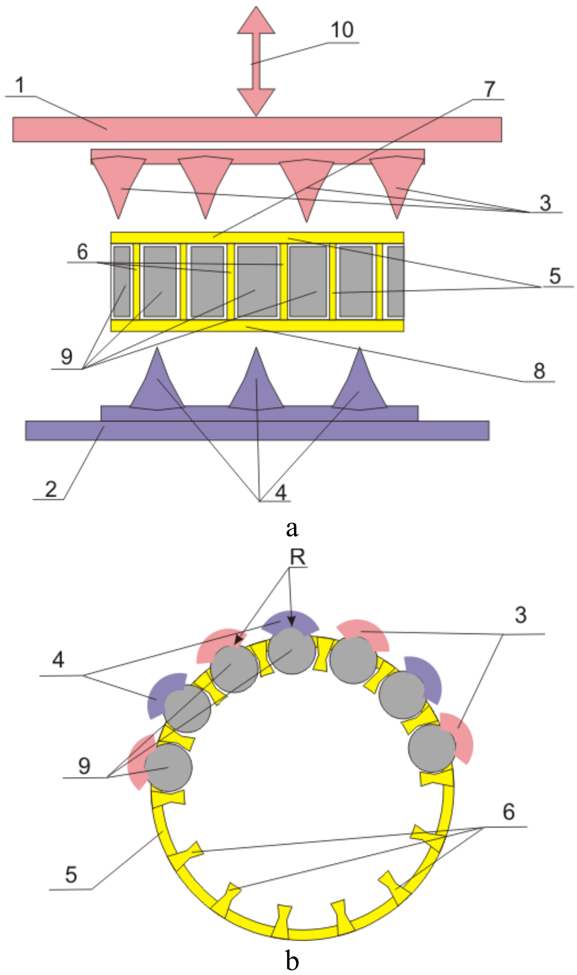


Figure 9. The diagrams of a device for high frequency treatment of parts: a – main view; b – top view; 1 – the top high-potential plate; 2 – the lower low-potential (grounded) plate; 3 – the upper contact block; 4 – the lower contact group; 5 – the cage; 6 – the plates of the cage; 7 – the upper rim of the cage; 8 – the lower rim of the cage; 9 – electrodes (rollers); 10 – the press; R – the radius of curvature.

From the above data it can be seen that the relative humidity at the initial rates of 5.6% after processing decreased to 0.7%, and the strength characteristics increased by 7.6%, which leads to the conclusion about the practical significance of this work.

5. Conclusion

The results obtained in the work fully confirm the prospects of using high-frequency electrothermy to restore and, moreover, to improve the strength performance properties of polyamide cages, as well as any parts of the rolling stock made of polar polymer materials (for example, polyurethane friction wedge plate in the bogie of a freight wagon). In addition, the high-frequency electrothermy in parallel with the drying also makes it possible to perform diagnosis of polymer parts for the waste casting and non-metallic inclusions [22].

References

[1] Yagodina E I, Suchkov R V 2018, Innovative solutions to improve the reliability of freight wagons Scientific community of students of the XXI century. Technical Sciences: collection of articles on the materials of LXV international student scientific-practical conference (5(64)) Dmitrieva N V (Novosibirsk: ASE Sibac), 355-360

[2] Actual problems in the field of repair of freight wagons, available at: http://www.rzd-partner.ru/zhd-transport/news/aktualnye-problemy-v-sfere-remonta-gruzovykh-vagonov-412278/

[3] In the first half of 2016, the number of failures of technical means on the infrastructure of JSC "Russian Railways" decreased by 20%, available at: http://www.rzd-partner.ru/zhd-transport/news/v-i-polugodii-2016-goda-kolichestvo-otkazov-tekhnicheskikh-sredstv-na-infrastrukture-oao--rzhd--sniz-414667/

[4] The number of failures of technical means is reduced, available at: http://www.gudok.ru/newspaper/?ID=1395012

[5] Popov S I 2013 *Automation of control of technological processes of restoration of operational properties of polymers* (Irkutsk: ISTU)

[6] LLC "EPK-Brenko Podshipnikovaya Kompaniya", available at: http://epk-brenco.ru/ru/

[7] OOO "SKF", available at: http://www.skf.com/ru/index.html

[8] The Timken Company, available at: https://www.timken.com/ru/

[9] Cassette bearings: an overview of the first operating results, available at: http://www.eav.ru/publ1.php?publid=2017-05a11

[10] Axle box with cassette bearings, available at: http://www.pomogala.ru/konsrukt/konstrukt_11.html

[11] Filippenko N G 2012 *Automation of process control of high-frequency processing of polymeric materials* (Irkutsk: ISTU)

[12] Livshits A V 2016 *Automated control of technological processes of high-frequency electrothermy of polymers* (Irkutsk: ISTU)

[13] Butorin D V, Filippenko N G, Livshits A V 2016 Complexed method of automated control high phase transformations in polymeric materials *Instruments and Systems: Monitoring, Control, and Diagnostics* **10** 10-18

[14] Livshits A V, Filippenko N G, Homenko A P, Kargapoltsev S K, Gozbenko V E, Dambaev Z G 2017 Mathematical modelling of the processes of the high-frequency heating of thermoplastics and quality improvement of welded polymeric items *JP JOURNAL OF HEAT AND MASS TRANSFER* **2(14)** 219-226

[15] Bader H 1996 High frequency drying of porous materials *Drying Technology* **7(14)** 1499-1523

[16] Hou A, Wang X, Wu L 2008 Effect of microwave irradiation on the physical properties and morphological structures of cotton cellulose *Carbonate Polymers* **74** 934-937

[17] Lyons P W, Hatcher J D, Sunderland J E 1972 Drying of porous medium with internal heat

generation *Int. J. Heat and Mass Transfer* **5(15)** 897-905
[18] Metaxas A C, Meredith R J 1983 Industrial Microwave Heating *Peter Peregrinus* 111-150
[19] Ohe T, Yoshimura Y 2009 Microwave Irradiation onto Nylon 6 Fibers in Organic Solvent *Sen'i Gakkaishi* **1(65)** 64-70
[20] Butorin D 2018 Automated control system to monitor dielectric losses in polymers *MATEC WEB OF CONFERENCES* (EDP Sciences) 02003
[21] Plant "Industrial electronics Gabrovo» 1987 *Passport UZP 2500A: installation for welding plastics* 60
[22] Larchenko A G 2014 *Automated control system for high-frequency diagnostics in the production and operation of polymer materials* (Irkutsk: ISTU)