Design of the tooling of a complex geometric shape for electrothermal processing of the polymer covering plate of the bogie friction wedge

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Abstract. The article analyzes the operation of the bogie friction wedge. It considers the question of the necessity and possibility of enhancing the reliability and operational resource of wedge-type shock absorbers of railway bogies by increasing the operational properties of a polymer covering plate of a bogie friction wedge. A method for increasing the operational properties of the polymer covering plate, consisting in its processing by high-frequency currents, is proposed. To implement the high-frequency processing of the considered polymeric covering plate and achieve its uniform warming-up throughout the volume, a specialized tooling is developed and constructed according to the technique established earlier. The developed tooling made it possible to implement a uniform non-inertial self-regulating high-frequency heating throughout the entire volume of the polymer covering plate in laboratory conditions with high intensity. As a result of full-scale tests of the developed tooling and the proposed method of high-frequency processing, deviations of temperature values in different parts of the heated polymer plate became apparent. All of this shows that the heating is not completely uniform. The greatest deviation value was 7.9%. As a result of the work, it was possible to establish the reasons for the lack of full uniformity and to determine the direction of further research.

1. Introduction

In the design of a number of modern railway freight bogies (models 18-578, 18-194, 18-194-1) to absorb the vibrations of the wagon arising under the influence of irregularities of the railway track, friction wedges made of heat-strengthened high-grade cast iron VCh 120 with polyurethane covering plates are used (Figure 1) [1-4]. At the same time, the inter-repair run of freight bogie friction wedges, in accordance with the design documentation (CD), should be at least 500 thousand km, and for new-generation freight bogies it should be at least 800 thousand km [5-7]. But despite such guarantees, the friction wedge breaks down much sooner due to the wide range of reasons, including the numerous operational malfunctions of the covering plate (wear, delamination, scuffs, deformation, ruptures, side and corner chipping, cracks, production (factory) rejects) (Figure 2) [8, 9] installed on the inclined surface of the wedge. All this makes it possible to state the relevance of the work on the diagnosis of defects and improvement of the performance of polyurethane covering plates by any suitable means [10].

Along with this, in works [11, 13-17] there is a high progressiveness and efficiency of high-frequency (HF) electrothermy in the processing and diagnosis of polymer products in order to restore and improve their performance properties, which is very appropriate for the problem considered in this paper.
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Figure 1. The friction wedge of the bogie model 18-194-1 with a polyurethane covering plate.

Figure 2. Some types of wear of the polyurethane covering plate by the example of the bogie model 18-194: a, b – wear and delamination; c – scuffs on the work surface

In high-frequency processing, the processed material is placed between the capacitor plates (high-potential and low-potential electrodes), to which a high-frequency current is supplied. When changing the charge on the plates, the polar dipoles of the material move in opposite directions, resulting in molecular friction with the release of heat. The energy of the electric field used to overcome these frictions will be converted into heat.

After analyzing the HF equipment and electrothermy process, as well as taking into account the geometric complexity (different thicknesses) of the polyurethane covering plate and the recommendations stated in [12], it was concluded that it is impossible to ensure the accuracy and efficiency of the HF processing without designing the appropriate tooling (complex profile electrodes) to achieve uniform heating of the covering plate throughout the volume. Based on the above, the purpose of this work was: to develop a tooling to implement the high-frequency processing of products of complex configuration by the example of the polymer covering plate of the freight wagon friction wedge in industrial conditions.

2. Tooling design procedure

Proceeding from the basic equation of electrothermy (1), it follows that the power released in the unit volume of the polymer in the form of heat quadratically reacts to the change in the interelectrode distance $d$ and the voltage on the plates of the working capacitor $U$.

$$P_{\text{unit}} = 5.53 \cdot 10^{-11} \cdot E^2 \cdot f \cdot \varepsilon' \cdot \varepsilon_0 \cdot \delta,$$

(1)
\[ E = \frac{U}{d} \]  \hspace{1cm} (2)

where \( P_{\text{unit}} \) is the specific power of dielectric losses, W/cm\(^3\); \( E \) is electric field strength, V/m; \( f \) is field frequency, Hz; \( \varepsilon' \) is the relative permittivity of the treated polymer; \( \text{tg} \delta \) is the dielectric loss tangent of the polymer.

And the voltage of a capacitor depends on its capacitance \( C \) (3):

\[ U = \frac{q}{C} = \frac{qd}{\varepsilon_0 \varepsilon' S}, \]  \hspace{1cm} (3)

where \( q \) is capacitor charge, C; \( S \) is the area of the capacitor plates, m\(^2\); \( \varepsilon_0 = 8.854 \cdot 10^{-12} \) F/m is dielectric constant.

Then, to solve the problem of the planned process of high-frequency processing, which consists in achieving a uniform heating of the polymer covering plate throughout the volume, it is necessary to ensure equal values of the capacity in each section of the part by introducing an air gap. To do this, it is required to make a conditional partition of the polyurethane covering plate into a number of individual elementary surfaces (Figure 3) with a set of equal in area, differentially small capacitors and to calculate the capacity of each capacitor obtained, which in turn will determine the value of the required air gap.

**Figure 3.** The partitioning scheme of the covering plate of the friction wedge of the bogie model 18-194-1 into elementary surfaces, where 1 is the cylindrical part; 2 is the lateral surface; 3, 5, 6 are lugs; 4 are depressions.

First of all, we calculate the capacitance of the conditional surface capacitors with the largest thickness (Figure 3, position 1). The distance between the electrodes is 35 mm. Since all the elementary surfaces obtained by separation are plane-parallel, it is sufficient to divide each surface into the \( i \)-th number of capacitors with an area of 1 c.u.\(^2\). Then the total capacitance of the capacitor is:

\[ C = \sum_{i=1}^{n} \frac{\varepsilon_0 \varepsilon' S_i}{d}, \]  \hspace{1cm} (4)

where \( n \) is the number of differentially small capacitors.

Based on the presence in the cylindrical part of the covering plate of the slot, the thickness of which is less than the total thickness of this part, it is necessary to calculate the capacitance of the capacitors.
consisting of the covering plate capacity and the air gap capacity. In this case, in accordance with Figure 4, we have a serial connection of the capacitor capacitance, which is calculated by the formula (5):

$$\frac{1}{C_1} = \frac{1}{C_2} + \frac{1}{C_{air}},$$

where $C_{air}$ is the capacitance of the air capacitor (gap), which is equal to:

$$C_{air} = \frac{C_1 C_2}{C_2 - C_1} = \frac{S_1 S_2}{d_1 S_2 - d_2 S_1},$$

then the value of the air gap is:

$$d_{air} = \frac{\varepsilon_0 \varepsilon_{air} (d_1 S_2 - d_2 S_1)}{S_1},$$

where $\varepsilon_{air}$ is the relative permittivity of air.

![Figure 4. The scheme of the cylindrical part of the covering plate.](image)

The next step is to calculate the capacitance of differentially small capacitors of the remaining surfaces in accordance with the scheme shown in Figure 5. The calculation of the capacitance of the other surfaces are produced similarly in accordance with equations (4)-(7). For the polyurethane covering plate of the friction wedge freight truck of model 18-194 (Figure 6) the tooling designing technique is similar.

![Figure 5. The scheme of condensers, surfaces 2-6.](image)

In accordance with the described technique, the values of air gaps necessary to achieve uniform heating of the polymer covering plate throughout the volume during HF processing were determined, which made it possible to start designing the tooling.

3. Tooling design

In the design of tooling was analyzed recommendations for materials for the manufacture of electrodes. The most suitable material was aluminum alloy AD1. Since this type of alloy has a high electrical conductivity, it is not subject to corrosion and has good technological properties. Based on the configuration of the product in question, it is most advisable to process the covering plate in two cycles, breaking the surface of the lining into flat and cylindrical parts. The general view of the obtained technological system and the tooling developed within this work with division into processing cycles is
presented in Figure 7.

![Diagram](image)

**Figure 6.** The scheme of partitioning the covering plate of the friction wedge of the bogie model 18-194 into elementary surfaces, where 1 is the cylindrical part; 2 is the side surface; 3 is the deepening; 4 is the ridge.

![Diagram](image)

**Figure 7.** The general view of the technological system of high-frequency processing of the polymer covering plate of the friction wedge of the bogie model 18-194 when heating the flat part (a) and the cylindrical part (b): 1 is the clamp; 2 is the high-potential electrode; 3 is the low-potential electrode; 4 is the polymer covering plate; 5 is the tooling.

**4. Experimental part**

Approbation of the described technique and the developed tooling for electrothermal treatment of the studied polyurethane covering plate of the friction wedge was carried out on the industrial installation of model UZP 2500 (Figure 8) with an operating frequency of 27.12 MHz [16].

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Figure 8. The installation of HF heating of model UZP 2500.

The investigated bogie friction wedge covering plate of model 18-194-1 and the tooling developed for it were installed by holddfasting the covering plate, while simultaneously applying pressure, with a low-potential electrode and of the tooling contact connected to a high-potential electrode of the working capacitor connected to a high-frequency generator (Figure 9).

Figure 9. The general view of the technological device for HF processing of the flat part (a) and the cylindrical part (b) of the polyurethane covering plate (c).

The processing cycle begins when the operator presses the "HEATING" button of the high-frequency generator located on the remote control. The moment of the end of the processing cycle is also recorded by the operator. For approbation of the works described above, the polyurethane covering plate was heated with a voltage of the tuning capacitor equal to \( U = 4000 \text{V} \) for 70 seconds.

Then a series of measurements of the covering plate temperature in different areas was made. As it was impossible to control direct temperature during the high-frequency processing, both on the surface and inside the polymer product, temperature measurements were carried out contactless on the side
surface of the covering plate (Figure 10) by the infrared pyrometer ADA TemPro 700 with a measurement accuracy of ±1.5 °C after 70 seconds of the HF heating.

![Figure 10](image)

**Figure 10.** Measuring the temperature of the side surface of the covering plate in the areas of different thickness.

5. Results and Discussion

The following average heating values temperatures were obtained experimentally for each section: section 1 – 137.4 °C; section 2 – 132.8 °C; section 3 – 149.2 °C. The obtained values reflect some deviations of the temperature values, the largest value of which is 7.9% of the experimentally obtained temperature value of section 3. The obtained deviations of the experimental data are due to: firstly, the accuracy of the measuring device; secondly, not taking into account the boundary effects (skin effect) of the electric capacitor, since the classical approach to determining the electrical parameters of the capacitor involves neglecting the overall dimensions of the capacitor plates and considers only a plane-parallel capacitor with electrodes of infinite length [19-21]. Therefore, the purpose of further research will be the development of the above methods, taking into account the skin effects of an electric capacitor.

Nevertheless, the obtained results allow us to state the efficiency of the proposed technique and move on to the development of high-frequency technology for diagnosing and improving the strength properties of polymer products of different configurations by HF energy.

6. Conclusion

The proposed method of calculation and design of tooling to implement the high-frequency processing of polymer products of complex configuration makes it possible to evenly warm the processed products throughout the volume.

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