Research of high-frequency influence on polymeric materials of rolling stock products

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Abstract. The paper presents the main directions of the technological process of high-frequency processing of polymeric materials used in rolling stock products. The necessity of developing a mathematical model of the critical process of exposure to high-frequency energy is substantiated. As a model, an imitational mathematical model of the process of high-frequency processing of polymeric materials that takes into account breakdown phenomena is proposed (based on experimental studies of a large number of the most used polymer materials).

1. Introduction
High-frequency (HF) processing of thermoplastic polymers used in the manufacture of parts and components of rolling stock has proven itself in industrial practice. The main advantages of the method, for example, HF welding, are fast and local (in the weld weld zone) heating of the joining surfaces without penetration of the entire volume of the material. At the same time, the quality of welded joints (strength, tightness), as a rule, exceeds the quality of joints with other welding methods. A self-regulating process, for example, drying polymeric and dielectric materials of large geometrical dimensions, makes HF electrothermal one of the main technological operations in this field [1, 2].

Due to the lack of technical ability to control the temperature in the field of HF exposure, a special role in the electrothermal processing technology is assigned to the task of correctly calculating the process time - the time it takes for the drying temperature or the melting temperature of the thermoplastic to be achieved in the material [1, 3, 4, 5]. But this technique leads to errors associated with the heterogeneity of materials of products, both in chemical composition and in physical condition. Attempts to create mathematical models of the process also do not allow to take into account the properties of polymer products that are changed during transportation, storage and operation. The disadvantages of the well-known mathematical models are also: neglect of changes in the specific power of internal heat sources during the processing cycle, idealization of the design of technological equipment that does not take into account the heterogeneity of the materials being processed, the presence of insulating inserts between the material being processed and the working capacitor electrodes, the critical effect of breakdown phenomena on the product being processed and costly electrodes. Using data from sources [8-10, 11], we can conclude that the defect in the production of the above-described technological preparation reaches 7-12%.

2. Materials and methods
Features of the control process RF processing
Taking into account the peculiarities of the HF process control technique by the parameters of the RF
generator, namely, the control of the pre-breakdown state and partial discharge dynamics (CR) [4-7, 12], it is obvious that the mathematical model of the process needs to be built based on this particular dependence of the technological system. Moreover, these parameters have a greater impact on the quality of the processed products, and their uncontrolled change leads to emergency stops and significant material losses. The inconstancy of the electrophysical properties of materials ε, tgδ, depending on temperature, the prehistory of the samples, manufacturers and changing technologies for producing polymers, the arrival of new materials in the industry can only be compensated by the results of experimental tests. With such complexity of the task, its solution was found in the compilation of a simulation mathematical model of the process of RF processing of polymeric materials, taking into account the occurrence of a breakdown state.

Experimental tests of polymeric materials significantly different in their physicochemical parameters were carried out. The graphical depiction of experimental data presented in figure 1 shows that the portion of the curves for the onset of the pre-breakdown state, characterizing the relationship between the time of occurrence of the CR and the number of the CR, has a significant view.

![Graph](image)

**Figure 1.** The empirical dependence of the occurrence of CR on the processing time

According to the results of the analysis of the distribution curves of the CR, we can conclude about the exponential development of events, and their characteristic distribution allows us to divide the materials into two groups:

- with the active development of a pre-breakdown state after the first discharge of CR1, when the following condition is fulfilled:

  \[ \Delta \tau_{CR1} = \tau_{CR2} - \tau_{CR1} < 1,2 \, \text{c}, \]  

  where \( \tau_{CR1}, \tau_{CR2} \) - the time of occurrence of the first and second partial discharges, respectively.

- with a long pre-breakdown condition (the time from the first to the subsequent CR is more than 2 s),

  \[ \Delta \tau_{CR1} = \tau_{CR2} - \tau_{CR1} > 2 \, \text{c}. \]  

Assuming that the n-th CR, for which

\[ \Delta \tau_{CR_n} > 1,2 \, \text{c} \]  

not the beginning of the development of the pre-breakdown state, we obtain the following family of graphs of the dynamics of the development of the breakdown of various materials, presented in figure
2. Figure 2. Graph of the dynamics of the development of electrical breakdown

3. Results

Methods of approximation, simplification of initial physical models, reduction of their order, linearization are the main directions, allowing to evaluate the possible dynamic properties of technical systems, the effectiveness of managing their state, to develop special tools to change the dynamic characteristics in the right direction.

Based on this, it was decided to build an imitational mathematical model of the technological process of RF processing of polymeric materials, taking into account the simulation of the development of breakdown by approximation of experimental data using the least squares method.

Having considered the totality of the graphs of occurrence of the CR, we identified a curve that is as far as possible from the others in inter-digit temporal parameters. After conducting a study of its graphical display and approximation by the least squares method, it was determined that this curve is subject to a functional relationship, which has the following form:

\[ Y = \exp(A + BX) \]  

or in our case:

\[ n_{CR} = \exp(A + B\tau_{CR_{pav}}) \]  

\[ \tau_{CR_{pav}} = \frac{\ln n_{CR} - A}{B} \]  

The obtained approximated curve (4) can be taken as a model of the RF processing process, since it
fully reflects the process of occurrence of the CR with the smallest dynamics of the development of the pre-breakdown state.

4. Discussion

In the further presentation of the research materials, the derived dependence (5) will be denoted by the term “partial discharge curve” (CDFR) presented in fig. 4.

A special property of the derived dependence is that it displays the maximum value of empirical data on the time of development of the CR of the polymeric materials under study. It should be noted that the tested samples of polymeric materials (with the aim of choosing homogeneous in composition and quality) underwent conditioning, cleaning, testing for inclusions, roughness, burrs, etc. on physical and chemical composition. At the same time, their humidity, due to the hygroscopicity of polymeric materials, can reach up to 8%. All this significantly reduces the electrophysical parameters of polymers used in industry. Reducing the quality of the material increases the likelihood of breakdown. The deterioration of the electrophysical parameters of polymers (always present in real conditions) leads to a shift in the data of its pre-breakdown state to the left area of the curves of our graph, in the area of materials with more active dynamic indicators of the Czech Republic. Therefore, we can say that the CDFR displays the indications of the time of development of the Czech Republic under ideal-laboratory conditions, which are absent in actual production situations. From here, the values of the CR dynamics of polymeric materials, as applied to production conditions, will always be within the zone of the delineated CDFR. Which once again confirms the correctness of the adopted mathematical model of the RF processing process with protection against breakdown phenomena.

Using the free software package Approximator ver. 1.6, we calculated the coefficients A and B, presented in figure 3. The approximation error was satisfactory and amounted to 0.98.

Substituting the coefficients in equation (7, 8), we obtain the equation for the occurrence of a CR in the RF processing for all polymeric materials.

\[
n_{CR} = e^{(-1.99 + 1.8\tau_{CR,pac})}
\]

\[
\tau_{CR,pac} = \frac{\ln n_{CR} + 1.99}{1.8}
\]

The mathematical model of the HF process, which takes into account the occurrence of a pre-breakdown state, corresponds to materials with significant differences in physicochemical parameters and geometrical dimensions (thickness).

**Figure 3.** A fragment of the data on the calculation of the CDFR
Figure 4. The curve of the dynamics of partial discharges (CDFR)

5. Conclusion

Thus, we can assume that the developed mathematical model of the HF process, which takes into account the occurrence of a pre-breakdown state, corresponds to materials with significant differences in physicochemical parameters and geometrical dimensions (thickness). In this case, it becomes possible, according to a mathematical model of the form (8) determined during the study, to calculate the time of occurrence of a CR event. That, in turn, allows in real time to find the algorithm for controlling the RF exposure process in order to prevent breakdown.

All this is possible and necessary to use for the organization of the control and management of the process of RF processing of polymeric materials, working in a pre-breakdown state, which is the most efficient way of working.

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