Diagnostic operation of fabrications of rolling stock by high-frequency method

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Abstract. In this scientific work, the authors consider the issue of non-destructive testing. In the article, the authors describe the process of improving the performance properties of polymeric products of complex configuration. In the article, the authors choose the method of high-frequency control as the most suitable for assessing the quality of products in the manufacture and during repair work. The scientific work describes the process of diagnosing products made from polymeric materials on the developed diagnostic device. This article describes the development of methods for designing a technological additional device for diagnosing products of complex configuration. In this paper, the authors solved the problem of manufacturing electrodes for experimental diagnostics. The authors drew conclusions and set goals for further research.

1. Introduction
Today, the engineering industry is the largest industry in the consumption of polymeric materials. The introduction of composite materials has significantly saved on the use of expensive metals; reduce the cost; increase the warranty period. But, at manufacturing plants and repair profile enterprises, the control of complex configuration products is carried out only by a visual method. The visual method cannot reveal hidden structural defects. Hidden defects lead to additional consumption of resources, reduced quality of products, and emergency situations. The purpose of a scientific article is the organization of the process of diagnosing products of complex spatial form.

2. High Frequency Method. Control device. Electrodes
Theoretical and experimental studies have shown that the most appropriate method of diagnosis in terms of safety and process efficiency is the method of high-frequency control. This method is based on the detection of defects in products made of polymeric materials, as a result of exposure to an electric field. This method can identify metallic and foreign inclusions, pores, voids [1-7]. The authors have developed a device for diagnosing polymeric materials. Figure 1 shows a diagnostic device. The device detects defects without changing the structure of the material. But without the use of electrodes it is impossible to diagnose products of complex spatial form. In the article, the authors developed a technique for the manufacture of electrodes for diagnosis. To design the electrodes, it is necessary to divide the product into sections, which are a sequence of elementary capacitors. The calculated gap between the electrode and the product was also introduced. For uniform energy impact on the elements of the product. The authors calculated the thickness of this gap. The calculations are described by the example of wear-resistant polymer linings of freight cars [8-11].
Figure 1. Diagnostic device. 1 is the protective screen; 2 is the top high-potential plate; 3 is the product; 4 is the timer; 5 is the drive; 6 is the cable, 7 is the high-frequency radiation generator, 8 is the variable capacitor controller, 9 is the automation unit.

The product is placed between the electrodes, thereby creating working capacitors, where the polymer acts as a dielectric. For uniform heating of the product throughout the volume, it is necessary to ensure equal values of the capacitance in each created condenser. Figure 2 shows a diagram of the dissection of a part into elementary geometric surfaces. The authors calculated the capacitor at each site.

Figure 2. Dissection of a part into elementary geometric surfaces.
1 - cylindrical part; 2 - side surface; 3,5,7 - ledges; 4,6 - grooves; 8 - technological groove.

The value of capacitors on each elementary surface is:

\[ C = \frac{\varepsilon \varepsilon_0 S}{d} \]  

(1)
where $C$ is the electric capacity, $F$; $\varepsilon$ is the dielectric constant; $S$ is the plate area, m$^2$; $d$ is the distance between the plates, m; $\varepsilon_0$ is the electric constant.

Next, the authors calculated the capacitance of the capacitors, consisting of the capacity of the product and the air gap. Figure 3 shows the serial connection of the capacitor capacitance, according to the expression:

$$1/C_1=(1/C_2)+(1/C_{air})$$

(2)

Air gap capacity:

$$C_{air}=(C_1C_2)/(C_2-C_1)$$

(3)

Air gap value:

$$d_{air}=\varepsilon\varepsilon_0S/C_{air}$$

(4)

Figure 3. Capacitors circuit diagram.

An important step in creating the process of diagnosing and improving the quality of products is the development of a methodology for calculating the parameters of the electrode design gap. This gap ensures uniform energy impact on the elements of the product. Since the surface of the polymer product in question (Figure 1) has a cylindrical shape and a technological groove, it is necessary to take into account the uneven air gap when designing the electrodes. To diagnose this area, it is necessary to determine the direction of the electric field strength on different planes of the product (Figure 4) when exposed to high-frequency radiation. Studies have shown that the tension in the process of diagnosis arises in different directions. Therefore, the heating of the product is uneven.

Figure 4. Electric field strength

The system electrode – air gap – the polymer can be represented as a capacitor circuit (Figure 5).
Figure 5. The system of replacing the electrode-air gap – polymer.

Based on figure 5:

\[
C_0 = \frac{(\varepsilon \varepsilon_0 S/\varepsilon_2)}{(d_2 \varepsilon_1 + d_1 \varepsilon_2)}
\]  

(5)

expression 5 determines the total capacitance of any system of series-connected capacitors during diagnosis. But, since the product has a complex geometric shape, it is necessary to take into account the change in the air gap and the polarity of the capacitors (Figure 6).

Figure 6. Air gap distance and capacitors polarity

To determine the distance between the plates, depending on the width of the air gap, an auxiliary triangle ABC was considered. Figure 7 shows the triangle.

Figure 7. ABC triangle.
Air gap size $\Delta d_1$:

$$\Delta d_1 = \sqrt{d_1^2 + a_1^2} - d_1$$  \hspace{1cm} (6)

$\Delta d_2$ in the polymer product:

$$\Delta d_2 = \sqrt{d_2^2 + a_2^2} - d_2.$$  \hspace{1cm} (7)

Capacitor values for air gap:

$$C'_1 = \frac{\varepsilon \varepsilon_0 S}{d_1 + \Delta d_1}$$  \hspace{1cm} (8)

$$C'_2 = \frac{\varepsilon \varepsilon_0 S}{d_2 + \Delta d_2}.$$  \hspace{1cm} (9)

The total value of the capacitance of the serial connection of elementary capacitors:

$$C = \left(\frac{\varepsilon \varepsilon_0 S}{d_2 + \Delta d_2}\right) / \left((d_2 + \Delta d_2) \varepsilon_1 + ((d_1 + \Delta d_1) \varepsilon_2)\right).$$  \hspace{1cm} (10)

The calculations made it possible to design electrodes for diagnosing a polymer product by uniformly heating with a high-frequency field. For all surfaces of the polymer product, together with the electrodes, the factors are calculated capacitance. This is necessary to ensure a constant and equal distribution of high-frequency radiation exposure over the entire surface of the part. Electrodes allow high-frequency diagnostics of all elements of the product connected to the electrodes simultaneously in one cycle. The developed technique is applicable to polymers of various grades. The authors conducted a series of diagnostic experiments. Figure 8 shows the electrodes made.

![Figure 8. Electrodes](image)

3. Conclusion

Experimental studies have allowed us to confirm the decisions made and theoretical studies. The results of the diagnostics showed that the high-frequency field affects the object of control evenly, the use of the developed equipment allows for the diagnosis of products in an industrial environment without damage.

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