In search of optimal mode of plasma polishing of surface of agricultural machinery parts when using a discharge with liquid cathode

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Abstract. The process of plasma polishing using a gas discharge with liquid electrolyte cathode was studied. The search for optimal modes was carried out by the method of multi-dimensional experiment. The heat flux density and interelectrode distance were considered as the main factors.

1. Introduction
The discharges with liquid electrodes are of great interest from the point of view of practical application and are studied in a wide range of changes in physical and geometric parameters [1-14]. They are implemented by relatively simple technical means. Weakly concentrated electrolytes are used as liquid electrodes. Depending on the polarity of connection to the power source, the electrolyte can serve as a cathode or anode. To date, significant progress has been made in study of electrical discharges in option with an electrolyte cathode. Discharge plasma with liquid electrolyte cathode can be most effectively used for cleaning, polishing, hardening, gas saturation and activation of metal surfaces. Such processes are promising for improving mechanical and operational characteristics of agricultural machinery parts that are subjected to significant dynamic loads. In this work, axes of bearing assembly of disc harrows were selected for plasma polishing.

2. Materials and techniques
As a result of studying the interaction of discharge with samples made of high-carbon chromium steel of ShH6 grade, the basic modes of polishing the working surface were established. It was found that the reduction of roughness is maximal when processing with heat fluxes in range from 7.4 to 8.2 kW·m⁻².

The value of studied profile with possible arithmetic mean deviation of $R_a$ was chosen as the response function. The independent factors that significantly on surface roughness were taken: heat flux $q$ and interelectrode distance $l$.

3. Experiment
A symmetric compositional plan Bk was chosen for setting up a two-factor experiment [15, 16]. Factors, intervals and levels of variation are presented in Table 1.
Table 1. Factors, intervals and levels of variation.

| Variable factors | Coded representations | Variation interval | Factor levels |
|------------------|-----------------------|--------------------|---------------|
| $q$, kW·m$^{-2}$  | $x_1$                 | 0.4                | +1 0 -1       |
| $l$, mm          | $x_2$                 | 1                  | 4 3 2         |

Factor levels were selected so that their optimal values fell into centres of variation intervals. Factors were encoded according to a well-known technique [15]:

$$x_i = \frac{X_i + X_{i0}}{\Delta_i}.$$  \hspace{1cm} (1)

Here $x_i$ and $X_i$ – are coded and natural values of $i$ factor; $X_{i0}$ – natural value of $i$ factor in center of plan of experiment; $\Delta_i$ – factor variation interval. The initial data for experiment and results obtained are presented in table 2.

Table 2. Planning matrix and response of experiment.

| $X_1$, kW·m$^{-2}$ | $X_2$, mm | $x_1$ | $x_2$ | Response, $R_a$ |
|-------------------|-----------|-------|-------|-----------------|
| 8.2               | 4         | +1    | +1    | 0.65            |
| 7.4               | 4         | -1    | +1    | 0.59            |
| 8.2               | 2         | +1    | -1    | 0.51            |
| 7.4               | 2         | -1    | -1    | 0.49            |
| 8.2               | 3         | +1    | 0     | 0.41            |
| 7.4               | 3         | -1    | 0     | 0.45            |
| 7.8               | 4         | 0     | +1    | 0.35            |
| 7.8               | 2         | 0     | -1    | 0.38            |
| 7.8               | 3         | 0     | 0     | 0.31            |

The response function was approximated by a second-order polynomial, since experiment is two-factor [15]. As a result of mathematical processing of numerical values of response, the following regression equation was obtained in coded form:

$$y = 0.031 + 0.010 x_1 + 0.035 x_2 + 0.010 x_1 x_2 + 0.170 x_1^2 + 0.105 x_2^2.$$  \hspace{1cm} (2)

Here $y$ – is coded designation of roughness $R_a$.

The resulting regression equation (2) was verified by F-test for adequacy [15]. The hypothesis about the statistical significance of obtained regression coefficients according by Student's t-test was also tested. It was found that all regression coefficients are statistically significant.

Using the method of searching of extremum of function, it was determined that extremum points of response surface have the coordinates: $x_1 = -0.024$; $x_2 = -0.166$. According to equation (2), to these values of $x_1$ and $x_2$ at extremum point corresponds $y_1 = 0.307$. The angle of rotation of initial axes of coordinates of response surface before alignment with main axes of the figure was $\alpha = 4.73^\circ$. By substituting available data, response surface equation is obtained in canonical form:
\[ y - y_s = 0.170X_1^2 + 0.105X_2^2. \]  
(3)

As can be seen, the coefficients of canonical equation (3) have the same signs. This means that response surface has the shape of a paraboloid of rotation and the smallest value of response function is at point with above coordinates. Figure 1 shows a three-dimensional image of response surface. Two-dimensional sections were used to study response surface (figure 2).

![Figure 1](image1.png)

**Figure 1.** The response surface in space with coordinate axes \( q, l \) and \( R_a \).

![Figure 2](image2.png)

**Figure 2.** Two-dimensional sections of response surface.
4. Conclusion
As a result of setting up a two-factor experiment on a symmetric compositional plan of type Bk the optimal parameters of the process of plasma polishing of surface of high-carbon steel were determined. It was found that the minimum surface roughness is achieved at a heat flux density of 7.79 kW·m$^{-2}$ and an interelectrode distance of 2.83 mm.

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