Justification of the choice of the optimal design of equipment for electrolyte-plasma polishing

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Abstract. The article proposes a method of complex comparison of equipment for electrolyte-plasma polishing of surfaces. The Harrington function is used to evaluate the equipment. The values of the function are limited by the numerical interval 0.2 - 0.8. The parameters of the equipment are selected as the evaluation parameters: maximum polishing area per cycle, productivity, power, area occupied by the installation, cost. As a result of a comprehensive assessment, the best type of equipment for electrolyte-plasma polishing, which provides a resource-saving and energy-saving mode of operation was selected. A computer program has been developed with the help of which a generalized evaluation parameter has been calculated and a comparative analysis of the equipment has been performed.

1. Introduction

The aim of the study is to substantiate the choice of the best design of equipment for electrolyte-plasma polishing using the upgraded Harrington function.

Polishing of metals and alloys by the electrolyte-plasma method is an effective technological process that saves resources used and has high environmental and economic parameters. Relatively new high-performance and environmentally friendly technology allows processing products made of stainless and carbon steels, copper and aluminum alloys, brass, zinc, titanium, silicon in aqueous solutions of salts. This technology of material processing has a sufficient number of advantages compared to traditional electrochemical polishing in acid solutions having a high concentration. In addition to saving material and financial resources and high productivity, the electrolyte-plasma polishing method has the best technical characteristics and allows getting a high quality of the processed surface: product processing speed, surface cleanliness class, absence of abrasive particles introduction, degreasing of the surface.

Many research papers have been shown the study of plasma methods of material processing [1-8]. Plasma polishing of metals and alloys can be carried out using an atmospheric pressure gas discharge with a liquid electrode [9-10].

2. Materials and methods

A generalized criterion of complex evaluation calculated using Harrington functions was adopted as a criterion for evaluating the best type of equipment for electrolyte-plasma polishing [11].

\[
D_i = \sqrt{\prod_j d_{ij}^{bj}} \rightarrow 1.0.
\]
Here $D_i$ – generalized parameter of integrated assessment $i$-th of the equipment; $d_{ij}$ – desirability of each $j$-th evaluation parameter of the $i$-th equipment; $n$ – number of equipment under consideration; $k_j$ – value coefficient of each $j$-th parameter.

The parameters that determine the choice of equipment are shown in the table 1. The Harrington function is modernized in the form of equation (2) and presented as a graph (figure 1)

$$d(y') = e^{-e^{-(y'-2)_1}}.$$  

Here $d(y')$ – a function that determines the significance of each evaluation parameter.

The natural values of the evaluation parameters are converted into dimensionless quantities according to formulas (3) - (7).

For maximum polishing area in one cycle ($S_{\text{max}}, \text{cm}^2$)

$$y'_1 = 0.0021x_{1,j} + 0.461.$$  

For productivity ($P_r, \text{m}^2/\text{h}$)

$$y'_2 = 0.068x_{2,j} + 0.05.$$  

For equipment capacity ($P, \text{kW}$)

$$y'_3 = 0.1228x_{3,j} - 2.0676.$$  

For the area occupied by the equipment ($S_{\text{in}}, \text{m}^2$)

$$y'_4 = -0.275x_{4,j} + 4.39.$$  

For cost ($C, \text{€}$)

$$y'_5 = -2.43x_{5,j} + 4.17.$$  

Table 1. Estimated $j$-th parameters of devices under consideration.

| Type of equipment ($i$) | Model of equipment | $S_{\text{max}}, \text{cm}^2$ | $P_r, \text{m}^2/\text{h}$ | $P, \text{kW}$ | $S_{\text{in}}, \text{m}^2$ | $C, \text{€}$ |
|------------------------|--------------------|------------------------------|----------------------------|---------------|----------------|-------------|
| 1                      | EPP-1000/2000      | 40000                        | 8.0                        | 2000          | 34             | 43400       |
| 2                      | EPP-400/500        | 10000                        | 4.2                        | 500           | 18             | 20000       |
| 3                      | PlasmaC-III        | 4000                         | 3.2                        | 250           | 15             | 28900       |
| 4                      | PlasmaC-V          | 20000                        | 6.0                        | 800           | 32             | 50500       |
| 5                      | UPP-630            | 11000                        | 4.6                        | 630           | 16             | 22500       |

The criteria for evaluating devices are given in tables 1 and 2. After finding the desirability functions $d(y')$ we calculate the generalized criterion $D_i$.  

The weighting factor

| Weighting factor | 0.3 | 0.3 | 0.1 | 0.1 | 0.2 |
3. Results and discussion

The results of the quality analysis of compared devices are presented in tables 2 and 3.

### Table 2. Desirability function of equipment evaluation parameters

| n  | Model of equipment | Desirability function of evaluation parameters | Generalized criterion of integrated assessment |
|----|--------------------|-----------------------------------------------|-----------------------------------------------|
|    |                    | $S_{\text{max}}, \text{cm}^2$ | $P_r, \text{m}^2/\text{h}$ | $P, \text{kW}$ | $S_{\text{in}}, \text{m}^2$ | $C, \text{€}$ | $D_i$ | $D_i^k$ |
| 1  | EPP-1000/2000      | 0.8                                        | 0.8                                         | 0.8                                         | 0.2                                        | 0.388                                        | 0.525                                        | 0.899                                        |
| 2  | EPP-400/500        | 0.388                                      | 0.364                                       | 0.253                                       | 0.708                                       | 0.8                                         | 0.458                                        | 0.881                                        |
| 3  | PlasmaC-III        | 0.2                                        | 0.2                                         | 0.2                                         | 0.8                                         | 0.708                                       | 0.331                                        | 0.785                                        |
| 4  | PlasmaC-V          | 0.512                                      | 0.575                                       | 0.427                                       | 0.308                                       | 0.2                                         | 0.36                                         | 0.838                                        |
| 5  | UPP-630            | 0.4                                        | 0.486                                       | 0.392                                       | 0.650                                       | 0.788                                       | 0.523                                        | 0.873                                        |

The equipment of the following models was studied: EPP-1000/2000, EPP-400/500, PlasmaC-III, PlasmaC-V, UPP-630. The devices differ in basic parameters. The comparison of equipment was made according to the estimated parameters shown in table 1.

As follows from the data in Table 2, the following devices correspond to the best (maximum) value of the desirability function (0.8) according to one of the parameters:
- according to the maximum polishing area in one cycle, productivity and capacity - the device of the EPP-1000/2000 model;
- by the area occupied by the equipment - PlasmaC-III;
- by cost – EPP-400/500.
Bat the same time, the Plasma C-III device has a low desirability (0.2) in terms of maximum polishing area per cycle, performance and capacity. The same (low) desirability value has the EPP-1000/2000 device in terms of the area occupied by the equipment and PlasmaC-V in terms of cost. These results of the research do not make it possible to form final conclusions about the preference of the particular equipment. The evaluation method using the upgraded Harrington function can be used to make a preliminary decision on the choice of equipment. Table 3 contains calculated data on the generalized evaluation criterion, taking into account the weighting factor $k_j$ and without taking it into account.

**Table 3. Generalized criteria for a comprehensive assessment of equipment.**

| № | Models of compared machines | Generalized estimated parameters | Taking into account the rounding |
|---|-----------------------------|---------------------------------|---------------------------------|
|   |                             | Without taking into account the weighting factor, $D_i$ | With taking into account the weighting factor, $D_i^k$ |                                  |
| 1 | EPP-1000/2000              | 0.525                           | 0.899                           | 0,9                              |
| 2 | EPP-400/500                | 0.458                           | 0.881                           | 0,9                              |
| 3 | PlasmaC-III                | 0.331                           | 0.785                           | 0,8                              |
| 4 | PlasmaC-V                  | 0.36                            | 0.838                           | 0,8                              |
| 5 | UPP-630                    | 0.523                           | 0.873                           | 0,9                              |

According to the results of the analysis of table 2, it becomes obvious that the UPP-630 machine does not occupy a leading position in terms of such parameters as the maximum polishing area per cycle, productivity and capacity from the point of view of desirability. But the relatively low cost and the occupied area contributed to the fact that the generalized criterion $D_i$ of a comprehensive assessment of the UPP-630 device differs from the EPP-1000/2000 by only 0.002.

It should be noted that the installation parameters according to table 1 are divided into two groups as shown in figure 1. Parameter group A: maximum polishing area per cycle $S_{max}$, cm$^2$; productivity, $P_r$, m$^2$/h; installation capacity $P$, kW – should have as much value as possible. Parameter group A': the area occupied by the installation $S_{in}$, m$^2$ and the cost $C$, € - should be as small as possible. According to the results of the calculation of the generalized desirability function $D_i^k$, which takes into account the degree of desirability of each of the parameters in the range from 0 to 1.0, the installations received the greatest preference: EPP-1000/2000, EPP-400/500 and UPP-630.

4. Conclusions

The proposed evaluation method allows an objective approach to solving the problem of choosing the best design of equipment for electrolyte-plasma polishing using the upgraded Harrington function in the range of desirability of the $j$-th evaluation parameters 0.2 - 0.8. Five evaluation parameters of installations with their own scales of permissible values of these parameters have been identified. The dependences of the transmission of the natural values of the selected evaluation parameters into dimensionless ones on the scale $y'$, which are used to calculate the desirability function in dimensionless quantities and the generalized criterion of complex evaluation, are determined. A necessary condition for an objective assessment of the quality of the compared machines is the same test conditions (temperature regime, single set of processed products, etc.). Calculations have shown that the application of the weighting factor of the compared parameters leads to smoothing the difference in the values of the generalized equipment evaluation criterion.
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