Application of the Harrington function in substantiating the choice of the best equipment for plasma processing of materials

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Abstract. The possibility of using the Harrington desirability function in choosing the most suitable equipment for plasma processing of materials is confirmed. The search for the optimal variant was carried out by calculating the maximum value of the generalized index of desirability. Four types of equipment for plasma cutting of metal are considered. A comparative analysis was carried out on the following indicators: the cost of equipment and technological cutting speeds for low carbon steel, stainless steel, and aluminum. An example of choosing the best equipment from an alternative series is considered. A system of four scales of partial evaluation indicators was used. Graphical and analytical evaluation methods are presented. The value of the generalized desirability index equal to 0.65 corresponds to the optimal variant of equipment for plasma cutting of metal.

1. Introduction
At present, to accelerate scientific and technological progress, new innovative approaches to increasing the technological level of production processes and creating machines with the best technical and economic indicators play an important role. But for scientifically based decision making on the choice of technological equipment, objective and reliable research methods are needed. It should be noted that growth in the productivity of new equipment is not always accompanied by adequate reduction in production costs. There is a need to develop new evaluation methods when choosing a final decision when choosing a particular machine or technology. In the study of high-tech equipment, a comprehensive assessment of the determining parameters should be carried out and only according to this indicator should preference be given to the best option. The purpose of the article is to show the possibility of using the Harrington desirability function [1] for objective decision making on the example of a comparative analysis of the parameters of metal plasma cutting. The advantage of the proposed approach is a comprehensive assessment of the advantages of the selected machine according to a complex (generalized) indicator. At the same time, the technological, economic, environmental and other parameters of the equipment should be considered in a comprehensive way.

2. Materials and methods
To make a decision about the choice of the best technique option from an alternative series, a complex assessment method is used according to the generalized index $D_o$, which takes into account the influence of many private assessment indicators with their own units of measurement. In the special literature [2],...
there are known methods for complex assessment of systems with many parameters that have different dimensions or without them at all using the desirability function [3], the values of which are in the range of zero to one (figure 1)

\[ d_{ij} = \exp\{-\exp[-y']\}, \]  

(1)

where \( d_{ij} \) – is the desirability function for the \( i \) option and the \( j \) evaluation indicator; \( y' \) – is a dimensionless quantity, as a rule, linearly related to the optimization parameter.

When performing calculations, it is customary to consider the lower level of desirability (not very desirable), equal to 0.2, and the upper level (excellent), equal to 0.8, to be acceptable. There is a known method for converting estimated dimensional parameters \( X_{ij} \) into dimensionless scale values \( y' \) using reference lines [4-8] and an analytical method, in the case of a large number of parameters.

Dimensionless evaluation indicators must be positive, so formula (1) should be reduced to the form

\[ d_{ij} = \exp\{-\exp[-(y'-2)]\}. \]  

(2)

Consider a graphical method for converting dimensional parameters \( X_{ij} \) into a dimensionless desirability value \( d \). To do this, it is necessary to plot the function, formula (2) - figure 2. On the graph, points A and B mark the limit values corresponding to the desirability of 0.2 and 0.8. On the scale \( y' \) they correspond to the values \( y'_A \) and \( y'_B \). To translate the dimensional parameters of a “direct” relationship (the larger the parameter value, the higher the desirability - for example, technological cutting speed, unit productivity, etc.), it is necessary to build an additional scale \( X_1 \) of the same direction under the scale \( y' \) – index 5. Its scale will be determined after the minimum and maximum values of this parameter are fixed on this scale - the points \( x_{\text{min}} \) and \( x_{\text{max}} \), which determine the value of the desirability function 0.2 and 0.8, respectively.

![Figure 1. Harrington function graph.](image-url)
Knowing the scale range, it is easy to put on it the current value of this parameter - the $X_c$ point. Having restored the perpendicular from this point to the intersection with the curve of the graph, it is necessary to draw a straight line through the intersection point $C^S$ and on the scale $d$ find the desired value of the dimensionless desirability $d_c^S$.

When translating the dimensional parameters of the “inverse” relationship (the larger the parameter, the lower the desirability; for example, the cost of equipment, the cost of consumed electricity, etc.), an additional $X_2$ scale is built inversely to the $X_1$, index $O$.

The method to convert a dimensional parameter into a dimensionless quantity $d_c$ has a similar algorithm.

As can be seen, the graphical method is clear, simple, and laborious.

The analytical method of converting the numerical value of any parameter of any dimension into a dimensionless desirability value allows one to solve the problem without constructing a graph of the function.

![Figure 2. Desirability function graph $d_{ij}$.](image)

To do this, it is necessary to determine the scale of conversion of the dimensional parameter to the scale $x$ of the graph - figure 1. It can be seen from the figure that it is equal to

$$M = \frac{x_{\text{max}} - x_{\text{min}}}{x_A - x_B},$$

where $M$ – translation scale; $x_{\text{max}}, x_{\text{min}}$ – limiting dimensional values of the translated parameter.

To convert the actual value of the dimensional parameter into a code value corresponding to the $y'$ scale of figure 1, we need to use the equations

$$x_c^s = x_A + \frac{x_{ci} - x_{i\text{min}}}{M}. \tag{4}$$

For the "reverse" dependence

$$x_c^o = x_A + \frac{x_{i\text{max}} - x_{ci}}{M}. \tag{5}$$
4

Here $x_C$, $x_C''$ – code value of the dimensional parameter in the scale range, $X$; $x_{Ci}$ – the current value of the $i$-dimension parameter.

By substituting the code value of the dimensional parameter into formula (4) or (5), one can determine the dimensionless numerical indicator of its effectiveness.

The generalized indicator of the efficiency of an individual machine or a system of machines can be determined by the following formula

$$D_i = \sqrt[n]{\prod_{j} d_{ij}} \rightarrow 1.0,$$

(6)

where $D_i$ – is a generalized performance indicator of each $i$ option; $d_{ij}$ – a private indicator of the desirability of the $j$-indicator of the assessment according to the $i$-variant; $n$ – number of indicators $j$.

3. Results and discussion

Table 1 shows the results of the calculations that were performed to select the optimal plasma cutting model.

| №   | Device Model | Equipment cost, $C_o$, € | Technological cutting speed, $v_1$, mm/min | Technological cutting speed, $v_2$, mm/min | Technological cutting speed, $v_3$, mm/min | Generalized index $D_i$ |
|-----|--------------|--------------------------|------------------------------------------|------------------------------------------|------------------------------------------|--------------------------|
| 1   | Powermax45   | 2 402                    | 400                                      | 540                                      | 745                                      | 0.41                     |
| 2   | Powermax65   | 2 774                    | 1140                                     | 920                                      | 1330                                     | 0.25                     |
| 3   | Powermax85   | 3 934                    | 1600                                     | 1400                                     | 1930                                     | 0.65                     |
| 4   | Powermax105  | 5 550                    | 2060                                     | 1860                                     | 2450                                     | 0.60                     |

The results of the calculation of the complex assessment indicator $D_i$ (table 1) showed the following: the best desirability (0.65) corresponds to device number 3. This was facilitated by the relatively low cost of equipment and high technological indicators.

Figure 3 shows a graph of desirability functions and their application to evaluate the devices compared and select the best option.

The points $B$ and $B'$, $C$ and $C'$ indicate the limiting values of the parameters studied of machines corresponding to the desirability 0.2 and 0.8, which on the scale $y'$ correspond to the values $y''_B$ and $y''_C$. To translate the dimensional parameters of the “direct” dependence $S$ (the higher the parameter value, the higher the desirability, for example, the productivity of the installation, etc.), it is necessary to build an additional scale $X_i$ under the scale $y'$ with the same direction $S$ (figure 2). Its scale will be determined after the maximum and minimum value of this parameter are fixed on this scale, satisfying the desirability of 0.2 and 0.8, respectively.

Knowing the scale of the range group $A$, it is not difficult to postpone the current value of this parameter to them. From these points $x_j$ the perpendiculars to the graph of the function $d_j(y')$ were reconstructed using the straight $BC$ or $B'C'$ and the values of $d_j$ were found.
Figure 3. Harrington's upgraded desirability function with forward and backward scale $B'C'$.  

When translating the dimensional parameters of the “inverse” dependence (the larger the parameter, the lower the desirability: for example, installation cost, electricity consumption, etc.), an additional scale 2 is built in the opposite direction to the scale $y'$, index $O$ (figure 2).

The scale range and the method for converting a dimensional parameter into a dimensionless quantity $d$ have a similar algorithm.

Thus, the proposed method for a comprehensive assessment of equipment, systems, or technologies is as follows:

1) using well-known methods, it is necessary to determine the largest possible number of factors affecting the system and establish the boundaries (limits) of their changes (for example: productivity, labor costs, fuel, energy, metal consumption, unit cost, serviceability, etc.);

2) after establishing (by calculation, measurements, according to reference data, etc.) the actual values of the parameter(s) (factors), determine the performance indicators (desirability) of each parameter in a graphical or analytical way;

3) determine the result criterion $D_i$;

4) analyze the $D_i$ values and make a conclusion on the most optimal option. The highest value of $D_i$, approaching one, determines the best option.

4. Conclusions

As a result of the research, the Harrington function was found to be an effective means of analysis when choosing the most preferred equipment for plasma cutting of metal. The use of a system of four partial evaluation indicators is substantiated when choosing the best equipment from alternative options according to the resulting indicator $D_i$. Reliable dependencies were obtained for converting values from natural to dimensionless (scale $y'$). The desirability $d_i$ of each particular indicator and the generalized criterion $D_i$ are calculated. As a result of the application of the Harrington function, it was found that the
highest value of the generalized indicator $D_i$ corresponds to the POWERMAX 85 plasma cutting machine.

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