

METHOD FOR SOLVING MULTIPLE CRITERIA DECISION MAKING (MCDM) PROBLEMS IN BUILDING-UP BY WELDING AREA

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Abstract: In this paper a method for solving nonlinear MCDM problems is presented. Its philosophy arises from the internal nature of application problems that we solve by using such MCDM model, namely, to solve problems for building-up by welding. This method is a non-interactive a priori method. The paper also presents the approach developed to determine the quantity of mechanical processing of plane-loaded layers under the conditions of electric arc welding in a gas mixture. The methods were applied after the experimental investigation and elaboration of regression dependencies of the surface geometry welded by electrode wire providing big stiffness and difficult mechanical processing.

Keywords: MCDM, BUILDING-UP BY WELDING, WELDING REGIMES OF HIGH PRODUCTIVITY

1. Introduction

It is a substantial problem in transport machine building and especially in the repair production to know the operational resource and the lifetime of parts facing. The resource depends on the chemical composition of building-up of welded metal and also on the type of its subsequent processing. The choice of one or another processing technology depends on the form and the size of the details and it determines the structure of the technological route.

The technological elaboration starts with the definition of the determined set of properties for the surface of the detail belonging to restoration. Strengthened layers that are the object of exploration are hard to process after building-up by welding. For this reason it is necessary to optimize technological mode parameters in such way that to create prerequisites for a minimal subsequent mechanical processing.

The practice of repair-restoration operates with a big variety of details that belong to facing reconstruction. Structural characteristics of the details and the models substantially influence the choice of methodology of reconstruction and testing the layers' properties.

It is defined in [1] that rotational details for two of the examined machines occupy more than 70% of the whole quantity of details. This is the reason that a part of the basic research is oriented at details with a form symmetrical to the axis.

The objective surface for restoration is determined by:

- dimensions (diameter, length and area);
- hardness, type and depth of strengthening;
- precision and roughness;
- oval-shape and coneshaped;
- form and building-up thickness;
- loading and wearing out.

The type of the basic metal for the reconstructed parts is examined by G.Tontchev in [1]. It is demonstrated that the share of the group of low-alloyed and carbon constructional steels is almost equal (about 40%). The following more important conclusions are defined in the exhaustive statistical research in [1]:

- the reconstruction diameters are in the 10÷90 mm range and the bigger percentage of details for restoration are in the 25÷45 mm range;
- more than 20% of the whole amount of reconstruction details use as a base/core C 20 and more than 45% use C 45 with respect to the percentage of carbon in the steel;
- 30% is the share of restored details with a subsequent thermal processing – cementation of the working area and more than 44% is thermal processing – surface tempered by a high-frequency current;
- 50% of the reconstructed details are set to a dynamic loading;
- about 20% of the details have a boundary of admissible wearing out in the range of 1,4÷1,8 mm;

- more than 25% of the details are set to an abrasive wearing out.

A typical pattern is chosen based on the mean values from the drawn conclusions, as a value of the diameter and the percentage of carbon in the basic metal.

Electric arc welding in a protective atmosphere of gas mixtures is one of the most widely included methods to restore worn out details. Its advantages are the high productivity, the simplicity of the technological process, the accessibility of equipment and the possibility for automation [4].

The welding with a tubular wire electrode with flux in a protective atmosphere of gas mixtures is one of the perspective methods with a wide productivity and a big economic effectiveness. One of its main advantages is that it is possible to obtain a welded metal with precisely defined qualities assisted by alloy elements in the wire core; this is difficult to obtain by welding with electrode wire. The composition of the tubular wire includes besides alloy elements also gas-producing and slag-forming components which ensure the protection of the arc and also the correct development of physical-chemical processes in the welding zone.

The main indicators that influence the geometry and the structure of the joint are the current, the voltage and the welding speed. These indicators are an object of technological design during the process of creating a specific technology.

The basic problem in the process of design, control and planning of functioning engineering systems is the determination of the system structure, the material and power balances, the dimensionality of the equipment, the controlling variables in normal and emergency modes of system operation and also of production planning for short-term / long-term exploitation – [2], [3]. The solution of this problem must be found under the restrictions of different requirements postulated by economic (minimization of material and power consumption, maximization the profit from the production), technical (minimization of the equipment size), ecological (minimal pollution of the environment by a specific waste product) and other specifications. It is evident that the requirements cannot be satisfied as a whole but a reasonable compromise is a solution of the problem. In fact this is a multicriteria model for solving such problems.

This reasoning can be denoted as it follows:

$$\max_x f(x) = (f_1(x), \dots, f_k(x)) \quad (1)$$

where x is an n -dimensional vector of the variables (alternatives) of the solution and $f(x)$ is a k -dimensional vector of the criteria (objective functions). We admit that the variables x_i are continuous for the set of admissible solutions.

The set of the admissible solutions is defined as it follows:

$$X = \{x \mid g_j(x) \geq 0, j = 1, 2, \dots, m; x \in R^n\} \quad (2)$$

where $g_j(x)$ are the functional constraints imposed by the multicriteria problem.

From an engineering and technological standpoint the criteria forming the problem (1) are very often loaded by a different physical meaning. For this reason it is necessary to normalize the physical criteria in dimensionless criteria. The normalization is realized introducing and using special dimensionless functions known as transforms (transforming coefficients). It is typical for these transformations that they include the option of interactivity to the solution of the MCDM problems. This is possible in accordance with the way of their generation. The next stage is finding a solution of the problem (1). Most often this takes place by a single-criteria (scaling) problem. The optimal solution of the scaling problem is a non-dominating problem solution (1) satisfying the DM most of all consistently with some additional conditions (criteria). There are several basic types of transforms in bibliography. Below we present an example with some of them.

In the transformation for an optimistic decision the DM initially defines optimistic (his best) values y_{jopt} for the object functions that cannot be obtained simultaneously: the process continues with a gradual decrease of the optimistic values.

An opposite approach is the so called 'pessimistic' approach. In this case the DM defines values for the object functions known as 'necessary' – y_j^{pes} that can be reached simultaneously. The decision is obtained by maximization of the excess for every object function in accordance with the necessary values. Once he/she has obtained a concrete decision, the DM can define other necessary values.

2. The proposed method

The aim of this paper is to propose an approach for solving the above MCDM model that comes from solving a number of technological problems from the area of building-up by welding – [2].

The main idea of method is to use a simple and effective tool for solving SC problem to present non-dominated solutions to the DM. For this purpose we use graphical method on the base of limits, given in advance by the DM. The DM can change them in the time until acceptable solution is located for the scalarising (SC) problem.

The general scheme of approach can be presented as follows:

1) Generating a MCDM model.

For this purpose for example regression models can be used. The result of first step is nonlinear multiple objective programming problem. It could include some or all discrete or integer variables.

2) Discretization of a feasible set.

For example if we use the interval $[-1, 1]$ it is recommended the step to be 0.25 for the technological problems.

3) Implementing an MCDM strategy (method) - scalarization function that combine heuristic rule and transformation property and interaction with the Decision Maker (DM).
In the points 2.1 and 2.2 we describe two MCDM methods.

4) Implementing graphical approach (two-way joining result) for solving the chosen scalarizing problem.
This method is presented in the following below part of the paper.

In this method the DM gives his/her preferences in terms of reservation levels in the objective space – f^r . In other words every solution with values greater than or equal to these levels (thresholds) is acceptable and vice versa. For each objective function a number of levels are defined. For example we use the interval $[0, 100]$ where the values of transformed objectives get. It can be divided into 6 portions by 5 levels – say 10, 35, 50, 65, 80. The sense of each level is acceptability of the solution by the DM with 10%, 35% etc. These levels can be changed during the process of solving and their number also can be decreased up to one or vice

versa. In our computer realization the maximal number of levels is limited up to 5. The reason is that the maximal number of values for easy and comfortable evaluation does not exceed 7 or 8.

The following SC problems are used:

a) linear filter - mean arithmetic:

$$l(x) = \sum_{i=1}^k \frac{f_i(x) + \dots + f_k(x)}{k} \quad (3)$$

b) mean geometrical

$$g(x) = \sqrt[k]{f_1(x) \dots f_k(x)} \quad (4)$$

c) max-min filter

$$m(x) = \min_{i=1, \dots, k} \{f_i(x)\} \quad (5)$$

Each of these filters is maximized over the feasible discrete set in the following way.

On the base of given set of levels for each objective a two-way joining results are plotted with corresponding color defined in advance.

The DM moves these limits along the scale and in this way he filters the visualized multi-dimensional spaces and focuses precisely on the decisions, which he/she is interested in.

In other words a graphical solution of one of the above filters is performed on the base of two-way joining results approach.

It is known that the solutions of linear, geometrical and max-min filter are efficient points.

For example we shall prove the result for max-min filter.

Proof:

The SC problem is: $\max_x m(x)$

Let us assume that x^* is an optimal solution and that it is not an efficient solution. Then another point x'' exists such that $f(x'') \geq f(x^*)$ and for at least one index strong inequality holds. Then $m(x'') \geq m(x^*)$ and this is in contradiction with the optimality of x^* .

Δ

Note that different filters produce different efficient points depending on the properties of the problem solved.

The algorithm of an apriori method can be summarized as follows:

Step1: Perform discretization of the feasible set.

Step2: Select number and values of limits for each objective

Step3: Select type of filter.

Step4: Solve the SC problem with chosen filter as objective function and by using two-way joining results.

Step5. Evaluate the received efficient solution. If it is satisfactory – stop. If not, start the procedure again.

Remarks:

1) In step 4 the DM locates the efficient point that is optimal solution of a filter by moving the limits and possibly changing their number.

2) In our realization the maximal number of levels for each objective is up to 5 and can be reduced up to 1.

3) As it is seen this approach is non-interactive. Its advantage is the simplicity and the new way of geometrical solving of scalarising problem.

4) When the number of decision variables is greater than 2, two-way joining result approach includes the next variables.

5) Current limitations of the proposed approach are that the number of decision variables has not to be too large. Also the number of levels is recommendable to be approximately no more than 5. :

3. The Building-up by Welding of Rotational Surfaces

The application of the proposed method for rotational building-up by welding possesses the following specifics.

An experiment was performed with variations of the control parameters shown in Table 1.

Table 1. Values of control factors building-up by welding for rotational surfaces

Levels	Control factors		
	X ₁ Current [A]	X ₂ Voltage [V]	X ₃ Step of overlapping [mm]
Lower boundary (-1)	150	19	2
Basic level (0)	180	21	3
Upper boundary (+1)	210	23	4
Step of changing	30	2	1

A defined plan for the experiment is fulfilled and adequate regression models are derived determined defining the examined values.

Each of the investigated values is scanned. Scanning is fulfilled in the range [-1;1] with a determined step for the calculation. A 4-dimensional space is examined formed by the three varying (research) controlling parameters and also by the investigated value. The following way of discretization of I, U, s is proposed.

The determined values of the examined quantity form a concrete array (YM) with a respective (defined) discretization. YM max and YM min are determined solving the optimization problem.

The values of the determined investigated value are transformed in an even percentage distribution. The transform is realized via the equation: $Y\% = (YM - YM_{min}) / (YM_{max} - YM_{min}) \cdot 100$

		X ₃					X ₂					X ₁				
		-1	-0,5	0	0,5	1			...			-1	-0,5	0	0,5	1
-1,00	-1															
	0															
	1															
	-1															
	0															
-0,67	-1															
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Fig. 1 Discretization scheme of three values for the parameter X₃.

The problem for analysis is realized via chromatic ranking of discretization cells from the definition area. It is possible to cover the whole research area using the "quadrant" tool (big and small). The intervals of separate colors of the ranking itself direct the decision maker (DM) towards the preferred values of the investigated quantity. The chosen quantity is determined as an even percentage distribution. It is possible to determine for it the real value of the examined quantity in the respective dimension and the concrete combination of factors from the technological mode.

A filter (generalized function) is constructed that contains information for all research criteria according to a definite arrangement.

Filters may be:

- min-max (pessimistic). The least percentage of all compared for the discrete value criteria is written in the generalized function.
- mean average. The mean arithmetic value of all analyzed criteria is written in the cell for the generalized function.
- mean geometric – the mean geometric value.

Each of the filters determines an effective non-dominated solution of the multicriteria problem.

Calculations are realized with the values of the even percentage distribution.

Ranks in the respective generalized function are defined via the interval approach. Again using a suitable coloring that is related to a definite interval the DM is assisted to choose the appropriate value related to his (hers) definite preferences.

The approach is developed via a combined problem for analysis and multicriteria optimization that are applied to applying electrode materials – LMN 420 and Fluxofil 58. A study of the influence from the welding mode parameters over the amount of the subsequent mechanical processing is performed.

The application of the multicriteria approach in the domain of building-up by welding may be realized after the definition of the multicriteria problem. The definition includes formulating the criteria depending on the mode parameters and defining the compromise of desired values from these criteria.

Control factors from Table 1 influence the geometric characteristics of the surface. The graphic interpretation of this is shown in Fig.2, where the amount of mechanical processing differs significantly for the depicted images.

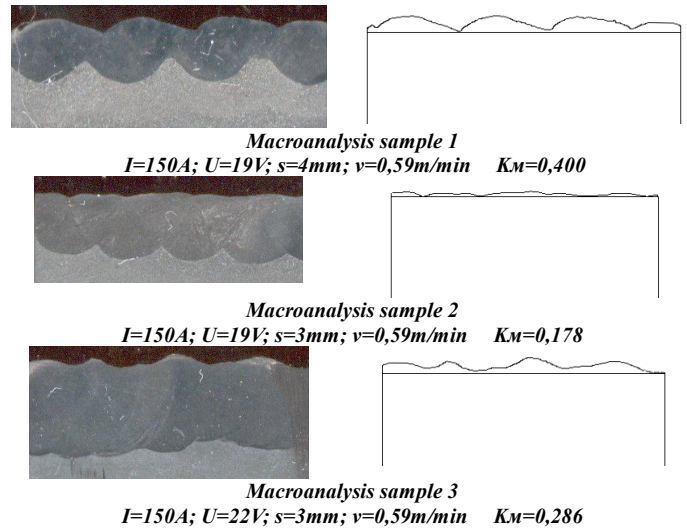


Fig. 2 Graphic interpretation of the amount of mechanical processing depending on the controlling factors.

The plain through the lowest hollow that is parallel to the central cut determines the amount of mechanical processing. As it is evident from the additional processing of the figures (to the right) this amount differs significantly and it is possible to be optimized. It is accepted that the amount of mechanical processing is reported via the coefficient of relative mechanical processing K_M.

This quantity is the criterion that must be defined and optimized.

A macroanalysis sample is produced for each performed mode. It possesses a displayed profile of the welded surface with a determined length. The macroanalysis samples are shot with an equal magnification and the shot is processed digitally to obtain an image corresponding to the profile of the built-up by welding

surface. A tangent plane is drawn through the lowest point of the profile that fixes the area of the fragment that will be removed.

The maximal value of the coefficient K_M is related to the maximal amount of mechanical processing and therefore preferable are technological modes that decrease K_M .

The application of the described in item 1 method leads to defining modes that ensure a better quality of the surface and guaranteeing less mechanical processing.

Besides the cited tubular wire Fluxofil 58 the research includes also the electrode material LNM 420FM (LINKOLN Co.) with a chemical composition C-0.45%; Mn-0.4%; Si-3%; Cr-9.5%.

We obtained the following regression models for the coefficient of relative mechanic processing K_M after a planned experiment and performed metallographic research for various electrode materials:

$$\begin{aligned} \text{For LNM 420 FM: } K_M(I, U, s) &= 0,269 - 0,023X_1 + 0,029X_2 - 0,042X_3 \\ &+ 0,067X_1 \cdot X_2 + 0,027X_2 \cdot X_3 + 0,081X_3^2 \\ \text{max } K_M &= 0,48 \quad (-1; -1; -1) \quad \text{min } K_M = 0,15 \quad (1; -1; 0) \\ \text{For FLUXOFIL 58: } K_M(I, U, s) &= 0,392 + 0,0089X_1 - 0,05X_2 + 0,097X_3 \\ &- 0,055X_2^2 - 0,102X_2 \cdot X_3 + 0,063X_3^2 \\ \text{max } K_M &= 0,658 \quad (1; -1; 1) \quad \text{min } K_M = 0,242 \quad (-1; -1; -1) \end{aligned}$$

The obtained results for $K_M\%$ for the introduced method from the pessimistic fiter for the two types of electrode material are shown in Fig.3.

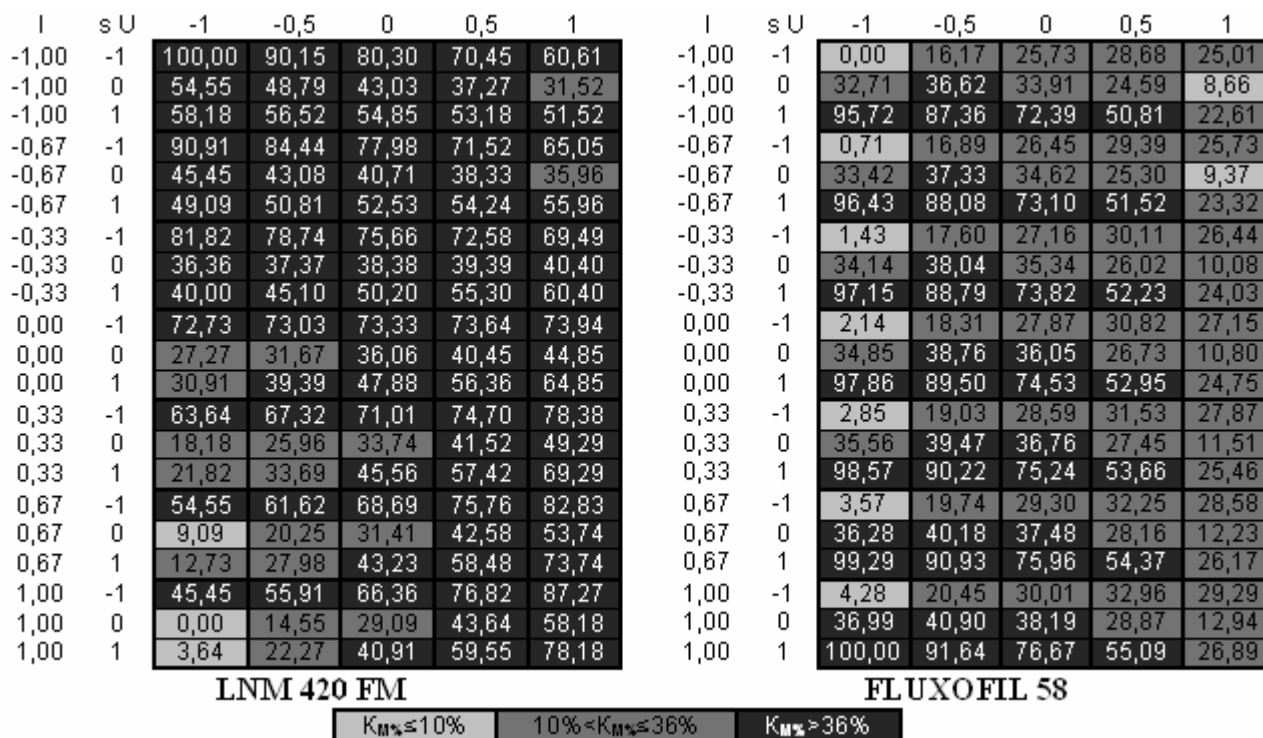


Fig. 3 Chromatic ranking the values from the relative coefficient of mechanical processing K_M of the examined electrode materials

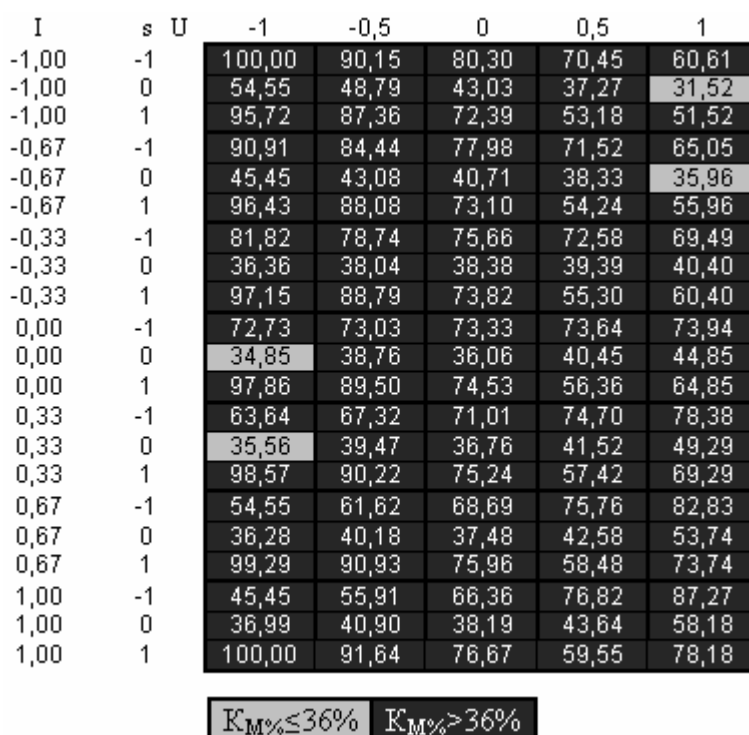


Fig. 4 Chromatic ranking for the influence of controlling factor over the relative coefficient of mechanical processing K_M

A generalized function is derived about the results from the multicriteria optimization: $F = \text{MAX}(K_{M\% \text{ LNM 420}}; K_{M\% \text{ FLUXOFIL 58}})$

The results from the multicriteria optimization up to 36% are presented at Fig.4 and the different modes – in Table 2.

Table 2. Solutions linking the relative minimal coefficients K_M together with the corresponding controlling parameters

X_1	I [A]	X_2	U [V]	X_3	s mm	LNM 420 FM		FLUXOFIL 58	
						$K_{M\%}$ [%]	K_M	$K_{M\%}$ [%]	K_M
-1	150	1	23	0	3	31,52	0,254	8,66	0,278
0	180	-1	19	0	3	27,27	0,24	34,85	0,387
-2/3	160	1	23	0	3	35,96	0,269	9,37	0,281
1/3	190	-1	19	0	3	18,18	0,21	35,56	0,39

4. Conclusion

A non-interactive a priori method for solving nonlinear MCDM problems is introduced. Its philosophy arises from the internal nature of application problems that we solve by using such MCDM model, namely, to solve problems for building-up by welding. The method is applied to determine solutions for reduction of the amount of mechanical processing after building-up by welding for productive technological modes of operation.

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