METHOD FOR ESTIMATION OF WELDING PROPERTIES OF POWER SOURCES FOR ARC WELDING

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Method for in-process monitoring of welding properties of power sources by their electric parameters using fuzzy logic algorithms was developed. Criteria for estimation of each indicator and an algorithm for obtaining a general estimate are proposed.

Keywords: *arc welding, power source, welding properties, method for estimation, fuzzy logic algorithms*

There is a necessity to monitor welding properties of the power sources during their production and process of operation. Today, the power sources are to fulfill the requirements of DSTU 60974–1 [1], in which a method for monitoring of welding properties is not indicated. Many enterprises still use the recommendations of GOST 25616 [2] which are based on indirect estimation of the power sources for manual arc and CO_2 welding by expert methods. Two high-qualified welders are recruited to perform that in accordance with the standard.

Differential method of monitoring is used for arc welding power sources in accordance with given standard and the following indicators of welding properties are estimated: initial arc ignition, stability of welding process, metal spattering, quality of weld formation and arc elasticity.

The indicator of welding properties of the power sources for CO_2 welding is estimated by reliability of establishing of welding process, metal loss and quality of weld formation.

There are methods based on simple calculations by overall indicator for objective decision-making which take into account contribution of each indicator [3–5]. Their disadvantage is caused by influence of human factor.

There is a possibility to determine parameters of all specified indicators on results of registration of energy parameters of the welding process, namely, welding current and voltage, without human assistance. Application of artificial intelligence systems, i.e. fuzzy logic algorithms, is one of the variants for solving the problems of influence of the human factor on estimation results.

Estimation of each quality indicator lies in referring it to one of the sets: «fulfill the requirements» or «do not fulfill the requirements». The fuzzy logic system allows estimating to which set a value of quality indicator refers as well as level of its membership in this set. For this, membership function $\mu A{:}X \to [0, 1]$ is used. It for each element x puts in correspondence figure $\mu A(x)$ from [0, 1] interval, where 0, 1 are the lowest and the highest level of membership of element in subset, respectively.

In general, a mechanism of logical conclusion (Figure 1) includes four stages [6]:

- introduction of fuzziness. Membership functions, determined on input variables, are applied to their true values for determining a degree of prerequisite validity of each rule;
- logic conclusion. Obtained value of validity for the prerequisites of each rule is applied to the conclusions of each rule;
- composition. Fuzzy subsets, specified for each conclusion variable (or one variable), are combined together for formation of one fuzzy subset;
- reduction to crispness (defuzziness).

This method is used when it is necessary to transfer from the fuzzy conclusion to crisp output value.

Initial arc ignition and reliability of establishing of MMA and MAG welding processes were estimated by amount of continuous short circuits or arc extinctions up to establishing of the stable mode. The initial ignition is considered unsatisfactory, if amount of short circuits or arc extinctions exceeds 5. Hence, a linear membership function (Figure 2, *a*) is taken, in

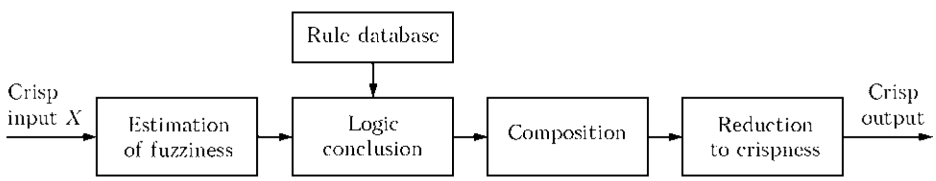

Figure 1. System of fuzzy logic conclusion

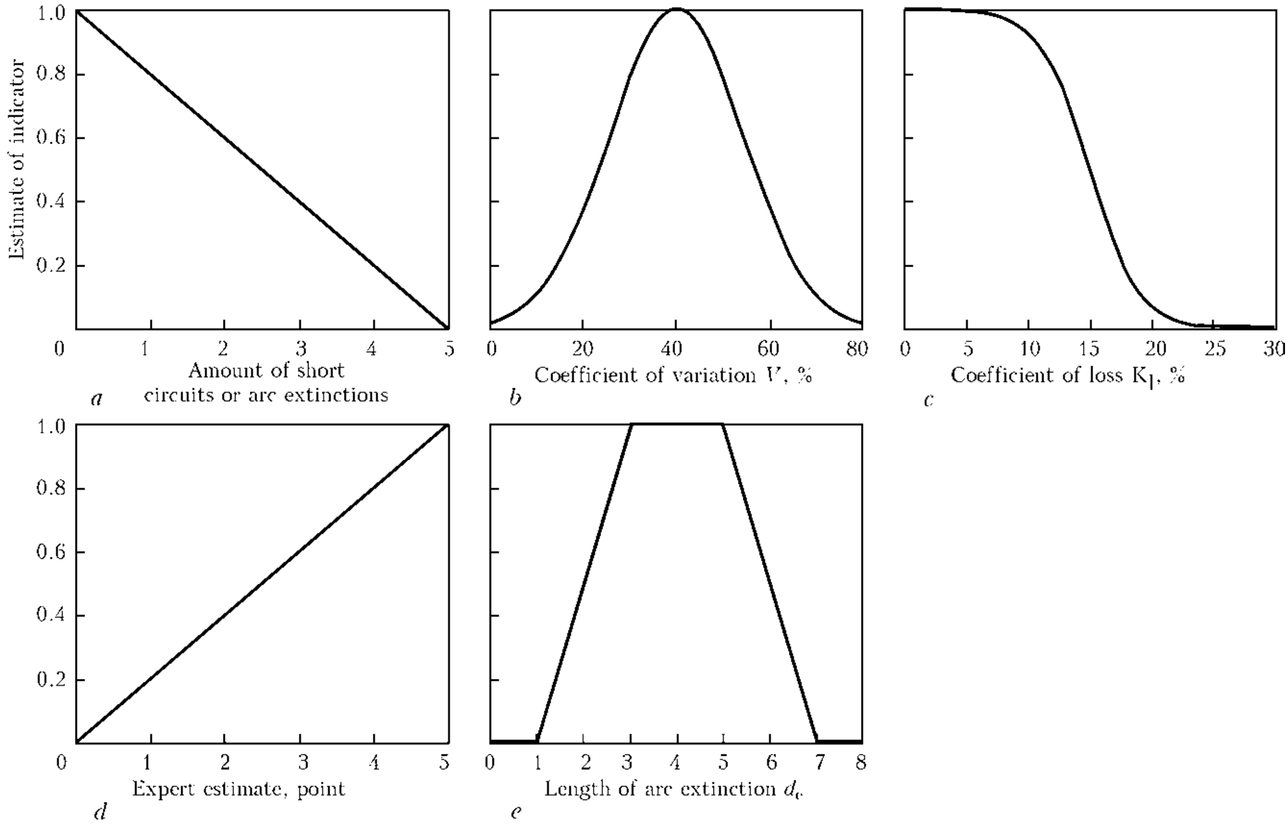

Figure 2. Membership function: *a* — initial arc ignition; *b* — stability of arcing; *c* — metal spattering; *d* — quality of weld formation; *e* — arc elasticity

which the maximum estimation corresponds with absence of short circuits or arc extinctions and the minimum if they make 5. Such a function follows the next equation:

$$\text{trim } f(x) = \max\left(\frac{5 - x}{5};\ 0\right),$$

where x is the amount of continuous short circuits or arc extinctions.

The amount of arc extinctions in the process of welding was estimated in the similar way.

The stability of MMA welding process is usually estimated by arc vibration and noise. They, in-turn, are generated by variations of electric parameters. Thus, noise and vibration of the arc can be estimated by deviations of electric parameters of the arc, namely, current and voltage. The deviation of parameters is characterized by their coefficient of variation (standard deviation to mathematical expectation ratio). The power source has an external dropping characteristic in manual arc welding. In this case, the coefficient of variation of arc voltage is good to be used for estimation of arcing stability. A value of coefficient of variation at stable welding process was determined experimentally. Welding of samples from low-carbon steel at different parameters of the power source by ANO-21 and UONI-13/45 electrodes was carried out. Stability of arcing was evaluated by expert estimation from welder. Dependence of coefficient of voltage variation on welding current was obtained for manual arc welding at stable arcing. Deviation from this value towards the lower or higher values means reduction of arcing stability. In this case, roof or Gaussian function of membership can be chosen. The roof function estimation is adequate only at significant deviations of input volue (coefficient of variation of welding voltage) from optimum value. In case of small deviations (up to 10 %), the estimation, obtained with the help of roof function, are to be low, that will result in reduction of accuracy of system operation in total. Therefore, Gaussian function of membership is taken. Its value equals 1 at optimum input value x for set mode (Figure 2, *b*). An equation of such a membership function for manual arc welding with 100 A current will be

$$\text{gaussm } f(x) = \exp\left(-\left(\frac{x - 40}{20}\right)^2\right),$$

where x is the coefficient of arc voltage variation.

Metal loss was estimated by furn-off loss and spattering coefficient K_l which is determined by formula

$$K_l = \left(1 - \frac{M_d}{M_m}\right) 100\ \%,$$

where M_d, M_m is the mass of deposited and molten electrode metal, respectively.

The coefficient of spattering up to 15 % [7] is considered to be acceptable in manual arc welding. A sigma function of membership (Figure 2, *c*) is built for specified quality indicator. Estimate 0.5 corresponds with input value x, equal 15 %. An equation of such a membership function is the following:

$$\mathrm{sigm}\, f(x) = \frac{1}{1 + \exp\,(0.5(x - 15))}.$$

The quality of weld formation was determined by appearance of a bead and its height to width ratio equal arithmetic mean of three measurements, carried out in the beginning, end and middle parts. The estimate is set by expert using points from 0 to 5, membership function is linear (Figure 2, d). An equation, describing this function, is

$$\mathrm{trim}\, f(x) = \max\left(\frac{x}{5};\ 0\right),$$

where x is the estimate of weld appearance in points.

The arc elasticity was estimated by its extinction length. Minimum satisfactory length of the arc is a length equal two diameters of the electrode. The length exceeding three diameters of the electrode [2] is considered to be a good result. However, too high arc elasticity prevents performance of normal welding in vertical and overhead positions. Therefore, it is reasonable to set an upper limit for normal arc length for extinction at the level of five diameters of the electrode (for general-purpose power sources, if no specific requirements to arc elasticity are set) [8]. The membership function is trapezoid (Figure 2, e) and is described by equation

$$\mathrm{trap}\, f(x) = \max\left(\min\left(\frac{x - 1}{2};\ 1;\ \frac{x - 7}{-2}\right);\ 0\right).$$

In general, a set of membership functions is determined by customer's requirements to welding properties of the power sources and their operation conditions.

Operation of the system is performed by Mamdani algorithm [6]. Weight coefficients of each input are set depending on power source requirements. For example, the indicators of initial ignition and arc elasticity are more significant for manual arc welding in vertical and overhead positions. At that, the weight coefficients of given inputs are higher than in the others. The weight coefficient is higher for «metal spattering» indicator etc. in welding of face surfaces or surfaces with corrosion-resistant coatings. If such additional requirements are not specified, then the weight coefficients of all inputs are selected equal 1.

«Cut off» levels for each input of the system are determined based on rulebase:

$$\text{«IF» } (\mathrm{Input}_1 - \mathrm{MF}_1) \text{ and } (\mathrm{Input}_2 - \mathrm{MF}_2) \text{ and}$$
$$\ldots\ (\mathrm{Input}_n - \mathrm{MF}_n) \text{ «THEN» } (\mathrm{Output} - \mathrm{MF}_{\mathrm{out}}),$$

where MF_1, ..., MF_n are the membership functions of system inputs; $\mathrm{MF}_{\mathrm{out}}$ is the membership function of system output.

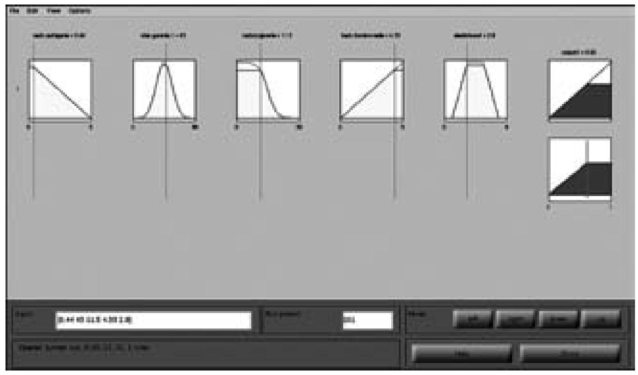

Figure 3. Fuzzy logic toolbox window with results of operation of system for estimation of welding properties

Further truncated functions of membership are determined. Joining of found truncated functions was performed using prod operation that results in obtaining of resultant fuzzy subset for output variable. Final stage is determining of crisp value of output variable by first maximum method. Membership function for output was assumed linear; 0 — when product of estimates of all outputs equal 0; 1 — when product equal 1. General estimate of all welding properties is determined as

$$\gamma = \prod_{n=1}^{N} x_n^{\varepsilon_n},$$

where N is the amount of indicators of welding properties; ε_n is the weight of n-th indicator; x_n is the value of estimate of each indicator.

As a result, the general estimate of welding properties of the power source which lies in the ranges [0, 1] (Figure 3) was obtained. The estimate is non-linear. The analysis showed that traditional estimate «excellent» corresponds with the value of general estimate in the range from 0.51 to 1, «good» — 0.28–0.50, «satisfactory» — 0.17–0.27 and «unsatisfactory» — 0–0.26. Construction of a system for estimation of welding properties was carried out in MatLab medium.

Table 1. Results of estimation of welding properties of «Fronius TPS 5000» power source by automated system

Parameter	Average value of parameter	Estimate by automated system
Initial arc ignition (amount of short circuits)	0.44	0.912
Stability of welding process (coefficient of voltage variation)	0.43	0.977
Metal spattering, %	11.5	0.852
Quality of weld formation (expert estimation)	4.33	0.866
Arc elasticity (diameter of electrode)	2.9	0.95
General estimate		0.62 (excellent)

Table 2. Comparison of results of estimation of welding properties (average values of indicators on results of deposition of several beads)

Parameter	Estimation by automated system	Average estimate of welder 1	Average estimate of welder 2
Initial arc ignition	4.6	4.5	5.0
Stability of welding process	4.9	4.0	4.0
Metal spattering	4.3	4.4	4.7
Quality of weld formation	4.3	4.1	4.0
Arc elasticity	4.8	4.7	4.6

Two methods were used for monitoring of system operation by comparison of results of estimation for «Fronius TPS 5000» inverter power source: in accordance with GOST 25616–83 standard, recruiting two high-qualified welders and using developed automated system. Estimation was carried out for the conditions of manual arc welding. Digital system for collection and recording of data was used for registration of welding current and voltage. It consists of current and voltage sensors based on Hall effect, analogue-to-digital transformer and PC. PowerGraph program was used for recording and analyzing of oscillograms.

As a result, the estimate of each welding property and general estimation by automated system were obtained (Table 1). Gathered data were transferred into a scale, regulated by GOST 25616–83 (Table 2) for comparison of results of automated system with results of welders' estimation. The result was multiplied 5 for transfer. The estimation of welding properties was carried out in accordance with test procedure, indicated in the standard.

CONCLUSIONS

1. Application of the automated systems based on fuzzy logic algorithms can solve a task of determination of windowed multicriteria estimation of quality indicators of the power sources.

2. Using of fuzzy logic and computer systems for data collection and processing provides the possibility of development of flexible systems for estimate of welding properties of the power sources for automatic arc welding. This allows reducing to minimum influence of the human factor on the estimation of welding properties.

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UPGRADING OF ELECTRIC CIRCUIT OF A-1150 MACHINE FOR VERTICAL WELDING

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A-1150U machine designed in 1960s is still in demand in its upgraded form in shipbuilding, bridge and storage tank construction. Pilot Plant of Welding Equipment of the E.O. Paton Electric Welding Institute (PWI PPWE) developed a new control circuit based on modern components and control units. The new circuit provides substantial improvement of technical and service characteristics of the machine, and simplifies implementation of the welding process with forced weld formation. The machine with the new electric circuit is additionally designated by «K» index (A-1150K).

Keywords: *A-1150K machine, welding process with forced formation, weld metal, new electric circuit, small-sized panel-handle, electronic control circuit with feedbacks*

The industry of CIS and foreign countries has used A-1150 machine for welding vertical and inclined welds for more than 40 years now. During this period PWI PPWE has manufactured more than 150 equipment sets based on orders from users, which points to a high quality of the development and need for it in production.

Idea of development of a self-propelled machine for automatic welding of vertical butt welds, which could move directly over the butt without any guides of rack type, was put forward by Prof. B.E. Paton. Such equipment was required in ship-building, and