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MONITORING OF TECHNOLOGICAL PROCESS OF ARC ROBOTIC WELDING

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Continuous monitoring of welded structure production is important to provide under conditions of robotic welding. As for MIG/MAG welding the preference should be given to control of electric parameters of arc, which generalize the conditions of technological process during 1 s. A complex evaluation of the electric parameters can be carried out in «arc current–arc voltage» area. The conclusions on presence of the disturbances should be made using coefficients of Haar wavelet decomposition. 5 Ref., 1 Table, 2 Figures.

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Assurance of welded joint quality under production conditions is mostly resulted in stabilizing production conditions in all aspects. This requires strict control of technology, equipment condition and support of respective personnel qualification. Robotization promotes fulfillment of indicated conditions, and, at the same time requires their strict execution. However, even strict keeping all the quality assurance requirements necessitates application of technological process control and testing of finished products. The most widespread procedures of production quality conformity assessment are as a rule statistically valid plans for random control using the procedures [1] adequate as for selected groups of defects. In regard to welding all known methods of joint quality control have limited application sphere, i.e. they can determine only some groups of defects.

These control procedures can be divided on two classes by their effect on material or product, namely methods of destructive and non-destructive testing. Obviously, that destructive testing methods are used only optionally and can provide evaluation of quality of the products being subjected to running with some probability. All non-destructive methods used in industry for welded joint testing are directed on detection of specific defects that result in violation of the conditions as for integrity, geometry, physical-mechanical properties or physical-chemical properties of the weld as well as near-weld zone. Due to technical and economical reasons the methods of non-destructive testing in the majority of cases are also used optionally and, therefore, can provide only probabilistic assessment of product quality.

This provokes a necessity in monitoring the process of welded structure manufacture that includes testing of quality of finished or intermediate product by destructive and non-destructive testing methods as well as control of conformity of the parameters of technological process to set ones.

Preparation of production in robotic welding is directed on development of the conditions that provide stability of welding conditions together with solution of other problems. However, this can not completely eliminate appearance of different formation defects and metallurgical defects, which appear due to series of energy, kinematic and technological disturbances, caused by random outside factors such as variation of mains voltage as well as failure of equipment. The latter can pollute welded surfaces with oil, break gas shield, etc. Some technological disturbances, as a rule, take place due to technical and economical restrictions on increase of accuracy of part preparation for welding. It is often impossible on technical or economical reasons to measure or at least evaluate the level of pollution in robotic welding. This, first of all, refers to such factors as break of gas shield, change of gap or exceed of edges, presence of pollution on the part surface. However, such disagreements of the conditions of welding process can have significant effect on weld formation. In robotic welding, joint quality control is carried out only at specific stages of technology process of structure manufacture. Therefore, disagreements in welding process can result in substantial material expenses.

Traditionally, monitoring of technological process mode parameters is carried out by means of registration of their deviations from set values. The number of parameters is determined by welding method and possibility of measurement of controlled parameters in welding of specific product. Some generalized evaluation of the parameter, i.e. average or root-mean-square value is subjected to control.

Large number of controlled parameters provokes a problem of their complex evaluation. Combination of values of large number of the parameters, which are within the limits of set tolerances, can sometimes result in a defect due to their unfavorable combination. Reduction of the tolerances at that can result in declaration of some part of quality products as invalid ones.

The most acceptable and physically grounded method of continuous monitoring of quality of welded joint made by electric welding is the analysis of energy parameters of welding process [2]. Presence of natural feedbacks between a heat source and a joint, that is formed, allows evaluating the process of joint formation using electric parameters of the heat source. Natural variation of formation process leads to appearance of stochastic component in electric parameters of the heat source. The stochastic component gives different reflection of process of joint formation for different methods of welding. Thus, in MIG/MAG welding, presence of the disturbances results in change of movement of electrode spot on pool surface and violation of axisymmetry of the forces acting the electrode metal drop, i.e. electrode metal transfer. This effects the instantaneous values of current and arc voltage and enters some stochastic components in oscillograms. So, the main idea of monitoring lies in comparison of some ideal image of stochastic process with current one.

The investigations were carried out in welding of sheet steel using consumable electrode ER-49-1 (Sv-08G2S) of 0.8 mm diameter in MIX1 (82 % Ar + 18 % CO_2) mixture at 80A current. Variations of arc electric parameters under disturbances effect were investigated.

Record of the arc electric parameters in welding was carried out by measurement system that included PC, probes of current LA-305S/SP1 and voltage LV-25P based on Hall effect, analogue-digital converter E-140 and PC with installed in it L-graph program. Frequency of analogue-digital conversion made 10 kHz for each channel.

Process of gas-shielded consumable welding can be divided on a range of similar cycles of melting and electrode metal transfer. Electric parameters of each cycle have some, often significant, differences from other due to presence of large number of various disturbances. Thus, evaluation of the process may be statistical and conclusions on presence of substantial disturbances of the process or defect formation are probabilistic.

Previous preparation of data lied in withdrawal of error values caused by electromagnetic interferences, from received oscillograms. Such error values are random, have significant amplitude and occur quite rarely, namely one-two for 30–50 thou of measurements. This allows changing them on an average sample value without loss of statistical reliability. In order to elimi-

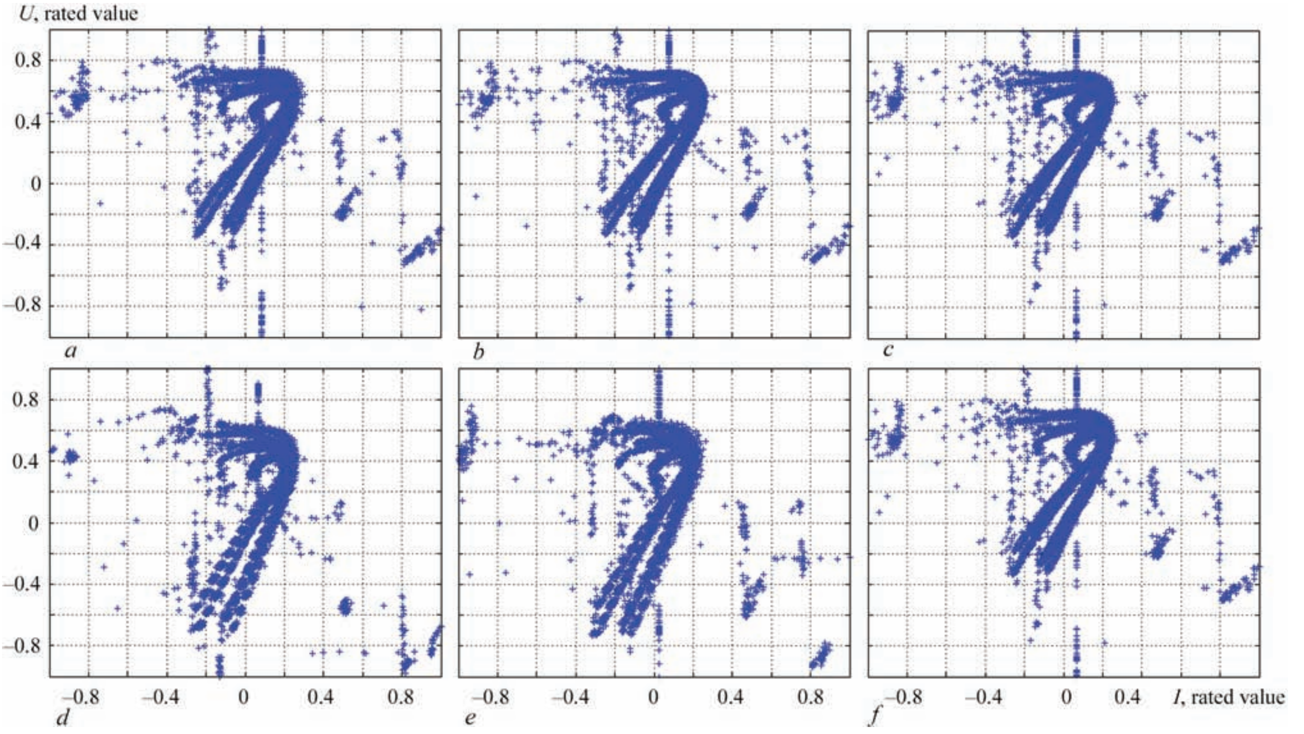

Figure 1. Rated diagrams of «current–voltage» of welding process (description *a*–*f*) see in the text)

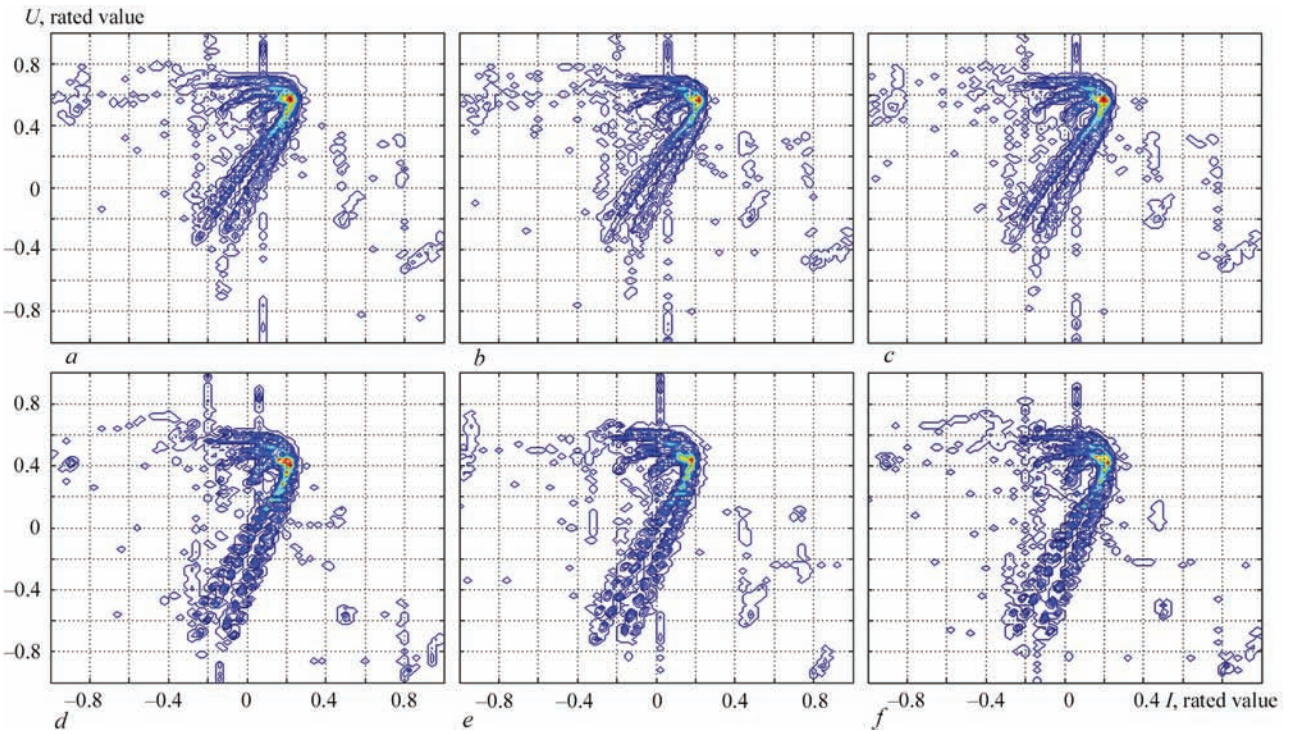

Figure 2. Density of location of points in «current–voltage» diagrams (*a*–*f* see Figure 1)

nate effect of scale factor in the analysis the welding process evaluation was carried out using rated to [–1, 1] range of current and voltage oscillograms.

Stability of arc burning in welding was evaluated on density of points location on a diagram of voltage-to-current dependence (Figure 1), received from current and voltage oscillograms. If process is stable, the diagram points should clearly match one with another forming even a complex trajectory line. However, stochastic nature of the process of electrode metal transfer, caused by random actions of different nature and intensity, results in diffusion of the diagram. It is reasonable for analysis to evaluate a process progress in a period of time that is insufficient for formation of joint defects, but not too long for «absorption» of effect of disturbances due to sample averaging. For the weld made without disturbances, the diagrams (Figure 1, *a*–*c*) of process progress in time intervals 10–11 s, 20–21 and 30–31 s have stationary stochastic component, i.e. the process can be regarded as ergodic. Introduction of a disturbance in welding (oil pollution of the specimens) results in change of diagram form with obvious increase of the stochastic component (Figure 1, *d*–*f*). Presence of the disturbances provokes not only increase of points spread, but also transform stochastic process in non-ergodic.

It is reasonable to calculate density of points location in Figure 1 on «current–voltage» area (Figure 2) for quantity evaluation of level of process stochastic property.

It can be seen that such a representation allows data reduction. Dividing the «current–voltage» area on 0.01×0.01 squares the amount of data for analysis of the process progress during 1 s decreases 10000 times. Received in such a way matrix of whole numbers can be analyzed as digital image. The main task of processing is to find effective presentation, which allows providing image in compact form. Current processing theory and practice widely use wavelet transforms [3–5].

The wavelets that are determined as a function of one real variable are used very often in practice. 2D discrete wavelet transform, that is based on one-dimensional wavelet transform and does not depend on number of columns and rows of the image, are used for the analysis. Therefore, the preference is given to horizontal and vertical directions. Haar wavelets made a good showing for processing of discrete

Specifying coefficients of Haar wavelet decomposition

Specifying coefficients of level 6		Diagram
–25.5787037037037	0.810185185185186	Fig. 1, a
–67.4479166666667	0.192901234567901	
–45.1976102941177	0.0574448529411765	Fig. 1, *d*
–59.2026654411765	0.0114889705882353	
–27.1956699346405	0.714869281045752	Fig. 1, *b*
–71.5788398692811	0.224673202614379	
–40.5063291139241	1.84928797468355	Fig. 1, *e*
–52.7986550632912	0	
–22.8591160220995	0.656077348066299	Fig. 1, *c*
–59.4872237569061	0.129488950276243	
–39.6990740740741	0.578703703703704	Fig. 1, *f*
–52.8549382716050	0.0385802469135803	

one-dimensional and 2D signals. Haar transform does not require complex calculations and is divisible.

The significant difference of the problems of traditional image analysis from the problems that requires monitoring of technological process progress is a need in evaluation of level of noises and not their suppression. In practice this means that it is necessary to evaluate the values of only specifying coefficients of wavelet transform.

Matrix of 100×100 size can have Haar decomposition up to level 7. However, the difference between a set of specifying coefficients becomes apparent only at level 6 (4 coefficients). Increase of level to the second allows determining more differences between the diagrams, but at the same time rises the number of coefficients for analysis (26×26) (Table).

Automation of the analysis is possible in application of methods of artificial intelligence based on artificial neuron nets.

Conclusions

1. Monitoring of conformity of technological process of MIG/MAG welding is reasonable to perform using arc electric parameters.

2. Monitoring should be carried out following the data, which average conditions of technological process progress in 1 s.

3. Complex evaluation of arc electric parameters on «arc current–arc voltage» area is reasonable for reduction of time of information processing without its loss.

4. Conclusions on presence of the disturbances is appropriate to make using the specifying coefficient of Haar wavelet decomposition.

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