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SYSTEM OF CONTROL, REGISTRATION OF PARAMETERS AND MONITORING IN THE PROCESS OF PRESS WELDING OF PIPES USING MAGNETICALLY-IMPELLED ARC

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The technical requirements to the basic elements of the control system are determined. The structural design of the control system is described. The influence of the process parameters of press welding using magnetically-impelled arc on the quality of the produced joints is investigated. The limits of fluctuations of values of the parameters and their influence on quality of the produced joint are determined. The software of the system for evaluation of quality of welded joints is developed. 7 Ref., 6 Figures.

Keywords: welding technology, press welding using magnetically-impelled arc, control system, registration of parameters, system for quality evaluation of produced joints, joints formation

Rapid development and widespread use of control systems in welding production [1] requires the developers of equipment to search new ways and hardware implementation to improve the efficiency of welding equipment in order to increase the efficiency of welding process and guaranteed quality of welded joints [2, 3]. The widespread use of press magnetically-impelled arc butt (PMIAB) welding in different industries and development of new welding machines to implement this method requires the improvement of existing systems for evaluating the quality of welded joints and control.

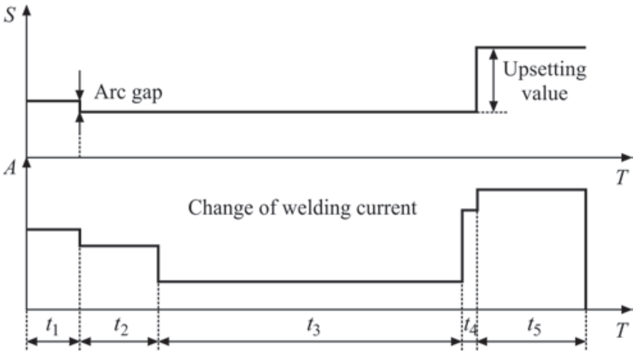

Figure 1. Changes in welding current and position of moving part of welding machine during welding: S — graphical representation of position of moving part of welding machine during welding process; A — sequence of changes of welding current during heating of parts; T — running time of heating and welding process; t_1 — time interval, during which the process is initialized (excitation of welding arc); t_2 — duration of stage of stabilization of process of moving welding arc along the edges of parts; t_3 — stage of heating welded parts; t_4 — endurance of time, during which a sharp increase in welding current occurs (stage of forcing heating process); t_5 — time of performing compression of heated parts to form a joint (upsetting) with the switched-on welding current

During resistance butt welding the use of parametric quality control of welding is known [4]. The use of this method of quality control is based on real-time registration of welding parameters and determination of probable deviations of parameters from the set program values. At the same time, the acceptability of these deviations and their impact on the quality of joints is determined and the quality of a produced joint is evaluated.

The appropriate programs for control of basic parameters are also used in PMIAB production, but the control of parameters has so far not been used in industrial conditions.

The differences in the technological process during resistance butt welding and PMIAB and namely, the presence of a controlling magnetic field, the nature of welding current (constant current), process duration, upsetting rate, etc., make the use of control methods [4] during resistance butt welding impossible.

The aim of the work is to develop the initial conditions, software and create a computerized control system for welding process and quality evaluation of welded joints produced by magnetically-impelled arc, analyzing the technological parameters.

Realization of the canonical scheme of PMIAB is implemented according to the program in which the change of a parameter (welding current) is performed over time and has the form shown in Figure 1.

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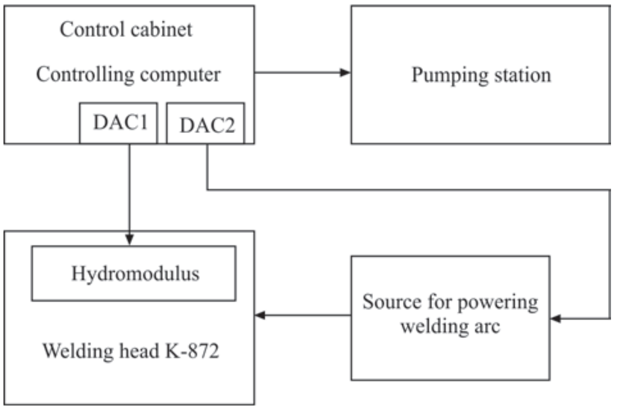

Figure 2. Block diagram of welding installation

When heating of pipes is performed, a step change of welding current occurs. Each of the current steps has a preliminary set duration. Programming a value of current over time has the following disadvantages:

● low repeatability of final temperature field formation during joining of parts;

● limited range of welded products;

● system of registration and quality evaluation that can be applied to such a system, will not have a high degree of reliability about the quality of a produced joint.

Taking into account the experience of operating of PMIAB equipment and taking into account the results of investigations [5, 6] and in order to eliminate the abovementioned drawbacks, the PMIAB method was tested, in which the process parameters are corrected without a rigid binding to the duration of welding program but taking into account the energy characteristics of welding arc in order to obtain the programmed temperature field required for the formation of a joint. This guarantees the repetition of heating process and formation of a joint.

The scheme of the system of control and evaluation of quality of welded joints was developed in the machine K-872 and in the composition of:

● control computation module (PC);

● devices for normalization of analogue input signals;

● analogue-to-digital converters;

● welding arc current sensor;

● arc voltage drop sensor;

● potentiometric sensor of moving part position;

● measuring sensor of absolute pressure in hydraulic system.

To provide implementation of the control and quality evaluation algorithm, the cabinet of control system was modernized (Figure 2). Registration of technological parameters of the PMIAB process in the modernized K-872 machine takes place according to the scheme shown in Figure 3.

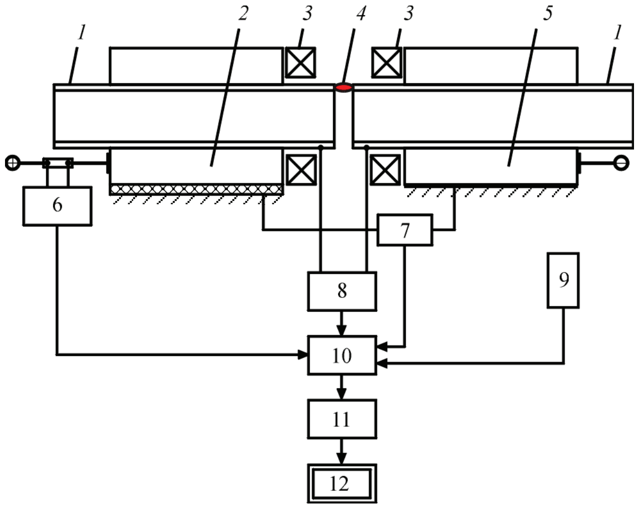

Figure 3. Block diagram of the model of quality evaluation of welded joints: *1* — welded pipes; *2* —movable clamping device; *3* — elements of magnetic system; *4* — electric arc column; *5* — fixed clamping device; *6* — current sensor; *7* — position sensor; *8* — voltage drop sensor on welding arc; *9* — sensor for measuring absolute pressure of hydraulic system; *10* — normalizing instrumental amplifier (with low-pass filter F_c = 100 Hz); *11* — receiving ADC; *12* — industrial computer

The compliance of the computer evaluation of quality control with the real situation is guaranteed by providing the system (Figure 3) with real output data, in case of PMIAB of pipes, such data are current, welding arc voltage, common arrangement of pipes in the clamping devices of the machine, pressure in hydraulic system during the performance of upsetting (as derivatives of this parameter, rate and value of upsetting).

For registration and analysis of the process parameters the multifunctional device USB-4711AE (Figure 4) was used, which has the following main characteristics:

Maximum sampling frequency of input signal, kHz	150
Operating range of input voltage, V	0−10
Maximum input voltage, V	30
Input resistance of analogue channel, MOhm	>1
Number of bits in ADC, bits	12
Sampling error, bits	+(m)1
Maximum number of reading channels	16

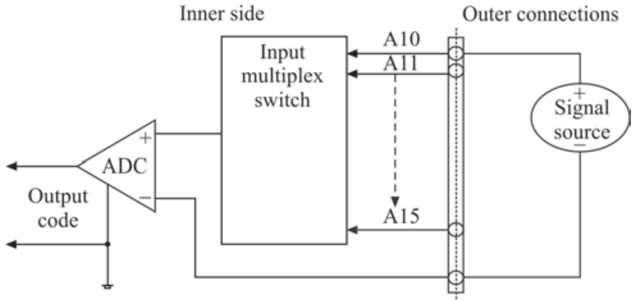

Figure 4. Diagram of connecting sensors of the system of recording PMIAB parameters and ADC structure

Current data from the sensors of the registration system during heating of the parts are obtained as follows (on the example of obtaining a voltage drop on welding arc). The input of the normalizing input amplifier 8 is connected directly to the terminals located on clamping devices of the welding machine (according to the electrical circuit, such a connection corresponds to the connection to the output terminals «+» and «–» of the welding arc power source). In the amplifier, the voltage drop of welding arc, which occurs at the beginning of the process and is in the range of 20−30 V of direct current (at the moment of constant arc movement along the edges of parts to be welded), is normalized to the output voltage of 2−3 V. The signal corresponding to the input voltage is filtered to a 100 Hz cut-off frequency of amplitude-frequency response. In this way, the derived voltage signal of welding arc is cleared from pulsations and interferences of harmonics of higher orders, but such a filtering frequency allows preserving the dynamics of tracking change in welding voltage drop and registering negligible deviations in welding voltage from a preliminary set one. For further processing and analysis, the derived signal of the welding voltage drop from the output of the amplifier 8 is sent to the input of the analogue-to-digital converter (ADC). During operation of the software (start of the quality evaluation program), the ADC is set so that interrogation frequency of the analogue inputs is 10 interrogation points per one reading of data from the ADC output. Therefore, a more accurate data transfer to the control program is achieved. This principle is shown in Figure 5.

The choice of such a type of device for reading data of running the technological process is predetermined by the versatility and mobility of the obtained system for registration of parameters. The complex of data collection devices, built on devices with a USB busbar for data transfer, is not tied to specific executive equipment and in case of need to solve new problems, the emergence of which is inevitable during any research work, allows a quick rearrangement of the system without a loss of data obtaining quality. Such a principle of building a data registering system allows using any main device, such as PC of «laptop» class and industrial computers.

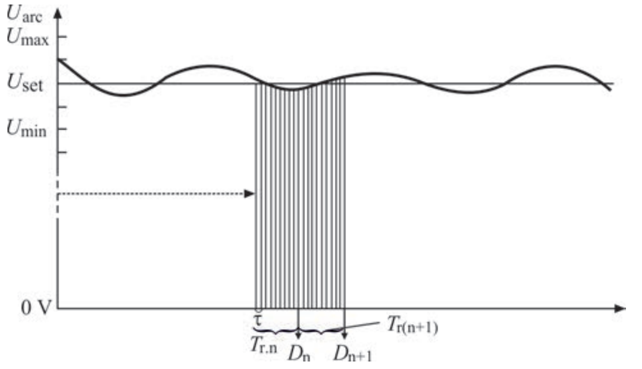

Figure 5. Cycles of interrogation one ADC input and reading data to the software of the model of quality control system

For setting the sampling frequency of analogue inputs the following parameters were determined;

U_{min} — minimum value of arc voltage drop, which occurs due to the influence of different factors during heating process;

U_{max} — maximum value under the same initial conditions;

U_{set} — technological parameter;

τ – delay between the reading cycles of one ADC input channel;

T_{rn} — total duration of one reading cycle of the ADC output (sampling duration for the formation of data package coming to the program of analysing parameters);

$T_{r(n+1)}$ — next package read from ADC;

D_n — data package read from ADC (consists of an array of interrogation points of four channels by *n*-times) (number of averaging points).

Averaging allows avoiding the phenomenon of the appearance of capacitive parasitics in building the circuit of the input ADC multiplex switch.

In the process of welding pipes, in the random access memory of the PC the accumulation and formation of an array of data from the four ADC channels is performed. This allows simplifying the procedure of processing and analysis of the data obtained after welding.

The customization of the software of the control complex was carried out by updating the parameters of the existing software modules. It allowed expanding the time and parametric limits of operating the actuating devices, performing more accurate adjustment of technological welding parameters and obtaining data on the process performance.

During welding process, the system sensors are scanned, the obtained data are processed and the formation of data files and a summarized file of a daily report is performed, in which the following parameters are fixed;

● welding time by stages of heating T_1, T_2, T_3, T_4, T_5, T_6;

● arc current by stages of heating I_2, I_3, I_4, I_5 (I_1 is the current of the initial stage of heating process during the analysis is not taken into account due to its small impact on welding process);

● voltage of welding arc at three stages of heating parts U_2, U_3, U_4 (U_1 is the voltage of excitation stage is not taken into account);

● total amount of energy spent on heating parts E_a;

● rate of upsetting V_{ups} (it was experimentally established that this is the average rate of the opposite movement on the first 1.5 mm of the arc gap before the contact of welded pipes);

● value of upsetting S_{ups} (value of total deformation L of parts during upsetting, for each of the parts is):

$$L = \frac{S_{ups}}{2} - l_{ag}, \qquad (1)$$

where l_{ag} is the value of arc gap between the parts before the beginning of upsetting; upsetting pressure P_{ups}; temperature of oil of the hydraulic system and the environment.

According to the data of reports, a database of variations in the values of these parameters during welding over the entire period of operation of the equipment is formed, which will be used in the future to optimize the technological process.

Deviation of these parameters beyond the tolerances depends on many reasons. Therefore, the following algorithms were developed:

● control for the two-level system, which provides correction of welding mode in order to stabilize the process;

● weld butt quality evaluation;

● evaluation of technical condition of welding machine;

● formation of recommendations with correction of technological process parameters.

The existing quality control, at which the obtained data are compared with the reference ones, is the simplest logical function — the quality indices are in the tolerance at a simultaneous existence of all the controlled parameters in the tolerance. However, during such a control the following factors are not taken into account:

● significance of the impact of each of the parameters on the quality index;

● uncertainty of the limit of tolerances of process parameters;

● probable increase in the influence of a totality of certain combination of deviations on the quality of welding.

For the control of welding quality the following algorithm was developed and tested, based on the analysis of process parameters at three stages of its implementation:

1 — excitation of welding arc and heating of pipes. Period of temperature field formation at the ends of pipes;

2 — increase in welding current;

3 — upsetting and formation of joints.

The conclusion on the quality of a produced welded joint with a certain degree of probability (truth) is carried out on the basis of logical rules which are made according to the results of investigations of technological features of the process of welding pipes [7].

To control the welding process, the following parameters are used:

● time (duration) of welding by stages ($T_1 - T_6$);

● value of current at the stages of heating ($I_2 - I_5$);

● value of voltage at the stages of arc existence ($U_2 - U_4$);

● rates and values of upsetting (V_{ups} and L_{ups});

● pressure in the hydraulic system during upsetting P_{ups};

● energy spent on heating of parts E_a.

To perform the simplest method of control in the system for evaluation of quality of produced welded joints, the following rule can be entered:

IF some technological parameter X is determined in the tolerance field, THEN the produced joint meets the quality requirements according to this parameter.

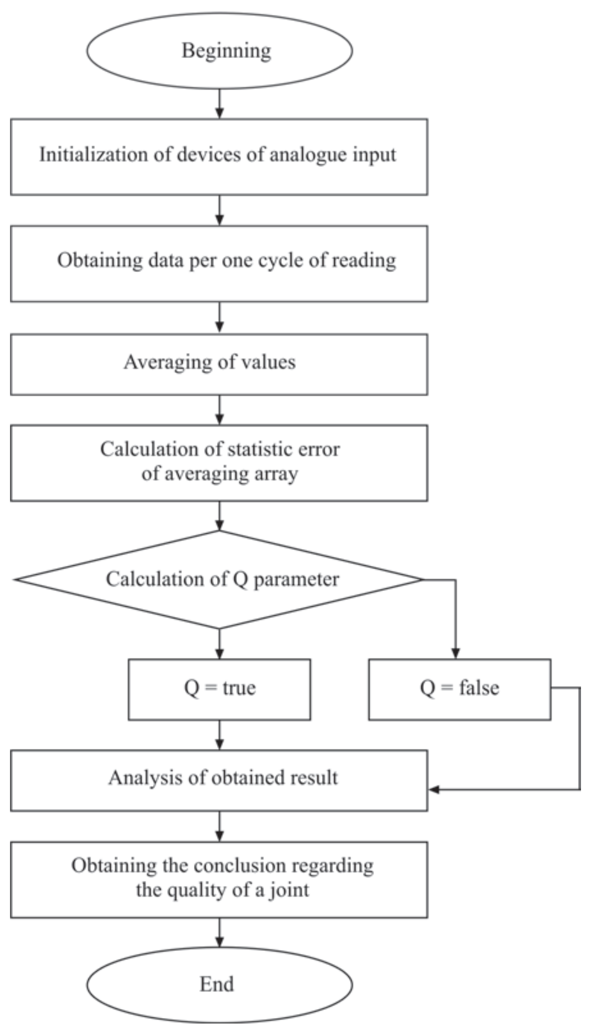

Figure 6. Algorithm for quality control of welded joints

According to the abovementioned, we obtain the following sequence to determine the quality of the produced joint:

IF in the tolerance the time intervals of the technological process $T_{1\text{-}6}$ are set AND the arc current $I_{1\text{-}4}$ is obtained AND the voltages $U_{2\text{-}4}$ are measured AND the upsetting rate V_{ups} in the tolerance AND the value of upsetting L_{ups} in the tolerance AND at the stage of upsetting slipping of pipes relatively to clamping devices is absent, THEN the welded butt is of high quality.

If a deviation of set time intervals of the technological process $T_{1\text{-}6}$ OR obtained arc current $I_{1\text{-}4}$ OR measured voltages $U_{2\text{-}4}$ are not within the established tolerances OR upsetting rate V_{ups} is lower than the lower limit of tolerance OR the value of upsetting L_{ups} is lower than that established in the tolerance OR at the stage of upsetting a longitudinal slipping of parts relative to the clamping devices takes place, THEN a welded joint is determined as low-quality.

In case of registering these process parameters using a computer control system, we have the following computational algorithm to determine the quality of welded joint.

$$\begin{cases} (T_{1\text{-}6})\,\&\,(I_{2\text{-}5})\,\&\,(U_{2\text{-}4})\,\&\,(V_{ups})\,\&\,(L_{ups})\,\&\,(P_{ups})\,\&\,!(S_{sl}) \\ !(T_{1\text{-}6})\,||\,!(I_{2\text{-}5})\,||\,!(U_{2\text{-}4})\,||\,!(V_{ups})\,||\,!(L_{ups})\,||\,!(P_{ups})\,||\,(S_{sl}) \end{cases}, \quad (2)$$

where Q is a logical correspondence, which can take the value «true» or «false» (respectively, «true» means that the quality of a produced joint meets the standards, «false» means that the quality of a produced joint does not meet the standards); $T_{1\text{-}6}$ are the values of duration of welding stages obtained during the technological process; $I_{1\text{-}4}$ are the measured values of welding current by stages of heating parts; $U_{2\text{-}4}$ is the welding arc voltage by heating stages; V_{ups} is the initial upsetting rate; L_{ups} is the value of upsetting; S_{sl} is a sign of existing longitudinal slipping of parts relative to the devices for holding welding machine; ! is a sign that corresponds to the value of the variable «does not meet the set tolerance»; & — meets the condition «YES»; || — meets the condition «OR».

The software realization of the abovementioned algorithm (2) is shown in Figure 6.

Conclusions

1. The initial requirements to the control system of basic technological parameters of PMIAB welding were determined.

2. The limits of changes of basic technological parameters in welding for producing sound joints were determined.

3. The software was developed to realize the algorithm of controlling the process of welding and quality control of joints.

4. The industrial technology of PMIAB welding of pipes was developed.

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