Intelligent Welding Control System

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Abstract

An intelligent welding control system, that allowing to receive an assessment of the quality of welding in real time, has been developed. Proposed intelligent control method differs in the use of the arc energy variation coefficient at the stage of formation of drops of electrode metal and additive indicator of normalized values of welding current and voltage deviations from optimal values.

Keywords

intelligent system, control of welding works, welding process recorder, welding mode parameters, arc energy, assessment of the quality of welding

1. Introduction

Intelligent process control systems are beginning to go beyond research organizations and are widely used in industry, which ensures the introduction of cyber-physical systems into welding production [1].

Welding control systems are most in-demand at pipeline transport facilities [2]. World-renowned welding equipment manufacturers supply automated welding control systems with the equipment: ESAB WeldQAS [3], Kemppi Weld Eye [4], Fronius Weld Cube [5], Ewm Xnet [6], Lorch Q-Data [7], some domestic manufacturers produce loggers of welding processes, for example, ITS RSP-102D [8], which allow you to collect data on the parameters of the welding mode and transfer them to the server.

An urgent task is the development of intelligent algorithms for processing data obtained from data loggers [9-11].

2. Description of the hardware and software of the system

The intelligent welding control system (Fig. 1) includes hardware and software.

The hardware part of the system contains a recorder of welding processes RSP-BRU-01, a sensor unit, and a welder's control panel. The recorder identifies the welding equipment, welders, and welding managers, determines the GPS coordinates, reads the welding task from the server, writes and sends the welding mode parameters to the server. LEMs compensation sensors, whose work is based on the Hall effect, measure instantaneous values of welding current and arc voltage at a frequency of 10kHz. The values are averaged over 1000 points before being transferred to the software module for processing data from the sensors. The values of the environment temperature and moisture, preheating temperature, and interlayer temperature are entered into the logger from the welder's control panel. If the welding mode params leave the acceptable values of the instruction of the welding process, the system sends corresponding signals to the welder's control panel, each of which corresponds to a specific sound emitted by the control panel.

Russian Advances in Fuzzy Systems and Soft Computing: Selected Contributions to the 10th International Conference «Integrated Models and Soft Computing in Artificial Intelligence» (IMSC-2021), May 17–20, 2021, Kolomna, Russian Federation
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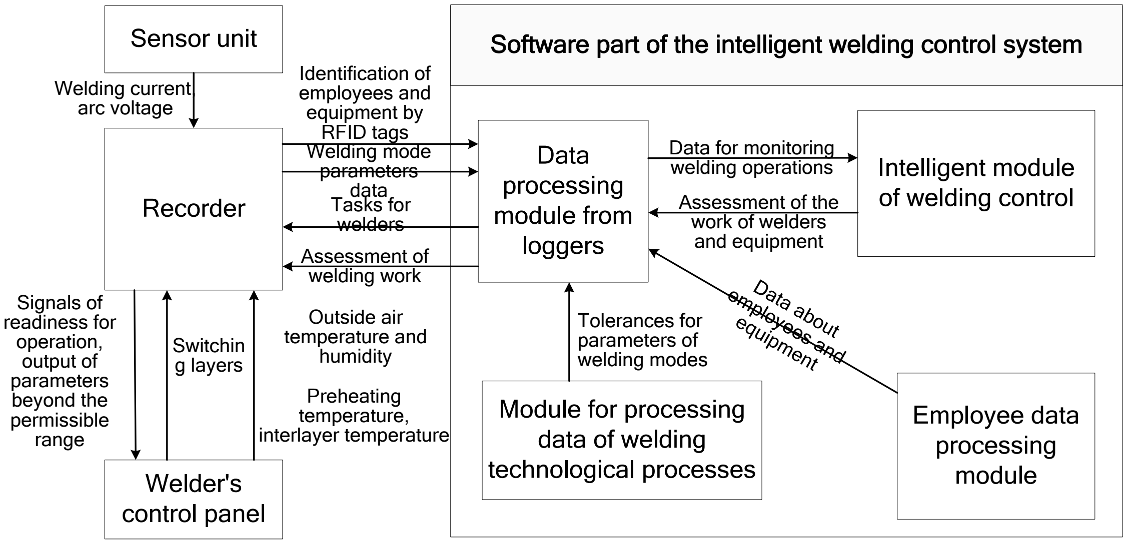


Figure 1: The structure of the intelligent welding control system

The algorithm of the hardware part of the system (Fig. 2) includes three main blocks:

1) Identification block. This block performs the identification of welding operations leaders, welders, and welding equipment using RFID tags. Geolocation of the welding equipment is carried out by GPS coordinates.

2) Logger preparation unit. In this block, a list of tasks for the welder is formed with an indication of the permissible parameters of the welding process, the outside air temperature and moisture, heating temperature, and interlayer temperature are readable from the welder's control panel.

3) Recording unit of parameters of the welding process. Registration of welding process parameters is carried out with a 10 kHz frequency. When the parameters go beyond the permissible values, a sound signal is generated by the welder's control panel, which differs depending on the parameter which has gone beyond the permissible values. Before sending data to the software part of the system, the values of the welding process parameters are averaged over 1000 points.

The software part of the intelligent welding control system includes the following main modules (Fig. 1):

1) Data processing module from loggers. This module receives information from the data loggers and from three other modules of the software part of the system. The module was produced for organizing data exchange between the hardware and software parts of the system. For welding control based on the parameters, the data is preprocessed. There is also a transferring process of the obtained values to the intelligent welding control module. Based on information from technical instructions about welding processes, welders, and equipment some tasks are formed for the various objects. This module generates necessary documents and reports on the results of work done (weld certificates, reports on the work of welders, and welding equipment).

2) The employee data processing module provides for the input, modification, deletion and search of the data about welding chiefs or foremen, brigades and welders. The processing results in this module are intended to show if the welder's qualification matches the standards of welding technological processes. Based on the results of data processing, tasks are formed.

3) The module for processing data of welding technological processes provides input, modification, deletion and search of data about technological instructions. The results of processing in this module are taken into account when forming tasks for welding.

4) The intelligent module of welding control is designed for evaluating the performance of welders and welding equipment. This module implements a method for intelligent control of welding operations based on the results of processing data of welding modes. Based on the results of the module's work, the results of the quality assessment of the welding process are transmitted to the welder's console every 0.5s.

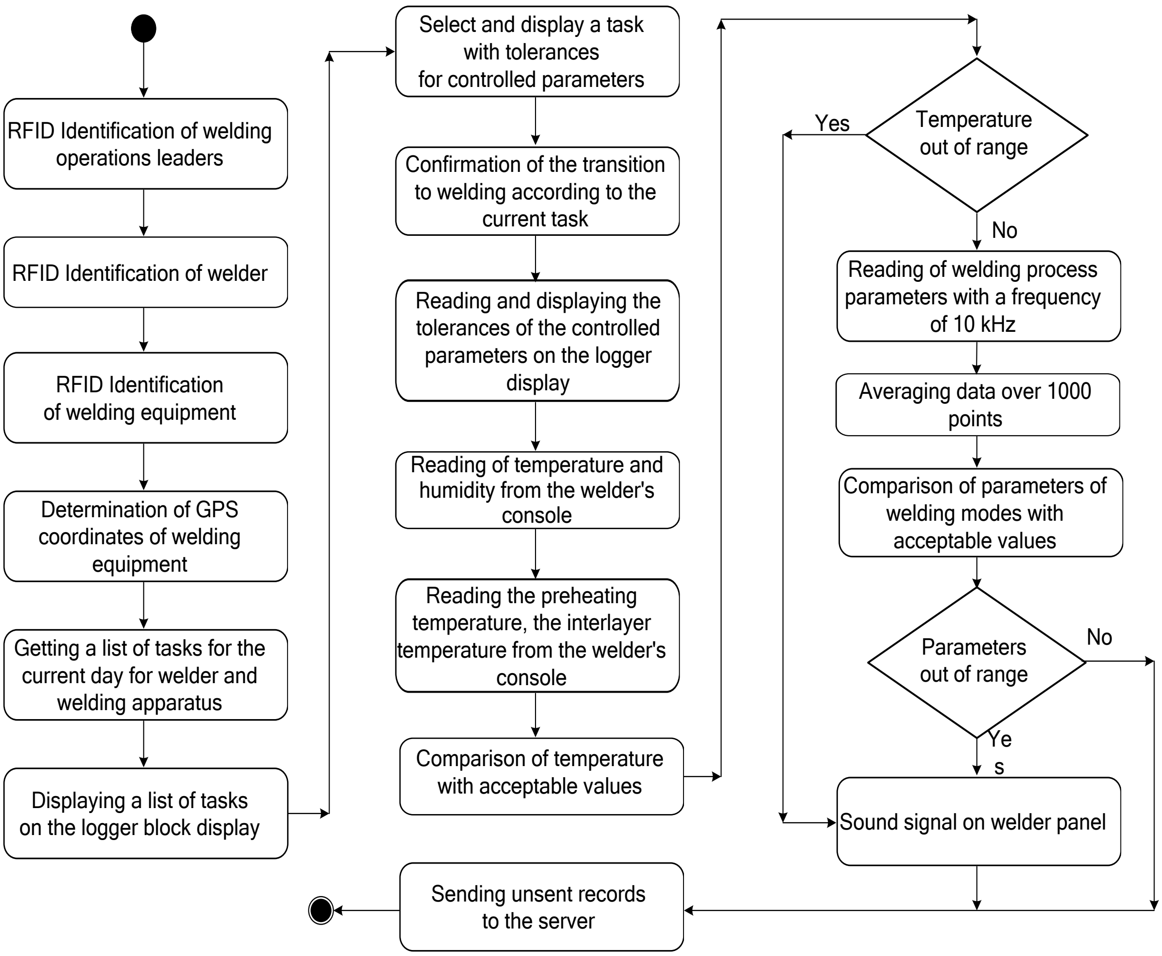


Figure 2: The algorithm of the hardware part of the system

3. System approbation results

The intelligent welding control system can be used with a manual arc-shaped welding process (MMA) and semi-automatic welding (MIG / MAG) [12]. In Fig. 3 there are oscillograms of current and voltage recorded by a recorder of welding processes with a sampling rate of 10 kHz. Welding (surfacing) was carried out on plates 100x200x10 mm made of steel St.3 with a wire Sv08G2S with a diameter of 1.2 mm in a shielding gas CO2 at a welding current of 200 A, a voltage of 21.3 V, a welding speed of 28.8 m/h.

The analysis of the presented oscillograms shows that the transfer of the electrode metal into the weld pool is carried out due to the short circuit of the arc gap [13-15].

In the course of experimental studies, it was found that software processing of oscillograms should be carried out in two frequency ranges [16, 11]:

1) Medium-frequency (up to 10 kHz) describes the processes of transfer of droplets of electrode metal into the weld pool;

2) Low-frequency (up to 10 Hz) describes the process of forming a weld pool (weld seam).

The following stages of the transfer process can be named (Fig. 3):

– arc burning (drop formation) with duration t_a;

– short circuit in the weld pool (droplet detachment) with the duration of $t_к$.

Full transfer cycle:

$$T_c = t_a + t_к.$$

To study the processes of transfer of electrode metal, special information-measuring complexes are used [17, 18]. Fig. 4 shows images that represent drop formation during the cycle of its transfer to the weld pool, corresponding to the moment of time indicated by points 1..4 in Fig. 3. The frames were obtained by high-speed shooting and combined with current and voltage oscillograms with the help of an information-measuring complex developed at the Belarusian-Russian University [19].

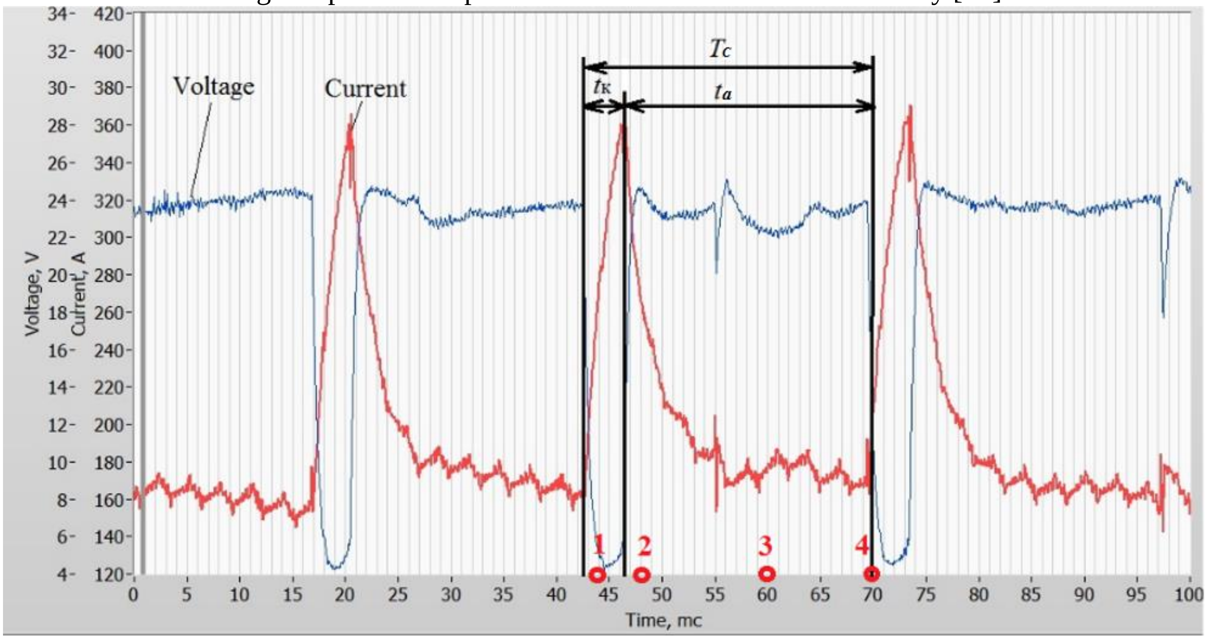


Figure 3: Oscillograms of the welding process

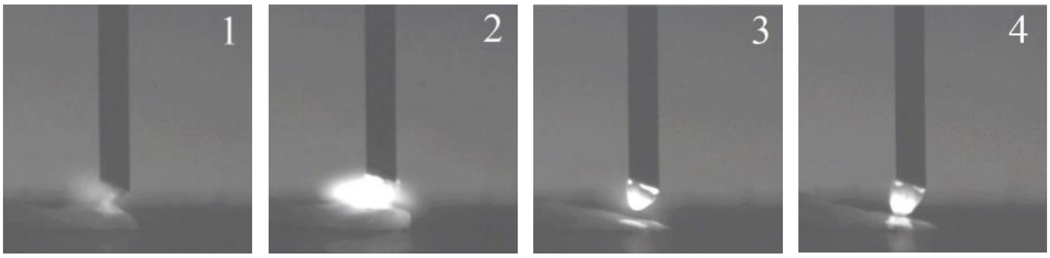


Figure 4: Pictures of the formation of a drop of molten metal

The stability of the process is ensured by the formation of droplets of the same size. The authors of works [13, 17, 20] investigated tests of the stability of the process of transfer of electrode metal. In theses [21, 22] it was found that the closest dependence between arc energy and the size (diameter) of the drop can be observed on the stage of its formation (during time t_a), which determined as:

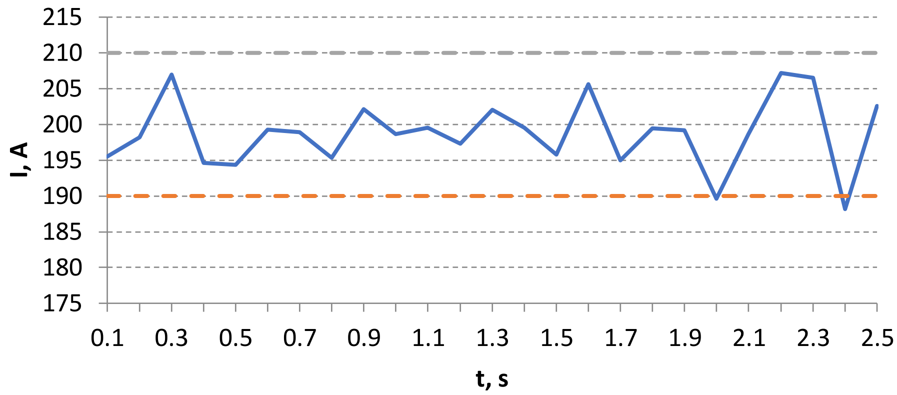
$$q_a=\Sigma(i_a \cdot u_a \cdot \Delta t),$$

where $i_a \cdot u_a$ – are instantaneous values of welding current and arc voltage;

Δt- sampling step of signal from current and voltage sensors.

The arc energy at the stage of formation of a drop of electrode metal depends on the welding mode and the effect of external disturbances to the power source system - the welding arc. Exemplary values of q_a are controlled with welding of control samples of the material with fixed parameters of the welding mode: welding current, arc voltage, welding speed, electrode stickout, shielding gas consumption, and are transferred to the data processing module.

To study the process of formation of a weld pool or weld seam, the instantaneous values of current and voltage are averaged, and originally they are taken by the recorder of welding processes with a frequency of 10 kHz. With averaging 1000, we obtain the data of the parameters of the welding mode with a frequency of 10 Hz (Fig. 5). Deviations of the welding voltage and changes in the process current mode are causing changes in the geometric dimensions of the weld, the formation of such defects as burn-through, pores, cracks, etc.



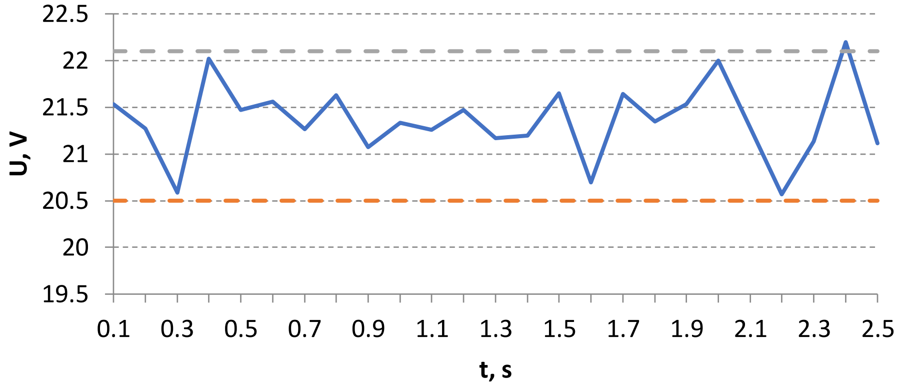


Figure 5: Average values of current and voltage, obtained from the recorder with a frequency of 10 Hz

The method of intelligent control of welding processes includes the following basic steps:

1. When the moment of ignition of the arc is detected (a sharp increase in voltage practically from zero to the working one), the arc energy q_a is calculated until the moment of a short circuit in the weld pool (the current increases from the working one to the short-circuit current). Arc energy values q_a are stored in the logger memory.

The results of the instantaneous values of the arc energy are shown in Table 1.

2. For a time interval of 0.5 s (time constant of solidification of the weld pool), the coefficient of variation of the arc energy KVq_a can be calculated as:

$$KVq_a = \frac{\sigma_{q_a}}{q_a}$$

Where σ_{q_a} - standard deviation of arc energy values q_a; average value of the arc energy q_a obtained within 0.5 s.

The results of the coefficient of variation of the arc energy are presented in Table 2.

3. Instantaneous values of welding current and voltage are averaged on the recorder and transmitted to the data processing module with a frequency of 10 Hz.

4. The overall assessment of the work of the welder and the equipment consists of three components (assessment of the welding current Io, assessment of the voltage *U*o and assessment of the welding process based on the coefficient of variation of the arc energy KVq_a) is set every 0.5 s. If the specified tolerance limits are exceeded by 0.5 s or more, the parameter value is zero. In this case, the maximum value of the welding current is 22.1 A, the minimum value of the welding current is 20.5 A; the maximum voltage value is 210 V, the minimum voltage value is 190 V. The value of the arc energy change coefficient KVq_a should not be higher than 0.3 [22-25].

Table 1

Results of registration of instantaneous values of arc energy for 2.5 s

Time t, s				
0,5	1	1,5	2	2,5
Arc energy q_a, W				
5,069	5,666	8,051	8,197	5,023
5,292	5,823	8,475	7,729	5,593
6,857	6,86	5,241	8,468	6,254
5,598	6,006	6,24	6,39	6,566
6,65	5,97	6,017	7,129	6,635
6,844	6,479	7,595	6,658	6,542
5,49	6,709	6,83	5,451	5,443
6,425	5,975	7,828	6,75	5,374
5,58	6,685	5,856	3,998	4,686
6,304	6,242	5,434	5,48	7,332
3,489	4,692	6,535	8,164	8,448
1,286	2,224	5,405	6,142	9,39
7,441	3,656	5,506	9,965	8,455
10,99	13,18	2,87	10,64	5,623
9,41	10,35	10,6	8,7	6,338

Table 2

Results of the calculations for the coefficient of variation of the arc energy

Time t, s	0,5	1	1,5	2	2,5
KVq_a	0,34	0,38	0,26	0,23	0,20

The evaluation of the welding current is carried out according to the following formula:

$$I_o = \frac{\left|\overline{I_{0,5}} - I_{mid}\right|}{(I_{max} - I_{mid})}$$

Where $\overline{I_{0,5}}$ – the average value of the welding current for 0.5 s;

I_{mid} – is the average between the maximum and minimum value of the welding current (in this case I_{mid} = 21,3 A); I_{max} – maximum value of the welding current.

The voltage estimation is performed according to the following formula:

$$U_o = \frac{\left|\overline{U_{0,5}} - U_{mid}\right|}{(U_{max} - U_{mid})}$$

Where $\overline{U_{0,5}}$ – average voltage value for 0.5 s; U_{mid} – is the average between the maximum and minimum voltage values (in this case, U_{mid} = 200 B); U_{max} – maximum voltage value.

Based on expert assessments, the estimated values for assessing the welding current ($\delta I_o = 3$), voltage ($\delta U_o = 3$) and the coefficient of variation of the arc energy ($\delta KVq_a = 4$). Accordingly, the assessment of welding work assessment of welding work on a 10-point system is calculated by the formula:

$$Mw = \delta I_o \cdot I_o + \delta U_o \cdot U_o + \delta KVq_a \cdot KVq_a$$

The results of evaluating the work of welders and welding equipment for the case under consideration are presented in Table 3.

Table 3

Results of evaluating the work of welders and welding equipment

Time t, s	Uo	Io	KVq_a	Assessment (*Mw*)
0,5	197,95	21,38	0,34	5,1
1	197,99	21,40	0,38	5,0
1,5	199,94	21,26	0,26	6,3
2	199,61	21,27	0,23	6,7
2,5	196,37	21,56	0,20	5,3

4. Conclusion

The article describes an intelligent welding control system containing hardware and software. The hardware part is presented by logger provides real-time acquisition of the parameters of welding processes to assess the quality of welding. The software part implements data processing and scoring depending on the parameters of welding processes.

The intelligent control system presented in the article allows obtaining estimates of the quality of various jobs in real-time (with an interval of 0.5 s), depending on the stability and the deviation of the welding mode from optimal values, as well as warn the welder and the welding manager at the exit of the welding mode beyond the permissible signal values by generating a sound on the console.

The proposed method for intelligent control of welding is distinguished by the use of an additive indicator of the deviation of the welding current and voltage from the optimal values, the use of the coefficient of variation of the arc energy at the stage of electrode metal drops. The result of applying the proposed technique in the developed intellectual system is the assessment of welding work on a 10-point scale, which is transmitted to the welder's console with an interval of 0.5 s and on the server. Information received by representative offices of welders and welding managers to ensure the improvement of welding quality.

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