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Application and Upgrading of On-line Monitoring System for Measurement and Processing of Electric Signals at Arc Stud Welding Process

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Preliminary note

As the application of on-line monitoring system is shown to be a good solution during monitoring of main welding parameters at different welding processes, this paper describes application and upgrading of an on-line monitoring system developed at the Mechanical Engineering Faculty in Slavonski Brod. The experiment described in the paper shows application of an on-line monitoring system during welding of two types of studs with application of activating flux for ATIG process (VS-2E) on the base metal surface. Monitoring of the main welding parameters (welding current and voltage) was conducted during welding of studs usually used in steam boiler production (stud diameter: 10 mm), and welding voltage was monitored on the studs (shear stud) of 22 mm diameters used in bridge construction. The goal of monitoring and analysis of main welding parameters is to evaluate the connection of electric arc parameters variations with the presence of an activating flux.

Primjena i nadogradnja on-line monitoring sustava za mjerenje i obradu električnih signala kod elektrolučnog zavarivanja svornjaka

Prethodno priopćenje

Kako se primjena on-line monitoringa pokazala kao dobro rješenje pri praćenju glavnih parametara zavarivanja kod različitih postupaka zavarivanja, u radu je opisana primjena i nadogradnja on-line monitoring sustava razvijenog na Strojarskom fakultetu u Slavonskom Brodu. U eksperimentalnom dijelu rada prikazana je primjena on-line monitoring sustava kod zavarivanja dviju vrsta svornjaka uz primjenu topitelja za ATIG postupak (VS-2E). Pri tome je izvršeno praćenje glavnih parametara zavarivanja (jakosti struje i napona električnog luka) kod zavarivanja svornjaka koji se primjenjuju u kotlogradnji (promjera 10 mm), te napona električnog luka kod svornjaka koji se primjenjuju na mosnim konstrukcijama (promjera 22,5 mm). Cilj praćenja i analize parametara zavarivanja primjenom on-line monitoringa je ocjena povezanosti promjena parametara električnog luka i prisustva aktivirajućeg topitelja.

1. Introduction

During automatic but also manual and semiautomatic welding, monitoring of the welding process stability and observation of unacceptable welding process parameters variation are of great importance.

A commonly used device for monitoring and validation of welding process stability is the on-line monitoring system for acquisition of welding currents and voltages. The correct choice of filler material and welding parameters will result in a stable welding process without the appearance of welded joint failures and quality deviations. Due to that, the monitoring and control of key welding process parameters is of the utmost importance for assuring the quality of welded joints. When referring to welding methods where the required energy is generated electrically, it is essential to know the distribution of voltage and current during the welding sequence at the particular weld location. The quality of the weld depends on the welding parameters and heat introduced both during the welding sequence and weld joint cooling [1-2]. Also, modern welding equipment has built-in welding parameter control, allowing control of selected welding parameters during the welding sequence. That equipment requires periodic calibration and adjustment in order to ensure the validity of the displayed values. Unfortunately, some pieces of equipment do not feature this option, but rather have vague adjustment of welding parameters – after the initial pre-process calibration. This calls for particular

Symbols/Oznake

ATIG	- Activated Tungsten Inert Gas welding - zavarivanje volframovom elektrodom pod zaštitom inertnog plina uz primjenu aktivirajućeg topitelja
VS-2E	- applied activating flux according to ТУ ИЭС №643-87 - primijenjen aktivirajući topitelj prema ТУ ИЭС №643-87
DAW	- Drawn Arc Stud Welding - elektrolučno zavarivanje svornjaka "povlačenjem" luka
I	- welding current, A - jakost struje zavarivanja
L	- lift, mm - odizanje svornjaka
P_s	- plunge, mm - napuštanje svornjaka
t	- welding time, s - vrijeme zavarivanja
E	- heat input, J - toplinski input
P	- power, W - snaga u električnom luku
U	- welding voltage V - napon zavarivanja
MAG	- Metal-arc Active Gas Welding - elektrolučno zavarivanje taljivom elektrodom pod zaštitom aktivnog plina
SMAW	- Shielded metal arc welding - ručno elektrolučno zavarivanje
FCAW	- Flux Cored Arc Welding - elektrolučno zavarivanje praškom punjenim žicama
PE-HD	- high-density polyethelene - polietilen visoke gustoće

control of welding parameters when welding critical structures (i.e. those of higher product or weld class). Independent of the particular requirement for calibration of modern equipment, selection of optimal parameters or the precise control of required welding parameters, the on-line monitoring system of welding parameters features precise, high quality monitoring, data gathering and processing [2]. This paper presents possibilities of measurement of on-line monitoring system developed at the Mechanical Engineering Faculty in Slavonski Brod and upgrading of the system performed in cooperation with the Faculty of Electrical Engineering in Osijek.

In the experimental part of the paper, the example of on-line monitoring application is presented where the arc stud welding with ceramic ferrule process (DAW with ceramic ferrule) is foreseen for two examples:

- monitoring of welding current and voltage during DAW with ceramic ferrule with stud diameter of 10 mm that is usually used in steam boiler production [3]
- monitoring of welding voltage during DAW with ceramic ferrule with stud diameter of 22 mm that is usually used in bridge construction (shear studs) [4].

2. Description of laboratory on-line monitoring system

Measurement of welding parameters is essential during the development and testing of new software programs for modern, programmable welding equipment, as well as during the calibration and certification of welding current sources, during research and development for base materials and during weldability research (selection of optimal filler material based on comparing various products, determination of optimal welding parameters for a given welding method, determination of heat input with higher precision, development of new base materials and fillers and welding parameter control for automatic welding methods) [5].

The on-line monitoring system used to acquire welding parameters (Figure 1) was composed of commercial components. Its key components are: voltage module, current module, Hall effect current sensor, signal conditioner backplane to accommodate the voltage and current modules and a power supply, A/D converter, flat cable and PC with suitable software for data measuring, recording and processing.

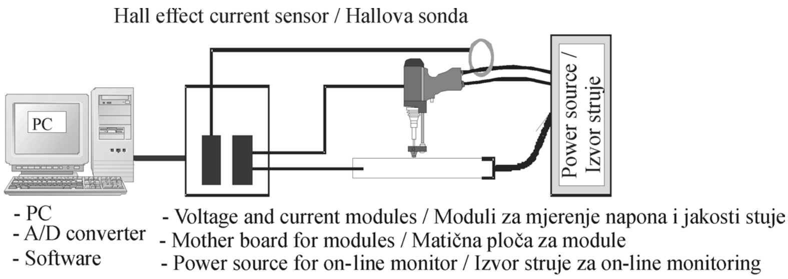


Figure 1. Scheme of equipment for monitoring of welding current and voltage during arc stud welding process
Slika 1. Shematski prikaz opreme za praćenje napona zavarivanja tijekom elektrolučnog zavarivanja svornjaka

The on-line monitoring system allows precise measurement, monitoring and recording of welding voltage U (V) and current I (A) during the cycle, as well as off-line analysis of derived values such as:

- mean voltage value

$$\overline{U} = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} U(t) \mathrm{d}t \ , \tag{1}$$

- mean current value

$$\overline{I} = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} I(t) \mathrm{d}t \ , \tag{2}$$

- instantaneous power

$$P = U \cdot I \ , \tag{3}$$

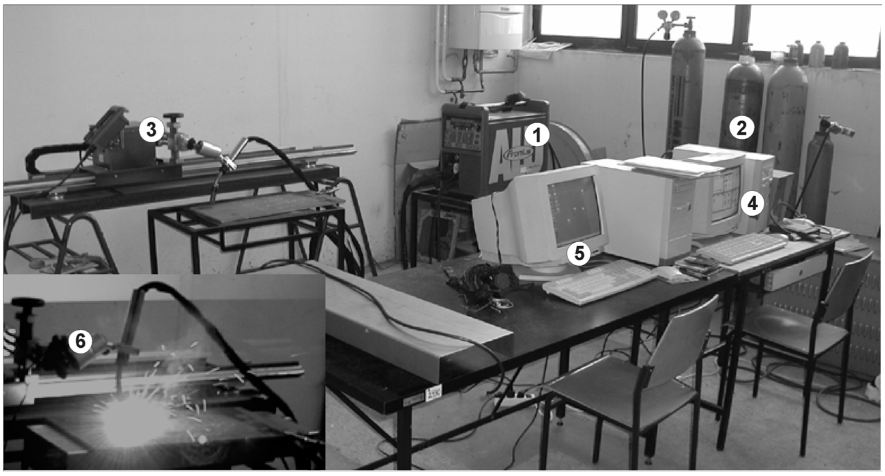
- instantaneous heat input

$$E = U \cdot I \cdot t = I^2 \cdot R \cdot t \ . \tag{4}$$

A laboratory system for the monitoring and registration of welding parameters is being developed at the Mechanical Engineering Faculty in Slavonski Brod. The system collects data up to 20 kHz on two channels (for both welding voltage and current). To date, it has been successfully used for monitoring, gathering and processing of voltage and current data at various welding methods (stud arc welding, metal arc welding (MAG), shielded metal arc welding (SMAW), flux cored arc welding (FCAW), fusion welding of high-density polyethelene (PE-HD), …) [2]. Figure 2 shows application of on-line monitoring during automatic MAG welding process. At this moment the laboratory system consists of on-line monitoring system for monitoring and acquisition of welding current and voltage, audible sound monitoring system and 1D motion control of work piece (Figure 2). A module for temperature field monitoring and an optical module for light intensity monitoring are still being developed.

2.1. Upgrading of on-line monitoring system

Through upgrading, the monitoring system achieved high-class insulation (class II.) that meets IEC standards [6-7]. This has enabled handling coupling measurement lines by measuring the process. Using the measurement card, a speed recording of measurement data is increased and is 333kS / s [8]. In order to meet standards, shielded cable at the communications card and the motherboard module are used. The modules are addressed and linked with NIDAQ interface drivers (Figure 3). Such drivers open graphical programming interface within the LabVIEW programming environment (Figure 4). Use of the two analogue inputs per module enables more efficient and more reliable measurement. LabVIEW software package enabled the extracted data in the form of Excel or Text files. Further mathematical treatment is much simpler in comparison with the previous version. The advantage of this system is that the results of real-time perform certain mathematical operations such as FFT or FFT2. LabVIEW is a software that allows graphical programming with specific icons. Specific API (Application Programming Interface) offers possibilities of communicating with an external card. Within the programming interface it is necessary to choose the channels that are used in the application. Analogue inputs are 16 bit, and this range refers to the voltage from 0 – 5 V or differential input – 10 to +10 V.



Legend:

1. Power source/Izvor struje
2. Shielding gas/Zaštitni plin
3. Driving system for automatic welding/Sustav za automatsko vođenje pištolja za zavarivanje
4. PC for welding parameters acquisition and processing/PC za akviziciju i obradu parametara zavarivanja
5. PC for sound signals acquisition and processing /PC za akviziciju i obradu zvučnih signala
6. Sound sensor/Senzor zvuka

Figure 2. Laboratory system for monitoring, acquisition and processing of main welding parameters [18]

Slika 2. Laboratorijski sustav za praćenje, akviziciju i obradu glavnih parametara zavarivanja [18]

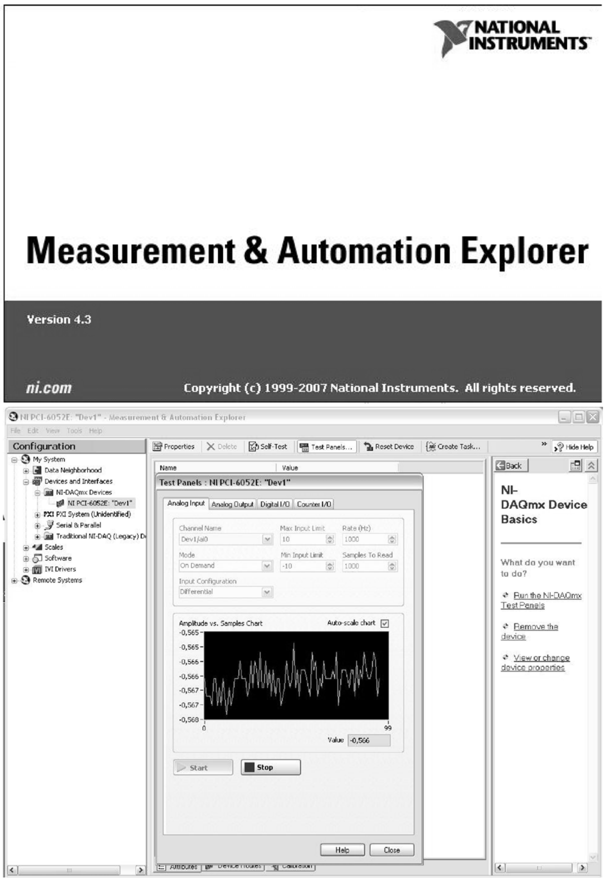


Figure 3. NIDAQ interface.

Slika 3. NIDAQ sučelje

Current (Hall) measuring probe used in the application is adapted and has the possibility of measuring AC and DC components of currents [9]. Thus, it is possible to measure currents in the two groups. Electric appliances which have a peak value 500 A to the catheter are used with the same measurement range. The module is used for indirectly measuring the current SCC-AI05 [5]. Also if showing major power arches appear power over 1000 A, CYHCS-C1 is used, which has a peak value of 2000 A maximum. Besides measuring current, parallel voltage is measured on the operating terminal. The high voltage used by (NMT hr. VIT en.) (Voltage Instrument Transformer 1:100), lowers the voltage and measures the scales towards stress measure module at 20 V (SCC-AI02) [10]. Module (SCC-TC02) [11], which allows measurement of temperature through the thermo couple, was opened by the majority of performances. These modules connect to the motherboard (NI SC-2350, Figure 5) that supports TEDS Class II. smart sensors that can upgrade the system.

3. Setup of experiment

The main goal of this experimental investigation is to monitor possible stability changes of welding current and voltage (or just changes of welding voltage) at drawn arc stud welding with ceramic ferrule process (DAW with ceramic ferrule) with presence of activating flux for ATIG process on the surface of the base metal.

Figure 5. Module motherboard

Slika 5. Matična ploča modula

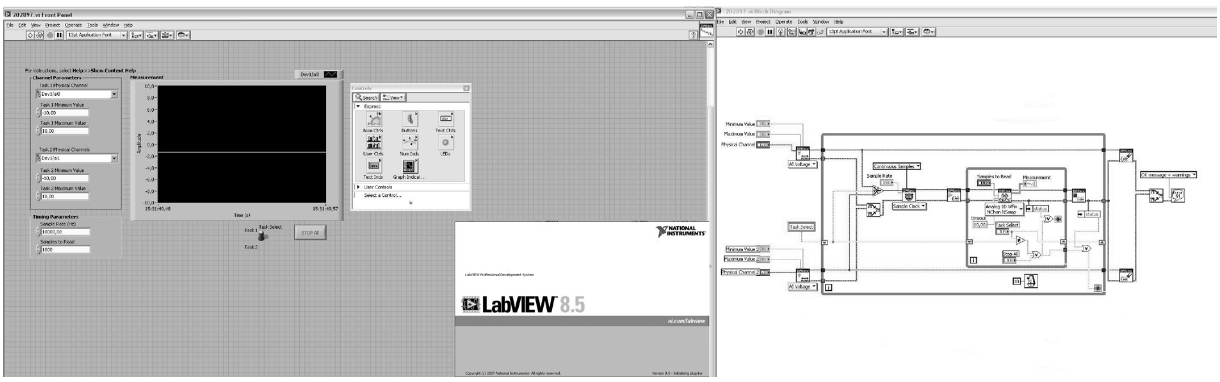


Figure 4. LabView interface

Slika 4. LabView sučelje

Table 1. Setup of experiment

Tablica 1. Postavke pokusa

Trial No.	11/12/13	21/22/23
Base metal/base metal thickness, mm / Osnovni materijal/Debljina osnovnog materijala, mm	16Mo3 (EN 10028-2) / 10	S355J2G3 (EN 10025) / 40
Stud material/ Designation of manufacturer / Materijal svornjaka/Oznaka proizvođača	X10CrAl18 (EN 10095) / Nelson KS 10,0×50	S235J2G3+C450 (EN 10025)/ KÖCO Type SD 22×175
Stud diameter, mm/Stud length, mm / Promjer svornjaka, mm/ Duljina svornjaka, mm	10/50	22/175
Ferrule type / Tip keramičkog prstena	Nelson KW 10/5.5	KÖCO SN 22
Welding equipment / Oprema za zavarivanje	ALPHA 850/Welding gun NS 40 B Nelson Bolzenschweiss-Technik GmbH Co. & KG	Nelweld 6000/Welding gun NS 20 BHD Nelson Bolzenschweiss-Technik GmbH Co. & KG

Table 2. Welding parameters setup

Tablica 2. Postavljeni parametri zavarivanja

Trial No. / Oznaka pokusa	Welding current / Jakost struje I, A	Welding time / Vrijeme zavarivanja t, s	Plunge / Napuštanje P_s, mm	Lift / Odizanje L, mm	Welding condition / Uvjeti zavarivanja
11	600	0,4	2,9	2,5	Clean surface of the base metal / Čista površina osnovnog materijala
12	400	0,55	1,5	2	Activating flux (VS-2E) on the surface of the base metal / Aktivirajući topitelj (VS-2E) na površini osnovnog materijala
13	600	0,55	1,5	2	Activating flux (VS-2E) on the surface of the base metal / Aktivirajući topitelj (VS-2E) na površini osnovnog materijala
21	1750	0,95	5	4,5	Clean surface of the base metal / Čista površina osnovnog materijala
22	1750	0,95	5	4,5	Activating flux (VS-2E) on the surface of the base metal / Aktivirajući topitelj (VS-2E) na površini osnovnog materijala
23	1750	0,85	5	4,5	Activating flux (VS-2E) on the surface of the base metal / Aktivirajući topitelj (VS-2E) na površini osnovnog materijala

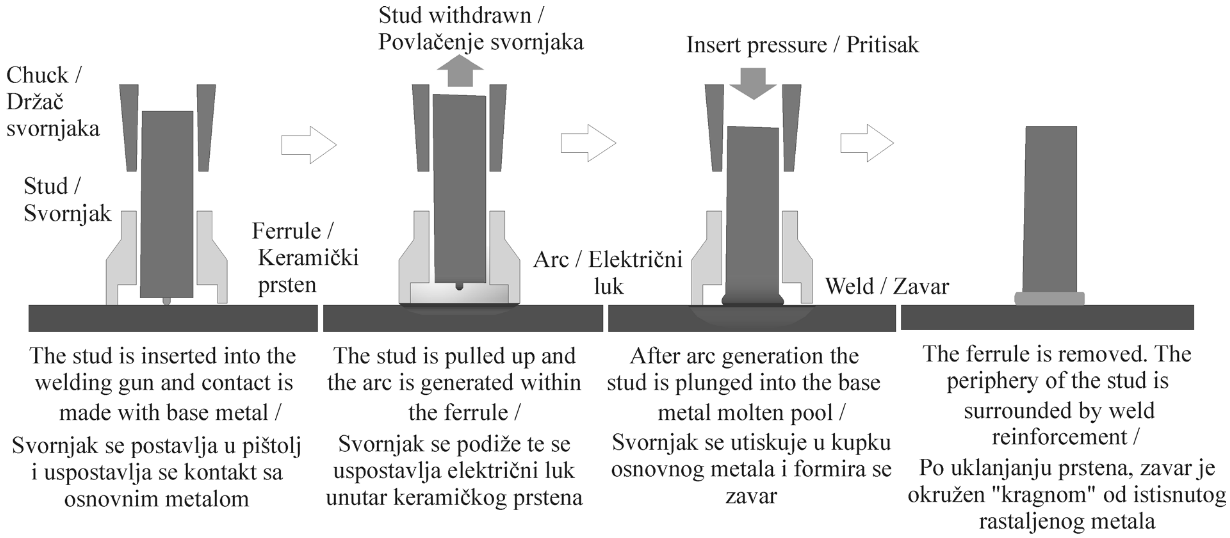
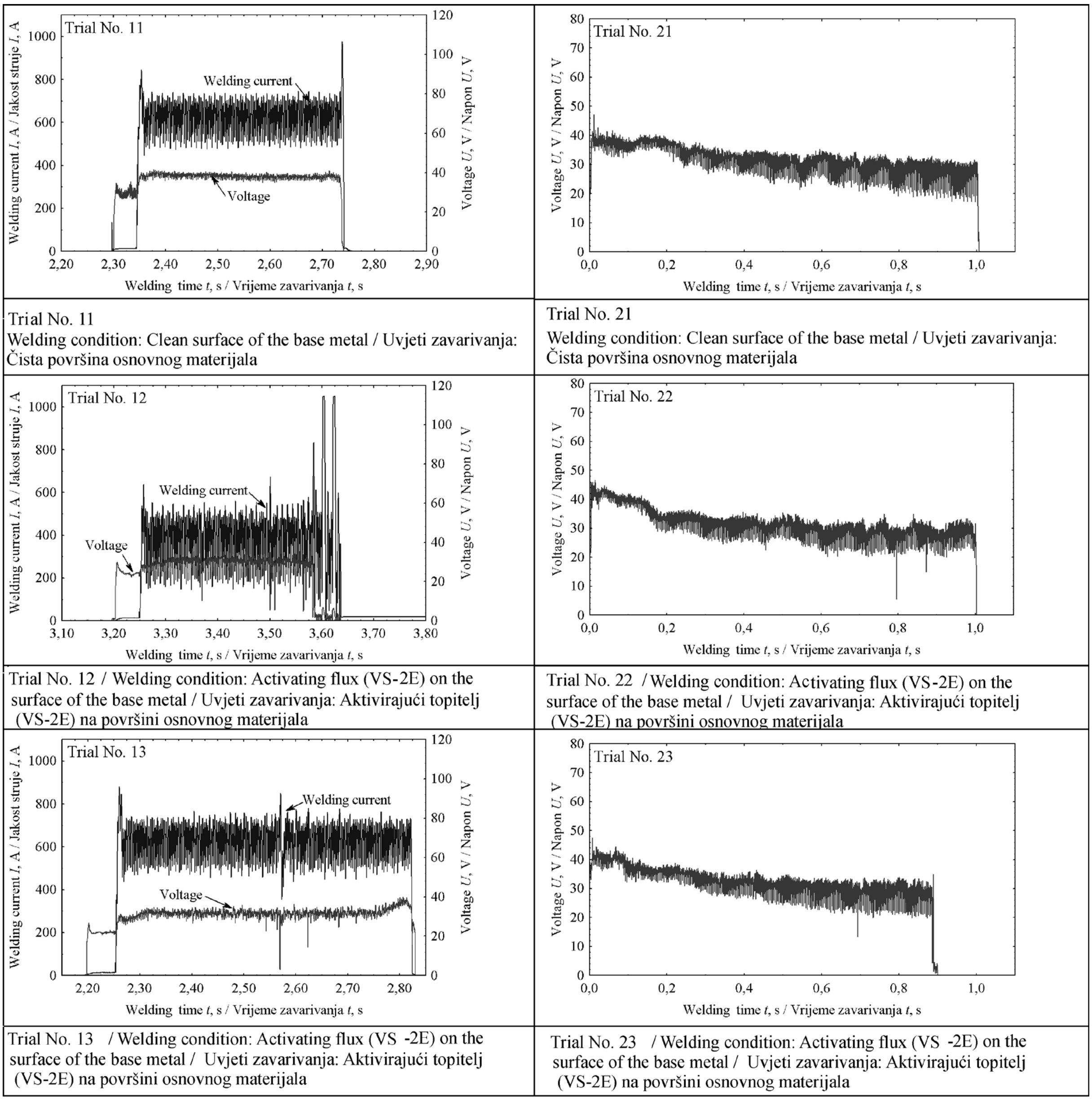


Figure 6. Welding operation sequence for drawn arc welding with ceramic ferrule [12]

Slika 6. Proces zavarivanja svornjaka ”povlačenjem” luka s keramičkim prstenom [12]

So, in this experimental research the welding was performed by drawn arc stud welding with ceramic ferrule process (DAW with ceramic ferrule), as this welding process is widely used in steam boiler manufacturing for placing the isolation coatings on boiler's walls, which are affected by flue gasses. The studs for this application are usually made from temperature resistant steels that can have conditional weldability. [3] One other wide area of stud welding application is also in composite steel/concrete structures [13]. The operation sequence for DAW process with ceramic ferrule is depicted in Figure 6.

Generally, the purpose of activating flux is to increase the efficiency and productivity of TIG process. With the presence of the activating flux and high temperature, the value of the surface tension of the melted metal is reduced, the electric arc is stabilised and summarised, and the weld bead width is reduced with increased penetration [14-15]. In the experimental part of the paper, the influence of the activating flux for ATIG process (developed at the E.O. Paton Electric Welding Institute, Kyiv) on the stability changes at the arc stud welding process is investigated. The applied activating flux for ATIG process is developed



Trial No. 11
Welding condition: Clean surface of the base metal / Uvjeti zavarivanja: Čista površina osnovnog materijala

Trial No. 21
Welding condition: Clean surface of the base metal / Uvjeti zavarivanja: Čista površina osnovnog materijala

Trial No. 12 / Welding condition: Activating flux (VS-2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala

Trial No. 22 / Welding condition: Activating flux (VS-2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala

Trial No. 13 / Welding condition: Activating flux (VS -2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala

Trial No. 23 / Welding condition: Activating flux (VS -2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala

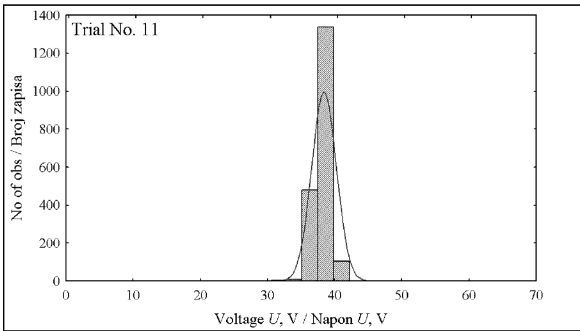
Figure 7. Welding parameters distribution for weldments with and without the activating flux VS-2E (setup of experiment in Table 2)

Slika 7. Distribucija parametara zavarivanja za zavare izvedene sa i bez primjene aktivirajućeg topitelja VS-2E (prema planu pokusa prikazanom u tablici 2) for welding of nonalloyed steel and is applied with a brush (as a suspension) on the base metal surface (the designation of the applied activating flux according to ТУ ИЭС №643-87 is ВС-2Э; or in Latin alphabet: VS-2E) [14]. Size and type of the base metal, type and diameter of studs, cheramic ferrule and type of power source applied in this experimental research are shown in Table 1. Table 2 shows the setup of welding parameters during experimental stud arc welding process

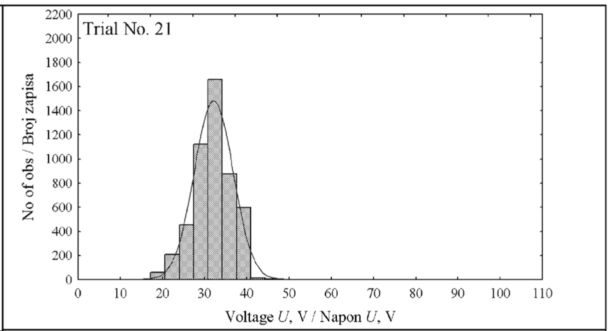
An on-line monitoring system described earlier in this paper is used for aquisition of main welding parameters (sampling frequency was 5 kHz). Figure 1 shows a scheme of the on-line monitoring system during arc stud welding process.

4. Analysis of results

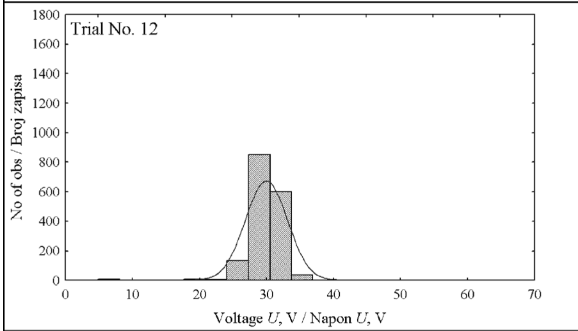
During experimental welding of studs welding current and voltage were recorded with sampling frequency 5 kHz (for studs of 10 mm diameter) and welding voltage for studs of 22 mm diameter for the complete welding cycle. The variations of welding parameters during arc stud welding process are shown in Figure 7. By analysis of these diagrams it is possible to compare variations of



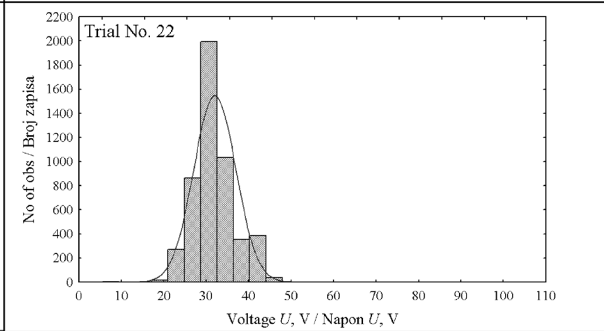
Trial No. 11
Welding condition: Clean surface of the base metal /
Uvjeti zavarivanja: Čista površina osnovnog materijala



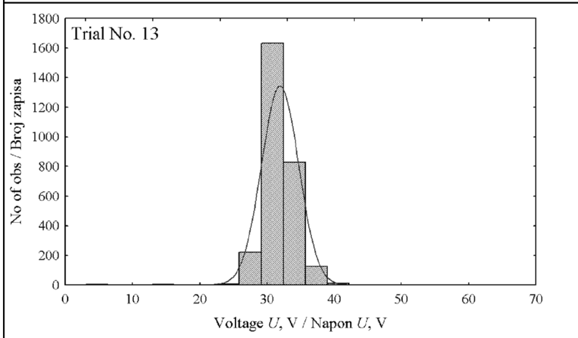
Trial No. 21
Welding condition: Clean surface of the base metal /
Uvjeti zavarivanja: Čista površina osnovnog materijala



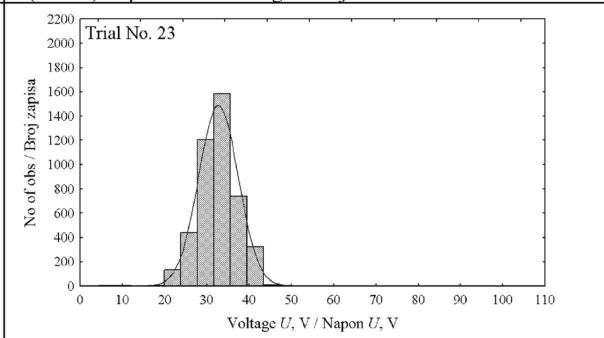
Trial No. 12 / Welding condition: Activating flux (VS -2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala



Trial No. 22 / Welding condition: Activating flux (VS -2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala



Trial No. 13 / Welding condition: Activating flux (VS -2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala



Trial No. 23 / Welding condition: Activating flux (VS -2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala

Figure 8. Frequency histograms of welding voltage for the stud arc welding process

Slika 8. Histogram frekvencija napona zavarivanja kod elektrolučnog zavarivanja svornjaka welding process during electric arc burning for welding with and without activating flux.

Validation of the welding process parameters variations was performed also by off-line analysis of recorded data. Before data processing, the welding process start and stop disturbances are excluded.

For trials No. 11, 12 and 13 the moment when the welding current value exceeds a value selected on the welding power source is the starting point of the analysis, and the voltage short circuit drop, due to submerging the stud into the base metal, marks the end of the analysis, [16]. For trials No. 21, 22 and 23 the moment when the measured value of welding voltage exceeds 30 V for the first time is the starting point of the analysis, and the voltage short circuit drops below 30 V, due to submerging the stud into the base metal is the end point of the analysis [17].

Figure 8 shows frequency histograms of welding voltage during the arc stud welding process.

In order to connect the arc stud welding process parameter changes with the quality of the weld joint, the macrosections of the welded studs for the trial no. 11 and 12 (stud diameter: 10 mm) are also analyzed, as the diagrams in Figures 7 and 8 show wider variations of welding parameters regarding other trials.

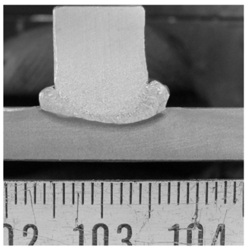
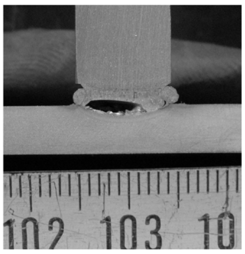
	Trial No. 11 Welding condition: Clean surface of the base metal / Uvjeti zavarivanja: Čista površina osnovnog materijala
	Trial No. 12 Welding condition: Activating flux (VS-2E) on the surface of the base metal / Uvjeti zavarivanja: Aktivirajući topitelj (VS-2E) na površini osnovnog materijala

Figure 9. Weld joint macrosections for weldments with and without the activating flux VS-2E (setup of experiment in Table 2)

Slika 9. Prikaz makro presjeka zavara izvedenih sa i bez primjene aktivirajućeg topitelja VS-2E (prema planu pokusa prikazanom u tablici 2)

From the electric arc stability point of view, according to diagrams in Figures 7 and 8 the most unstable is welding process for trial No. 12 where instability and variations of welding parameters are noticed. The connection between parameters variations and weld quality can be noticed on the weld macrosections shown in Figure 9; for trial No. 12 welded with the activating flux and lower welding parameters (Table 2) the porosity and lack of fusion can be noticed.

5. Conclusion

The first part of the paper deals with the possibilities of application and upgrading of an on-line monitoring system for welding process parameters monitoring.

In the experimental part of the paper, the influence of the activating flux on the changes of the welding parameters is presented. Conducted research has shown that failures in welded joint can be connected with unstability of welding parameters monitored by on-line monitoring system (for example: welding with low welding parameters in the presence of activating flux for ATIG process).

In further research, the activating flux for ATIG welding process VS-2E (developed for application on nonalloyed steels) will be applied for analysis of the activating flux influence on the properties of the joint welded with the arc stud welding process.

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