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Reliability of Welding Parameters Monitoring System

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Preliminary note

This paper presents application of self developed On-line monitoring system for main welding parameters acquisition and data processing at arc welding and resistant welding process. Recorded data by On-line monitoring system is compared with data measured by oscilloscope. Based on comparation of both methods, it is possible to conclude that there are no significant differences between recorded data. Presented On-line monitoring system is appropriate and accurate enough for welding parameters monitoring and control.

Pouzdanost sustava za praćenje parametara zavarivanja

Prethodno priopćenje

U radu se predstavljaju primjene vlastitog razvijenog On-line monitoring sustava za prikupljanje i obradu glavnih parametara zavarivanja kod elektrolučnog i elektrootpornog zavarivanja. Snimljeni podaci pomoću On-line monitoring sustava su uspoređeni s podacima izmjerenim pomoću osciloskopa. Temeljem usporedbe obiju navedenih metoda, može se zaključiti da nema značajnih razlika između registriranih podataka. Predstavljeni On-line monitoring sustav je prikladan i dovoljno precizan za monitoring i kontrolu parametara zavarivanja.

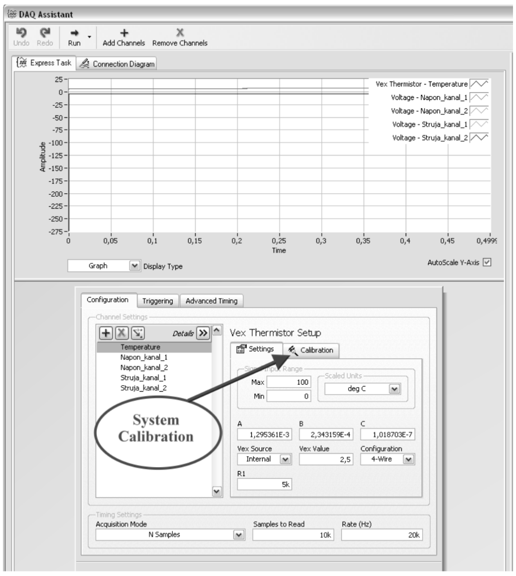
1. Introduction

Monitoring of main welding parameters (welding current and voltage, welding speed) and other welding variables (preheating and interpass temperature, cooling time and cooling rate, arc length, stick-out, …) is very important due to stability and repeatability of welding process. Modern welding equipment is very sophisticated and relatively not so easy to use and that is the main reason of permanent insisting on strict determination of welding parameters. Welding parameters have direct influence on weld joint properties (mechanical, geometrical and other properties). In order to avoid collapse of welding joint on the construction or product the challenge of determination & control and recording of welding parameters was presented from welding technology in practical application. Development of equipments for welding parameters control and recording followed development of power sources for welding. Thanks to the modern electronic industry and hardware & software for data acquisition and processing it was possible to develop and implement On-line monitoring system for on-line and off-line data processing. This is an important step forward in quality and reliability assurance of modern welding constructions and plants. In this paper authors present self developed monitoring system based on long time practical experience and international cooperation [1-9].

2. Upgraded On-line monitoring system version

The measurement done with On-line monitoring system based on the previous work, [1-9] are suitable only for the DC measurements. Thus, when applied to the AC welding processes, only the upper half-period of the voltage and current waveforms can be obtained. The mentioned On-line monitoring system is build upon the basic modules from Analog Devices, and together with a PC forms a working system environment. Cable used for connections has CLASS I. isolation level, and as such is not suitable for measurements in the welding processes due to the electromagnetic compatibility. The system upgrade is based on products presented by National Instruments (NI), which has in the last decade, shown significant results both in hardware and software support, with usage of the LabView Environment [10]. The proposed On-line welding monitoring system is based on PCI-6052E measurement card with capability of 333 kS/s. Cable used for connection between the mentioned measurement card and process unit is a CLASS III. cable, which compiles to the regulative with respect to the electromagnetic compatibility for welding related measurements. PCI-6052E card operates with digital inputs and outputs (I/O), and has 16-bit A/D converter with capability of multiplexing 16 analog inputs. Besides the analog inputs, the card also has 16-bit analog outputs with controlled voltage range of ±10 V. The card can control 8 digital inputs/outputs (24-bit counters included) in total. The monitoring system is a real-time application, with no delay in data acquisition. The measurements and system monitoring is based upon A/D inputs that determine the accuracy and the calibration. The device (when observed as a unity) can undergo a self-testing and a calibration process with international certificate from the International Measurements Assosiation. By contracted license with NI we have the needed basis for the Measurements in industrial conditions. (Figure 1)

In order to ensure the quality in the On-line monitoring of given parameters, the external process unit SC-2350 (Figure 2) is used. The SC-2350 unit has additional ports for configurable modules (Figure 3). Besides the support for highly accurate modules with galvanic isolation, the process unit has also a TEDS (*Transducer Electronic Data Sheet*) sensors support based on IEEE 1451.1 standard. Each module has a different measure range, so for the proposed monitoring system, the following modules are used: SCC-AI02, SCC – AI05 and SCC – TC02. SCC-AI02 is a module with galvanic isolation for measure range of ±20V [10]. This module, with two analog inputs, is used for voltage measurement in welding monitoring system. There is a possibility of an upgrade towards greater measure range. The SCC-AI05 is a module with ±1V of measure range, and the SCC-TC02 is a temperate module with support for a thermo-couple based measurements. The compensation for a temperature module is done by using RTD resistor, which is implemented in the module. Very important parameter is the sampling frequency which is set to 10 kHz. This is a very significant improvement when compared to the previously reported monitoring system [1-9]. The current measurement is realized with indirect current measurement through Hall probes with various ranges (0-500 A and 0-2000 A) [11] and with Rogowski coil. As Rogowski coil is not suitable for DC measurements, the Hall probes are used instead (Figure 4). The advantage of the Rogowski coil with respect to the Hall probes is larger measure range for AC measurements.



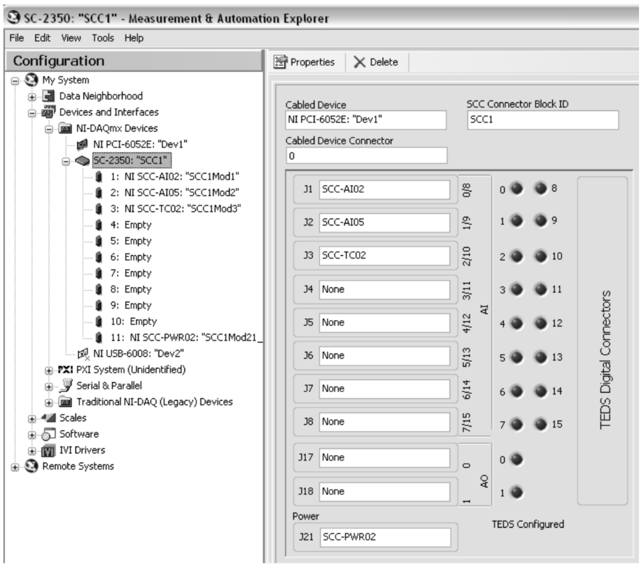


Figure 1. NI System Calibration

Slika 1. NI kalibracijski sustav

Figure 2. Connecting peripherals measuring station
Slika 2. Spojiva periferna mjerna stanica

Figure 3. Measurement modules
Slika 3. Mjerni moduli

Block scheme of welding parameters (Figure 5) is based on PC data acquisition and analysis through LabView program package. The data is stored in the Excel worksheet, which are then used to generate the traces of the measured welding voltage and current. In order to enable the data acquisition the PCI measure card is used. By connecting the PCI card with the measure station (containing the measure modules) the compact measurement system is realized. The sensor elements are then connected to the system and the needed scaling is employed.

This paper presents an On-line monitoring system for welding voltage and current. Due to different welding methods, the system must be set up for a given welding method. The welding methods used in this paper are resistance spot welding and manual arc welding by coated electrode. The photographs of the real components used for measurement are given by Figure 6.

3. Application of On-line monitoring system at arc welding and resistant welding

Observed application and control system is divided into two methods of measuring current. During the current measurement of resistant welding we make use of the Rogowski coil, which has three operating or measuring ranges. With the active switch we select the measuring

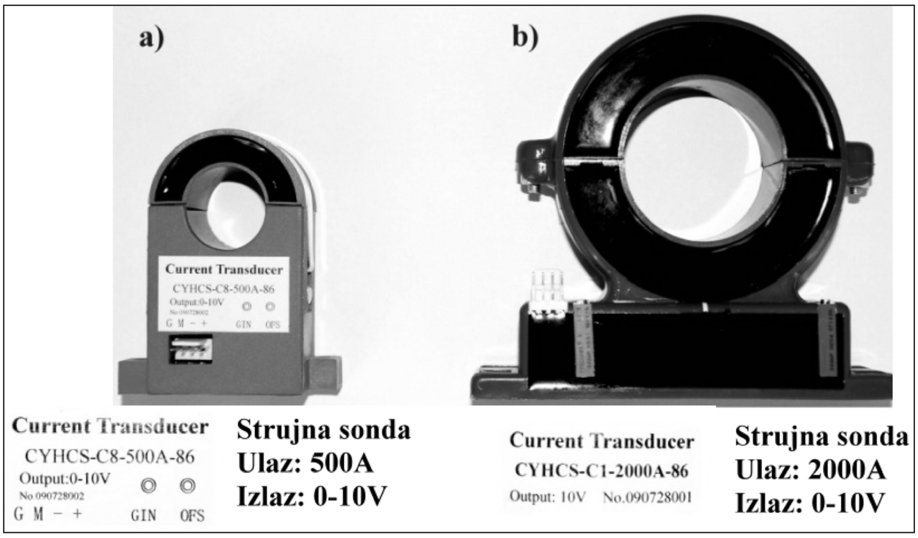


Figure 4. Versions of Hall probes with active power: a) 0 – 500A ; b) 0 – 2kA
Slika 4. Varijante Hall sondi aktivne snage a) 0 – 500A ; b) 0 – 2kA

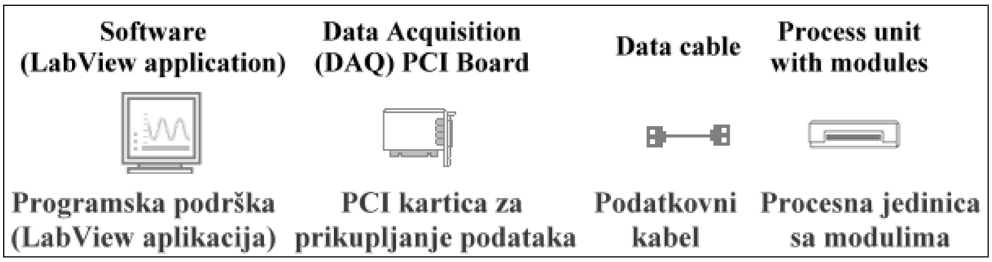


Figure 5. Block scheme of welding parameters measurement system
Slika 5. Block shema mjernih parametara sustava

range and define the analog output signal. Active switch has a battery supply, and is galvanic detached (GD) from the rest of the measured circuit.

Table 1 shows the basic characteristics of the device for resistant welding. Such equipment can work on 230V (single-phase) and on 0.4kV (three-phase). With the use of the three-phase electrical transformer higher output voltage and current are attempted. This automatically increases power and the welding current, what must be in concordance with given material and weld time. A very important parameter except the welding current and voltage in the single-phase and three-phase connection is intermittency, which is defined with 50. That means that the percentage of welding time is equal to the percentage of the cooling time of the transformer. The device is air cooled (marked N in Table 1), with upper working temperatures of 180 °C (marked F in Table 1).

Table 1. Resistant welding power source display with specific data by producer

Table 1. Pločica uređaja za elektrootporno zavarivanje sa specifičnim podacima proizvođača

gorenje varstroj Lendava				
Ručni točkasti z. ~ ~ Manual spot welder		JUS N.H9.221		
Typ: VST 3		N° 641 468		
Napon napajanja / Supply voltage	V	380	220	
Napon praznog hoda / Idle voltage	V	2,7	1,5	
Nazivna snaga / Nominal power	kVA	1,8	1	
Intermitencija / Duty cycle	%	50	50	
Hlađenje / Cooling		N	N	
Razred izolacije / Insulation class		F	F	
Točkanje / Spoting	mm	2+2	1+1	
Zavarivanje / Welding	mm	5+5	4+4	
RSO: NN 0590086	Masa / Mass 15kg		Godina proizvodnje / Manufacturing year: 1991	

Except used Rogowski coil, for the manual arc welding Hall probes were used in the form of an current transformer. Such a current transformer has an opened control loop and makes possible its introduction to an electric circuit without interruption of the same. Dependent on the manufacture technology Halls probes can be selected for the alternating current or direct current component. It is necessarily to supply Halls probes with an external voltage. Dependent on the measuring range, each Halls probe has an output voltage with 0-10 V range. On the indicated voltage this range scales from 0-500 A or 0-2 kA. Thus the output voltage on the clamps appears we must supply the Halls probe with a symmetrical power supply (±15 V) from a measuring station SC-2350. Realization of the power supply is possible with the transformer with middle point on the secondary (which is realized on the older monitoring system) or with a modern approach in electronics, witch uses impulse process of the transformers on higher frequencies. Systems with such a feedback are reliable and contain compensation of external influences, which is in our case the temperature. Then the measurements of the welding current is more precise and temperature independent.

Figure 6. Measurement system parameters during welding

Slika 6. Elemeti mjernog sustava parametara zavarivanja

3.1. Resistant spot welding

During the resistant spot welding laboratory conditions for the measurement of the welding parameters were obtained. The measuring equipment with the appropriate transformers [230V/2kVA] with a galvanic detachment is used, so that the higher welding currents do not have significant influence on the measurement. Except the measuring devices, galvanically separated are the oscilloscope and the computer from the rest of the supply network in order to obtain better measuring quality. A representation of such work place and the connection of the instrumentation are shown in Figure 7.

During the resistant welding the measurements were performed in two modes, with the oscilloscope [Tektronix TDS224] and by a monitoring measuring system. With relatively low measuring voltage, we entered the measurement with the oscilloscope. Taking into consideration very high welding current which is in kA, the Rogowski coil corresponded to the measuring range. Considering high current results, the oscilloscope is galvanically separated with the laboratory transformer with relationship 1:1. Figures 9. a) and (b), show a wave shape of the voltage and current in the different times of the welding cycle. The first channel shows the voltage which decreases in consideration of the duration of welding, and the second channel shows current which is decreased. Figure 9. a) shows the channels 1V/Div, while the Figure 9. b) shows the second channel 5 V/Div. With the active switch for the Rogowski coil was adjusted 3kA (1mv/A), what means that 1V corresponds to 1kA (Figure 9, a).

By using the monitoring measuring system which is connected to the computer, results in Figure 10 are obtained. The measuring blocks and converter blocks were defined by the LabView program package, which creates its graphics and tables, too. From the generated table precise data were obtained and presented in Figure 11 and Figure 12. Such representation shows the trajectory, from which one can pick out the critical points.

The critical points in the Figure 12 characterize the beginning of welding (detail “A”), while the end of welding characterizes detail “B”. At the beginning of welding it comes to asymmetrical curvatures, the cause of it is the air distance between two materials and impurities on the material surface. In the voltage diagram one can see a small increase of the voltage in the beginning of the process. With the separation of the connecting electrodes it comes to interruption of the electric circuit, then detail “B” reveals itself, it represents the phenomenon of the self induction which appears during an interruption of the electric circuit, released by the current of the

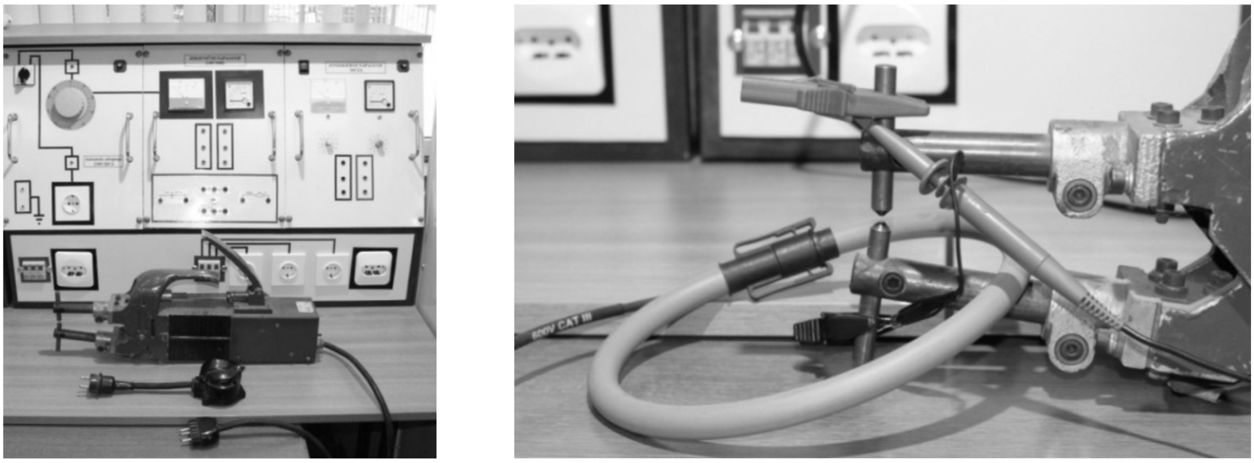


Figure 7. Working place: a) connection to laboratory desk; b) connection of Rogowski coil and oscilloscope clamps for voltage measurement

Slika 7. Radno mjesto: a) priključak na laboratorijski stol; b) spoj Rogovski svitka i sonde osciloskopa za mjerenje napona

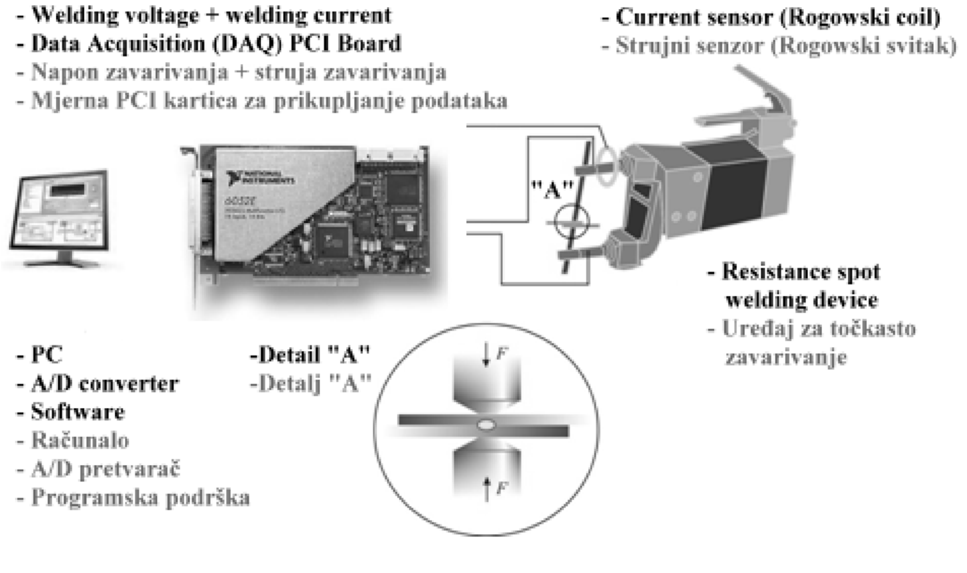


Figure 8. Monitoring of voltage and current

Slika 8. Mjerenje napona i jakosti struje

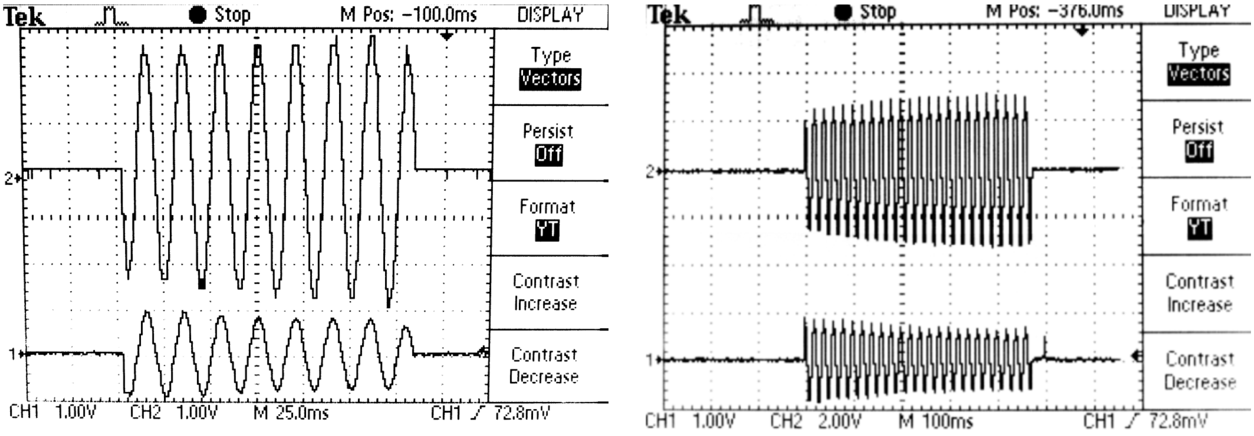


Figure 9. Measuring voltage and current with an oscilloscope: a) weld time 160 ms; b) weld time 455 ms

Slika 9. Mjerenje napona i jakosti struje pomoću osciloskopa: a) trajanje zavarivanja 160 ms; b) trajanje zavarivanja 455 ms

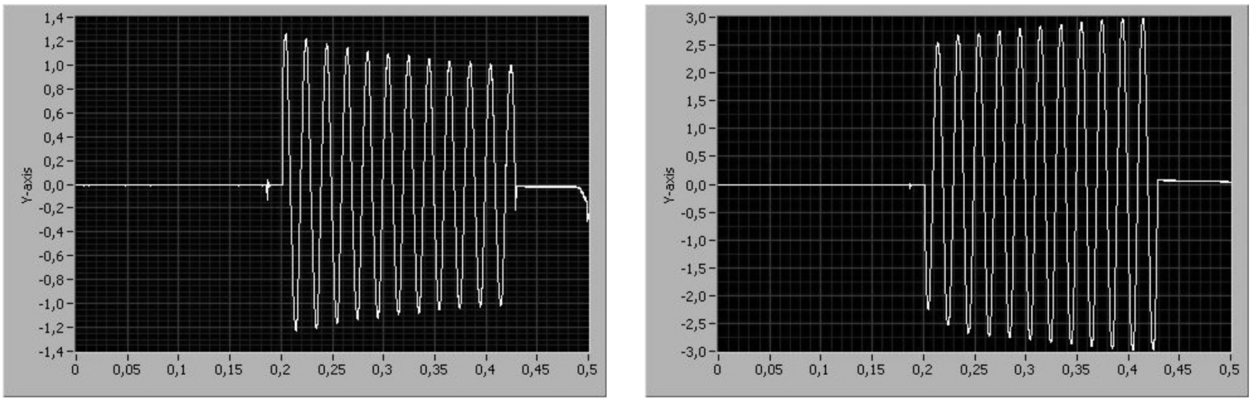


Figure 10. a) Graphic display of voltage [V] and b) current [kA] in the LabView programming environment

Slika 10. a) Grafički prikaz napona [V] i b) jakosti struje [kA] u okruženju programa LabView

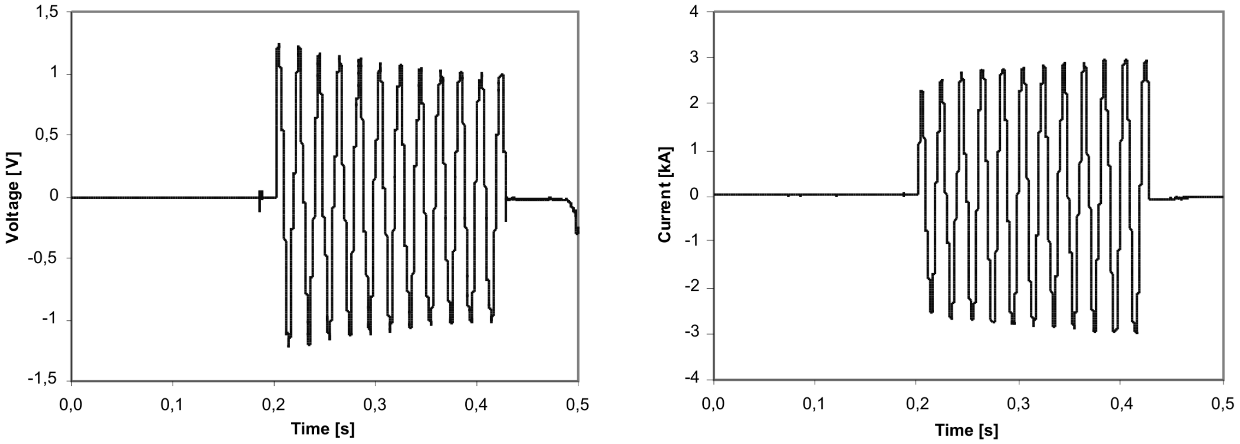


Figure 11. View of voltage and current from the table generated by LabView Report MSOffice block set

Slika 11. Izgled napona i jakosti struje generiranih iz tablice LabView Report MSOffice block set

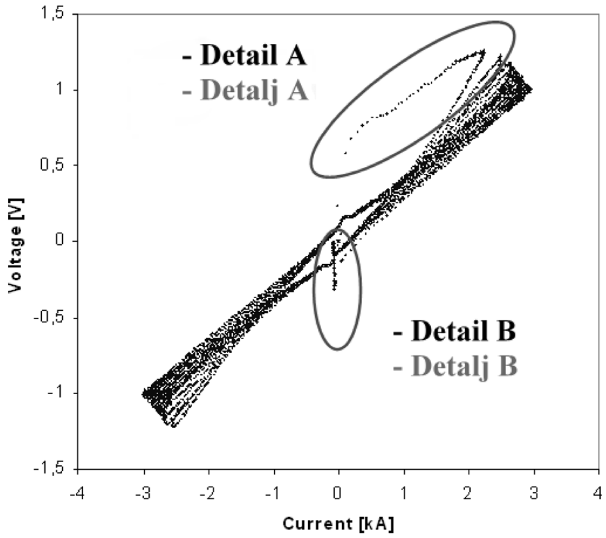


Figure 12. Trajectory of voltage and current

Slika 12. Trajektorije napona i jakosti struje

magnetization of the transformer. This phenomenon is not as much visible on the standard transformers, due to relatively smaller currents.

3.2. Manual metal arc welding (MMAW)

Manual arc welding represents a procedure that is simple to use. It applied for welding and to weld each kind of metals with the help of the direct current or alternating current. With the following measurements the monitoring of the parameters for the direct current welding device is accomplished. The electrical arc commences with a short-circuit between the point of the electrode and the working material. The procedure is manual, which means that a welder (person) is necessary. Illustration of a laboratory work place is shown on Figure 13. Fundamental characteristics of the welding machine are shown on Table 2.

Figure 13. Laboratory working conditions

Slika 13. Laboratorijski radni uvjeti

Table 2 represents the block draft of the rectifier in the impulse regime as well as the direct current adapter. The basic principle of the work is based on the rectification of the single-phase voltage supply of 230V and raising the working frequency to few kHz. Thus avoids the mass of the transformer because the power of the transformer is no longer important, but only the condition for the work in the impulse regime. On the secondary side of the impulse transformer the adapter is realized with the hardware of energy electronics (Trijac, Diac or MOSFET). Such converter, (normally carries out with paired MOSFET transistors) grants low voltage and higher current. This converter is also called the direct current down converter. Thus the cos φ = 0.99 was obtained, that is the indicator of the minimum losses in the turn and the iron core of the sheet metal. Thus they fulfill the prescribed standards of the International Electronical Commission 974-1, YDE0544-1, EN60974-1 and EN 60 974-1 with the minimum THDI (*Total Harmonic Distortion of Current*). This equipment is intended for long weldings, its marked therefore with „AF“, it stands for air cooling with 50 % work and exactly the same much cooling of the equipment. The isolation-gradates of the equipment is IP23 with the limities for the voltage and the current of 25.6 V and 140 A, respectively. As is visible from the following figures,

Table 2. MMAW power source display (inverter) with specific data by producer

Tablica 2. Pločica REL uređaja za zavarivanje (inverter) sa specifičnim parametrima proizvođača

Fronius	TIP / TYPE TRANSPOCKET 1400			
	IEC 974-1	YDE 0544-1	NF EN60974-1	0VE N/EN 60 9741
5A/20.2V-140A/25.5V	X(48°C)	%	35%	100%
	I_z	A	140 A	100 A
	U_z	V	25.6 V	24 V
	U_1	I_1	I_1	I_1
cosφ /cosphi 0.99 (140 A)	230 V 50 60 Hz	16 A	16 A	16A
Razred izolacije / Insulation classB		kVA	6.1 kVA	3.8 kVA
Hlađenje / CoolingAF	IP23	S		

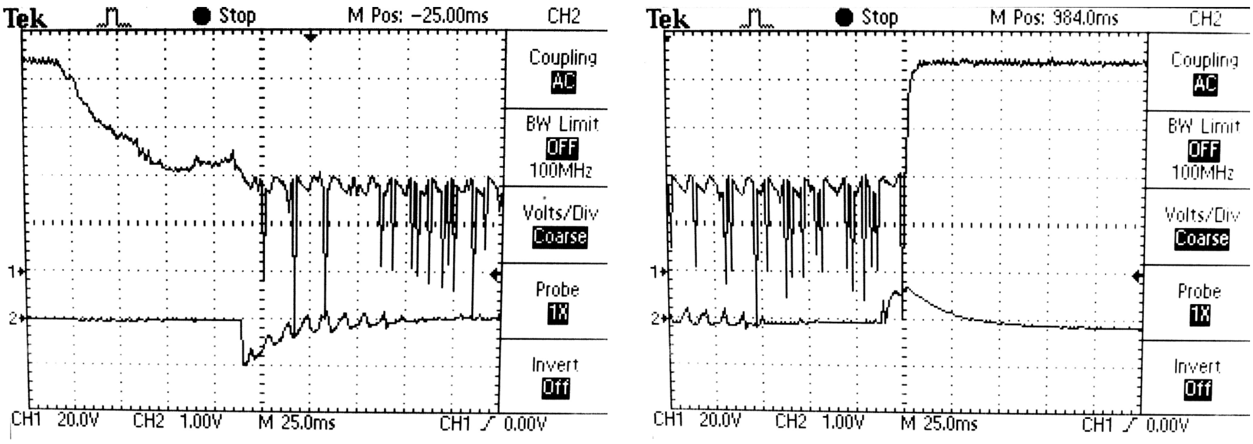


Figure 14. a) Start welding (electric arc establishment), b) End welding (electric arc suppression)

Slika 14. a) Početak zavara (uspostavljanje električnog luka) i b) kraj zavara (gašenje električnog luka)

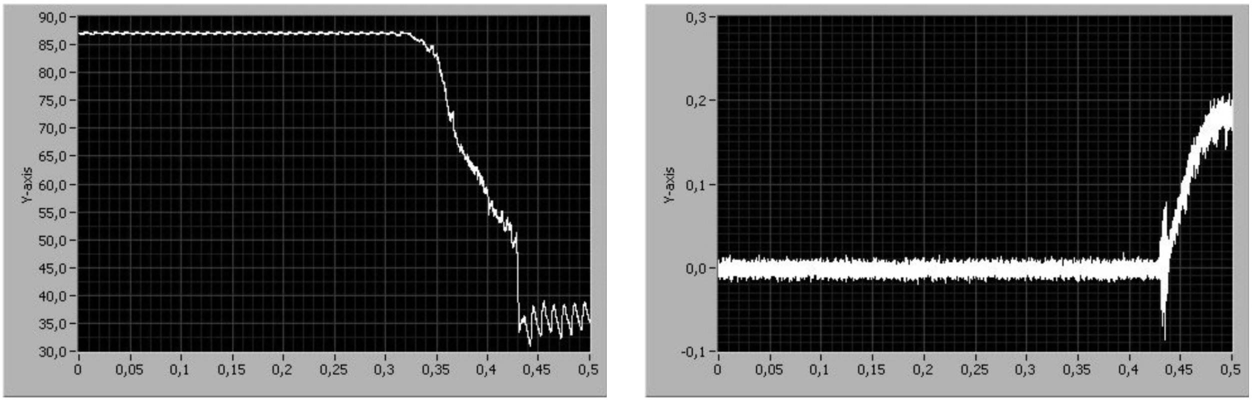


Figure 15. a) Weld start run idle and operating voltage and b) current [0.2 V ≡ 100 A]

Slika 15. Početak zavara: a) Napon praznog hoda i radni napon [V]; b) Struja zavarivanja [0.2 V ≡ 100 A]

the voltage of the idle run is present and it equals to 87,8 V. After the established electrical arc, the voltage drops to the nominal working voltage, while the current increases. The nominal current depends on the electrodes used, and also upon the welding device set up. The Figure 14 a) is a measured representation of the voltage parameters (channel 1) and the current parameter (channel 2). The voltage is measured with the oscilloscope, while for the current measurement, the Halls probe with the measuring range was up to 500 A is used. Interruption of the electrical arc is shown in Figure 14 b).

When using monitoring measuring system, with the computer application LabView we got the results, which are presented in Figure 15a) and 15b). Because the measurements of the current with the Halls probe, the indirect measurement is taken in consideration, with appropriate scaling (0.2 V equals to 100 A). The results of the measurements follow the transition phenomenon obtained with the oscilloscope in previous measurement, even if it's a different weld. Simultaneous measurement with the oscilloscope and the monitoring measuring system is not possible, therefore welds are settled in the different interval of duration.

Halls probe 0-500 A has an output voltage of 0-10 V, which can be attached without problems to measuring instruments like the oscilloscope and monitoring measuring system SC-2350 in the combination with the PCI-6052E. That is how the electrical arc suppression during the separation from the piece of work was measured, the Figure 16. It can be seen that the working voltage increases and the energy adapter goes into the condition of the idle run, Figure 16 a). During the suppression of the electrical arc, the current, Figure 16 b), falls on zero. with the statement for Y-axis [0.2 V ≡ 100 A].

High-quality representation of the voltage and current during the beginning, expiration and end of the welding is given in the Figure 17. Beginning of the weld sets a voltage diagram and the voltage of the idle run which falls with the production of the electrical arc to a somewhat lower value. Measured voltage of the idle run equals to

87,8 V, whereby the voltage after the production of the electrical arc equals to a value between 33 V and 39 V. Detail A in the Figure 17 represents the voltage during the production of the electrical arc. Detail B characterizes the behavior of the current during the production of the electrical arc. Here are the imperfections and uncertainty of the hands of manual welding visible. During the welding measuring parameters should be steady. In the

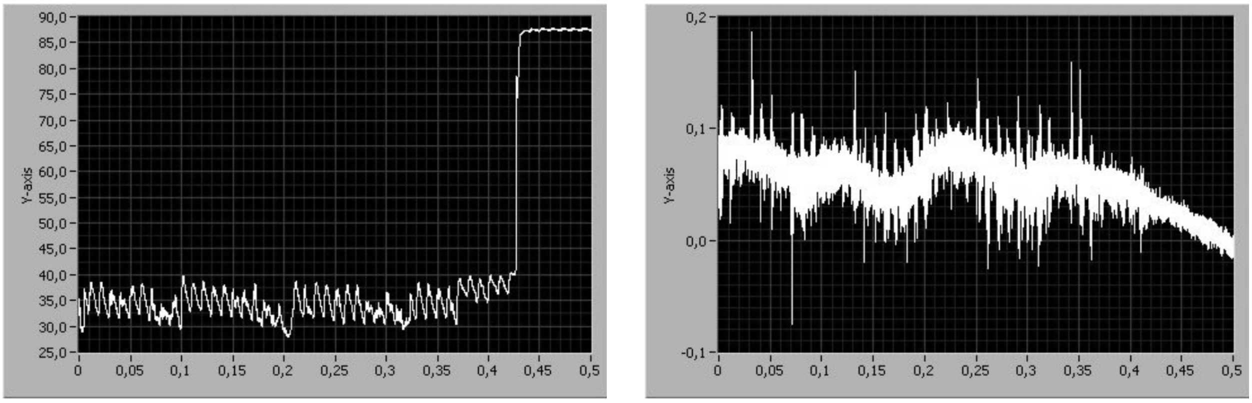


Figure 16. a) Voltage [V] at electric arc suppression and b) current [0.2 V ≡ 100 A]

Slika 16. a) Napon gašenje električnog luka; b) Struja zavarivanja [0.2 V ≡ 100 A]

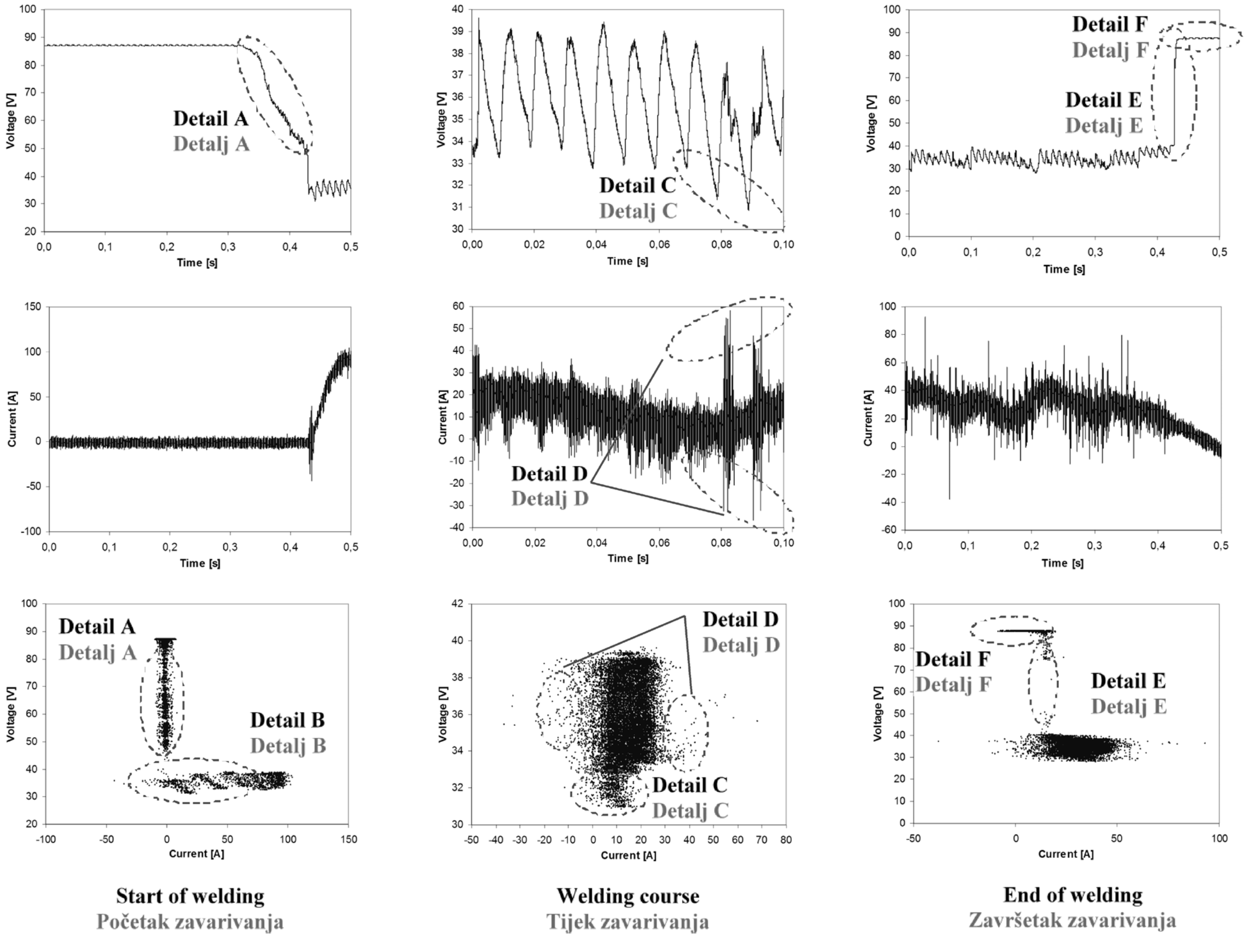


Figure 17. Recorded welding parameters (welding voltage and current)

Slika 17. Snimljeni parametri zavarivanja (napon i jaksot struje zavarivanja) midst of the imperfections and hand welding comes it to small final results (peaks), detail C. Trajectory which is defined during the welding procedure shows the experience of the welder. The less "points" on the details C and D are, the higher-quality welds are obtained. Electrical arc suppression results with the end of welding. Then a sudden voltage change appears, detail E, where the electric circuit, or the electrical arc is interrupted. Such phenomenon is much shorter in duration with respect to electric arc production, what can be seen from the detail A. Then the system returns to the idle run and the detail F defines the voltage of the idle run. On the trajectory can also be seen the crossing from working voltage to idle voltage, with simultaneous current decrease.

4. Conclusions

This paper presents practical examples of On-line monitoring system application as well as application of other laboratory methods for the same measurements as a confirmation and validation of data recorded by On-line monitoring system. Self developed monitoring system is applied on two different welding processes: resistant spot welding Manual Metal Arc Welding (by direct current). Based on obtained results it is possible to conclude that presented monitoring system is very suitable for practical application. Differences between data recorded by On-line monitoring system and by oscilloscope for laboratory data acquisition are not significant. Sampling frequency at performed experimental measurements of welding parameters was 10 kHz what is relatively appropriate sampling frequency for commonly used and modern welding processes. That means that self developed On-line monitoring system has good chances for application on other, more sophisticated welding processes. So, next step in developing of On-line monitoring system will be application on other welding processes, especially at welding processes which use high frequency for electric arc ignition (Tungsten inert gas welding, submerged arc welding …).

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