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ON-LINE MONITORING SYSTEM - AN APPLICATION FOR MONITORING KEY WELDING PARAMETERS OF DIFFERENT WELDING PROCESSES[1)]

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Original scientific paper

This paper describes the application of an on-line system for the monitoring, aquisition and processing of key welding parameters. The on-line monitoring system has been successfully applied in practice to measure key welding parameters for different welding processes. Relevant examples of the information that can be obtained from the system during a welding cycle are presented.

Key words: *on-line monitoring system, welding parameters, welding processes*

Primjena on-line monitoring sustava za praćenje glavnih parametara zavarivanja kod različitih postupaka zavarivanja

Izvorni znanstveni članak

U radu se obrazlaže primjena on-line sustava za praćenje, prikupljanje i obradu glavnih parametara zavarivanja. On-line monitoring sustav uspješno je primijenjen za mjerenje glavnih parametara zavarivanja kod različitih postupaka zavarivanja u praksi. U ovom se radu daje prikaz najznačajnijih primjera primjene on-line monitoring sustava tijekom trajanja procesa zavarivanja.

Ključne riječi: *on-line monitoring sustav, parametri zavarivanja, postupci zavarivanja*

1 Introduction
Uvod

The monitoring and control of key welding process parameters is of 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. Depending on the particular welding process chosen, other relevant parameters may have to be considered (welding speed for electric arc welding, wire-feed speed for electric arc welding with consumable electrodes and a shielding gas, the duration of current flow for stud arc welding and resistance welding, etc.). The quality of the weld depends on the welding parameters and heat introduced both during the welding sequence (i.e., some welding parameters have a lesser or greater effect on the geometric shape of the welded joint) and weld joint cooling (here, the joint cools down more or less rapidly in relation to the input of thermal energy, which in turn affects the metallurgical structure of the joint, its mechanical properties and resistance to miscellaneous defects within the joint). 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 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. In this paper, some application examples of the system are described for several different processes.

2 Basic characteristics of the on-line monitoring system
Osnovne karakteristike on-line monitoring sustava

A more complex 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 [1].

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 accomodate 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.

A few of the applications of the on-line monitoring system are: calibration and characterization of the welding power source, 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.

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

- mean voltage value: $$\overline{U} = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} U(t)\mathrm{d}t, \text{ V}$$

[1)] Contribution of NIST: Not subject to copyright in the U. S. Some tradenames are included to fully describe the equipment; no endorsement or criticism is intended.

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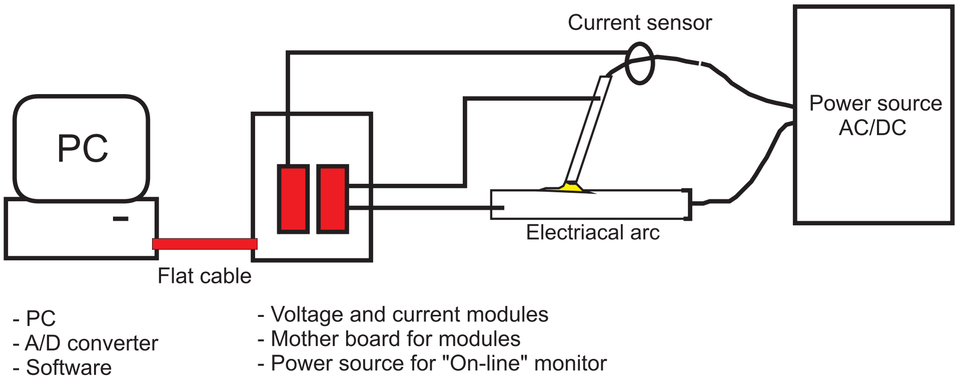


Figure 1 Schematic of the on-line monitoring system used for gathering data during electrical arc welding.
Slika 1. Shematski prikaz on-line monitoring sustava za prikupljanje podataka tijekom elektrolučnog zavarivanja

- mean current value: $\overline{I} = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} I(t)\mathrm{d}t$, A
- instantaneous power: $P = U \cdot I$, W
- instantaneous heat input: $E = U \cdot I \cdot t = I^2 \cdot R \cdot t$, J

The system collects data at 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), …).

3 Application examples of the on-line monitoring system
Primjeri primjene on-line monitoring sustava

Through continuous development over the years, the on-line monitoring system has been significantly advanced and successfully applied for obtaining welding parameters from different welding methods, mainly for characterization purposes. Later in this paper, some examples of successful system applications are presented.

3.1 Monitoring of welding parameters for the MAG-STT welding process [2-4]
Praćenje parametara kod MAG-STT postupka zavarivanja

MAG-STT (Surface Tension Transfer) is a modern welding technology that is very suitable for welding thin plates. The MAG-STT power source does not have a falling characteristic (CC) or a flat one (CV) [2]. Based on current demands of the electrical circuit, the unit provides output parameters that allow welding in short circuits, where the molten droplet is conveyed to the weld bead by the surface tension between the droplet and the weld pool. The MAG-STT unit circuitry monitors and precisely controls the welding current at all stages, while optimal arc characteristics are maintained even for significant alterations of the electrode extension. In principle, the unit is capable of adjusting the required welding current each microsecond. It can operate with various shielding gases and their mixtures (such as CO_2, Ar-82 %+CO_2-18 %, Ar-98 %+CO_2-2 %,…), depending on the welded type of material. Decreased spatter of molten metal, less fumes and lower heat radiation contribute to a more operater-friendly environment. In addition, lower heat input means lower deformation and residual stresses as side-effects of welding.

One of the disadvantages of this particular technology lies with its narrow field of application, being root welding and the welding of thin plates. Consequently, its full scope of advantages only appears in a suitable combination with other high-efficiency technologies that fill the weld groove more efficiently.

An on-line monitoring system has been used to record alterations of current and voltage during MAG-STT welding in vessel construction. Specifically, it has been used during root pass welding of a pipe butt joint. For the filler material, wire specified as DMO-IG of diameter 1 mm was selected; the shielding gas used was Ar-82 %+CO_2-18 %. The welding unit was a LINCOLN STT II with a wire feeder type LF 30.

On the control panel of the STT device, these parameters were set: I_{PC} = 265 A (peak current), I_{BC} = 65 A (base current), v_z = 3 m/min (wire-feed speed), v = 150 mm/min (welding speed) and Q_{gas} = 15 l/min (shielding gas flow). During the cycle, the pipe was rotated at constant speed, while the operator kept the arc between the 12 o'clock and the 2 o'clock positions, slightly down-hill.

During the welding, voltage and current were tracked and recorded using the on-line monitoring system. The sampling frequency was 20 kHz on each measurement channel. Figure 2a and 2b show the distribution of the mean voltage (a) and current (b) as recorded during the third segment of the circumferential root weld on the pipe perimeter. The arithmetic mean was developed for every 1000 values. The resulting 20 averages per second show a smoothed record of the voltage and current.

Figure 3 illustrates the voltage (upper curve) and current (lower curve) records in a randomly chosen weld segment of 0,012 seconds recorded at a sampling rate of 20 kHz.

3.2 Monitoring of welding parameters for the MAG process [5, 6]
Praćenje parametara kod MAG postupka zavarivanja

During research of MAG process stability under the application of solid and flux-cored electrodes, experimental welding of test specimen plates was performed. Optimal welding parameters were selected for each combination of electrode and shielding gas.

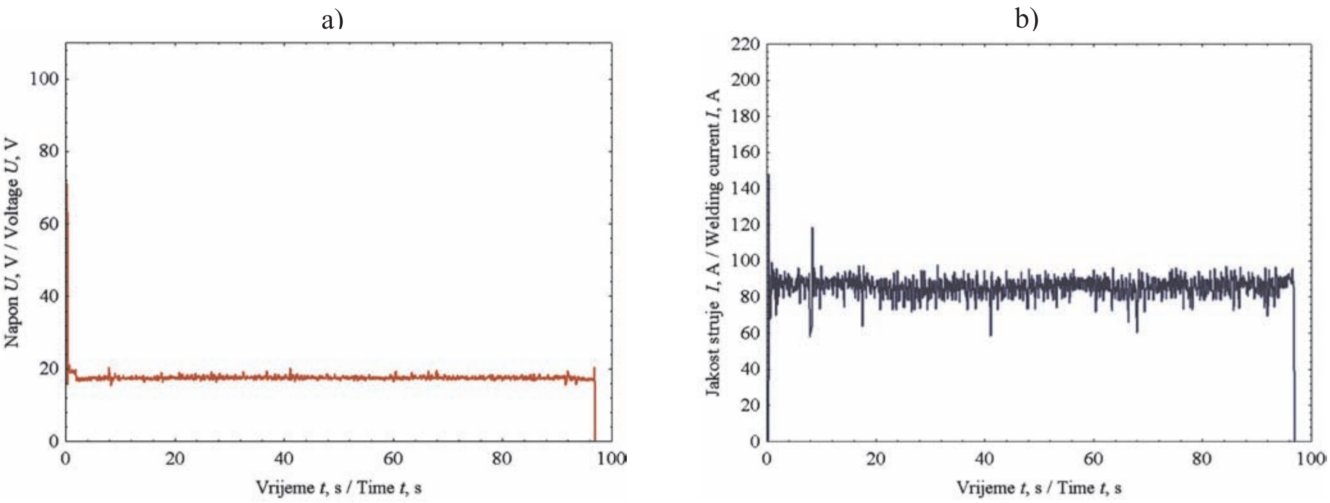


Figure 2 The distribution of average values of voltage (a) and current (b) during the welding of the chamber section, lasting 97 seconds. The sampling frequency applied was 20 kHz. The mean of the welding parameters was established for every 1000 measurements.
Slika 2. Distribucija prosječnih vrijednosti napona (a) i jakosti struje (b) tijekom zavarivanja dijela korijena zavara u trajanju od 97 sekundi. Frekvencija uzorkovanja: 20 kHz. Srednja vrijednost parametara zavarivanja je izračunata za svakih 1000 mjerenja.

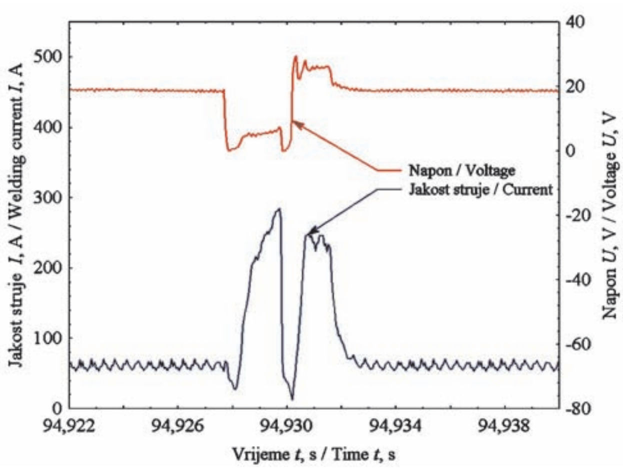


Figure 3 Voltage (upper curve) and current (lower curve) records for a randomly chosen welding duration of 0,012 seconds.
Slika 3. Zapisi napona (gornja krivulja) i jakosti struje (donja krivulja) za slučajno odabran vremenski interval od 0,012 sekundi

The welding experiment was structured into four levels, the shielding gas flow was kept constant at 16 l/min; other details of the welding procedures for the four welds were as follows in table 1.

Figure 4 shows distribution diagrams for welding voltage and current for the different experimental welds. Based on these visualizations and on additional statistical data processing off-line, conclusions can be drawn about the welding process stability, indicating optimal welding parameters. During this particular experiment, process stability indicators suggested a preference for flux-cored electrodes. Figure 5 shows the relationship between voltage and current during the welding procedure.

Table 1 Experiment setup for the MAG welding process
Tablica 1. Postavke pokusa za MAG postupak zavarivanja

Experiment level	Filler metal	Shielding gas	Wire feed speed v_z, m/min	Welding current I, A	Welding voltage U, V
A	Solid electrode (VAC60 Ø1,2 mm)	CO_2	5	265	26
B	Solid electrode (VAC60 Ø1,2 mm)	82 % Ar + 18 % CO_2	5	250	27
C	Flux-cored electrode (rutile type, Ø1,2 mm)	CO_2	8,5	200	28
D	Flux-cored electrode (rutile type, Ø1,2 mm)	82 % Ar + 18 % CO_2	8,5	200	28

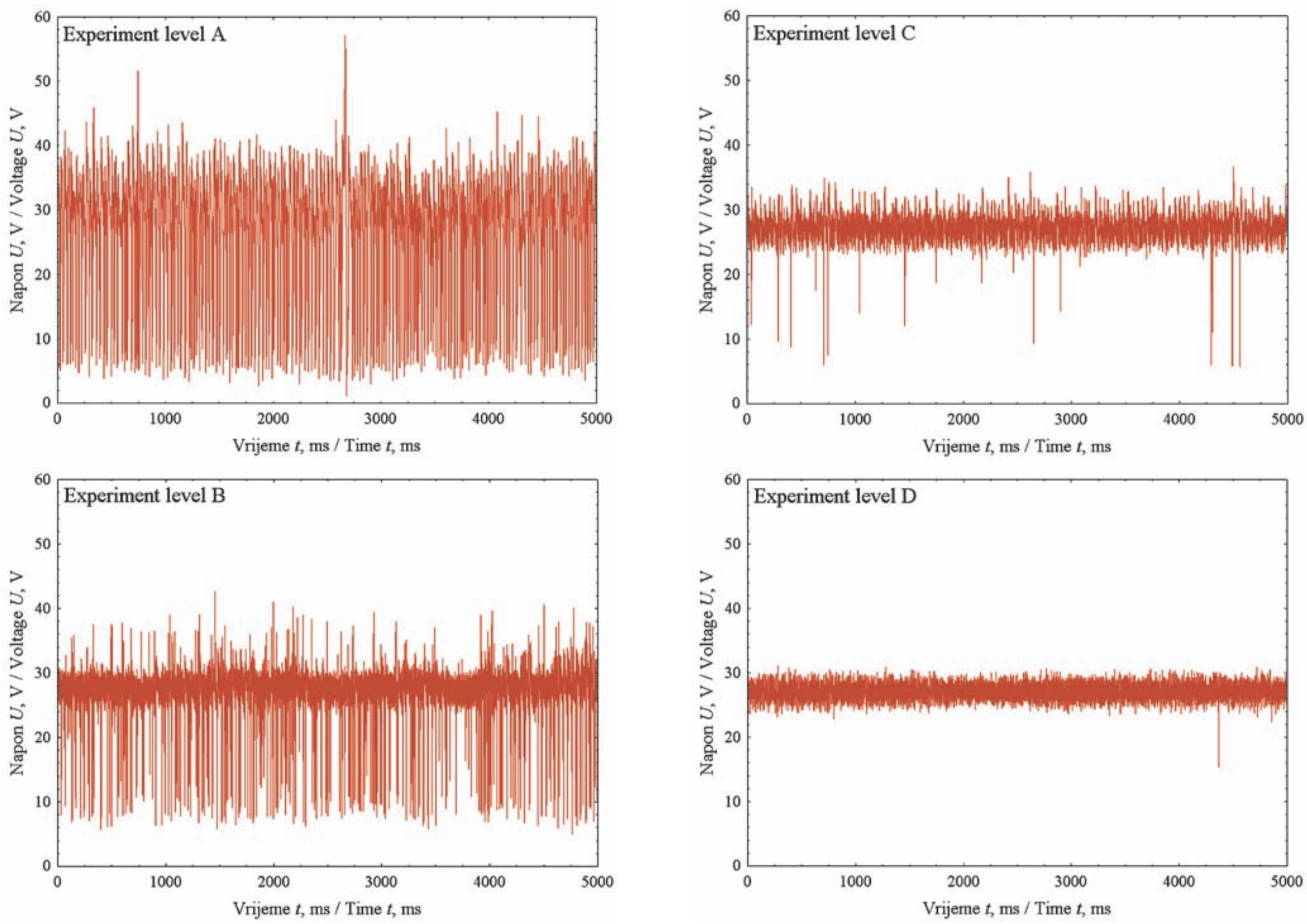


Figure 4 Real-time welding voltage distribution during MAG welding (according to the design of experiments in Table 1). Sampling frequency: 1 kHz
Slika 4. Distribucija napona u realnom vremenu tijekom MAG zavarivanja (prema postavkama eksperimenta u tablici 1). Frekvencija uzorkovanja: 1kHz

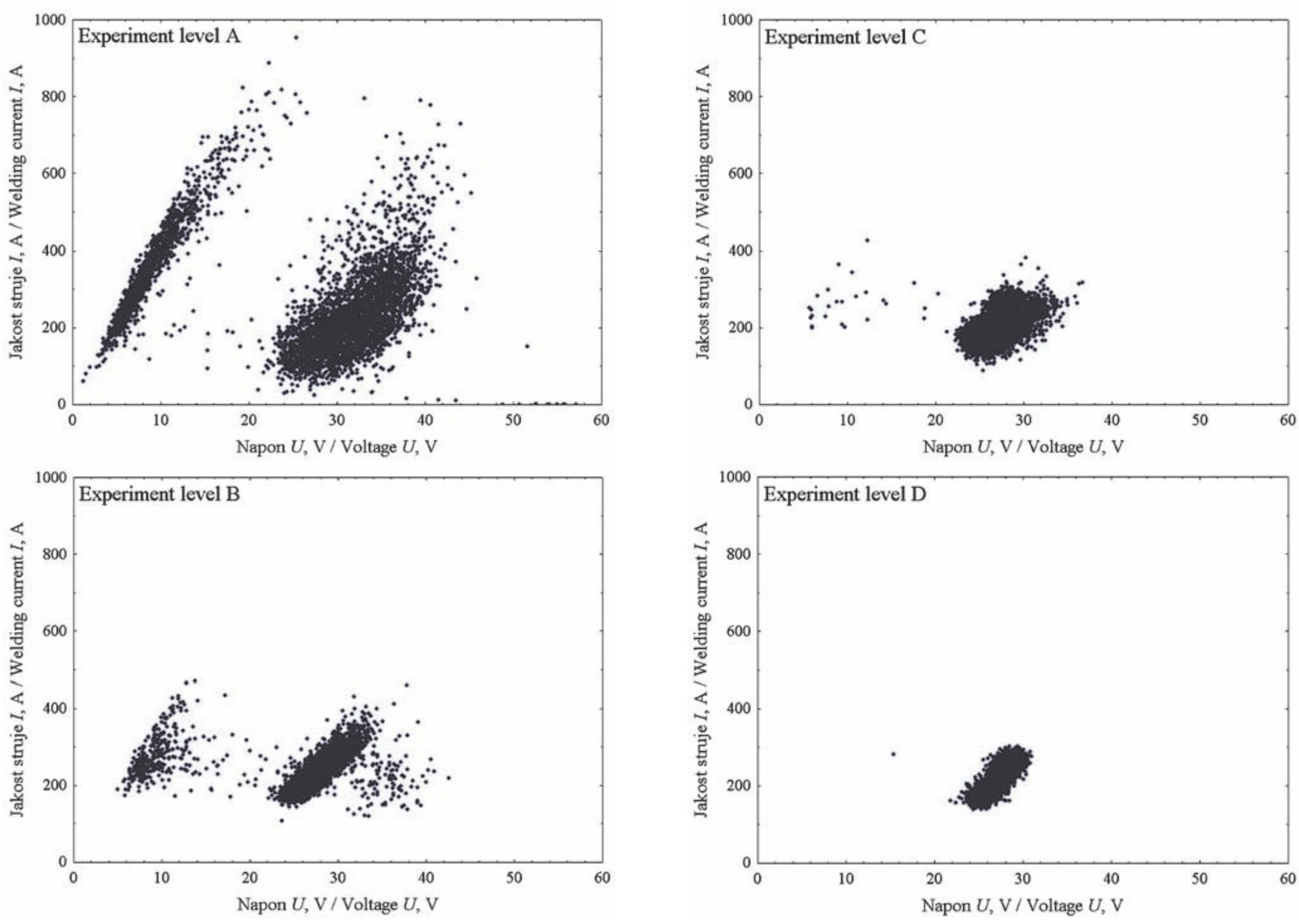


Figure 5 Relationship of current and voltage for all experiment levels.
Slika 5. Odnos jakosti struje i napona za sva stanja pokusa

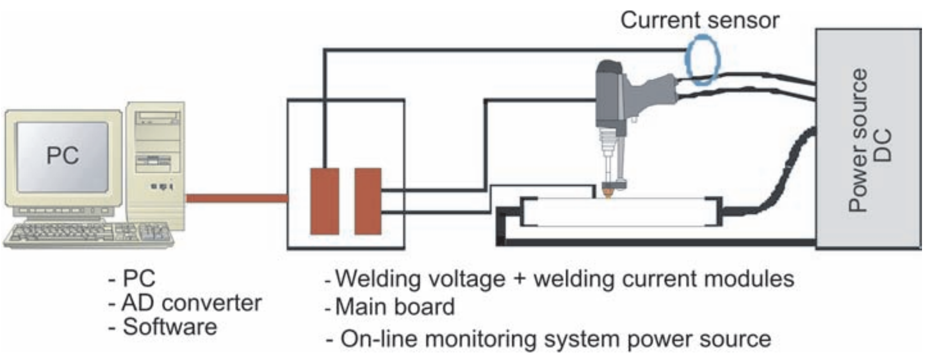


Figure 6 On-line monitoring system scheme for the acquisition of key welding parameters during stud arc welding
Slika 6. Shema on-line monitoring sustava za akviziciju glavnih parametara zavarivanja tijekom elektrolučnog zavarivanja svornjaka

3.3 Monitoring of welding parameters for the stud arc welding process [7-9]

Praćenje parametara kod elektrolučnog zavarivanja svornjaka

Stud arc welding (Figure 6) is a technology often applied in the construction of bridges and vessels, where dozens of different attachments are needed. Due to its simplicity, this technology is considered a high-efficiency welding method. The key parameters for stud arc welding with a ceramic ferrule are: welding current I, A; arc voltage U, V; electrical arc duration t ,s; stud retraction L, mm; stud retraction speed v, mm/s; and length of stud protrusion (plunge) P, mm.

This section briefly describes the data collection for voltage and current during stud arc welding in vessel construction.

According to the experiment plan, values for stud retraction (L = 2 mm) and plunge (P = 2,5 mm) were kept constant, while the duration of the electric arc and the welding current were being altered. As an illustration of how monitoring distinguishes good from bad welds, Figure 7 shows examples of a good weld joint (a) and that of an unstable welding process (b).

Figure 8 shows a correlation of welding current and voltage during the cycle (The welding process starts and stops are excluded according to Figure 9). Details of the cycle start and end are given in Figure 9a and 9b.

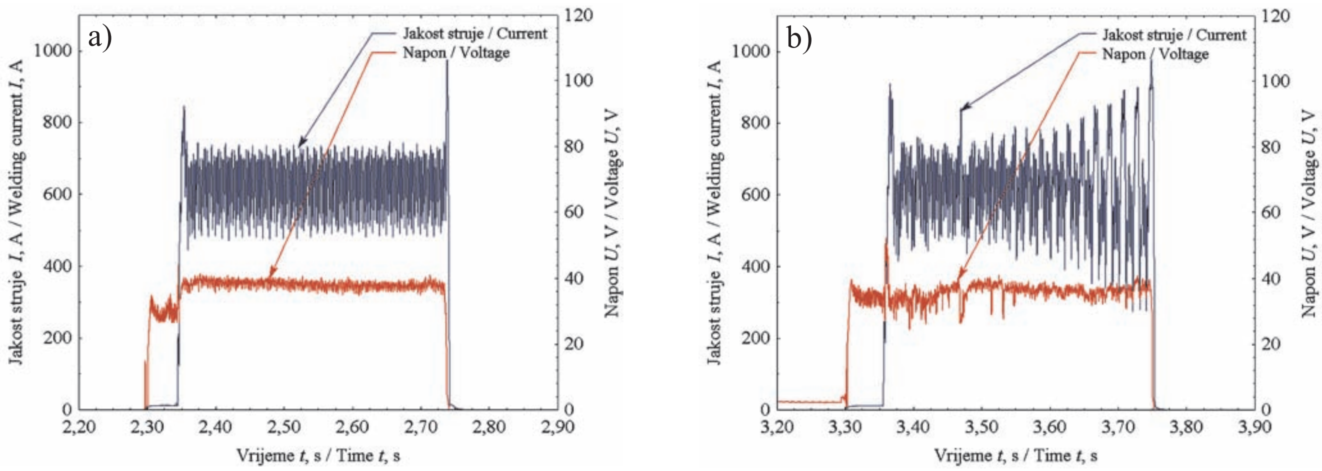


Figure 7 Welding current and voltage distribution during a complete stud welding process cycle.
Slika 7. Razdioba jakosti struje i napona tijekom cijelog ciklusa elektrolučnog zavarivanja svornjaka.

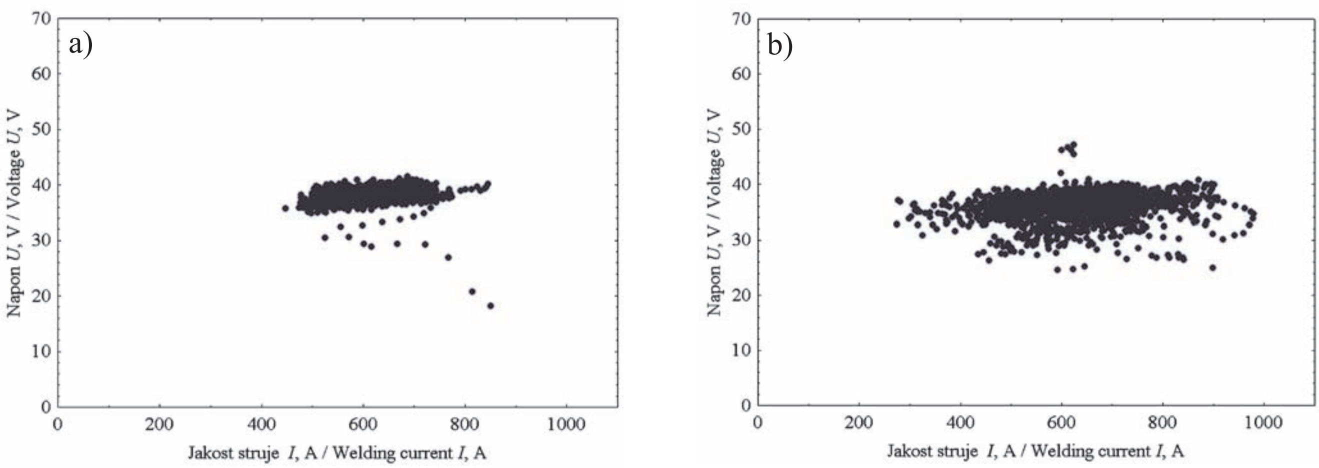


Figure 8 Dependence of the arc voltage on the welding current for the stud welding process
Slika 8. Zavisnost napona električnog luka o struji zavarivanja kod elektrolučnog zavarivanje svornjaka

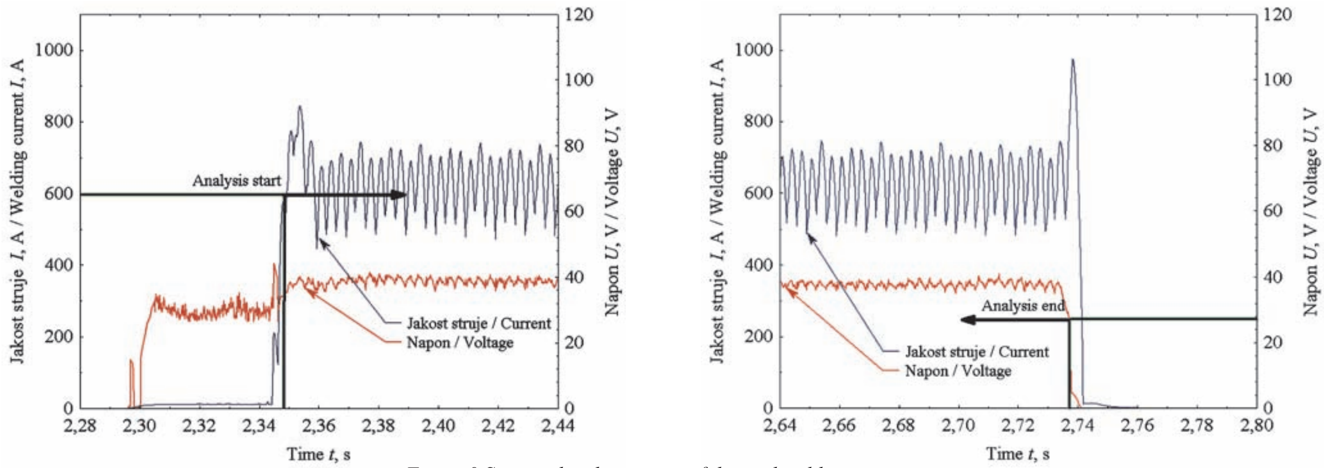


Figure 9 Start and end sequence of the stud welding process.
Slika 9. Početna i završna sekvenca procesa elektrolučnog zavarivanja svornjaka

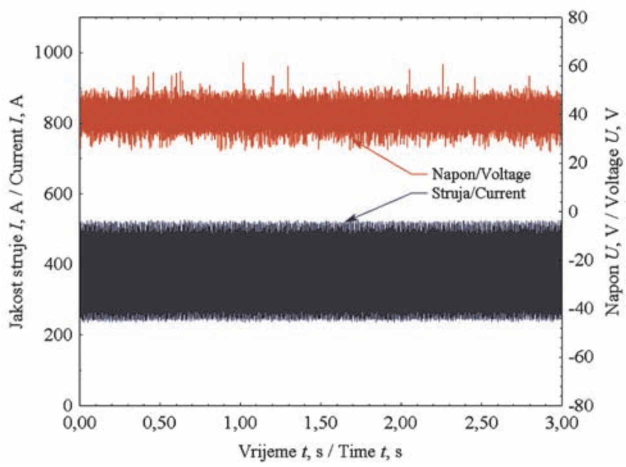


Figure 10 Oscillations of voltage and current during a TIME welding cycle
Slika 10. Promjene napona i jakosti struje tijekom TIME procesa zavarivanja

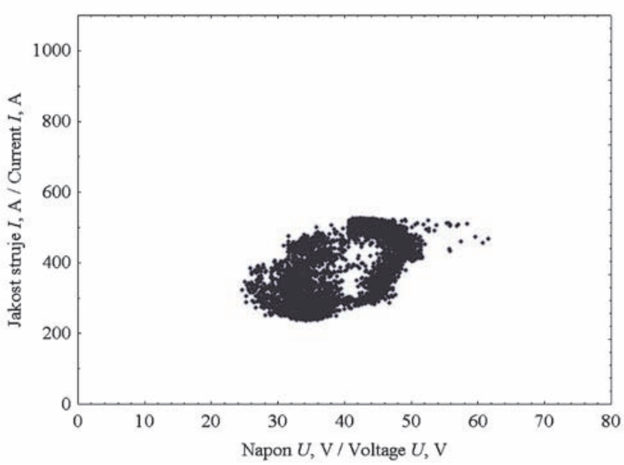


Figure 11 Correlation of voltage and current for a random interval of 3,0 sec
Slika 11. Odnos napona i jakosti struje za slučajno odabrani interval od 3,0 sekunde

3.4 Monitoring of welding parameters for MAG welding with "TIME" shielding gas [10]

Praćenje parametara kod MAG postupka zavarivanja s "TIME" zaštitnim plinom

The on-line monitoring system was used to register oscillations of voltage and current during welding with the TIME gas. Figure 10 illustrates the oscillation of welding voltage and current for a period of 0,77 seconds at a sampling rate of 5 kHz. Fig. 11 shows the correlation of the same parameters for a recording period of 3,0 seconds (a total of 15 000 recordings).

It has proven more convenient to evaluate the welding process when oscillations of the voltage and current are collected for a short timeframe (fractions of a second). For that reason, during TIME welding an interval of 0,024 seconds was selected (120 recordings of voltage and current each) voltage and current records for that interval are given in Figure 12.

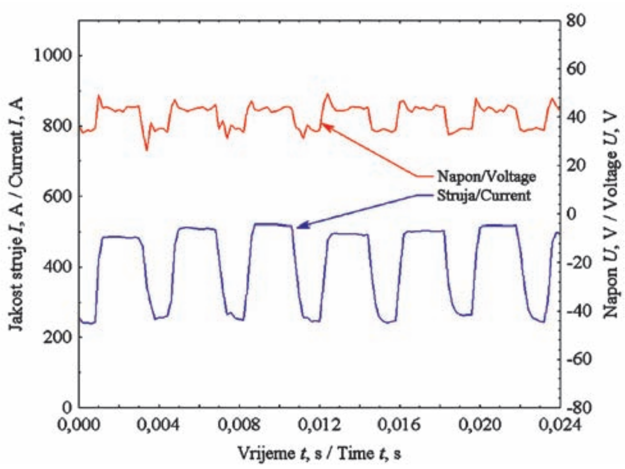


Figure 12 Voltage and current oscillations during an interval of 0,024 seconds (120 recordings of voltage and current each). TIME welding process, sampling frequency - 5 kHz
Slika 12. Promjene napona i jakosti struje tijekom intervala od 0,024 s (120 zapisa vrijednosti napona i jakosti struje). TIME postupak zavarivanja, frekvencija uzorkovanja - 5 kHz

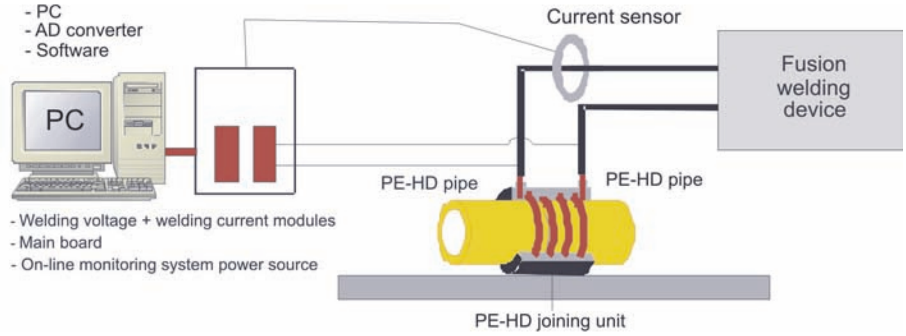


Figure 13 Schematic of the on-line monitoring system for recording oscillations of key parameters during an electro-fusion welding cycle
Slika 13. Shematski prikaz on-line monitoring sustava za praćenje oscilacija glavnih parametara tijekom ciklusa elektrofuzijskog zavarivanja

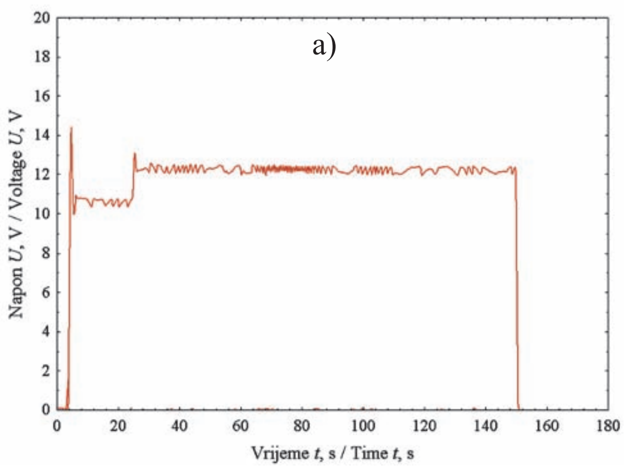
3.5 Monitoring of welding parameters for fusion welding of high-density polyethelene (PE-HD) [11]
Praćenje parametara kod elektrofuzijskog zavarivanja polietilena visoke gustoće (PE-HD)

During a fusion welding process of PE-HD pipe, voltage and current oscillations were recorded using the on-line monitoring system. Frequently used to join polymer materials, fusion welding is characterized by these key parameters: voltage *U*, V; current *I*, A; duration of current flow *t,* s; ambient temperature *T*, °C; electrical resistance of the spiral *R*, Ω.

During welding, a PE-HD pipe of diameter 90 mm was used.

Figure 13 gives a schematic principle of voltage and current measurement during PE-HD fusion welding.

Figure 14 shows the distribution of average values for voltage and current during 150-second welding, at a sampling rate of 5 kHz. The on-line monitoring system used for welding parameter acquisition offers a recording option for DC parameters. Since AC was being used in the experiments, the measurements only recorded those voltage and currency signals for half the cycle. Simply switching poles of the measurement sensors allowed the recording of the other side of the signal (as in Figures 15 and 16), which is symmetrical to the upper side of the signal. Since only one side of the signal was recorded, the average values for voltage and current - presented in Figure 14 - must be multiplied by a factor of 2. The records allow the process to be benchmarked.



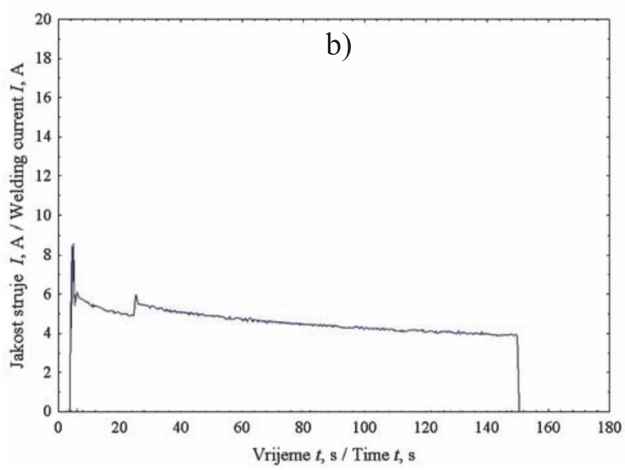


Figure 14 Mean of voltage (a) and current (b) records during electro-fusion welding of a 90-mm-diameter PE-HD pipe
Slika 14. Srednja vrijednost zapisa napona (a) i jakosti struje (b) za vrijeme elektrofuzijskog zavarivanja PE-HD cijevi promjera 90 mm

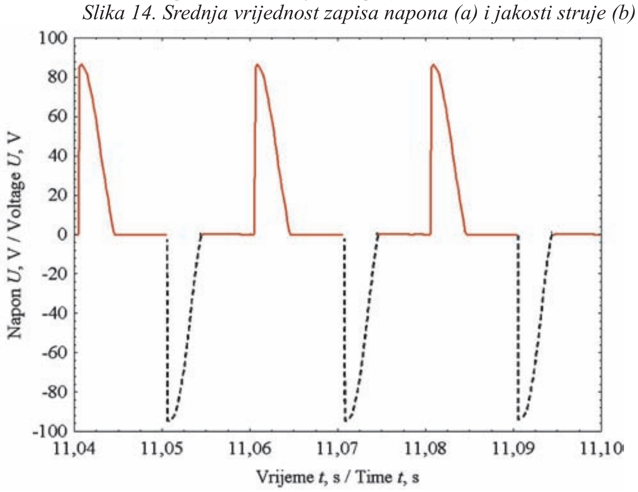


Figure 15 Welding voltage oscillation of a 0,06 second duration. Symmetric signals on the lower side of the U(t) diagram were added later.
Slika 15. Oscilacije napona zavarivanja tijekom 0,06 sekundi. Simetrični dio signala na donjoj strani dijagrama U(t) je dodan kasnije.

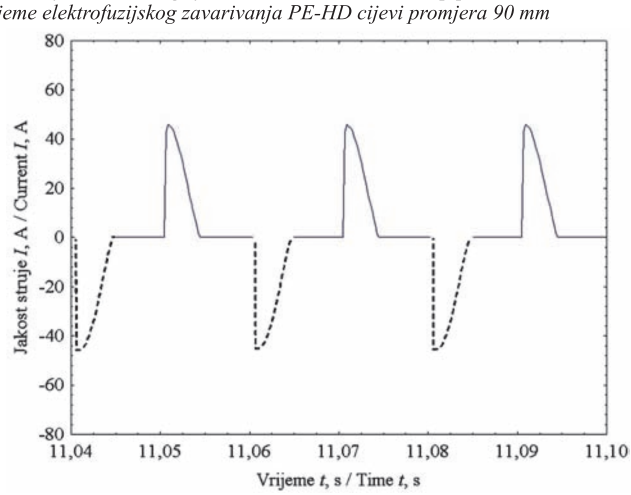


Figure 16 Welding current oscillation of 0,06 seconds. Symmetric signals on the lower side of the I(t) diagram were added later.
Slika 16. Oscilacije jakosti struje zavarivanja tijekom 0,06 s. Simetrični dio signala na donjoj strani dijagrama I(t) je dodan kasnije.

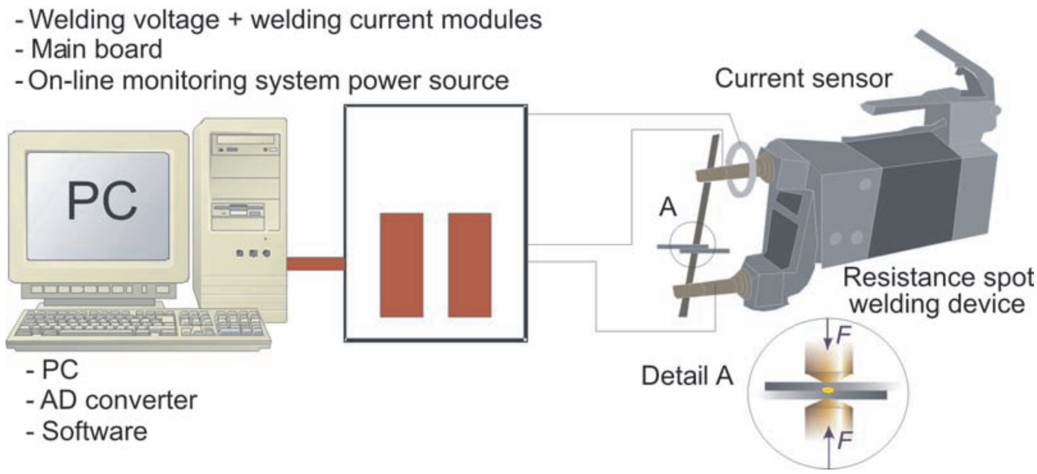


Figure 17 Scheme of on-line monitoring during resistance spot welding
Slika 17. Shematski prikaz on-line monitoringa tijekom elektrootpornog točkastog zavarivanja

3.6
Monitoring of welding parameters for resistance spot welding
Praćenje parametara kod elektrootpornog točkastog zavarivanja

The on-line monitoring system was also used to monitor resistance spot welding. Here, AC from the powerline is being transformed into parameters suitable for the particular welding technology (high current values, low voltages). Conducting high AC during a few seconds causes maximal electrical resistance at the welding spot and triggers softening and eventual melting of the material. Applying pressure locally, with simultaneous cooling of the weld pool, induces the formation of the weld nugget.

Figure 17 schematically presents experimental measurement of voltage and current during the welding cycle.

During experimental welding of lap joint 2 (zinc-coated plate, 1 mm plate thickness), the welding voltage was recorded at a sampling frequency of 5 kHz. The system only recorded one side of the signal because of design limitations related to transformed AC, as explained earlier in this paper. As the experiment was performed with AC, identical signals can be assumed on the opposite side of the *U(t)* diagrams. Consequently, symmetrical signals due to DC must be assumed on any lower side of the diagrams in Figure 19. Average current was 700 A. *I(t)* remained unrecorded due to inherent limitations of the particular monitoring system beyond 1000 A. Again, we can benchmark the welding process with the monitor records.

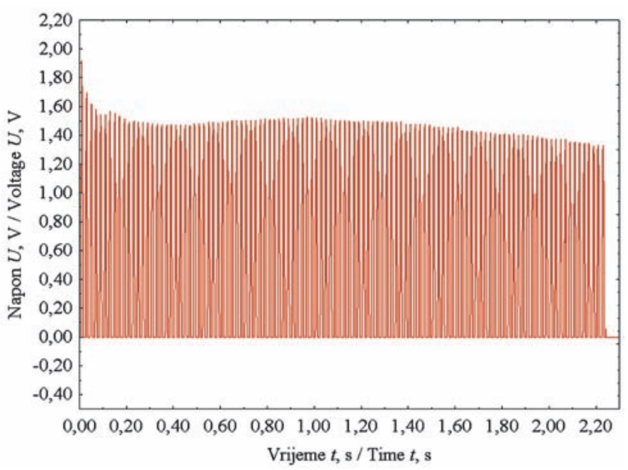


Figure 18 Welding voltage oscillation during a resistance spot welding cycle
Slika 18. Oscilacije napona zavarivanja tijekom ciklusa elektrootpornog točkastog zavarivanja

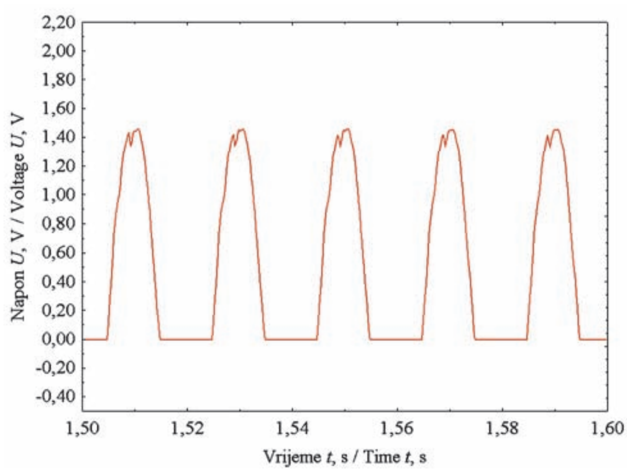


Figure 19 Welding voltage oscilations in the middle cycle of resistance spot welding (total duration 0,1 sec)
Slika 19. Oscilacije napona zavarivanja u središnjem dijelu ciklusa elektrootpornog točkastog zavarivanja (ukupno trajanje 0,1 s)

3.7
Monitoring of SMAW parameters during natural gas pipe welding
Praćenje parametara REL postupka tijekom zavarivanja čeličnih plinovodnih cijevi

During downhill SMAW of gas pipes, welding parameters were recorded for cellulosic electrodes (Figure 20 and 21) and for basic electrodes (Fig. 22 and 23).

3.7.1
Cellulosic coated electrode for "down hill" welding (direct current)
Celulozna elektroda za silaznu tehniku zavarivanja (istosmjerna struja)

3.7.2
Basic coated electrode for "down hill" welding (direct current)
Bazična elektroda za silaznu tehniku zavarivanja (istosmjerna struja)

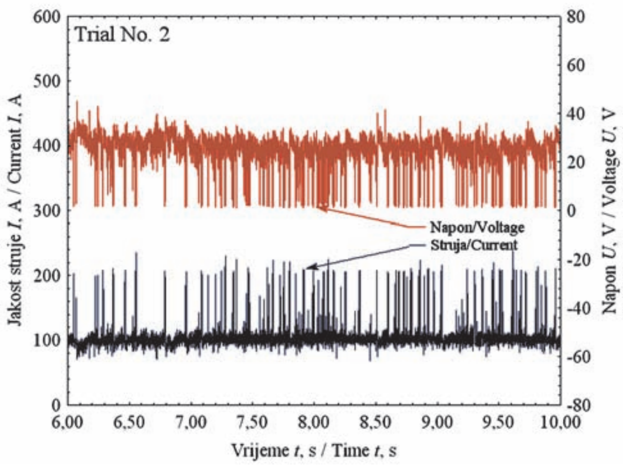


Figure 20 Voltage and current distribution during a randomly chosen SMAW segment. Downhill welding using a cellulose coated electrode. Sampling frequency during recording - 5 kHz.
Slika 20. Distribucija napona i jakosti struje tijekom slučajno odabranog segmenta kod REL postupka zavarivanja. Silazna tehnika zavarivanja celuloznom elektrodom. Frekvencija uzorkovanja 5 kHz.

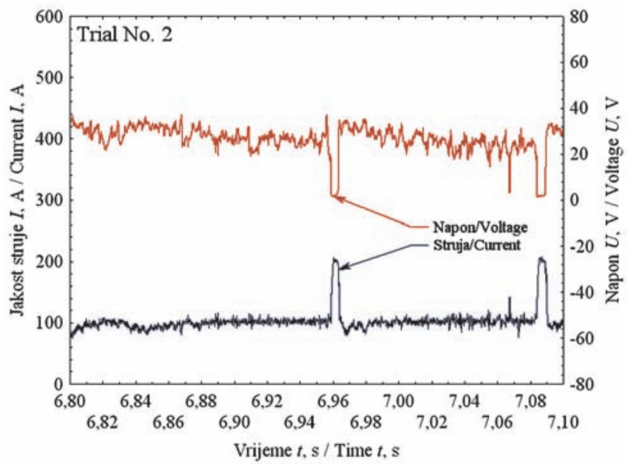


Figure 21 Voltage and current distribution during a 0.3 second welding sequence as shown in Figure 20.
Slika 21. Distribucija napona i jakosti struje tijekom sekvence zavarivanja od 0,3 sekunde kako je prikazano na slici 20.

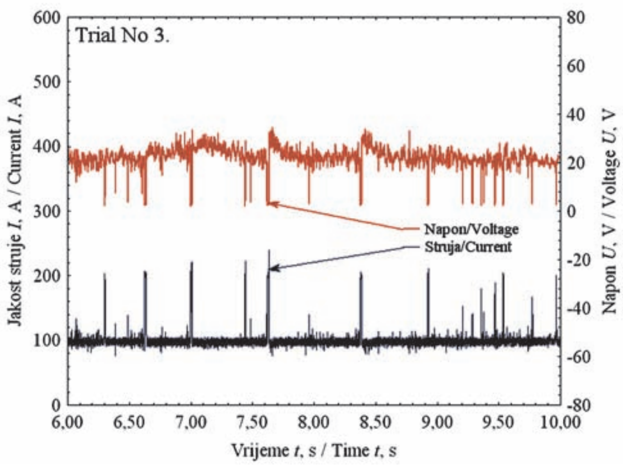


Figure 22 Voltage and current distribution during a randomly chosen SMAW sequence. Downhill welding using a basic electrode. Sampling frequency during recording 5 kHz.
Slika 22. Distribucija napona i jakosti struje tijekom slučajno odabranog segmenta kod REL postupka zavarivanja. Silazna tehnika zavarivanja bazičnom elektrodom. Frekvencija uzorkovanja 5 kHz.

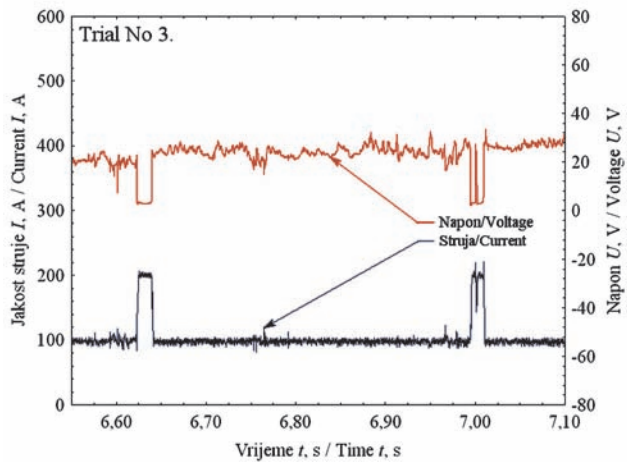


Figure 23 Voltage and current distribution during a 0,6 second welding sequence as shown in Figure 22.
Slika 23. Distribucija napona i jakosti struje tijekom sekvence zavarivanja od 0,6 sekundi kako je prikazano na slici 22.

4 Conclusion
Zaključak

On-line monitoring systems allow the tracking of key welding parameters and consequently an evaluation of process stability. Thus, it serves as a supervisory tool for the welding process as well as determination of optimal welding parameters in relation to weld quality (i.e. visual appearance, NDE inspection, mechanical property tests).

This paper presented some experience-based examples of on-line monitoring system applications for different welding technologies. In the future, the monitor will be applied for evaluation of the dynamic characteristics of welding power sources and of other electric arc welding technologies.

References
Literatura

[1] Madigan, R. B.; Quinn, T. P.; Siewert T. A. Control of Gas-Metal-Arc Welding Using Arc-Light Sensing, Boulder, Colorado, SAD, Materials Reliability Division, Materials Science and Engineering Laboratory, National Institute of Standards and Technology, 1995.

[2] Neessen, F.; Naber, F. The GMAW - STT process - An advanced welding process. Lincoln Smitweld B.V, Lincoln Electric Europe B.V. The Netherlands, October 2003.

[3] Despotović, B.; Samardžić, I.; Marsenić, T.; Brechelmacher, B. Neki aspekti primjene STT postupka zavarivanja u kotlogradnji // *3rd International Conference on Mechanization, Automation and Robotization in Welding and Allied Processes* / Kožuh, Zoran (ur.). Zagreb : Hrvatsko društvo za tehniku zavarivanja, 2005. pp. 71-78.

[4] Dunđer, M.; Samardžić, I.; Klarić, Š. Monitoring Of Main Welding Parameters At STT Welding Process // *Proceedings/9th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2005, Antalya, Turkey, 26-30 September, 2005.* pp. 219-222.

[5] Siewert, T.; Samardžić, I.; Kolumbić, Z. Estimation of process stability in the MAG welding process by monitoring the welding parameters. International scientific-professional conference "Economical and qualitative aspects of highly effective welding processes", Publisher: Đuro Đaković, Slavonski Brod, 2001. pp. 1-13.

[6] Samardžić, I.; Kolumbić, Z.; Baotić, M. Doprinos primjeni praškom punjenih žica za zavarivanje MAG postupkom. Znanstveno-stručni časopis Tehnički vjesnik, (3,4)(2001), pp. 23-37.

[7] Siewert, T.; Samardžić, I.; Klarić, Š. Application of an on-line weld monitoring system. Proceedings of 1st DAAAM International Conference on Advanced Technologies for Developing Countries, Sl. Brod, 2002. pp. 227-232.

[8] Samardžić, I.; Klarić, Š.; Siewert, T. Analysis Of Welding Parameters Distribution In Stud Arc Welding // *WELDING & MATERIALS Technical, Economic and Ecological Aspects* / Prof.dr.sc. Zoran Kožuh (ur.). Dubrovnik - Cavtat, 2007. pp. 791-800

[9] Samardžić, I.; Klarić, Š.; Pecić, V. The Influence Of Welding Parameter Modifications On Electric Arc Stud Welding Process Stability, Zavarivanje. 49(2006) 3/4, pp. 71-80.

[10] Samardžić, I.; Köveš, A. Osiguranje kvalitete zavarivačkih radova podržano sustavom za mjerenje i registraciju parametara zavarivanja. Međunarodno savjetovanje "Zavarivanje u pomorstvu", Haludovo (Krk), listopad, 1998., str. 437-448

[11] Samardžić, I.; Raos, P.; Klarić, Š.; Blažević, M. Monitoring parametara elektrofuzijskog zavarivanja PE-HD cijevi. IV skup o prirodnom plinu, Osijek 2006.

[12] Lundqvist, B. Sandvik welding handbook, Sweden. Palmeblads, Göteborg, 1977.

[13] Pavić, J.;Samardžić, I.; Klarić, Š.; Dunđer, M. Primjena elektrootpornog šavnog zavarivanja kod izrade kompenzatora // *3rd International Conference Mechanization, Automation and Robotization in Welding and Allied Processes* / Kožuh, Zoran (ur.). Zagreb : Hrvatsko društvo za tehniku zavarivanja, 2005. pp. 99-108.

[14] Samardžić, I.; Lukačević, Z. Mogućnosti dinamičkog praćenja glavnih parametara pri elektrolučnom zavarivanju. Časopis Zavarivanje 42(1999)1-2, pp. 11-16.

[15] Lukačević, Z.; Samardžić,I., Siewert,T. Characterization of a Welding Procedure Based on Monitoring of Welding Variables. International Institute of Welding (IIW) Conference Doc. XII-1627-00, Firenca, 9-14 srpanj 2000.

[16] Lukačević, Z.; Samardžić, I. Mogućnosti dinamičkog praćenja zavarivanja i otkrivanja grešaka. Međunarodno savjetovanje "Revitalizacija Dijagnostika", Hrvatsko društvo za kontrolu bez razaranja, Dubrovnik, 1996.

[17] Kolumbić, Z.; Samardžić, I.; Klarić, Š. Comparison of main welding parameter stability - automatic and semiautomatic MAG welding // *Manufacturing and Management in the 21st Century: Conference proceedings*/Skopje, Makedonija: Production and Industrial Engineering Association, 2004. pp. M1-67.

[18] Kolumbic, Z.; Samardzic, I.; Klaric, Š. Dynamics of gas metal arc welding process research laboratory system and sound monitoring module, Proceedings of the 12th International DAAAM symposium "Intelligent manufacturing & automation: Focus on precision engineering", Jena, October 2001. pp. 237-238.

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