PRIMJENA ON-LINE MONITORING SUSTAVA ZA PRAĆENJE GLAVNIH PARAMETARA ZAVARIVANJA KOD RAZLIČITIH POSTUPAKA ZAVARIVANJA

ON LINE MONITORING SYSTEM ─ AN APPLICATION FOR MONITORING KEY WELDING PARAMETERS OF DIFFERENT WELDING PROCESSES

Keynote paper

Thomas SIEWERT [1], Ivan SAMARDŽIĆ [2], Zvonimir KOLUMBIĆ [2]

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

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

Sažetak: U radu se obrazlaže primjena on-line monitoring 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.

Abstract: This paper describes the application of an on-line monitoring system for the monitoring, acquisition 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 on-line monitoring system during a welding cycle are presented.

[1] Dr. Thomas Siewert, NIST, Boulder, Colorado, USA
[2] Prof. dr. sc. Ivan Samardžić, EWE; Strojarski fakultet u Slavonskom Brodu, Trg I. B. Mažuranić 2, 35000 Slavonski Brod
[2] Prof. dr. sc. Zvonimir Kolumbić; Strojarski fakultet u Slavonskom Brodu, Trg I. B. Mažuranić 2, 35000 Slavonski Brod

1 INTRODUCTION

The monitoring and control of key welding process parameters is of utmost importance for assuring the quality of welded joints. When refering 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 a built-in welding parameter control, allowing control of selected welding parameters during the welding sequence. That equipment requires periodical 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 fro several different processes.

2 BASIC CHARACTERISTICS OF THE ON-LINE MONITORING SYSTEM

A more complex measurement of welding parameters is essential during the development and testing of new software programs for modern, programmable welding equipment, but also during the calibration and certification of welding current sources, during research and development for base materials and during weldability research.

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
- 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
- Welding parameter control for automatic welding methods.

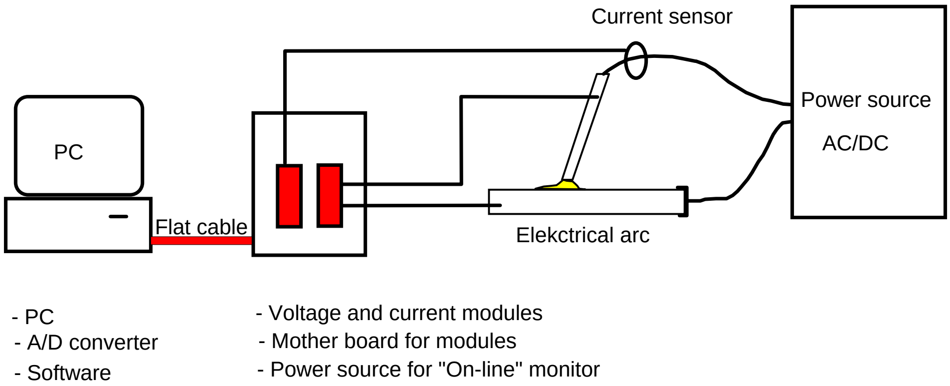


Figure 1 Schematic of the on-line monitoring system used for gathering data during arc welding

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: $\overline{U} = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} U(t)\mathrm{d}t$, (V)
- 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, MAG - Metal Arc Welding, SMAW – Shielded Metal Arc Welding, FCAW – Flux Cored Arc Welding, fusion welding of PE-HD, ...).

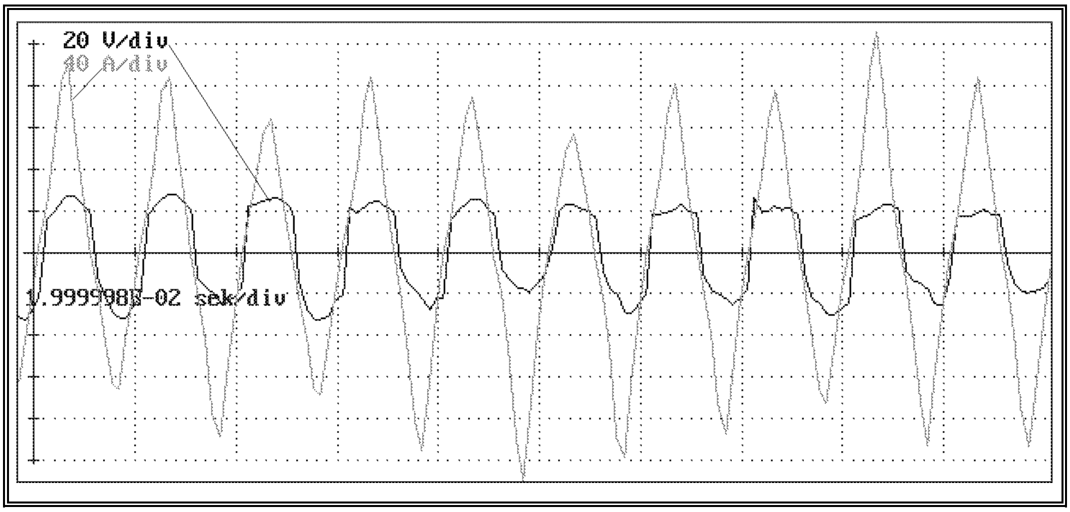
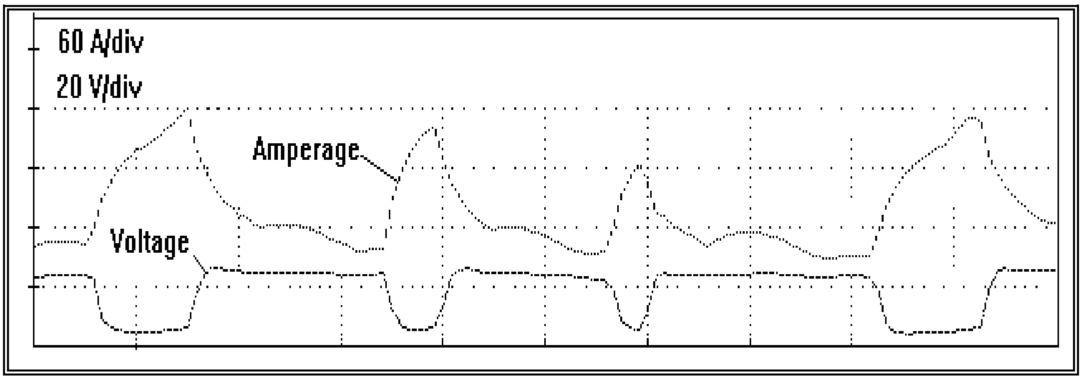


Figure 2 Visualization of recorded results as obtained during AC powered SMAW with a 3.25 mm. diameter electrode and an earlier system. Horizontal scale increments are 0,02 sec [2, 3]

3 APPLICATION EXAMPLES OF THE ON-LINE MONITORING SYSTEM

During early development of the system, welding parameters of commonly used AC power sources for SMAW and MAG welding were measured (Figure 2 and 3) [2, 3]. The sampling frequencies of just a few hundred Hz proved insufficient for satisfactory resolution of the response of more advanced welding technologies, and demonstrated the need for the advanced system described in this paper.



0,03 sec/separation

Figure 3 Visualization of recorded results as obtained during DC powered semi-automatic MAG welding and an earlier system. Horizontal scale increments are 0,03 sec [2, 3]

Through continuous development over the past 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 application are presented.

3.1 Monitoring of welding parameters for the MAG-STT welding process [5, 6]

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) nor a flat one (CV).[4] 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 operator-friendly environment. In addition, lower heat input means lower deformations and residue stresses as side-effects of welding.

One of the disadvantages of the 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.

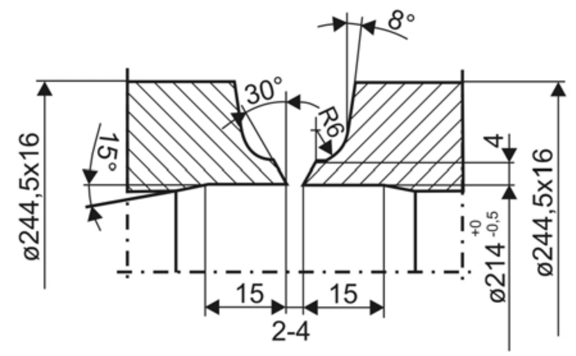
An on-line monitoring system has been used to record alterations of current and voltage during MAG-STT welding in vessel construction. Specifically, it has been used during root pass welding of a pipe butt joint. The component was designed with a pipe of composition 15 Mo3, a diameter of 244.5 mm, and a thickness of 16 mm. A butt joint was selected (Figure 4) and the tacking was performed at three spots, roughly at every 120º around the circumference. For the filler material, wire specified as DMO-IG in 1 mm diameter 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.

a)



b)

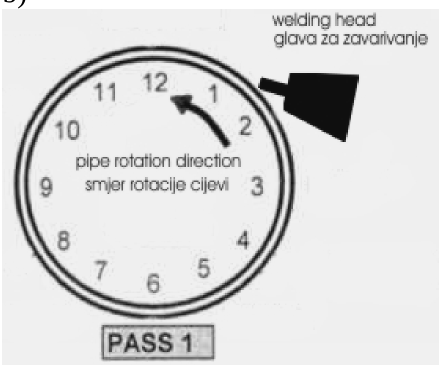


Figure 4 Shape and dimensions of the butt joint on a pipe section (a) and the position of the welding head during the cycle (b)

Figure 5 The weld root from within the pipe (inner view of the root weld) produced with STT

Figure 6 The face of the STT root weld (note the smooth appearance of the weld surface, without any cracks)

Figure 5 shows the appearance of the weld root from within the pipe (inner view of the root weld) produced with STT. Figure 6 shows the face of the STT root weld.

During the weld, voltage and current were tracked and recorded using the on-line monitoring system. The sampling frequency was 20 kHz on each measurement channel. Figures 7a and 7b 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.

a)

b)

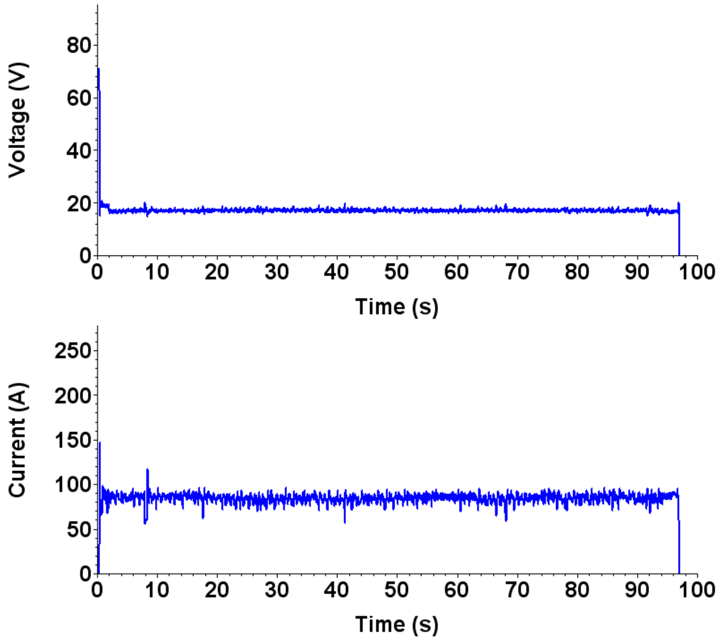


Figure 7 The distribution of average values of voltage (a) and current (b) during the welding of the third chamber section, lasting 97 seconds. The sampling frequency applied was 20 Hz. The mean of the welding parameters was established for every 1000 measurements.

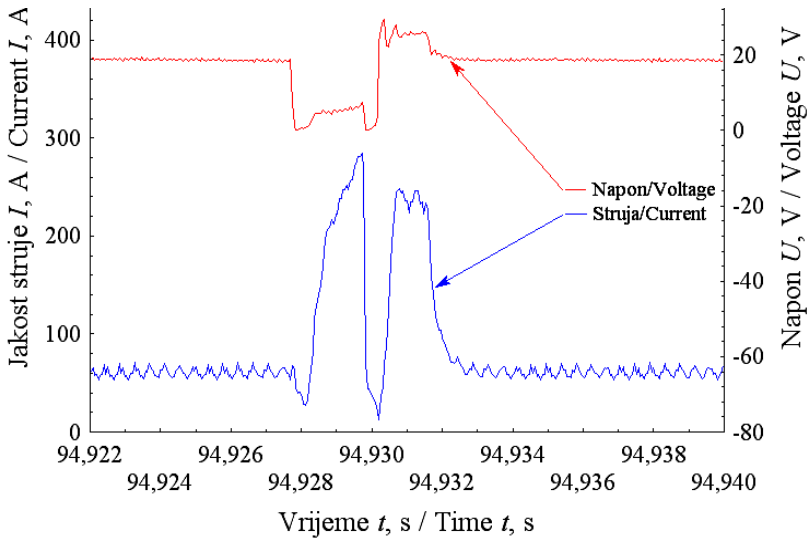


Figure 8 Voltage (lower curve) and current (upper curve) records for a randomly chosen welding duration of 0.012 seconds

Figure 8 illustrates the voltage (lower curve) and current (upper curve) records in a randomly chosen weld segment of 0.012 seconds recorded at a sampling rate of 20 kHz. Figures 9 and 10 show the histograms for current and for welding voltage respectively, during an extended welding sequence, with multiple droplet transfer events.

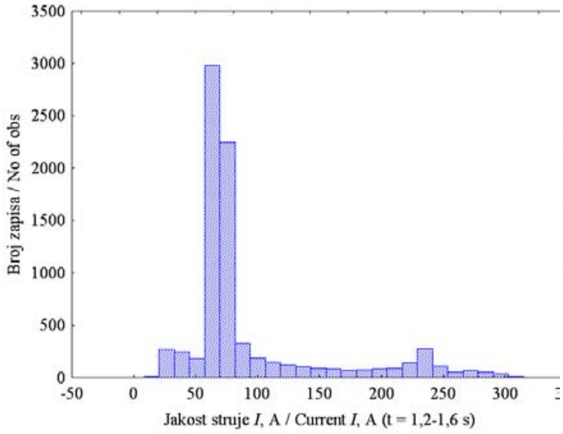


Figure 9 Current frequency histogram for an extended welding sequence at a sampling rate of 20 kHz

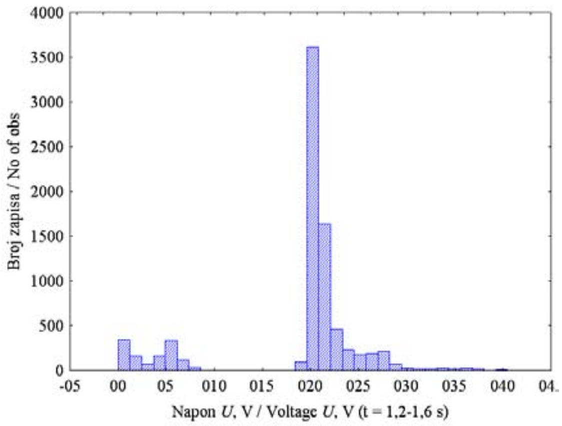


Figure 10 Voltage frequency histogram for an extended welding sequence at a sampling rate of 20 kH z

3.2 Monitoring of welding parameters for the MAG process [7, 8]

During research of the 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.

The welding experiment was structured into four levels (A to D):

A… Solid electrode (VAC60 Ø1,2 mm) with CO_2
B… Solid electrode (VAC60 Ø1,2 mm) with 82 % Ar + 18 % CO_2
C… Flux-cored electrode (rutile type, Ø1,2 mm) with CO_2
D… Flux-cored electrode (rutile type, Ø1,2 mm) with 82 % Ar + 18 % CO_2

The shielding gas flow was kept constant at 16 l/min; other details of the welding procedures for the four welds were as follows:

A… Wire-feed speed: 5 m/min, Current 265 A, Voltage 26 V.
B... Wire-feed speed: 5 m/min, Current 250 A, Voltage 27 V.
C… Wire-feed speed: 8,5 m/min, Current 200 A, Voltage 28 V.
D… Wire-feed speed: 8,5 m/min, Current 200 A, Voltage 28 V.

Figures 11 and 12 show distribution diagrams for welding voltage and current for specific 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 13 shows the relationship between voltage and current during the weld.

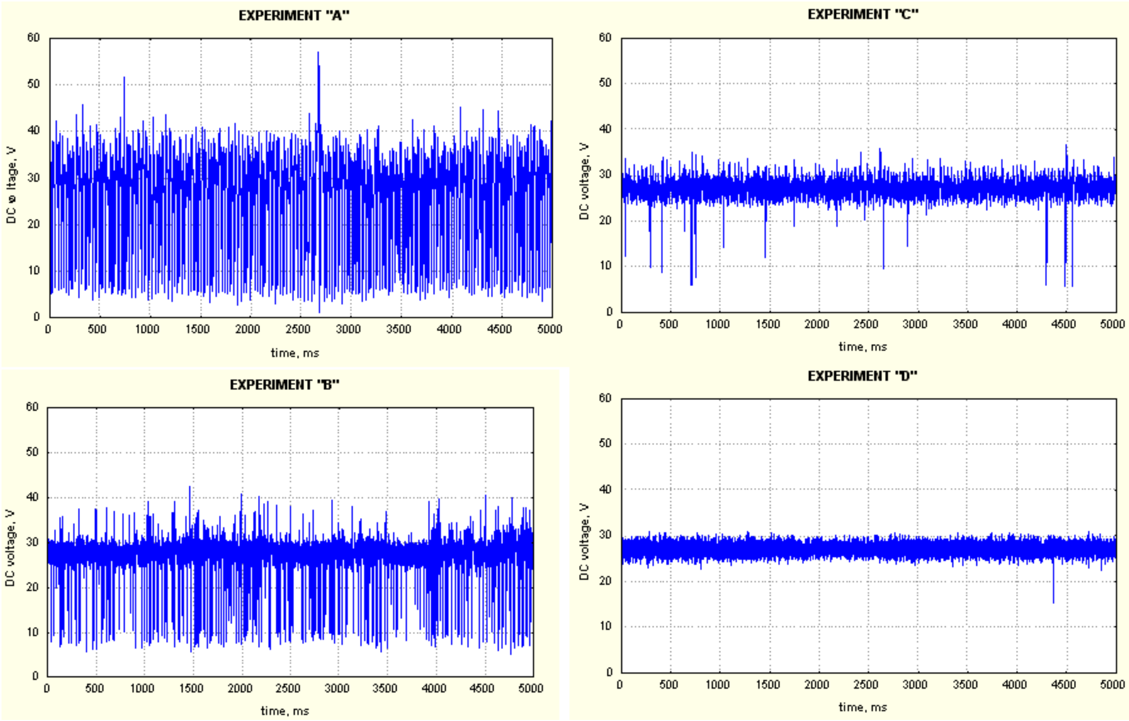


Figure 11 Real-time welding voltage distribution during MAG welding with two electrodes (solid and flux cored), and two shielding gases (CO2 and 82 % Ar + 18 % CO2), according to the design of experiments in table 1. Sampling frequency: 1 kHz

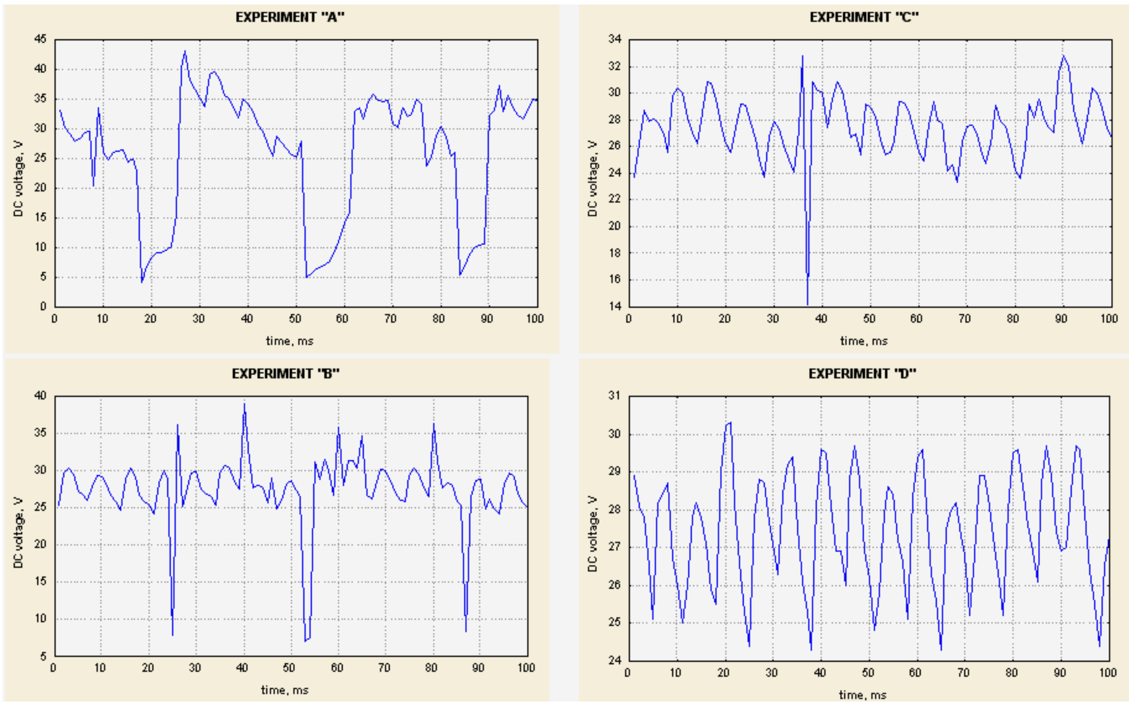


Figure 12 Real-time welding voltage distribution during MAG welding with two electrodes (solid and flux cored), and two shielding gases (CO2 and 82 % Ar + 18 % CO2), according to the design of experiment in table 1. Sampling frequency: 1 kHz

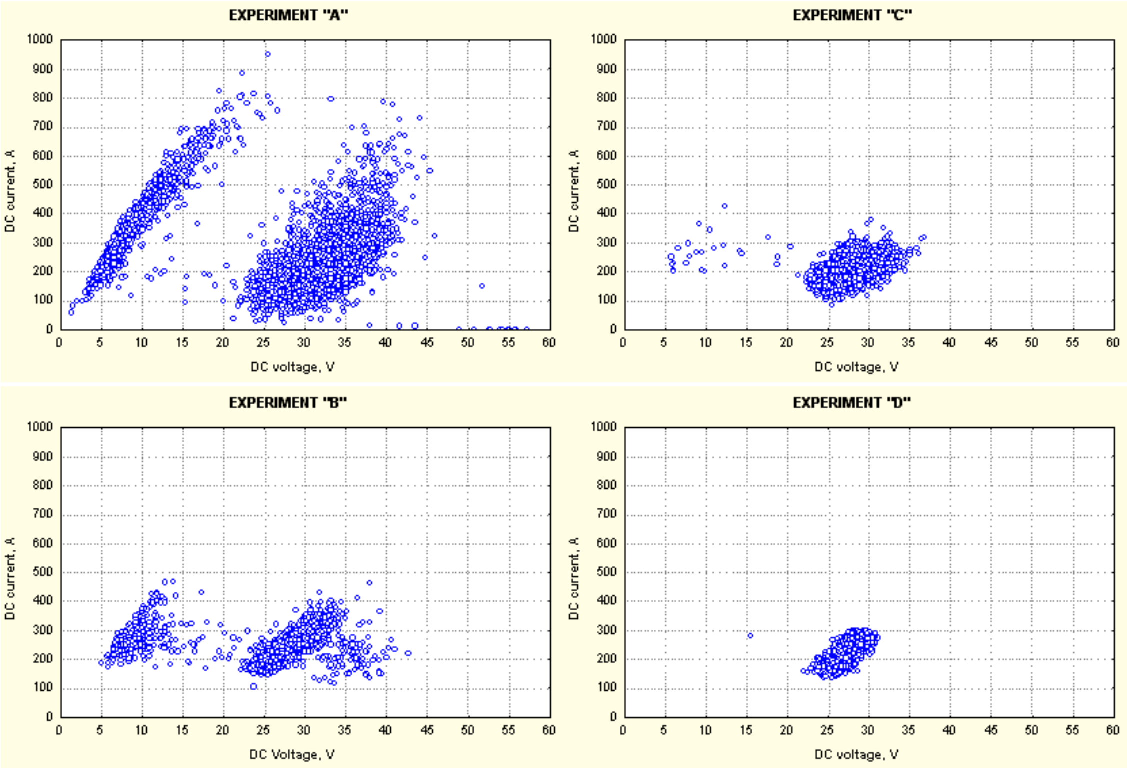


Figure 13 Relationship of current and voltage for all experiment levels

3.3 Monitoring of welding parameters for the stud arc welding process [10, 11]

Stud arc welding is a welding technology often applied in the construction of bridges and vessels, where dozens of different attachments are needed. Due to its and 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), the stud retraction speed v (mm/s), and length of stud protrusion (plunge) P (mm).

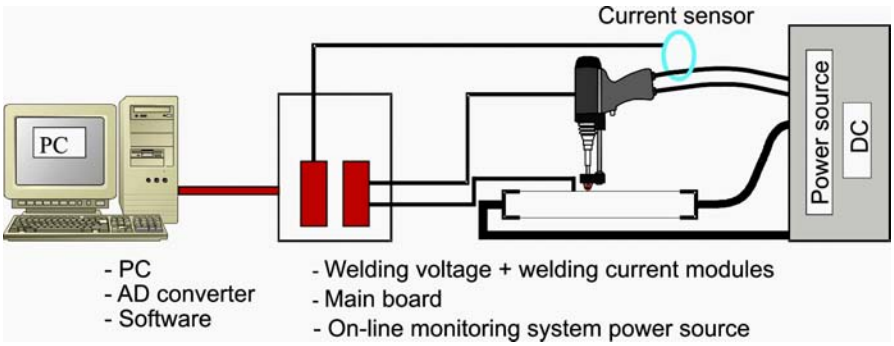


Figure 14 On-line monitoring system scheme for the acquisition of key welding parameters during stud arc welding

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, Figure 15 shows examples of a good weld joint (trial No. 1) and that of an unstable welding process (trial No. 4).

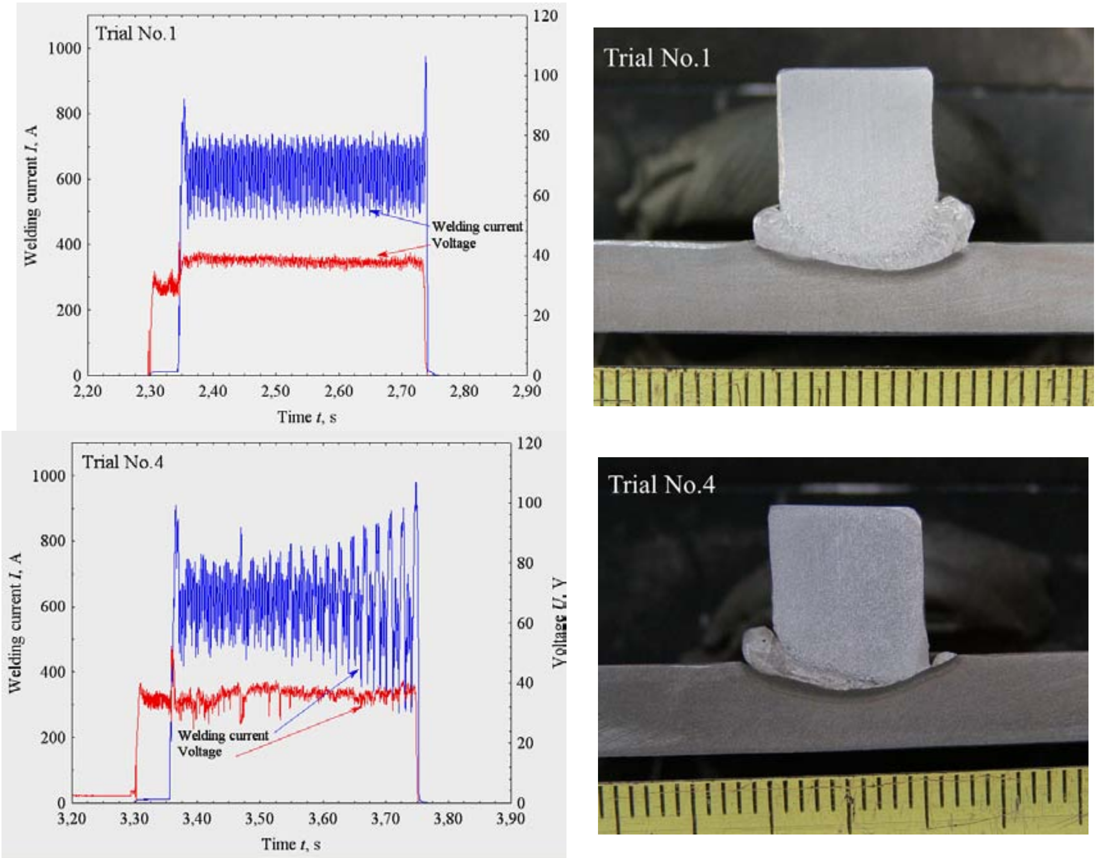


Figure 15 Welding current and voltage distribution during a complete stud welding process cycle and the macro section of related weld joints

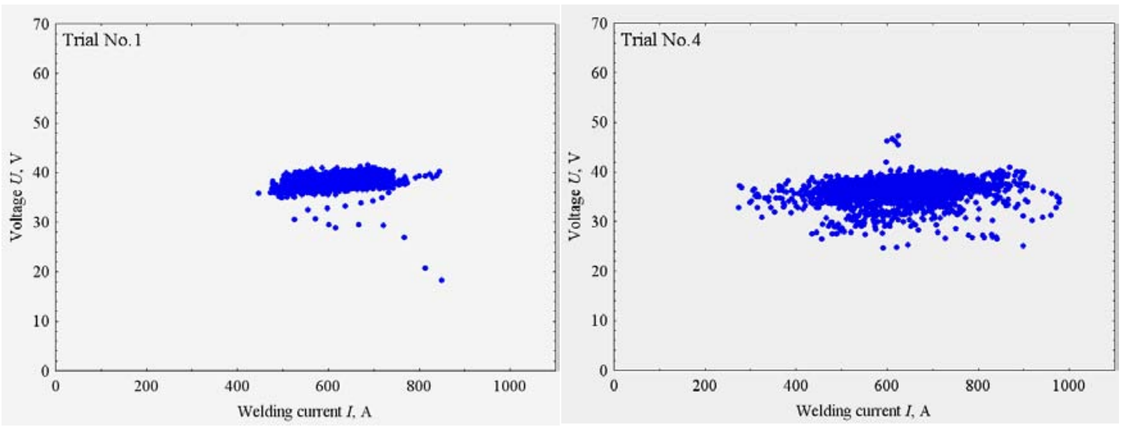


Figure 16 Dependence of the arc voltage on the welding current for the welding parameters

Figure 16 shows a correlation of welding current and voltage during the cycle; Figure 17 shows voltage frequency histograms as recorded during the cycle. Details of the cycle start and end for specimen no.1 are given in Figure 18 a and b.

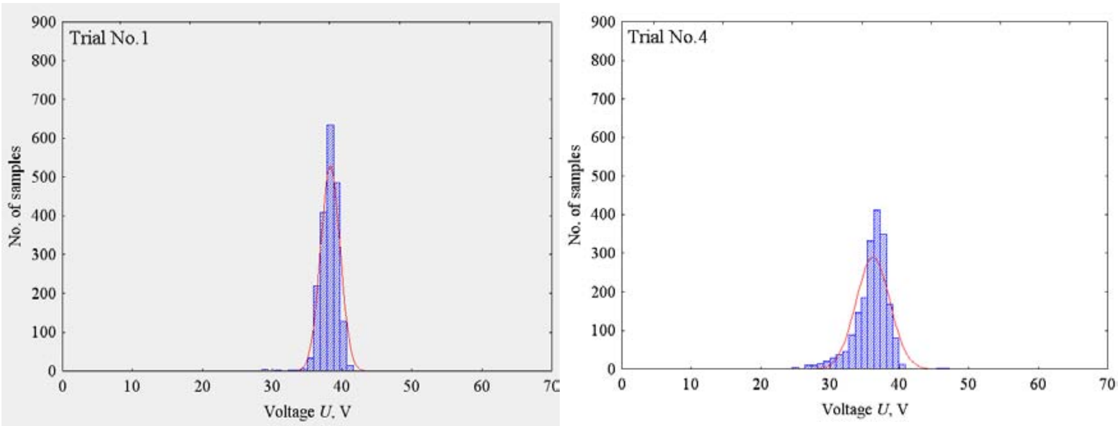


Figure 17 Frequency histograms of welding voltage for the welding parameters

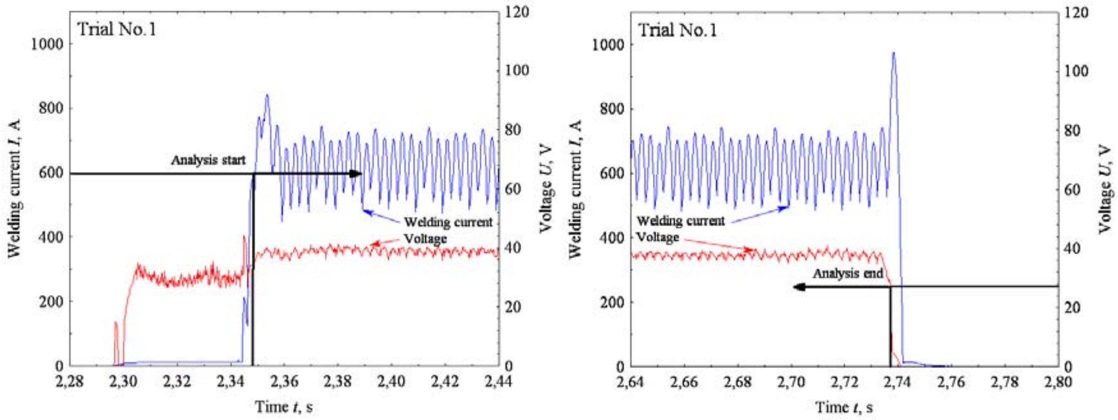


Figure 18 Start and end sequence of the stud welding process for specimen No.1

3.4 Monitoring of welding parameters for MAG welding with TIME shielding gas [12]

The on-line monitoring system was used to register oscillations of voltage and current during a weld with the TIME gas. Figure 19 illustrates the oscillation of welding voltage and current for a period of 0.77 seconds at a sampling rate of 5 kHz. Fig. 20 shows the correlation of the same parameters for a recording period of 3.0 seconds (a total of 15 000 recordings).

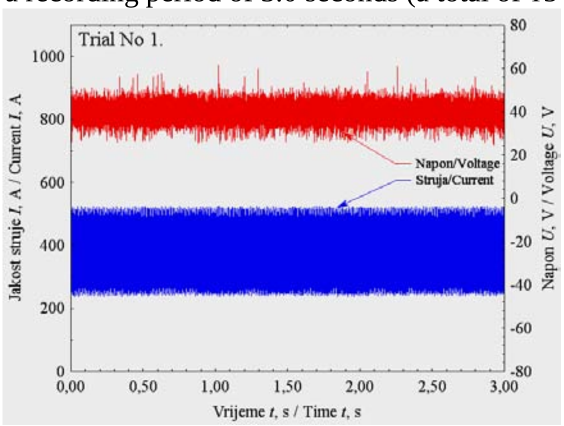


Figure 19 Oscillations of voltage (a) and current (b) during a TIME welding cycle

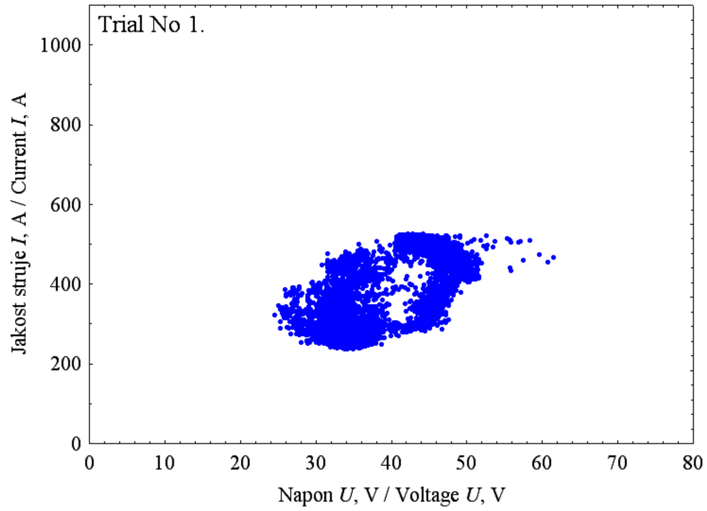


Figure 20 Correlation of voltage and current for a random interval of 3,0 sec

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 a random interval of 0,024 seconds was selected (120 recordings of voltage and current each) – voltage and current oscillations for that interval are given in Fig. 21.

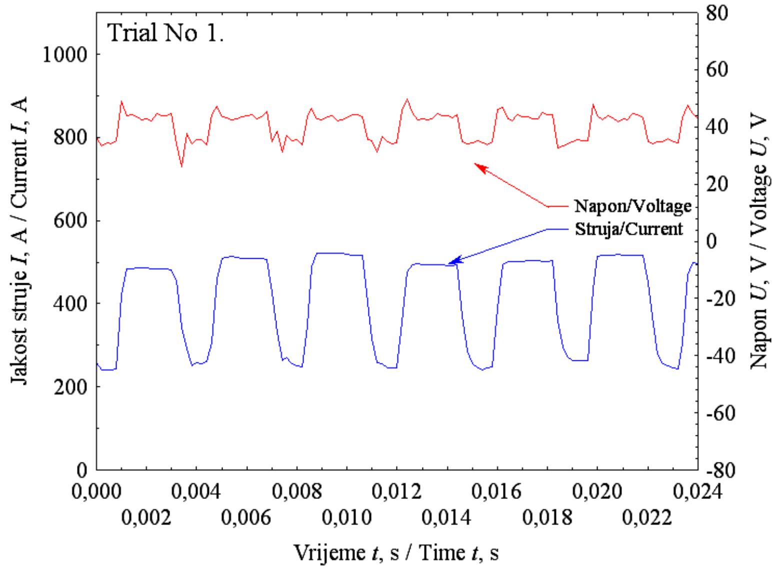


Figure 21 Voltage and current oscillations during an interval of 0,024 seconds (120 recordings of voltage and current each). TIME welding process, sampling frequency - 5 kHz

3.5 Monitoring of welding parameters for a fusion weld of high-density polyethylene (PE-HD) [13]

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, an PE-HD joining unit, diameter 90 mm was used. Figure 22 gives a schematic principle of voltage and current measurement during PE-HD fusion welding.

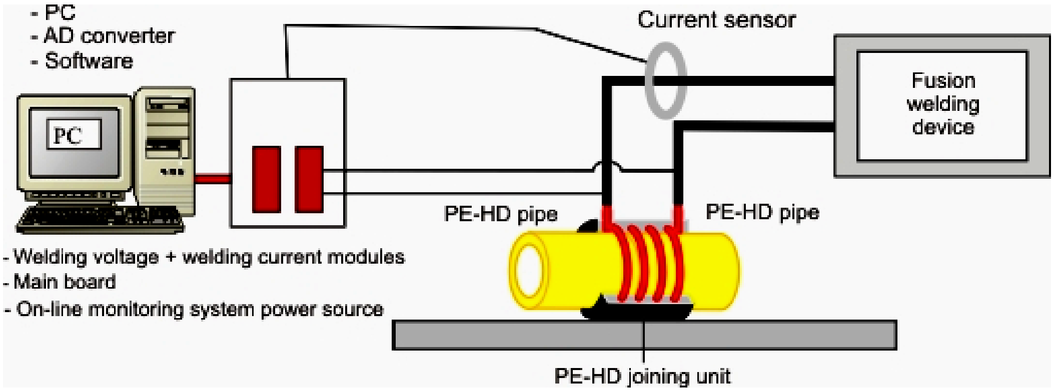


Figure 22 Schematic of the on-line monitoring system for recording oscillations of key parameters during an electro-fusion welding cycle

a)

b)

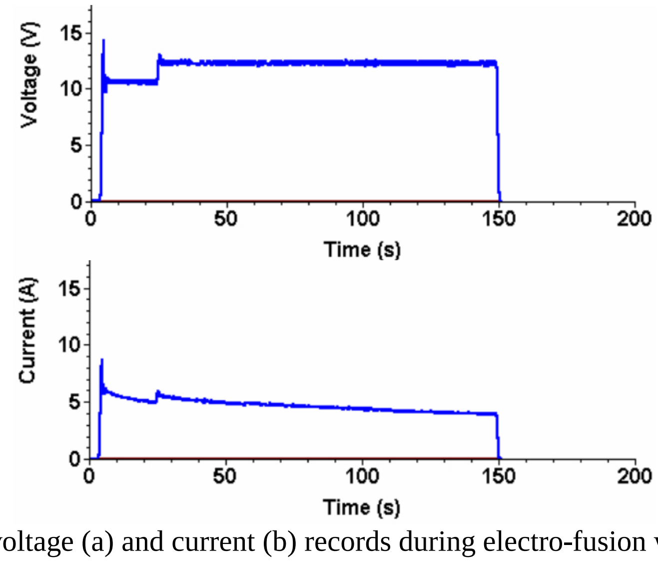


Figure 23 Mean of voltage (a) and current (b) records during electro-fusion welding of a 63-mm-diameter PE-HD pipe

Figure 23 shows the distribution of average values for voltage and current during a 150 second weld, 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 (other half of the cycle), 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 23 – must be multiplied by a factor of 2.

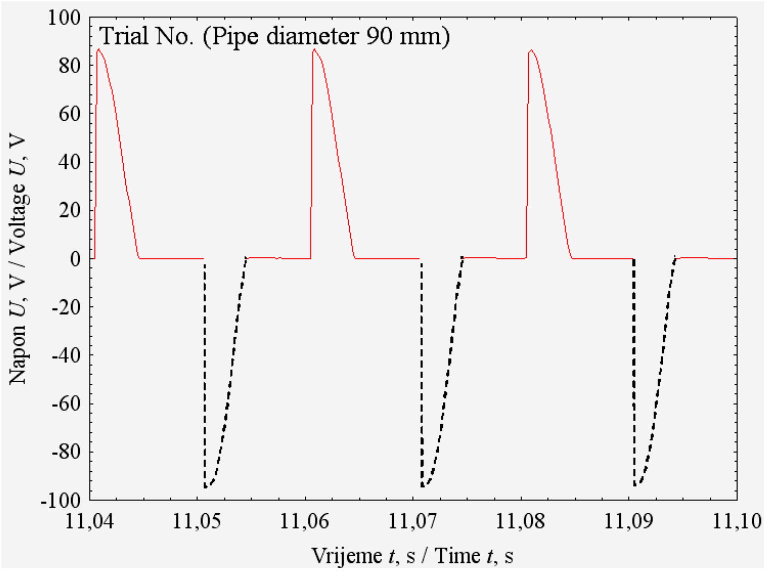


Figure 24 Welding voltage oscillations of 0.06 second – duration. Symmetric signals on the lower side of the *U(t)* diagram were added later

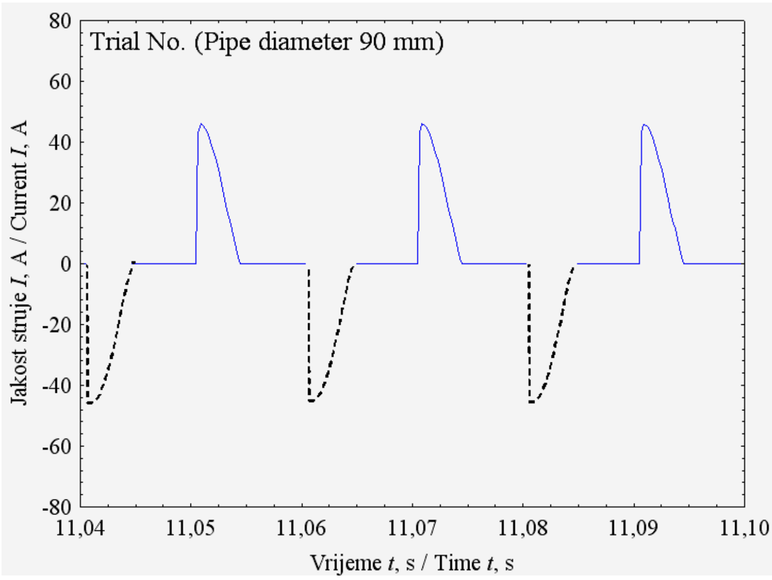


Figure 25 Welding current oscillations of 0,06 seconds – duration. Symmetric signals on the lower side of the *I(t)* diagram were added later

3.6 Monitoring of welding parameters for resistance spot welding

The on-line monitoring system was also used to monitor a resistance spot weld. 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. A schematic of the process and expected temperatures of the joint are given in Figure 26. Figure 27 schematically presents experimental measurement of voltage and current during the welding cycle.

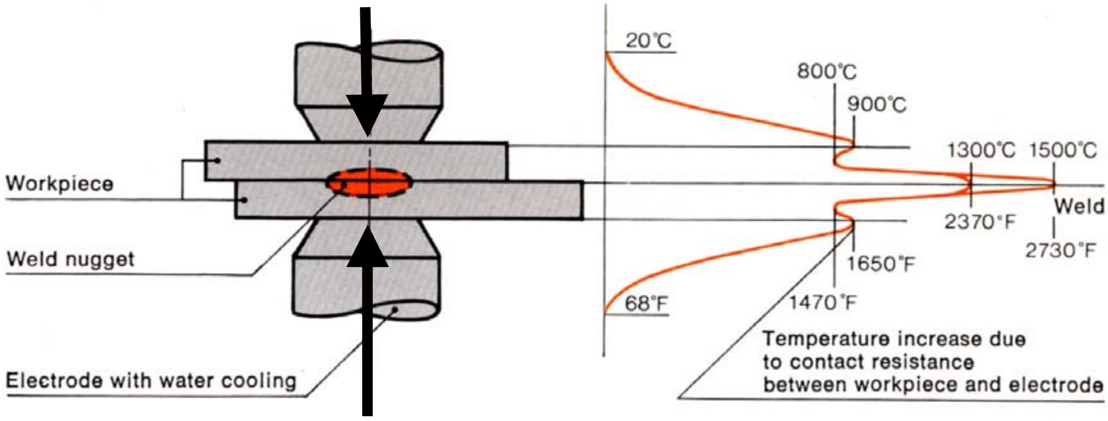


Figure 26 Schematic process for resistance spot welding and expected temperatures during welding [14]

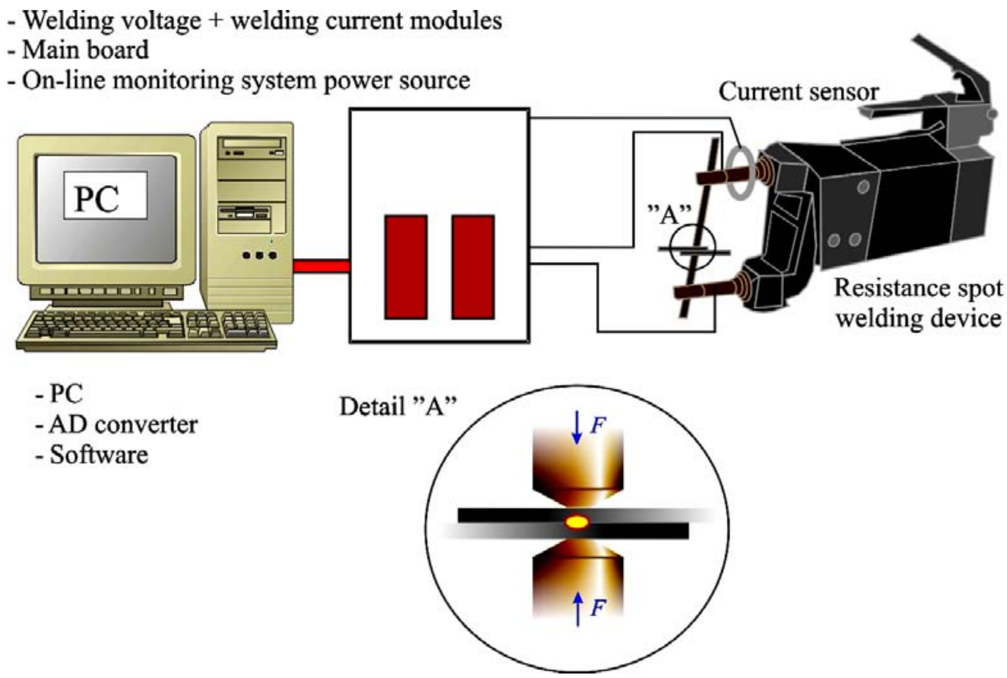


Figure 27 Scheme of on-line monitoring during resistance spot welding

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)* and *I(t)* diagrams. Consequently, symmetrical signals due to DC must be assumed on any lower side of the diagrams in Figure 28, 29 and 30. Average current was 700 A. *I(t)* remained unrecorded due to inherent limitations of the particular monitoring system beyond 1000 A.

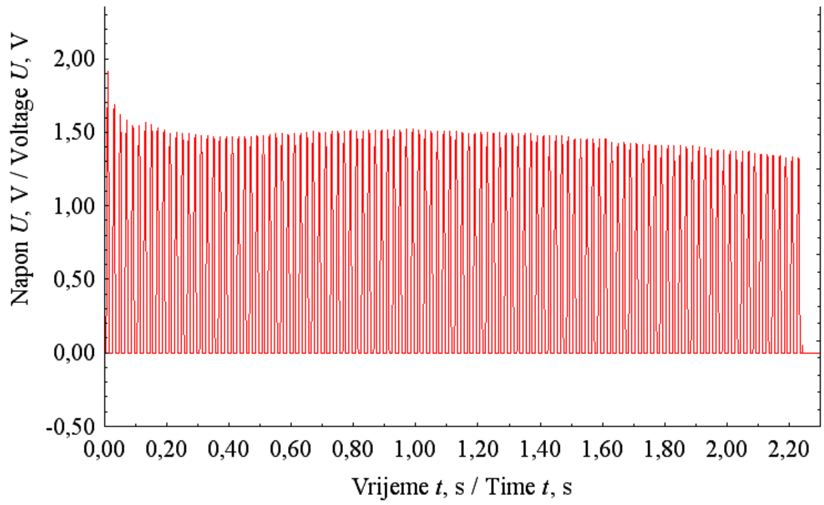


Figure 28 Welding voltage oscillation during a resistance spot welding cycle

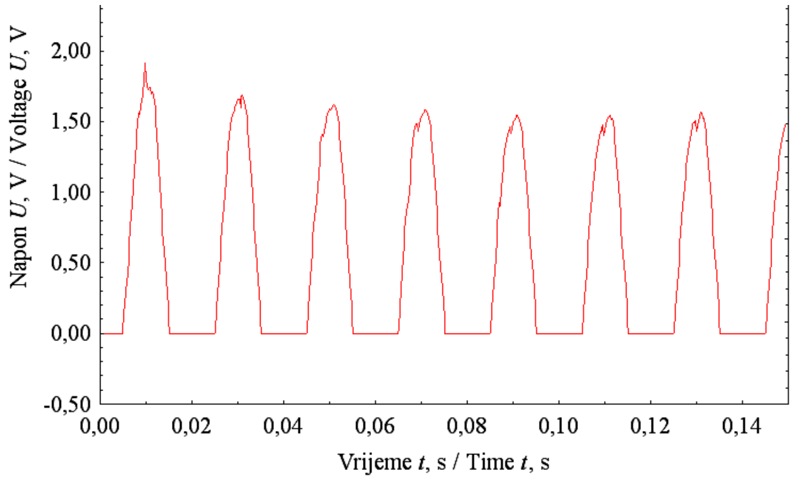


Figure 29 Welding voltage oscillations during the first 0.15 sec of resistance spot welding

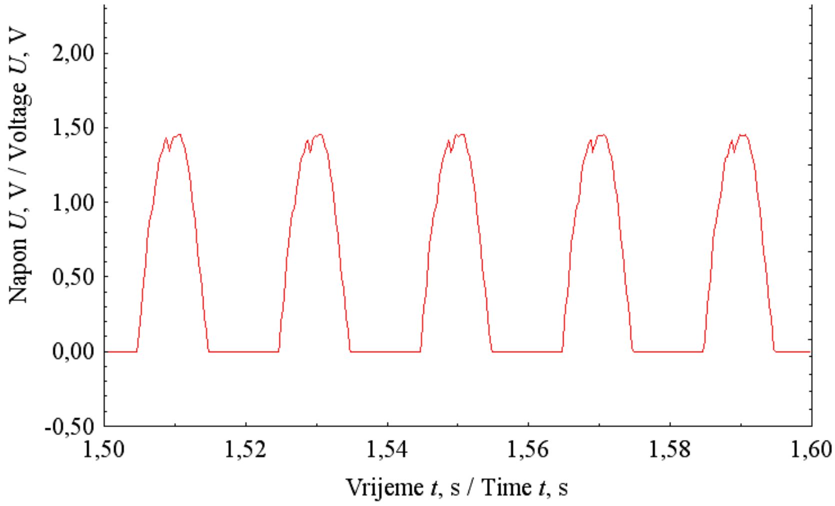


Figure 30 Welding voltage oscilations in the middle cycle of resistance spot welding (total duration 0.1 sec)

3.7 Monitoring of SMAW parameters at natural gas pipes welding

During downhill SMAW of gas pipes, welding parameters were recorded for celullosic electrodes (Fig. 31 to 35) and for basic electrodes (Fig. 36 to 40). SMAW with a rutile electrode at AC is shown in Figure 41. Due to monitoring system constraints, Figure 41 only shows the upper part of the *I(t)* and *U(t)* signal.

3.7.1 Celullosic coated electrode for "downhill" welding (direct current)

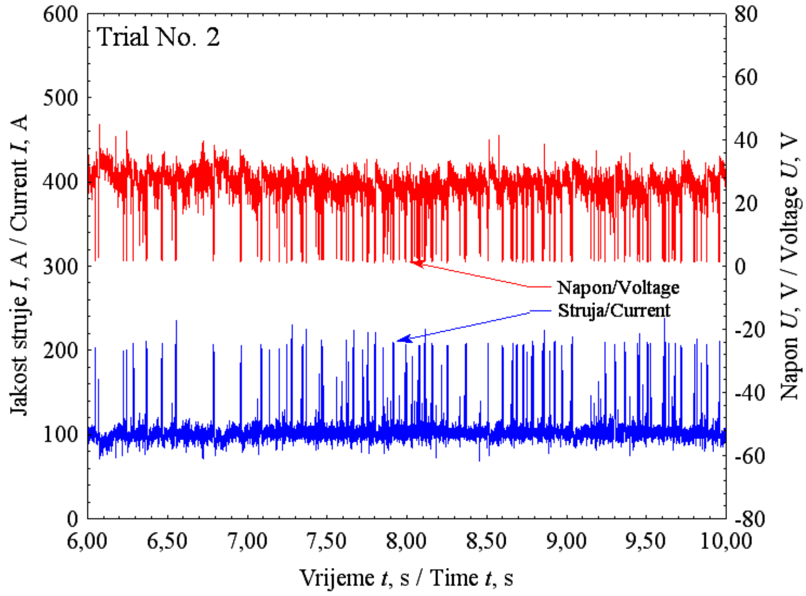


Figure 31 Voltage and current distribution during a randomly chosen SMAW segment. Downhill welding using a celulose coated electrode. Sampling frequency during recording - 5 kHz

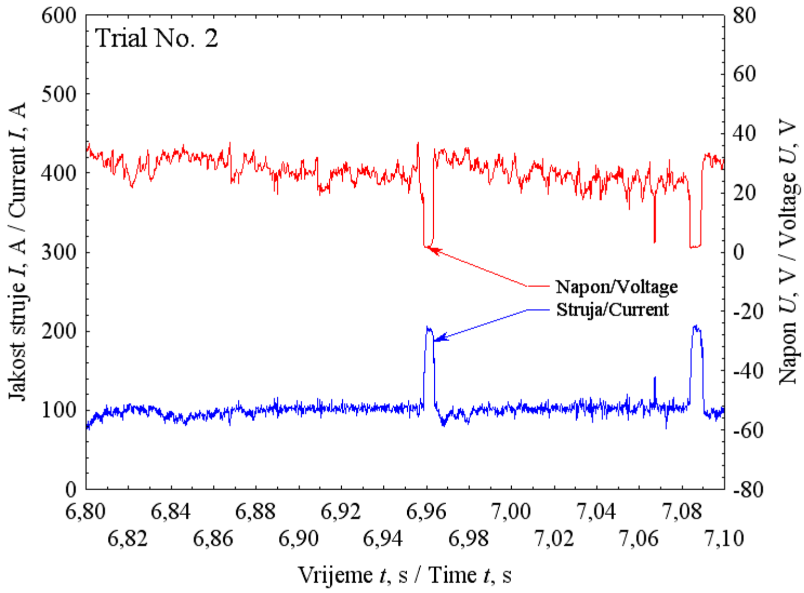


Figure 32 Voltage and current distribution during a 0,3 second welding sequence as shown in Figure 31

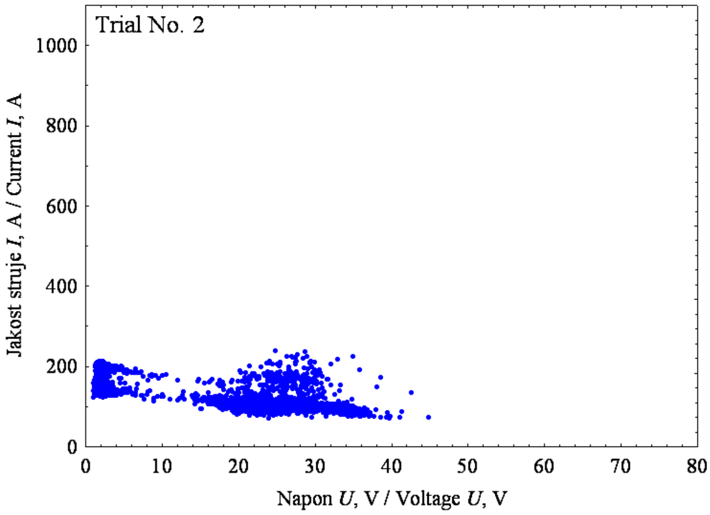


Figure 33 Correlation of welding voltage and current to data as shown in Figure 31

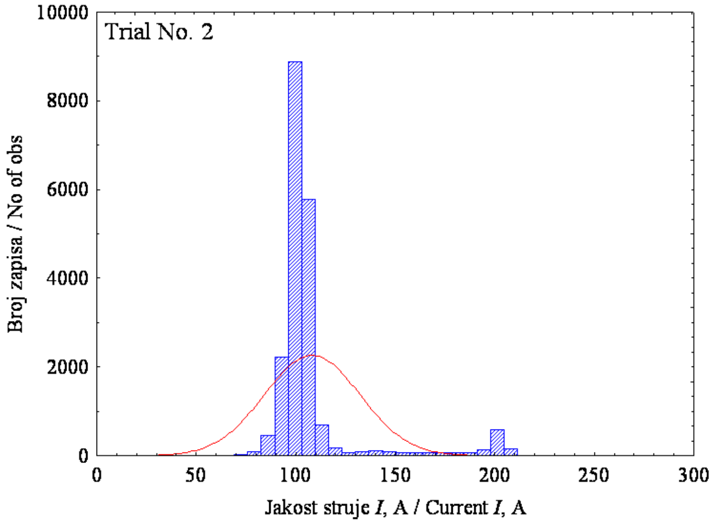


Figure 34 Histogram of the current frequencies as shown in Figure 31

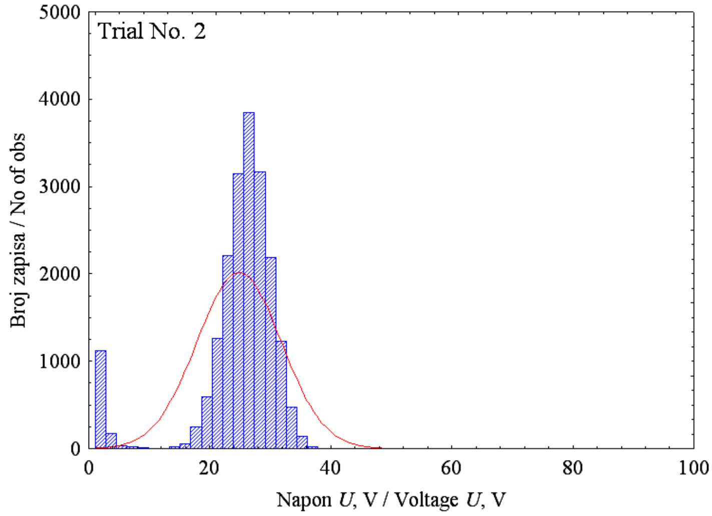


Figure 35 Histogram of welding voltage frequencies as shown in Figure 31

3.7.2 Basic coated electrode for "down hill" welding (direct current)

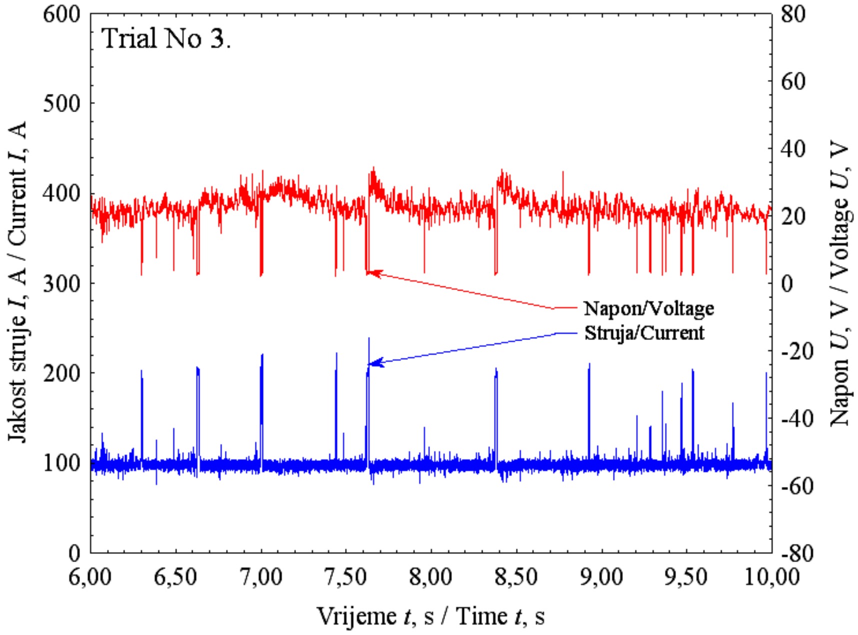


Figure 36 Voltage and current distribution during a randomly chosen SMAW sequence. Downhill welding using a basic electrode. Sampling frequency during recording 5 kHz

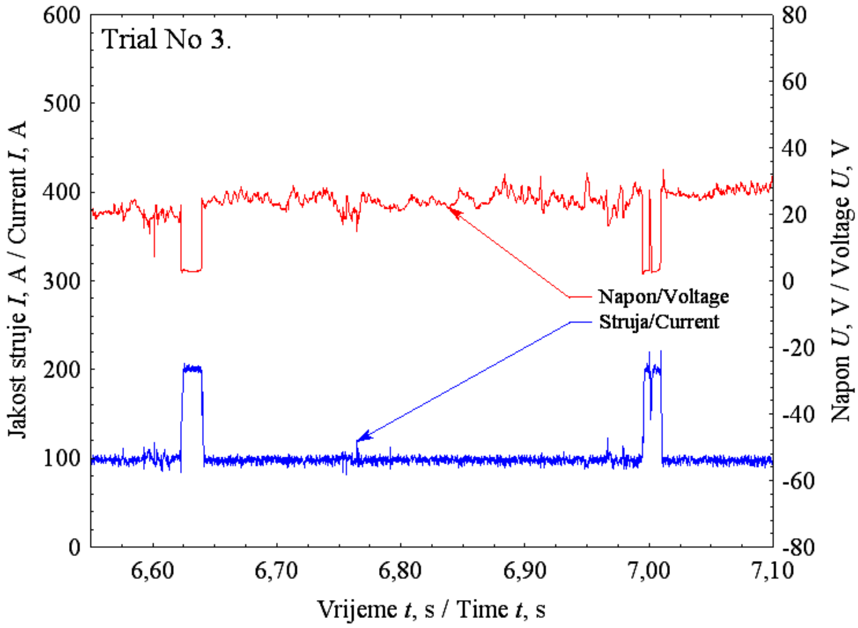


Figure 37 Voltage and current distribution during a 0,6 second welding sequence as shown in Figure 36

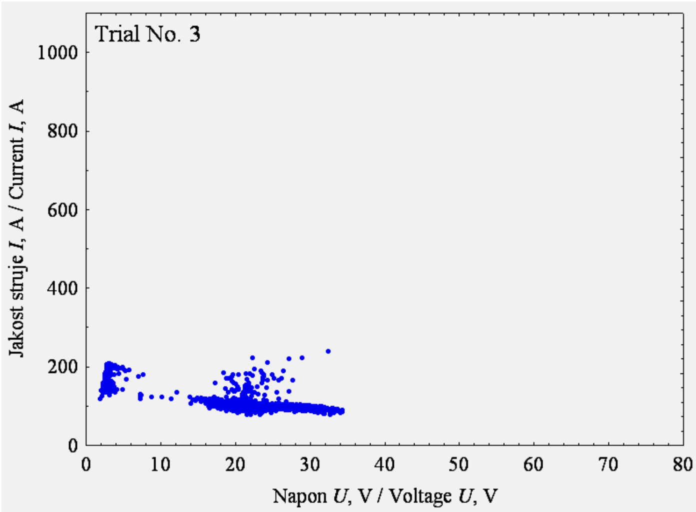


Figure 38 Correlation of welding voltage and current for data shown in Figure 36

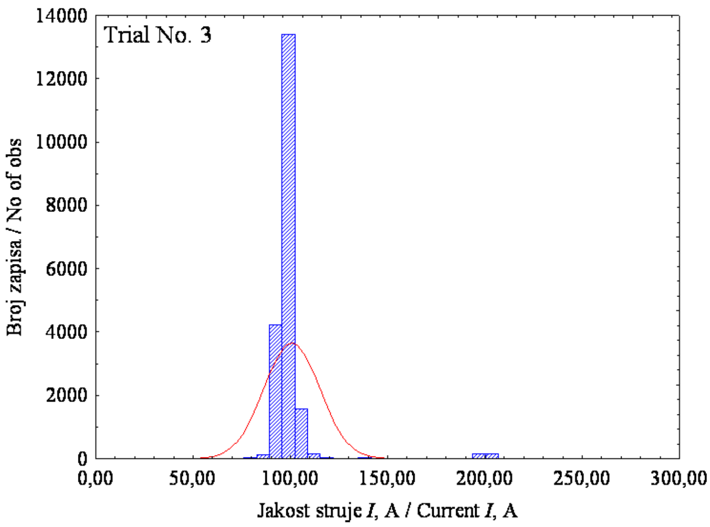


Figure 39 Frequency histogram for currents shown in Figure 36

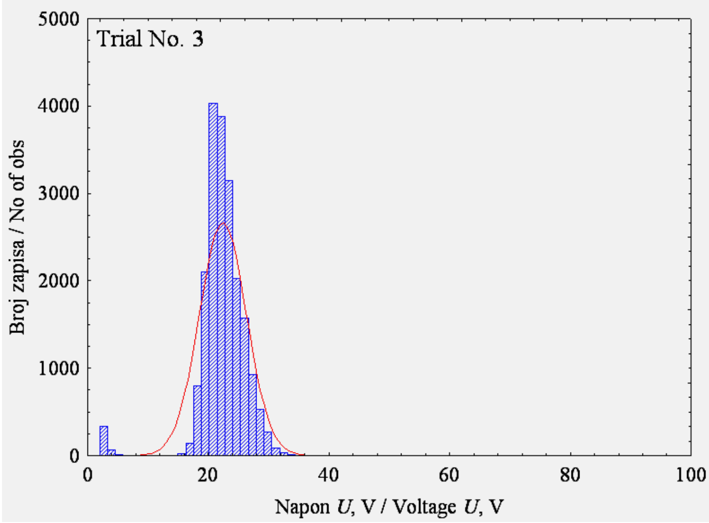


Figure 40 Frequency histogram for welding voltage shown in Figure 36

3.7.3 Rutile coated electrode (alternating current)

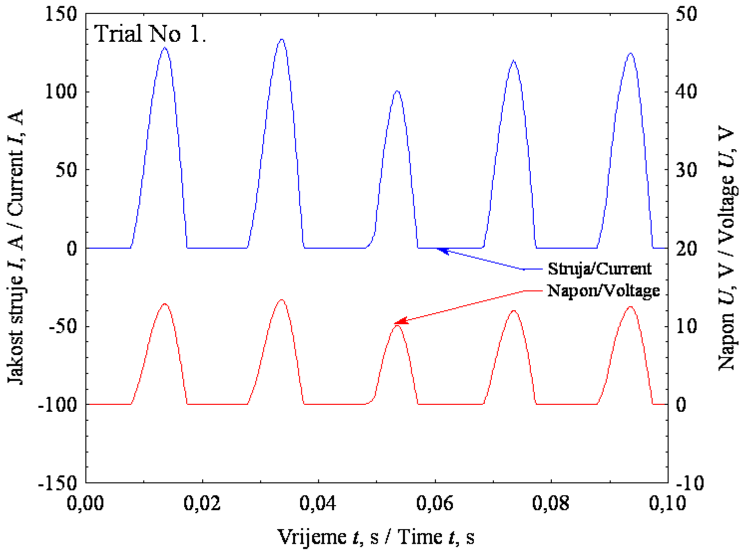


Figure 41 Oscillations in voltage and current during manual metal arc welding (MMAW) with AC power as recorded with an on-line monitoring system at a sampling frequency of 10 kHz.

Only signals on the upper side of the *U(t)* and *I(t)* diagram are shown. Since alternating current is applied, the bottom side would record symmetrical signals, but they are not depicted here.

4 CONCLUSION

On-line monitoring systems allow the tracking of key welding parameters and consequentially 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 presents some experience-based examples of on-line monitoring system application for different welding technologies. In the future, the monitor will be applied to evaluating the dynamic characteristics of welding power sources and of other electric arc welding technologies.

5 REFERENCES

[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] Antulov, D.; Lukačević, Z.; Samardžić, I.; Kolakovski, D. "On-line" mjerenje parametara zavarivanja. 2. međunarodno savjetovanje proizvodnog strojarstva, Zagreb, 18.11.1993., str. C27-C35, bibl. 3.

[3] Samardžić, I.; Grubić, K. Computer aided welding parameter monitorin69g. Časopis Zavarivanje 39(1996)1/2, 23-28.

[4] F. Neessen, F. Naber. The GMAW – STT process – An advance welding process. Lincoln Smitweld B.V, Lincoln Electric Europe B.V. The Niederland, October 2003.

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

[6] Dunđer, Marko; Samardžić, Ivan; Klarić, Štefanija. 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*. pg. 219-222.

[7] 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 high effective welding processes", page 1-13. UDK 621.791 (082), ISBN 958-98688-0-7, Publisher: Đuro Đaković, Slavonski brod, 2001.

[8] Samardžić, I., Kolumbić, Z., Baotić, M. Doprinos primjeni praškom punjenih žica za zavarivanje MAG postupkom. Znanstveno-stručni časopis Tehnički vijesnik, (2001)(3,4)23-37. UDK 621.792.3:620.17, ISSN 1330-3651.

[9] 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. page 227-232. UDK 621(063)=111=163.42, ISBN 3-901509-32-1.

[10] 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. 791-800

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

[12] 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.Haludovo (Krk) listopad, 1998., str. 437-448, bibl. 19., UDK 621-791, ISBN 953-96 454-9-1

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

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

[15] 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. 99-108.

[16] Samardžić,I.; Lukačević,Z. Mogućnosti dinamičkog praćenja glavnih parametara pri elektrolučnom zavarivanju. Časopis Zavarivanje 42(1999)1-2, str. 11-16. UDK 621.791, ISSN 0044-1902.

[17] 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.

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

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

[20] Samardžić, I., Kolumbić, Z., Klarić, Š. Study of shielding gas and filler material influence on MAG welding process stability - an application of the developed on-line monitoring system // *Proceedings of 8th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2004* / pg. 183-186.

[21] Samardžić, I., Kolumbić, Z., Klarić, Š. Arc stud welding process monitoring // *CIM 2005 Computer Integrated Manufacturing and High Speed Machining* / Cebalo, Roko ; Schulz, Herbert (ur.). Zagreb : Croatian Association of Production Engineering, 2005. V-27 - V-36.

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

[23] Kolumbić, Z., Samardžić, I., Matić, Z. Development of the 3D/PC motion control subsystem for the laboratory GMAW process research system. 7'th International conference on production engineering (CIM), Lumbarda (Croatia), 2001., str.V-11 do V-18., UDK 621(963), 658.52.56(03)., ISBN 953-97181-3-9.