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Measuring methods of welding process parameters

Abstract

The paper focuses on the problems of monitoring the resistance spot welding process of thin metal sheets used in aircraft structures. The welding process is conducted using welders with software control which allows the welding cycle to be established. Essential parameters in the welding process include: electrode profiles, establishing electrode force as well as the shape and the intensity of the current heating the weld. The paper proposes using a measurement system which registers the above-mentioned welding process parameters and utilises the modules of data acquisition, series NI 9215 operating in a set with NI cDAQ-9178. Software which uses the LabVIEW environment was implemented into the measurement system. The measurement of the welding current intensity was made using a Rogowski coil, while other measurement signals were obtained from the diagnostic interface of the programmable controller of the welder. The paper presents preliminary results of the research. The objective of the initial research is the preparation of a calibration method of welder measurement systems.

Keywords: Rogowski coil, welding current measurement, data acquisition card, LabVIEW environment.

1. Introduction

The processes of resistance welding are commonly used in various sectors of the industry. Processes which constitute a particular technological challenge are the spot welding processes of parts for aircraft structures made from austenitic alloy steel and strong hardened aluminium alloys. The ability to combine such materials is limited and depends on their properties and technological assumptions. Factors which hinder the performance of production processes include the sensitivity to thermal processes, the narrow range of welding temperatures, the susceptibility to fracture and the creation of contraction cavities as well as the presence of refractory oxides on the surface. For these types of materials, the recognised production practice uses special high-powered welders which enable a weld to be formed by dividing the welding process into several controlled stages. During the process, the following parameters are usually monitored: the profile and value of the electrode welding force, the shape and value of the heating current, the time spans of the heating current impact and the displacement of the electrodes which have a direct effect on the heat supplied to the weld:

$$Q = I^2 Rt , \tag{1}$$

where: Q - heat, I - current, R - resistance of the weld, t - welding time.

The diameter, profile and quality of electrodes are monitored regardless of the quality control procedures [1]. Of crucial importance is the correlation between the time spans of the acting electrode force and the heating current. The heating current is generated in the welder transducer systems and its value is monitored in line with the firing of a thyristor system by means of a programmable controller of the welder. The controller monitors the value of the heating current with the use of a measurement circuit built-into the welder.

Typical values of the electrode force range between 1000 and 13000 N, the root-mean-square values of the heating current amount to 15-64 kA, while the time spans of the individual stages of the cycle cover the range between 20 ms and several seconds.

The proposed measurement system makes the measurement of the heating current intensity in a separate measuring element (except the welder circuits) using the Rogowski coil which includes the welder electrodes in its measuring way. Other measurement signals are obtained from the diagnostic interface of the programmable controller of the welder. For the purpose of calibration of the measurement paths of the heating current, a typical measurement device was used - a "portable weld checker" MM-122A (MIYACHI) which operates alongside the Rogowski coil, type MB-800K (Fig. 1).

Fig. 1. Portable weld checker MM-122A for measuring the welding current

An independent measurement circuit of the electrode force, which uses a microprocessor device E725, was also suggested; however, because of the issues with the correct installation of the measurement sensor in the welder, the studies are to be continued.

The primary objective of the presented research is the creation of a methodology of calibration of welder measurement systems.

2. Rogowski coil

A Rogowski coil is a device used for current measurements. It is an inductive current transducer used to measure an alternating current without the need to cut and connect it to the analysed object, for instance, a welder.

A Rogowski coil consists of a toroidal coreless transformer - secondary winding, while primary winding forms a conductor with the measured current (Fig. 2).

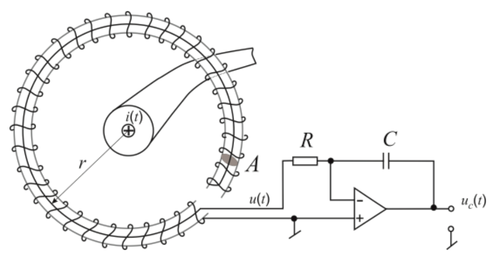

Fig. 2. The measuring system with the Rogowski coil with an electronic integrator circuit

The voltage induced in the secondary winding is proportional to the derivative of the current intensity, while the typical sensitivity is 1 mV/A and amounts to [2, 3]:

$$u(t) = -M \frac{di}{dt} , \tag{1}$$

$$u(t) = -\mu_0 N \frac{A}{l} \frac{di}{dt} , \tag{2}$$

where: M - mutual inductance between the conductor with current and the coil, N - number of secondary coil windings, A - surface of a single winding of the coil, $l = 2\pi \cdot r$ - coil length, $\frac{\mathrm{d}i}{\mathrm{d}t}$ - rate of change of current in the conductor.

3. Measurement target

The measurement target is a spot and continuous welder with a programmable controller (PLC) (Fig. 3).

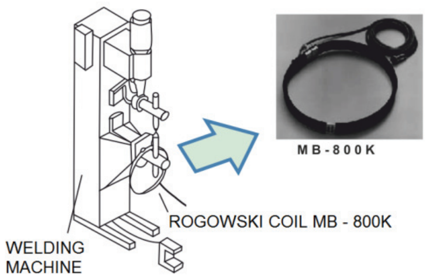

Fig. 3. Spot welding machine with the Rogowski coil, type MB-800 K [4]

Spot resistance welding is a process [4] in which two solid materials are joined together. Heat is generated during the flow of electrical current through the electrodes - in accordance with the Joule–Lenz law, and the welded materials are simultaneously pressed together [5]. Most of the heat accumulates between the surfaces of the materials, a melting process takes place and the metal sheets become joined (Fig. 4).

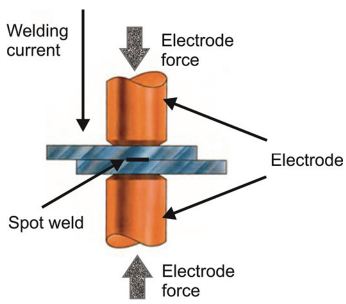

Fig. 4. Illustration of resistance spot welding [5]

A typical welding cycle includes the following stages:

A – pressing the two elements together,

B – heating the elements in the location of the joint and creation of a liquid weld nugget,

C – cooling the weld nugget under the electrode force.

The correct performance of the welding process necessitates the verification of the essential parameters of the welding process monitored by the controller of the welder and periodical calibration of the welder built-in measurement circuits [6, 7]. Fig. 5 shows a typical course of the changes in the electrode force during the welding process and the change in the welding current impulses.

The measurement of these parameters is an important element in the quality control process of the weld.

4. Measurement station

As a part of the works aimed at the creation of a workstation for the calibration of a welder, a measurement station was set up for monitoring the following parameters during welding:

- welding current [8, 9],
- electrode force,
- electrode voltage,
- displacement of electrodes.

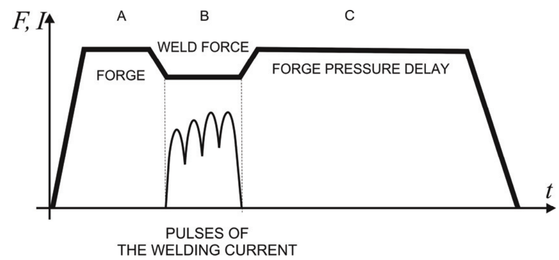

Fig. 4. Variable electrode force during the welding of aluminium

The proposed measurement system was based on the module of data acquisition operating in a set with NI cDAQ-9178. During the analysis, the following signals were simultaneously registered:

$u_R(t)$ – loss of the electrode voltage,

$l(t)$ – displacement of the electrodes,

$u_c(t)$ – Rogowski coil voltage proportional to the current (after the integrator),

$u_f(t)$ – voltage proportional to the electrode force.

The measurement of the welding current intensity was made using the Rogowski coil MB-800K, while other measurement signals were obtained from the diagnostic interface of the programmable controller of the welder. In order to recreate the signal measured using the Rogowski coil, it is necessary to perform an integration process, which could be made by means of a digital filter [2].

Fig. 6 shows a block diagram of the workstation.

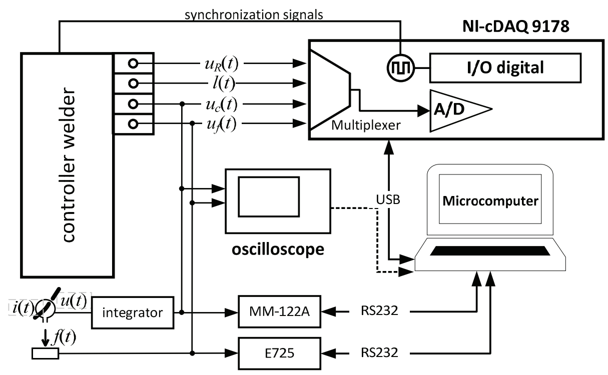

Fig. 6. The measuring system

For the purpose of registration, a four-channel A/C processing module with with simultaneous sampling - NI 9215, with a voltage range of ±10 V and a maximum sampling frequency of 100 kHz [10] was used. Also, a digital oscillogram was used to facilitate observation and registration of the examined cycles.

Software which uses the LabVIEW environment was implemented into the measurement system. The initial change in the electrode force, defined with the level of voltage u_f, released signal registration. The algorithm used takes into consideration the selection of physical AC processing channels, the adaptation of the scope and scale of channel processing, the selection of sampling frequency and the number of samples in preliminary signal sampling (pre-triggering). The use of the external release of the measurement and pre-triggering enables an unhindered observation of the welding process.

5. Preliminary research results

During the analysis of the welding process of aircraft skin elements conducted in manufacturing conditions, the following elements were analysed:

- loss of the voltage in the electrodes in the range up to 1V,
- welding current (RMS value for every half of the powering cycle, the value range between 15 and 64 kA),

- variable (in the welding cycle) electrode force measured on the welder electrodes, the value range between 1 kN and 13 kN,
- displacement of the electrodes up to 500 µm.

The time span of the observation cycle of the creation of the weld varied between 0.02 s to several seconds (depending on the operation mode of the welder; relating to the number of three-phase voltage periods supplying the welder).

Fig. 7 shows an oscillogram of changes in the electrode pressure adjustment and the course of the welding current registered during the analysis.

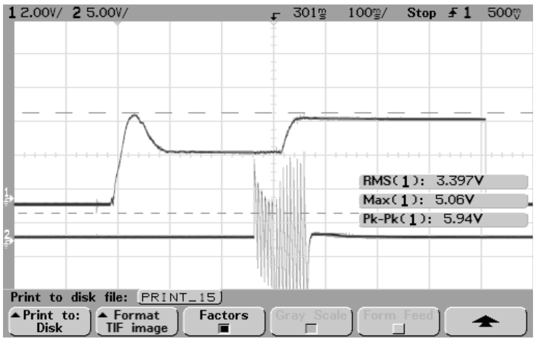

Fig. 7. Oscillogram of the changes in the value of the welding current and electrode pressure adjustment

6. Conclusions

The use of the data acquisition module NI-USB 9215 and the LabVIEW environment enabled the creation of an application to monitor the main parameters of the welding process. The workstation presented in this paper determined the preliminary operating results of the analysis. The course of the registered electrode force corresponds to the typical diagram of changes to the welder electrode force specified by the manufacturer.

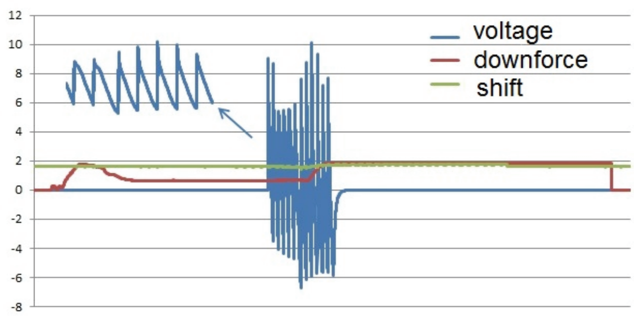

Fig. 8. Course of the registered voltage signals on the coil, downforce and movement during the welding process

The proposed measurement system monitors the essential parameters of the welding process. On the basis of the preliminary analyses performed, the authors believe that in order to prepare a full methodology of the welder calibration, it is necessary to expand the research. Other parameter which can have an impact on the repeatability of the welding process are, first and foremost, environmental conditions (temperature, humidity, atmospheric pressure), energy parameters of the supply network as well as types of elements which are joined together during welding. Also, the assessment of the preparation degree of the welded materials may be crucial (surface etching processes and the surface oxidisation state - measured directly by means of the volume resistance measurements of material samples and the results of the welder operation - the quality of the welds assessed in the conventional manner.

The next stage of the work will consist in the creation of a methodology for the calibration of the welder measurement systems. For this purpose, it will be necessary to perform analyses of the recorded selected parameters of the welding process alongside the quality control results of the manufactured welds. A full statistical analysis of all the process monitoring parameters and the knowledge of the above-mentioned factors will enable a determination of the impact of the individual factors on the quality of welded joints.

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