Resistance Spot Welding Control from Recycled Components

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Abstract - This article provides a comprehensive overview of microcontroller-controlled resistance spot welding machines, emphasizing both the design and operational aspects, as well as the benefits of using recyclable components. It details the electrical and mechanical parameters of the equipment, along with the control electronics and regulatory processes. Additionally, the physical principles of resistance welding are explained, followed by an analysis of the main challenges in control theory related to the process. Solutions to these issues are presented, focusing on the types of measured signals and the control strategies employed.

Keywords - spot welder, resistance spot welder, welding current control, recyclable electronics, reusable electronics

I. Introduction

Resistance spot welding is one of the most common welding processes in industry, especially in the automotive industry and other metalworking fields. During the process, the workpieces are held between electrodes, where heat is generated as a result of a high current, which melts the surface of the metal and creates a permanent bond with the help of pressure. The success of the process is highly dependent on the precise control of welding parameters such as current, duration and electrode force, which is a challenge due to changing environmental conditions and different materials used [1-4].

This study aims to provide a comprehensive picture of modern approaches to the control of resistance spot welding, with particular attention to the application of microcontrollers and the integration of recyclable components. Microcontrollers enable accurate and fast control of welding parameters, while the use of recycled components reduces costs and enables more sustainable production processes. The purpose of the thesis is also to reveal the physical background of the welding process, problems related to control, and different measurement and control strategies.

Resistance welding is a welding process that uses heat generated by electrical resistance between workpieces to fuse metals together. In the process, two electrodes are placed between the workpieces, through which a high-current electric current flows, while the electrodes apply pressure to the metals. The increase in temperature results in local melting on the surface of the metals, which creates the welding joint with the help of the electrode force. The use of spot welding is particularly widespread in mass production because it is fast, can be automated, and does not require any added material such as shielding gases or welding wire [5,6].

II. The Physics of the Spot Welding Process

In resistance welding, electric current flows through the electrodes through the workpieces, and the electrical resistance between the materials generates heat, which melts the surface of the metal. Heat production is based on the following equation:

$$Q_G = \int_0^{t_w} i_w^2(t) \sum_{i=1}^{n} R_i(t)dt \qquad (1)$$

where: Q_G is the amount of heat generated, i_w is the welding current, R_i is the resistive components present in the welding current path, t_w is the welding time and n is the number of measurements.

The amount of heat generated is directly proportional to the welding current and welding time. The largest part of the resistance is the contact resistance of the workpieces, which is crucial for the quality of welding. The resistance between the electrodes and the workpiece (approximately one-sixth of the previous value - for a steel workpiece and a copper electrode) is also significant, so these surfaces must be cooled frequently to avoid excessive heat generation and electrode wear.

A. The application of microcontrollers in the control of resistance spot welding

One of the biggest challenges in controlling resistance spot welding is the precise control and adjustment of welding parameters. Conventional welding machines operated with mechanical switches or simple timers, which did not allow dynamic control of the welding process. In recent years, the use of microcontrollers has brought significant progress in this field, as these devices allow accurate real-time control of welding current, voltage, time, and temperature [7].

The advantage of microcontrollers is that they have both digital and analog inputs, so they can process signals from various sensors, such as current, temperature, and pressure sensors [8]. Based on the sensed data, the controller is able to modify the welding process in real time to ensure the desired quality of the joint. Below is an overview of some of the key control tasks that can be performed efficiently with a microcontroller [9].

Continuous measurement and control of the welding current ensures that the workpieces receive the right amount of heat without overheating the material or insufficient heat generation. For this, a Rogowsky coil and a current sensor based on the Hall effect are often used, which enable fast and accurate measurement. Continuous monitoring of the temperature [10] during the welding process helps to avoid overheating of the electrodes, which can lead to electrode wear and deterioration of welding quality. Based on the temperature measurement results, the controller can regulate the cooling system [11]. The quality and temperature of the welding can also be easily monitored with an acoustic microphone, by detecting the emitted infrared light, or by measuring the thermal voltage.

Setting the correct welding time is critical to the strength of the weld joint. The welding time can be accurately regulated with the help of a microcontroller depending on the thickness and type of the welded material. The advance of the electrodes, the applied pressure, is also controlled, and piezoelectric, ultrasonic or laser distance measurement can also be used.

B. *Control strategies and solutions*

The success of resistance spot welding is highly dependent on the choice and application of control strategies. The basic challenge of traditional resistance spot welding systems is that it is difficult to set and maintain welding parameters that ensure optimal welding strength, especially under changing conditions. Early RSW machines were controlled by mechanical switches and simple timers that allowed only basic parameter control. However, systems with programmed controls allow real-time monitoring and intervention of the welding process.

Modern resistance spot welding systems work with feedback control solutions that automatically adjust the welding parameters based on the measured signals. The control system uses sensors to measure welding parameters such as dynamic resistance, welding current or electrode displacement. Based on these, the output unit adjusts the current, voltage and welding time to ensure the desired joint quality.

The advantage of the feedback control system is that disturbances occurring during the welding process (such as changes in the surface condition of the workpieces, wear of the electrodes or fluctuations in the thickness of the workpiece) can be automatically corrected based on real-time data. In the following, the three main types of feedback control systems are presented: the direct feedback control system (FCS), the weld-to-weld control system (WWCS), and the monitoring system (MS).

The FCS system controls welding parameters in real time based on measured variables such as dynamic resistance or current. The essence of FCS is that the controller constantly compares the desired values with the actual measured data and intervenes in the process based on them – similar data processing tasks are presented in the following works [12, 13]. For example, if the welding current or dynamic resistance deviates from the desired level, the system automatically adjusts the current or welding time. This type of control is especially useful if there are frequent disturbances in the process, as it is able to correct them immediately. The advantage of the FCS system is that it ensures uniform welding quality even in the presence of disturbances during the welding process, thus ensuring the optimal quality of the welding joint. These algorithms and their advantages and disadvantages are detailed below.

Constant current control (CCC) is based on the assumption that the welding current must be kept stable during the welding process (1). The continuous measurement and control of the current makes it possible to ensure a constant value of the amount of heat during the welding cycle. The value of the current is determined in combination with the current transformer and hall sensor, thus also taking into account the contact resistance between the workpieces. The advantage is that keeping the current stable helps to accurately control the size of the welding nugget and the strength of the bond and is suitable for welding applications where sudden changes in the current are undesirable. The disadvantage is that the constant current algorithm does not take into account the changing dynamic resistance, so heat production may not remain optimal. In reality, the resistance often changes during the welding cycle, which can affect the welding quality, and is not applicable to a wide range of materials, where different welding parameters are required for different materials.

Constant voltage control (CVC) is similar to the constant current algorithm, but focuses on stabilizing the welding voltage (2). The continuous measurement of the voltage allows the welding current and heat production to remain at the correct level. The algorithm focuses on keeping the welding voltage at a constant level, thus reducing the effect of current fluctuations during the welding cycle. The voltage is measured directly on the electrodes, so the quality of the welding process can be monitored. The advantage is that maintaining a constant voltage helps to stabilize the welding quality and ensure the optimal amount of heat, and measuring the voltage is often simpler than measuring the current. The disadvantage is that the algorithm does not take into account the changing dynamic resistance, which can also change in connection with temperature changes during the welding process. Furthermore, voltage control can be problematic when the resistance between the workpieces changes suddenly, since the voltage does not always reflect the actual welding condition.

$$Q_G = \int_0^{t_w} \frac{u_w(t)^2}{\sum_{i=1}^{n} R_i(t)} dt \qquad (2)$$

where, u_w is the voltage measured on the welding tips.

Constant power control (CPC) is the most advanced FCS approach that focuses on keeping welding power stable throughout the welding cycle. The algorithm regulates the welding performance by continuously monitoring the current and voltage, so that the optimal amount of heat remains at a constant level (3). This approach minimizes the risk of weld nugget size and temperature fluctuations. The advantage is that maintaining constant power reduces the risk of welding errors and ensures the optimal size of the welding nugget. It enables the welding of a wide range of different materials and thicknesses as it adapts to different material characteristics. The disadvantage is that the sensors and measurement technology required to stabilize the performance are more expensive, and the implementation of the algorithm is more complicated and requires more computing power from the control unit.

$$Q_G = \int_0^{t_w} u_w i_w dt \qquad (2)$$

The tracking controller is designed to track a predetermined reference signal of different measured variables, for example welding current, electrode movement, aquistic transmission [14-16]. PID control algorithms are often used for this purpose [17, 18].

Neural networks, fuzzy logic, and expert systems are the AI techniques commonly employed in resistance spot welding (RSW) applications. Expert systems are often used for the selection of appropriate welding parameters. Fuzzy logic-based control systems are typically used in tracking-type controllers, where dynamic resistance or electrode displacement is used as a reference. Neural networks are the most widely used AI techniques in RSW. They are employed for predicting weld nugget diameter, weld strength, or for weld classification. A commonly used network is the multilayer perceptron, which is combined with a backpropagation learning algorithm for function approximation; however, other types of neural networks have also been tested in RSW control [19, 20].

C. *Educational acpects and practical application of recyclable components*

The spot welding device, constructed from recycled components and described in this article, serves as an effective educational tool for demonstrating the control methodologies discussed in the previous subsection. This device is particularly valuable in higher education and engineering training, especially in fields related to sensors and actuators. It supports hands-on, hardware-focused applications, including microcontroller and industrial computer programming, as well as the teaching of algorithm theory and control systems technology [21-24].

One of the key aspects of modern industrial production is sustainability, which includes the efficient use of resources and the recycling of materials. The use of recyclable electrical components in resistance spot welding offers significant cost savings and environmental benefits. Integrating recyclable components not only reduces production costs, but also minimizes production waste, contributing to more sustainable industrial practices [25-28].

The benefits of recycled parts include cost reduction as companies need to purchase fewer new parts, thereby increasing their competitiveness. In addition, the use of new raw materials and energy costs can be reduced, as the incorporation of recycled components requires less energy than the production of new components. Moreover, recycling also contributes to job creation and innovation, as special labor is needed to disassemble and process used devices.

However, the use of recyclable components can present challenges, for example due to variability in quality and reliability. Certain recycled components may be outdated or no longer meet current technical requirements, which may reduce equipment performance and reliability. Therefore, when using such components, careful monitoring and testing is required, which also requires additional resource expenditure.

III. HARDWARE AND SOFTWARE IMPLEMENTATION

The transformer used is a 1500VA one. The outer winding is 400V and the inner winding is 230V. Then the outer winding had to be dismantled, the secondary winding was kept in its original state. After idle and load measurements, the following data can be measured: idle voltages $U1=236V$, $U2=4.7V$; load currents $I1=17.8A$, $I2=889A$, where U1 and I1 are the primary electrical parameters, U2 and I2 are the secondary electrical parameters of the transformer. The gear ratio is calculated as $a=U1/U2\approx 50$.

The frame had been built from aluminum profile from out-of-plant production machines, the construction can be seen on Fig. 1. The size of the workpiece and welding technology gives the design of electrodes. For the electrodes, the available 8 mm diameter piece of bronze was used. Textile bakelite was used to hold the electrodes, it insulates and heat-resistant, also tolerates mechanical stresses. With ten continuous welding, with only air cooling a 40°C temperature rise can be measured, see on Fig. 2.

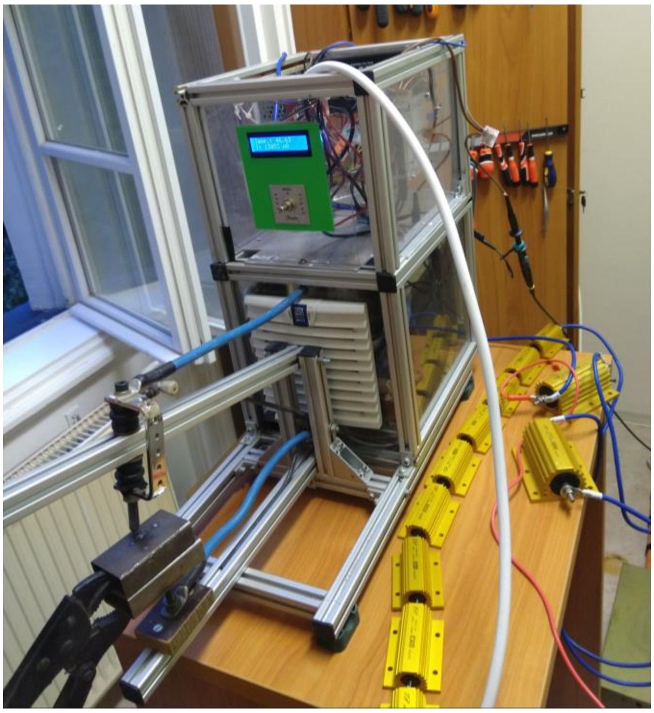
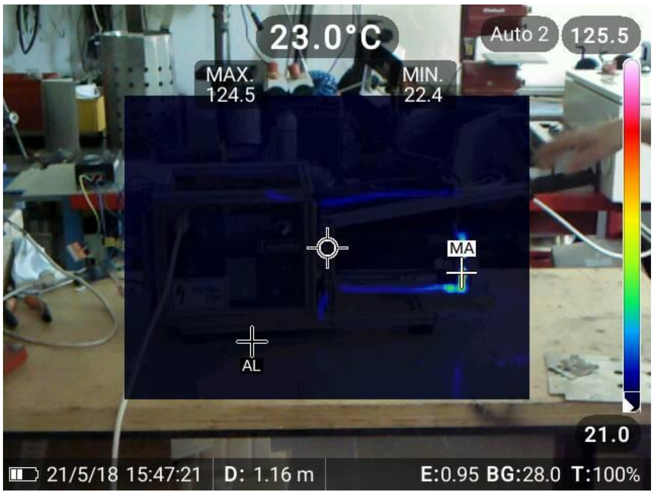


Figure 1: The finished equipment



2. Figure Thermal image of the electrodes after multiple welds

A. *Software & Control*

A microcontroller has been selected to control the device. A block diagram of the equipment can be found in Fig. 3. For user interface, a 16x2 line LCD display has been installed.

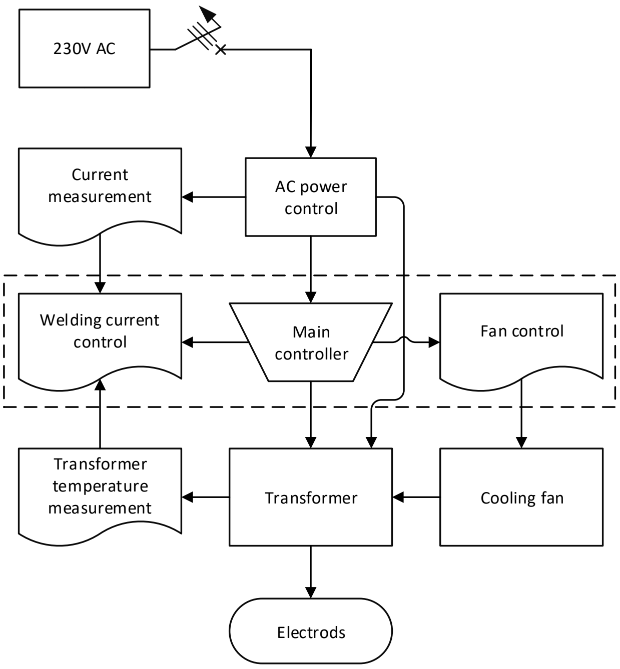


Figure 3: System design

Among several options for current measurement, a hall sensor current measuring module was selected and installed on the primary side of the transformer, for voltage measurement, an optocoupler based circuit been made to separate line voltage from the microcontroller, for temperature measurement, a silicon based component was selected.

Frequent use of equipment containing transformers creates a noise in the electrical network (Fig. 4. and Fig. 5), in order to reduce the effect, a properly designed mains filter has been installed and so that the disturbance at startup is acceptable, see on Fig. 6.

The transformer is continuously pre-excited through a resistor after sensing the welding tip contacts, when welding starts and the current increases, then the SSR2 (solid-state relay) will shunt out R1 and the current will flow through the relay. Timing is controlled from software, the process can be followed in Fig. 7.

Detailed description of the operation can be follow at Fig. 7. At start-up, it is checking is it the first start, and with electrical measurement it preventing the device from starting with burnt-in electrodes, in case of failure, it turns off the SSR1 relay and writes an error message to the display.

Temperature measurements are also performed to avoid overheating. If the preset value is exceeded, it turns off the equipment and informs the user with an error message.

Cyclically, the number of welds are counted. The electrodes can deteriorate during high-current welds. After the precalculated cycles, the operator receives a notification to check and clean the electrodes and then shuts off the device for the time of the operation.

After turning on the SSR1 relay, a current measurement is made, and if its value exceeds 2A, the SSR2 relay is turned on for the welding period. See the system architecture in Fig. 8.

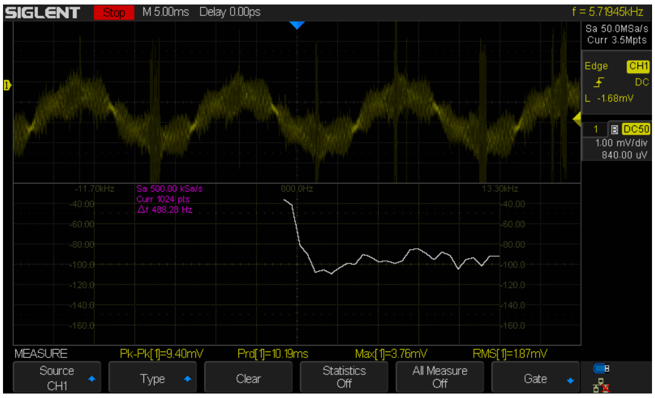


Figure 4: Noise spectrum before filtering

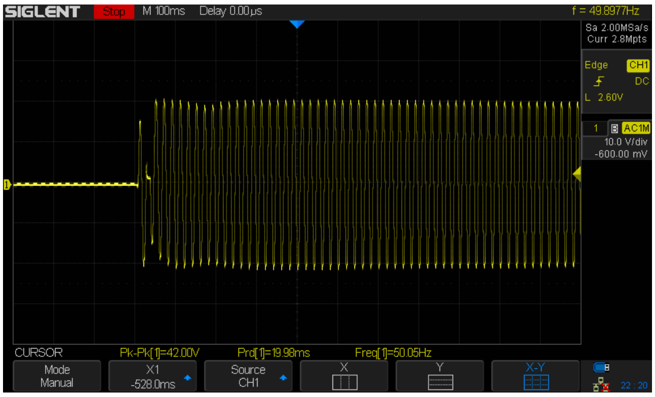


Figure 5: Noisy switching current diagram

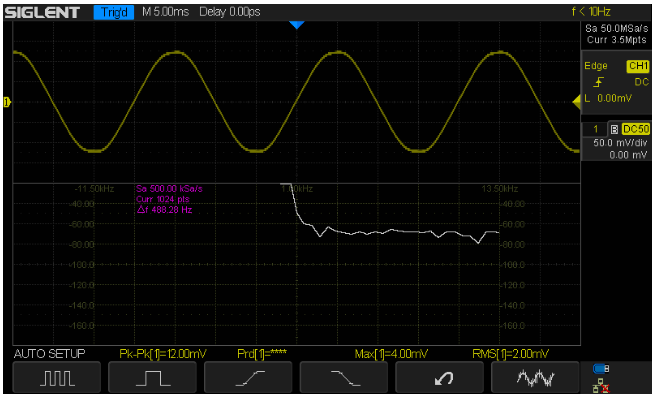


Figure 6: Noise spectrum after filtering

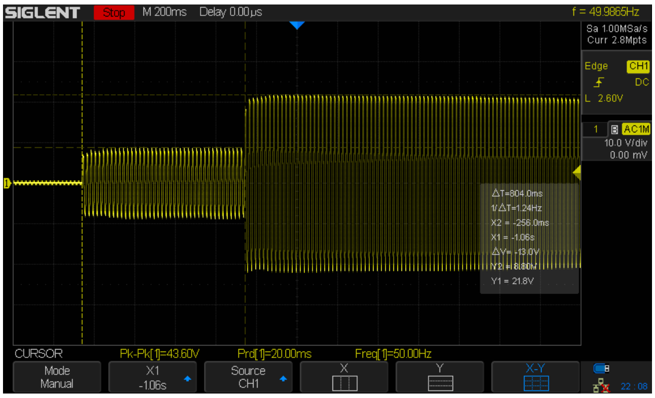


Figure 7: Timed welding process

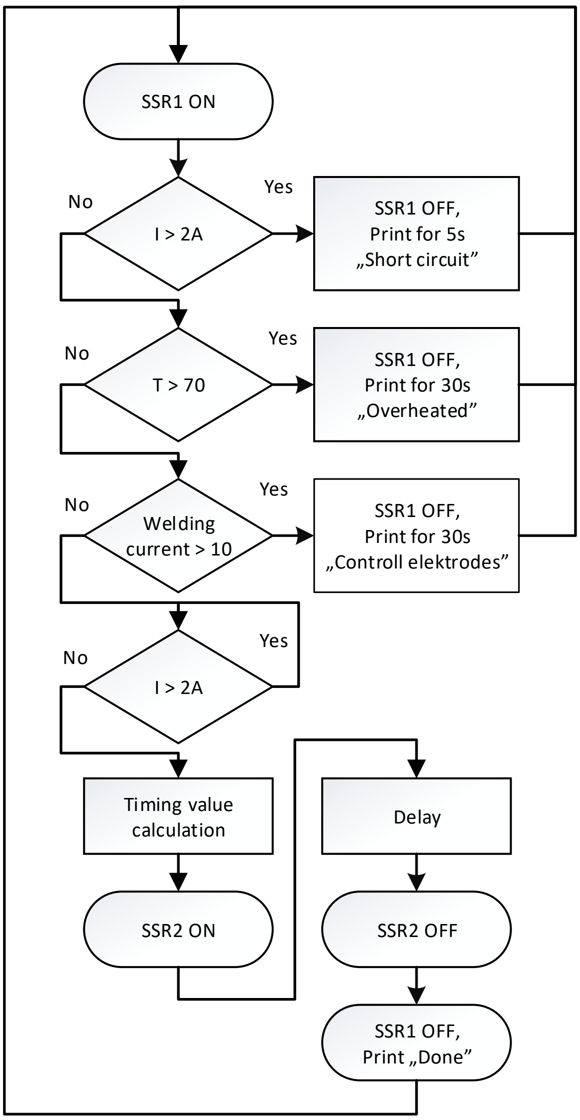


Figure 8: Flowchart of the main program

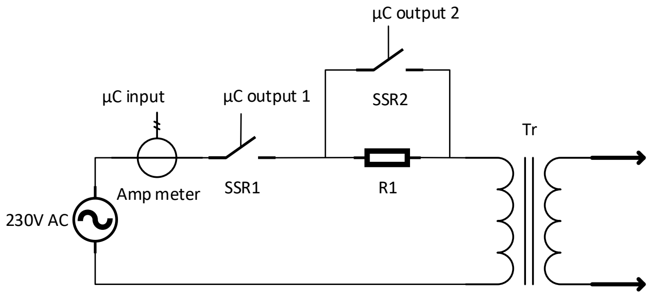


Figure 9: Primary side control elements

CONCLUSION

Resistance spot welding remains an essential industrial process, having undergone significant advancements with the integration of microcontrollers. These devices enable precise, real-time control of welding parameters, while the use of recycled components contributes to more sustainable manufacturing practices. Feedback control systems and monitoring of key variables in RSW play a critical role in improving weld quality and mitigating disturbances. Continuous innovation is vital for the welding industry to keep pace with technological advancements and address environmental and economic challenges. Additionally, the integration of control systems, microcontrollers, and recycled elements is not only crucial for the industry but also central to modernizing engineering education. By combining theoretical and practical learning, students gain valuable, industry-relevant knowledge in areas such as electrical engineering, materials science, and control systems, equipping them to become engineers who prioritize sustainability and innovation.

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