Determination of electrical energy consumption of welding cylindrical workpieces from alloy AA6060-T66 with TIG method

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Abstract: *The paper presents an informational measurement system for measuring electricity consumption from a three-phase grid during welding of AA6060-T66 aluminium alloy cylindrical workpieces using the TIG (Tungsten Inert Gas) method. In addition to electricity consumption, the developed system can also monitor other related electrical quantities that give an image of the load that the consumer exerts on the grid. The importance of knowing these quantities is reflected in the fact that it can provide us with information about the energy efficiency of the method, as well as the possibility to determine the economic benefits of the chosen process and technology with the knowledge of the welding input parameters. These electricity consumption values affect the sustainability and have an impact on the environment. Energy input also directly affects the quality of the welded joint, which is reflected in penetration, formed microstructure and mechanical properties. Also, knowing this information opens up opportunities to compare performance with other methods. The paper presents the development of such a system, which includes the necessary hardware components, communication and software through which data acquisition is performed.*

Keywords*: ELECTRICAL ENERGY CONSUMPTION, INFORMATION MEASUREMENT SYSTEM, ALUMINIUM ALLOY, TIG WELDING*

1. Introduction

Welding is defined as the localized joining of metals or non-metals caused either by heating the material to a suitable temperature with or without the effect of pressure or only by the effect of pressure, with or without the use of additional material [1]. Conventional welding processes work on the principle of melting the material mainly by usage of an electric arc, which is accompanied by a large consumption of electricity.

In order to estimate the cost of a welding technology, it is necessary to determine several different factors [2], and from those one of the most important is consumed electrical energy. In addition to economic analyses, the consumption of electricity is directly reflected in the environmental sustainability of the process.

When it comes to the problem of environmental pollution, the manufacturing sector plays a significant role in CO_2 emissions. This gas is one of the main causes of climate change in the form of global warming of the planet. Harmful emissions originating from the production sector can be divided into direct and indirect. The direct ones come from the process of burning fossil fuels, while the indirect ones are the result of the use of a large amount of electricity, which according to some estimates amounts to about 35% [3].

Different welding processes have different consumption of electricity. By monitoring the consumption of this energy, we can detect inefficient parameters of the welding process as well as deviations in the welding performance between the prescribed and applied technology. Based on this information, we can optimize the process as a function of the minimum consumption of electricity, taking into account the quality of the welded joint. This information allows us to define the cost price of the welded joint per unit length. We can also use the measurement of electricity consumption to monitor the state of the equipment (bad ground, damaged cables or welding machine), which leaves room for predictive maintenance and reduction of downtime.

Electricity consumption can be measured in several ways. By using Electrical Meters that enable precise monitoring of basic electrical parameters. Also by using Grid Analyzers and Data Loggers that are more accurate than Meters and can monitor harmonics reflected to the grid, Root Mean Square (RMS) voltage and current and other parameters, while some modern welding machines have built-in sensors to monitor parameters that can be accessed using different communication protocol.

Researchers have developed various alternative methods for measuring these quantities, such as acoustic principles [4]. A certain number of papers deal with the analysis of the electrical energy efficiency of the welding process [5-7] and robotic stations [8], while some authors deal with the efficiency of the heat input itself in the welded joint [9].

In this research, an information measurement system was developed for monitoring the energy efficiency of the welding process, specifically at welding aluminium cylindrical workpieces. The principle of a Smart Electric Meter, which represents the measuring module of the information measuring system, was adopted.

2. Information measurement system

The information measuring system for measuring electricity consumption consists of a measuring module and a computer with acquisition software, which is connected to the welding machine. In Fig. 1 shows the measurement process with the components of the formed information measurement system.

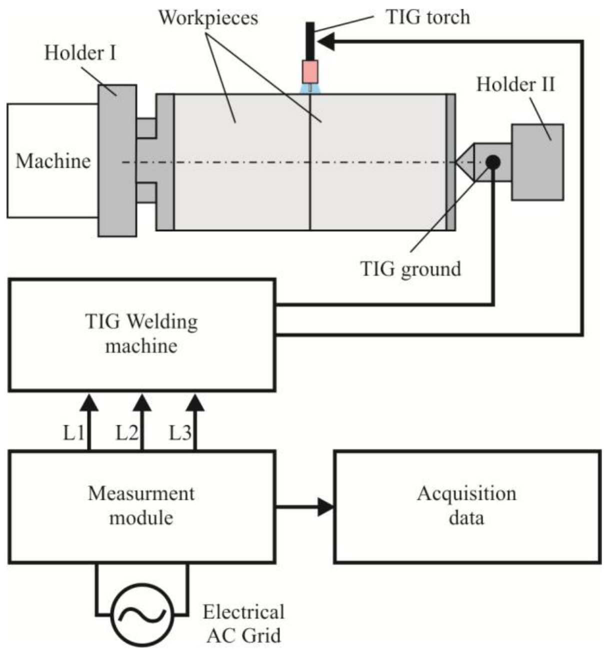

Fig. 1 *Block diagram of the information measurement system connected to the welding machine and positioned workpieces*

The workpieces are tubes made of aluminium alloy AA6060-T66, the outer diameter of which is Ø150 *mm*, and the wall thickness is 5 *mm*. They are welded in butt configuration and are positioned for welding on a machine that allows us to rotate the workpieces and base them between two supports. Welding is done by the TIG process, where the ground is fed directly over one of the supports.

The Schneider IEM3155 measuring module enables the monitoring of various electrical quantities, of which the most important for this research are electrical energy consumption and active power. The module is and Electrical Meter, which is powered from the grid. It is typically used to monitor and measure electricity in commercial and industrial applications. Through the module, the consumer device is fed from the three-phase grid, whereby the module monitors the parameters of the consumed electricity and forwards this data to the computer via the RS485 communication protocol, where it is acquisited in the appropriate software. Input voltage up to 400 *V* can be measured, while the maximum current is 63 *A* [10]. The module functions on the principle of direct current measurement without the use of external current transformers. Some of the other electrical parameters that the module can monitor are apparent and reactive power, phase voltage and current, power factor and current frequency. In Fig. 2 shows the measuring module with the used components.

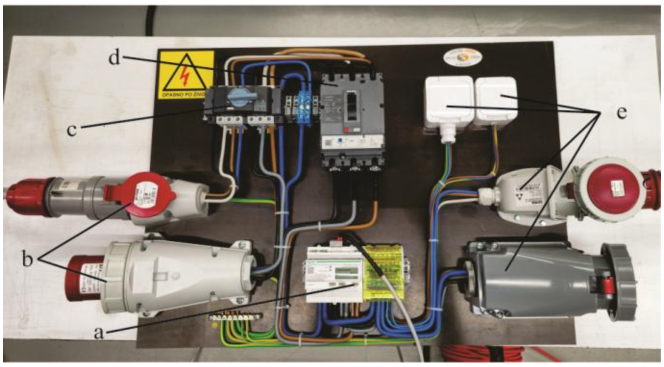

Fig. 2 *Measurement module*

The central unit (CU) - the smart electric meter Fig. 2 (a) is mounted on a phenolic cotton laminate plate that meets the electrical safety regulations in terms of non-flammability and electrical insulation. The CU is powered by one of two industrial sockets at the input Fig. 2 (b), one of which is used for consumers up to 32 *A*, and the other up to the maximum input current for the CU, which is 63 *A*. In order to avoid the situation where the user mistakenly connects two inputs to the device at the same time, which could result in a short circuit and breakdown, power is supplied to the module via a three-position switch Fig. 2 (c) which allows only one input to be selected and also has a middle neutral position, in which the circuit is not powered. For additional safety, an automatic three-pole fuse was added to the circuit Fig. 2 (d). These fuses are used to protect electrical circuits from overloads and short circuits in low voltage electrical distribution systems. The output from the measuring device Fig. 2 (e) are the four most commercially presented sockets (single-phase, three-phase, industrial socket of 32 *A* and industrial socket of 63 *A*), which enables the use of the developed system for monitoring electricity consumption of different consumer devices.

In this case, the consumer is a TIG welding machine, which enables obtaining a high-quality joint when welding aluminium alloys. The current used for aluminium welding is alternating, of high frequency. Also the electric arc at this process is started by a high-frequency generator that outputs a high voltage of up to 11 *kV*. Also, the device has a coolant pump and a fan in it, which are part of the torch cooling system and enable welding with current of up to 300 *A*. This indicates that it is a demanding consumer, which emits a wide range of electromagnetic interference that complicates the operation of the information measurement system. Therefore, the RS485 cable which is used for communication with computer is shielded and grounded at one end. Care was taken to keep its length as short as possible and to avoid its parallelism with the input and output conductors, as well as the cables from the apparatus. Communication with the computer is achieved through an adapter, which converts the RS485 signal to USB communication. This adapter and shielded cable are shown in Fig 3.

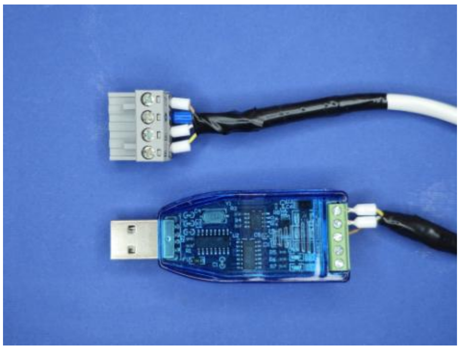

Fig. 3 *Adapter with shielded cable*

Communication with the measuring module is achieved via the Modbus protocol. This is a simple communication protocol where one device is the master, which sends a request for data, while the other device is the slave, and it responds with values over a wired connection. The minimum number of wires for this protocol to work is two communication wires (A and B), while for a more stable connection it is recommended to connect with a common ground (GND) wire, so this approach was adopted. The fourth wire represents the shield connection and it is recommended to connect it only on one side, in order to avoid the effect of eddy current (ground loop).

In Fig. 4 shows a research site for measuring electricity consumption with connected measuring equipment in the information measurement system.

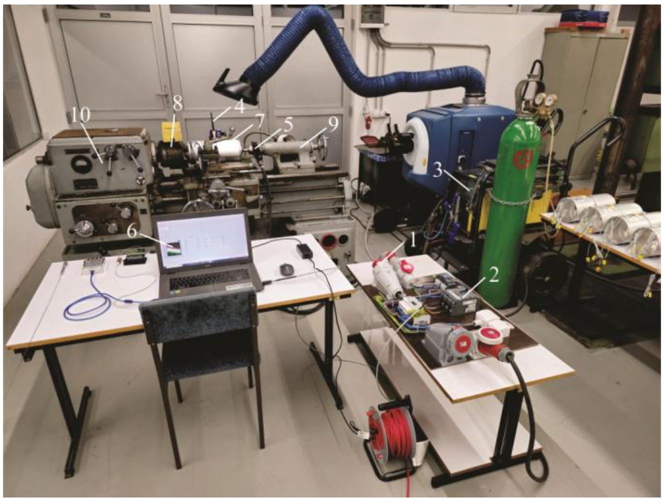

Fig. 4 *Research site:*
1 – Electrical source; 2 – Measurement module; 3 – Welding machine; 4 – TIG welding torch; 5 – Ground clamp; 6 – Computer with software for data acquisition; 7 – Workpieces; 8 – Holder I; 9 – Holder II; 10 – Machine

3. Measurement of electrical energy consumption

The welding process is mechanized in the sense that the rotation and welding speed are defined by a stepper motor. The role of the welder is to start the electric arc at the given time and to manually feed additional material. The measurement was started immediately before the start of the welding process itself.

Using the program obtained in the *LabVIEW* software of the company *National Instruments*, in which the electrical quantities were monitored, the values were obtained in graphic and DATA form. The diagrams obtained in this way are a function of energy (*kWs*) and time (*s*), as well as power (*kW*) and time (*s*). Fig. 5 shows the block diagram of the created interface for measuring electricity consumption in the LabView software.

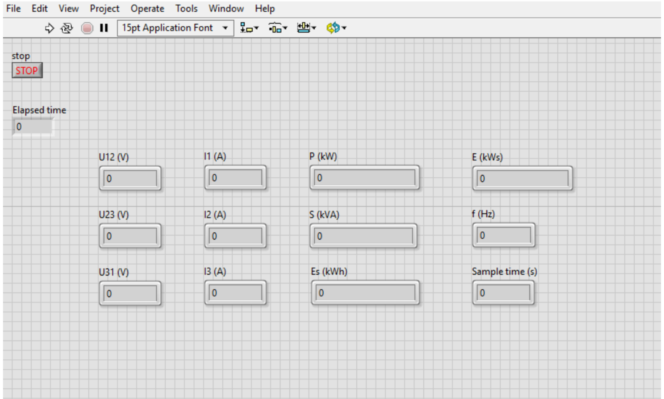

***Fig. 5** Interface for measuring electrical energy consumption created in Labview software*

The values of active power P (kW) and consumed electrical energy E (kWs) can be calculated based on expressions (1), (2) and (3),

$$P = \sqrt{3} \cdot U_L \cdot I_L \cdot P_f \tag{1}$$

$$P_f = \cos\varphi \tag{2}$$

$$E = P \cdot t \tag{3}$$

where U_L (V) line voltge, I_L (A) line current, P_f power factor and t (s) elapsed time. Power factor is a dimensionless quantity that represents the cosine of the phase angle between voltage and current.
The obtained results were processed in the *MATLAB* software. The diagram of the measured consumed electrical energy and active power as a function of time during the welding process is given in Fig. 6. The welding process lasts 266 s, on a length of 471 mm, which is realized in two passes with an additional 30 mm overpass. The maximum measured consumption of electrical energy for the welding process in two passes with overpass amounts to E_{max} = 858.8 kWs,= 0.2385 KWh, and maxium active power is P_{max} = 4.6 kW.

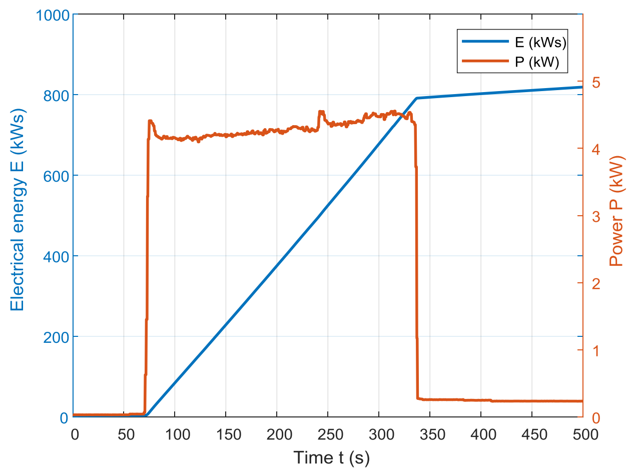

***Fig. 6** Measured electrical energy consumption and active power when welding cylindrical aluminum alloy workpieces in two passes*

We can see that the active power and consumption of electrical energy at the very beginning before the start of the arc tends to zero. Then we have a constant power value and linear power consumption, with a slight increase in power at the beginning of the second welding pass. After the end of the process, the active power value drops sharply, but not to the initial value. This is due to the operation of auxiliary devices, pumps and fans in the welding machine, which work for some time to cool the device. As a result, energy consumption recorded a sharp decline.

4. Conclusion

Electricity consumption is an important process parameter in welding. It provides information on the economic profitability and environmental sustainability of the process.

Considering the indicated complexity of measuring electrical energy consumption under conditions of strong electromagnetic interferences originating from TIG welding, the developed information measurement system has been confirmed as reliable and practical. The information measuring system and other used equipment are adapted to measure the consumption of electricity when welding cylindrical workpieces made of aluminum alloy AA6060-T66, but it can also be used to measure the consumption of electricity in other welding processes, as well as to measure the consumption of other electrical consumers. Based on the measurements of electricity consumption for the adopted technological parameters of the TIG welding method, we obtained that the electricity consumption per unit length of the welded joint is 0.4664 kWh/m.

The measurement performed is part of larger research into the energy efficiency of the welding process for a wider class of welded workpieces of various shapes and dimensions.

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