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Investigation on the arc light spectrum in GTA welding

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ABSTRACT

Purpose: In the paper there are presented results of the influence of welding parameters on spectral intensity of the welding arc in the range of 340÷860 nm. The main goal was checking whether the visible radiation of the arc provides information which might prove to be useful in monitoring of the welding process, similarly as the signals recorded in the electric circuit of the welding arc.
Design/methodology/approach: The experimental station was designed and build. A spectrophotometer, in the visible spectral range of 340 nm to 860 nm, was used. The investigations were conducted on the automated GTA welding station. For each welding parameter the arc light spectrum was measured
Findings: Research results presented in this paper indicate that the welding arc radiation contains a number of information concerning the course of the welding process. That signal is much more sensitive to the changes of welding conditions and should be used as a tool for monitoring of the TIG welding process
Research limitations/implications: The fiber spectrophotometer in the visible spectral range of 340 nm to 860 nm is an expensive instrument and that fore it can be used only as a complementary tool in monitoring of welding processes.
Practical implications: The gained experience allows directing farther research on the welding arc radiation phenomenon and the possibilities of using this signal for on-line monitoring of the welding process on automated and robotized stands.
This sensing system will be particularly attractive for welded structures manufacturing industry because it could significantly reduce the cost for post weld analysis and repairs
Originality/value: Three fitting functions: Lorentz, Gauss and Voight were investigated as a means to simulate the spectrum distribution. The mathematical-physical model of the arc light emission and neural networks were compared
Keywords: Welding; Arc light intensity; Arc length; Spectrum

1. Introduction

The welding arc is a source of many signals which may be used to investigate the stability of arc burning, and indirectly also the stability of the welding process. Basing on the assessment concerning the stability of the welding arc, in many cases the quality of the joint can be evaluated. Up to now the stability of arc burning was assessed mostly basing on recorded signals of the welding voltage and the welding current [1,2]. As the appearance of many kinds of welding imperfections are not accompanied by any distinct changes of the welding parameters which might be interpreted explicitly, any inference concerning the stability of the welding process and the quality of the joint basing on the results of monitoring of the welding parameters is not to be considered as the method which can be applied independently.

The detection and anticipation of possibilities of the appearance of weld imperfections require an extension of the range of investigated signals resulting from the welding process. Besides the welding parameters, such signals may be also the sound [3, 4] as well as the visible radiation of the welding arc.

The welding arc light occurs in all arc welding methods, and in the most cases it can be observed directly, being a hazard for the welder's eyes [5]. It may be also considered to be one of the signals emitted in the course of welding and utilized as a carrier of information about the welding process [6, 7].

The intensity of radiation produced by the welding arc is a function of the welding process itself and of the welding variables. Sources of visible radiation in the welding arc are the following: the arc column, the regions close to the electrodes, the liquid metal transported across the welding arc, the molten pool, the heated region of base material around the molten pool and the heated end of the electrode wire.

Measurements and the analysis of the spectrum of the visible radiation of the welding arc are applied in investigations of the welding process in order to find out the temperature distribution in the arc [8], to calculate the mean temperature of the welding arc [9], the amount of hydrogen in the gaseous shield of the welding arc. Investigations on the visible radiation of the GMA welding method helps also to monitor the way in which the metal is transferred through the arc, particularly during the spray transfer. Optical methods are also applied to scan the length of the welding arc in the GMA and the GTA method [10 ÷ 14].

2. Experimental

2.1. Experimental setup

The tests have been performed on the stand for automatic TIG welding. The measuring system consists of the welding current and the voltage transducers, an electrooptical converter, a measurement card and a PC computer. The analyzed beam of the visible radiation is fed into the electrooptical converter by means of a standard optical wave guide. The electrical signal corresponding to the visible light intensity, and signals from the welding circuit, are recorded on the PC by the recording device, equipped with the NI DAQ 6036 measuring card. The recorded signals were than analyzed. The intensity of the visible light radiation of the welding arc was measured in conventional units.

A spectrophotometer was used in the research, which has been designed for the remote fiber spectroscopy in the visible spectral range of 380 nm to 780 nm. It is based on a reflection grating and CCD array with 1024 elements (pixels). The spectrophotometer was controlled by the PC computer with a sophisticated control program.

2.2. Experimental procedure

The following experiment conditions were approved: the arc burns between the thoriated tungsten electrode (cathode) and a copper plate (anode), the welding torch is fixed, argon (Ar) as the shielding gas, the welding current in the range of 30÷300 A. It was assumed that the arc length is equal to the distance between the electrode tip and the welded metal surface. The range of the welding arc length L=2÷5 mm.

The CCD sensor allowed us to capture the whole spectrum in the range of 340÷860 nm at the same instant. This method proved to be reliable and capable of giving reproducible results. Fig. 1 shows the arc spectrum obtained in the range of 340÷860 nm at the welding current of 200 A, arc length in range of 1÷6 mm and 100 % Ar as the shielding gas.

The entire arc column will be analysed as a single object. The objective will reveal the roles of different welding parameters in determining the overall spectral characteristics of the arc light.

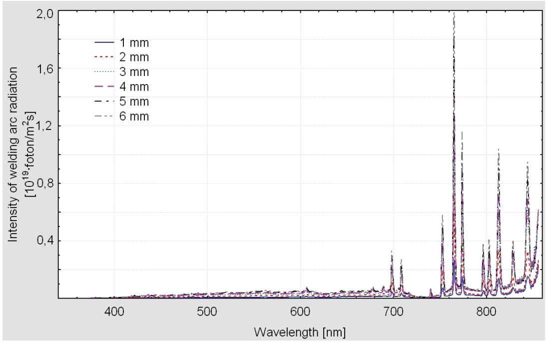

Fig. 1. Effect of the arc length on the arc light spectrum. The welding current 200 A, the arc length in the range of 1÷6 mm, the shielding gas – 100 %Ar, wavelength in the range of 340÷860 nm

3. Fitting of spectrum profile

To establish the characteristic of the values: the centre and the width of the line emission of selected wavelength the fitting of the three functions: Gaussian, Lorentz and Voight was carried out. The least square method and Levenberg-Marquardt algorithm had been used.

The fitting was carried out for single line emission and for multi-emission line simultaneously. All result were compared with the real value.

Descriptive equations for each fitting function is presented below together with characteristic parameters for the wavelength 813,22 nm. The same procedure for all emission lines had been carried out.

The one of the main goal was to fit the profile by the Lorentz function:

$$y = y_0 + \frac{2A}{\pi}\frac{w}{4(x-x_c)^2 + w^2} \qquad (1)$$

The initial conditions for calculation were:
offset: y_0=0
centre: x_c=5
width: w=2
amplitude: A=1

In Fig. 2. the calculated line profile of the wavelength 813,22 nm compared with measured values is presented.

The Lorentz function was chosen to subsequent calculation [15]. This function has a better fitting result to real values for each wavelength.

The fitting curve was calculated for the single wavelength (Fig. 2) and for many wavelengths simultaneously.

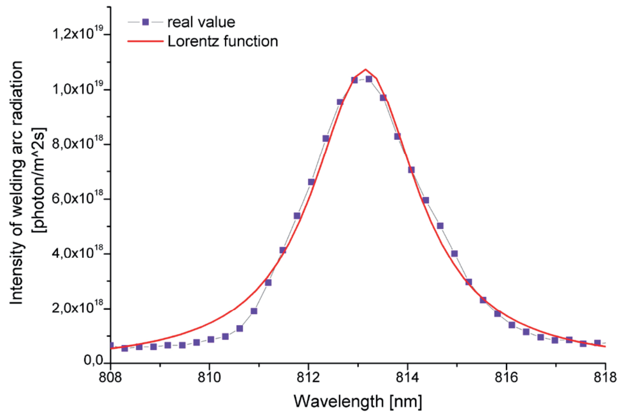

Fig. 2. Calculated line profile of the wavelength 813,22 nm compared with measured values. The Lorentz function with the characteristic qualities

4. Sensing of arc length

Based on the wavelength tables [16] the emission lines were selected and then detailed analysis was carried out. Generally 44 different emission lines were selected.

For the sensing system the shielding gas emission line was choosen in order to make it suitable for all kinds of welding procedures, whatever the chemical composition of the metal to be welded. The one single line corresponding to argon atomic line (696,23 nm- ArI) was used to investigate the influence of the welding parameters on the arc light emission.

Although commercial equipment is available to achieve far more than adequate accuracy for the welding current and travel speed, the precise and the low cost sensors are strongly needed for length control.

Figure 3 shows the influence of arc length L on the visible light intensity and arc voltage for the welding currents in the range of 50÷300 A. It can be seen that considerable changes of the arc length are followed by substantial changes of radiation intensity of the welding arc (wave length 698 nm) and only by small changes of the arc voltage.

On the basis of the collected test data and equation 2 [17] a relationship combining the intensity of welding arc radiation (B_{iv}) with the arc length (L) and the welding current intensity (I) can be determined. The arc length is in the range of 2÷5 mm (Fig. 3) [14].

$$B_{iv} = G_1 L I^2 \left(e^{\frac{G_2}{I}} - \frac{1}{2} \right) + G_3 I^2 + G_4 + \varepsilon \qquad (2)$$

where: ε is the combined uncertainty.

By using a computer program, coefficients G_i have been calculated on the basis of accumulated data for an arc length in the range of 2 ÷5 mm. The equation 1 assumes the form:

$$Biv = 0{,}00004 L I^2 \left(e^{\frac{35{,}3604}{I}} - \frac{1}{2} \right) - 0{,}00000 I^2 + 0{,}52399 \pm 1{,}41\% \qquad (3)$$

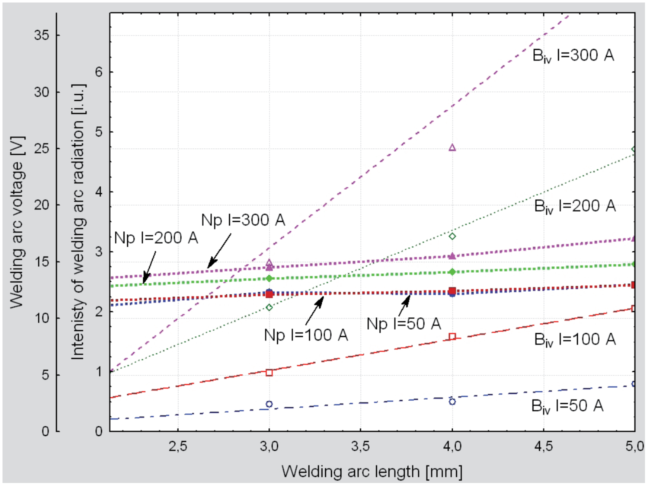

Fig. 3. The influence of the welding arc length on the radiation intensity (B_{iv}) and the arc voltage (N_p) at the welding current in the range of 50÷300 A. The Argon as shielding gas

The equation (3) is satisfied for the wave length of 698 nm and the welding current not greater than 150 A at the arc length 2÷5 mm. The correlation factor K=0,97.

5. The use of artificial neural networks for solving the regression problem

To find a dependence combining the intensity of the visible arc radiation with the welding current in a wider range (30÷300 A) and the arc length in the range of 2÷5 mm, the artificial neural networks have been applied. The neural net has been built by means of an automatic net creator from the neural network software. As input to the neural network welding current values in

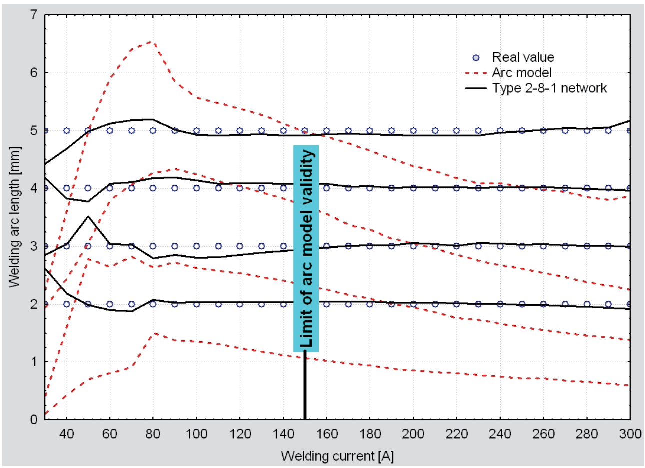

Fig. 4. Scatter diagram for calculation results obtained by using the welding arc model, artificial neural network in comparison with the real values of the welding arc length

the range of 30÷300 A and intensity values of visible radiation (wave length 698 nm) in the range of 0,06-8,35 i.u. were introduced. The automatic creator have tested successively 1000 nets [14], while the quantity of the learning subset was 78, validation subset – 28 and testing subset – 6. As the result the three-layer perceptron net type 2:2-8:1 has been chosen.

In Figure 4 the results obtained by application of the artificial neuron network and by using the welding arc model (equation 3) are compared.

6. Conclusions

In this paper, measurements are presented of the spectral intensity of the welding arc in the range of 340÷860 nm. The measuring system is based on a spectrophotometer, able to measure the arc light emission spectrum.

In this research, the distribution of arc light spectrum was examined. Three fitting functions: Lorentz, Gauss and Voight were investigated as a means to simulate the spectrum distribution. The fitting for single wavelength and multi wavelengths was carried out. The best result was obtained by the Lorentz function.

By using the mathematical-physical model, the relationship (equation 3) between the intensity of welding arc visible radiation and the welding current and arc length has been determined. For arc length changes in the range from 2 to 5 mm, the used welding arc model (equation 3) is valid only for welding currents not higher than 150 A. Above that value other regression methods have to be applied. In this study artificial neural networks have been used. After testing of successive neural networks, it was found, that the best regression results can be gained by using the three-layer perceptron network type 2:2-8:1. Small differences between the real values (Fig. 4) and the calculated ones indicate a very good adjustment of the designed neural network.

The gained experience allows directing farther research on the welding arc radiation phenomenon and the possibilities of using this signal for on-line monitoring of the welding process on automated and robotized stands.

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