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SHORT-CIRCUIT DURATION AS A CRITERION FOR ELECTRIC MEASUREMENTS ON ARC[1]

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High welding currents induce disturbant voltage pulses of the same order as the measured potential drops. The pulses have an unfavourable influence on the potential measurements especially when the wire electrode polarity changes. An equipment to overcome these disturbances was designed. A dependence between the welding current and the short-circuiting duration was used for testing the designed equipment operation at both positive and negative polarities of the wire electrode.

I. INTRODUCTION

The measurement of current and voltage across an arc is of great importance in comprehension and automation of the arc welding process. Thus a voltage waveform during an arc quenching at electrode short-circuiting enables to determine potential drops in the cathode and anode regions of a welding arc [1] and consequently the energy transport to the corresponding electrodes. Current measurements allow to estimate forces which are responsible for the spattering of the melted electrode metal [2,3]. However, quick changes of the welding current induce interference signals and high value of the current produces across the power leads voltage drops which are comparable with the anode and the cathode potential. Moreover, the interference potentials change when polarity of electrodes and geometry of circuits is changed.

The aim of this article is to show an experimental set-up and necessary precautions for suppression of the misleading potentials. It is difficult to test the functioning of the set-up by a well-known signal. It is easier to do so by a physical law insensitive to waveform and polarity of the testing signal. It seems convenient to utilize as such the dependence of a short-circuit duration on a mean-square of the short-circuit current.

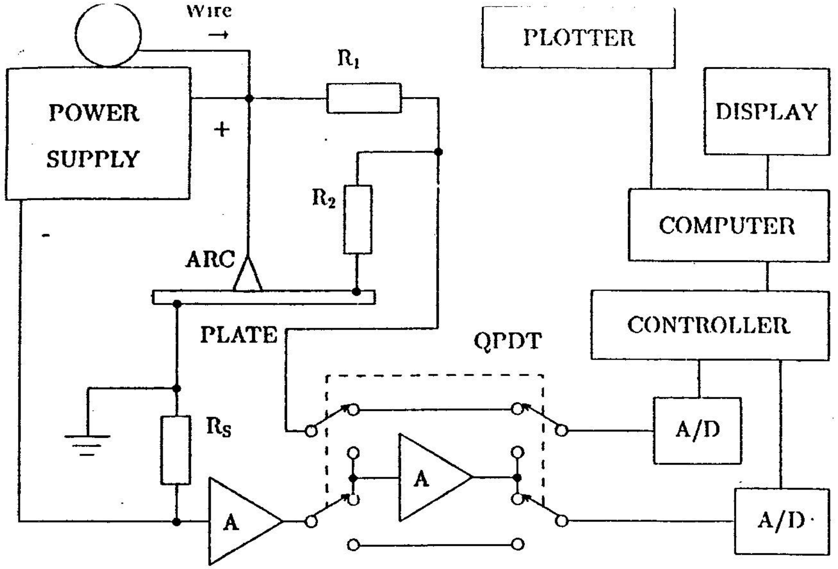

Fig. 1. The experimental set-up. Welding current is measured by means of a shunt R_s and a non-inverting operational-amplifier A. Voltage divider R_1, R_2 serves for voltage measurements. Change of welding wire polarity is reached by a QPDT-switch and an inverting amplifier I of unity gain.

II. METHODS OF ELECTRIC MEASUREMENTS AT A WELDING ARC

Equipment

Quick but chaotic voltage and current changes at an arc welding with a consumable electrode (a so called GMAW process) require to use a suitable microprocessor system for measurement, storage and statistical treatment of data. Such an experimental set-up for the voltage and current measurement can be seen in Fig. 1.

A real GMA welding process with a standard thyristor welding source (UNIMIG 400) with a feeding mechanism for a consumable electrode (mild steel wires) was used. Moving a steel plate (of thickness 10 mm) provided the desired welding velocity. The welding current passes through the shunt (R_s) developing

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a voltage that is amplified by a non-inverting op-amp (A) and measured via A/D converter. The arc voltage is measured by means of a voltage divider R_1, R_2 and another A/D converter.

In order to perform measurements with positive or negative polarity of welding wire an inverting amplifier of unity gain (I) and a quad-pole double-throw (QPDT) switch has been used. Besides at the wire polarity change it has been necessary to exchange by hand the high-current lead to power supply. (The set-up in Fig. 1 corresponds to the positive polarity of welding wire). In order to prove the polarity independence it was inevitable to use careful grounding, to decouple grounds of different instruments, to reduce interference signals appearing on the shunt and lead inductances by moving the low-current wires close to the high-current ones (making actually, a 1:1 transmission-line transformer [4]).

8/bit A/D converters were governed by a controller. Sampling frequency of the controller (a microprocessor system based on INTEL 8080A) was 61.32 μs. Values of current and voltage were recorded simultaneously with an accuracy of 2 A and 0.25 V, respectively. The final data processing and storing were performed by a PC/AT computer.

At measurements of a short-circuit duration a special program with a sampling frequency of 16 μs has been used. (The program monitored only the logical value of a welding voltage.)

A correct functioning of the set-up has been tested upon thermal effects during short-circuits of arc electrodes. A correctly acting set-up could measure the effects forecast by a theory.

Theory of a thermal interruption of a solid short- circuiting bridge

At the beginning of welding the tip of the consumable electrode (wire) is cold and therefore solid. During a short-circuit (SC) the wire is heated by an electric current. Its temperature increases. After reaching the temperature of melting the SC bridge loses its rigidity and breaks. The interruption occurs at the place with maximal temperature. The SC duration can be determined from a balance between dissipated electric energy $\gamma L I^2 \mathrm{d}t/S$ and a corresponding increase of internal energy $\rho CSL\mathrm{d}T$ for a cylindrical wire element with electric resistivity γ, length L, cross-section area S, density ρ and specific heat C. Heating during a time interval $\mathrm{d}t$ increases the element temperature by $\mathrm{d}T$. For the element with the maximal temperature T_m the energy balance, after separation of variables dependent on time and temperature, gives

$$\int_{T_0}^{T_m} (S^2\rho C/\gamma)\mathrm{d}T = \int_{O}^{t_{sc}} I^2 \mathrm{d}t = I_{ms}^2 t_{sc}, \qquad (1)$$

where T_O is an initial wire temperature, I_{ms}^2 is a mean-square value of the welding current I during the SC.

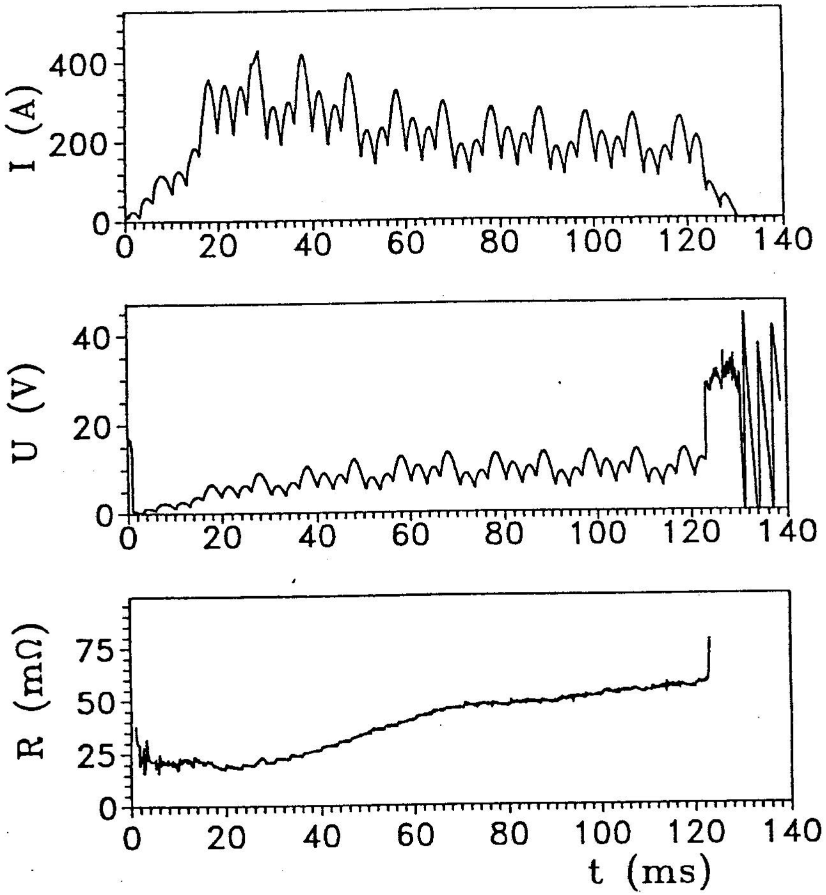

Fig. 2. Time variation of welding voltage $U(t)$, current $I(t)$ and corresponding time dependency of resistance $R(t)$ after starting a welding with a wire 1.03 mm diameter, feeding velocity 80 mm/s, welding velocity 28 cm/min, the wire as an anode.

Following forecasts can be made from the relation (1): - For a given wire the SC duration t_{sc} is proportional to $1/I_{ms}^2$, since the left integral in (1) is a constant.
- For a given material the SC duration strongly depends (as D^4) on diameter D of the used welding wire.
- The SC duration does not depend on the actual polarity and waveform of the arc current.

III. RESULTS

A typical time dependence of the arc voltage and current obtained by means of the described set-up after starting a welding process is shown in Fig. 2. Besides the monitored short-circuit (voltage less then 12 V and non zero current) and arc burning (voltage higher than 12 V and non zero current) there is also a part with absenting arc (voltage pulses of unloaded welding source, zero current). It is possible to determine the duration of short-circuits or arcs from the time dependence of voltage and current in GMAW. It follows from Fig. 2 that the duration of the first short-circuit after a welding start lasts about 100 ms. (The duration of the later short-circuits strongly decreases as the initial temperature of an SC bridge increases due to Joule and arc preheating).

A lowered level of interference signals can be estimated from a smoothness of the resistance R(t) plot in Fig. 2.

(Jumps at the beginning of the plot are caused by voltage steps produced by A/D converter and by short lasting contact interruptions. The resistance value results from a division and therefore could be altered by the offset potential of the operational amplifier used to measure the current. However, the influence of the offset potential was excluded.)

All statements which follow from Eq. (1) linearity of t_{sc} versus $1/I^2_{ms}$, a strong dependence on diameter, independence on polarity) are confirmed by Fig. 3. The figure compiles results obtained for two different types of welding wires (1.03 and 1.17 mm), for both positive and negative wire potentials.

IV. DISCUSSION

A value of the constant in (1) is determined by slopes of the strait lines in Fig. 3. The slope K can be calculated from corresponding experimental pairs of SC duration t_{sci} and mean-square current I^2_{ms} by means of the least-square method as $K = (\sigma t_{sci}/I^2_{si})/\sigma(I^2_{si})^2$. Thus, as it follows from Fig. 3, the constant (slope) has for wire diameters 1.17 and 1.03 mm values 11487 ± 52 and 6436 ± 38 A^2s, respectively. Ratio of the constants 11487/6436 = 1.797 (or 11266/6368 = 1.769) little differs (7.5 %) from 1.66 ± 0.02 forecast by D^4-diameter dependence.

One of the reasons of this difference is not quite identical materials of both used wires. Furthermore the slopes K found on Fig. 3 are based on the hypothesis that the point 0,0 belongs to the curves. Actual slopes seem slightly different, since A/D converter limits currents peaks at the smallest values of SC duration when higher short-circuit currents occur.

In the energy balance (1) thermal conductive and radiative losses were neglected. The neglection of the losses against the Joule heating in the energy balance (1) can be justified by simple numerical estimates:

1 mm - long of a welding wire with a diameter 1 mm, the resistivity $\gamma = 1\mu\Omega$m [5] at 250 A is heated by a power $\gamma LI^2/S = 80$ W while it loses only $\pi DL\delta T^4 = 1.8$ W by radiation (as a black-body at melting temperature, $\delta = 5.7\ 10^{-8}$ W m^{-2} K^{-1}) and $\pi DL\alpha T_m = 0.9$ W by thermal conductivity of air ($\alpha = 163$ W m^{-2} K^{-1}). As the Grashof and Prandtl numbers describing a free convection of air along a red-hot SC bridge are: $Gr = gd^3T_m/(T_o\nu^2) = 700$

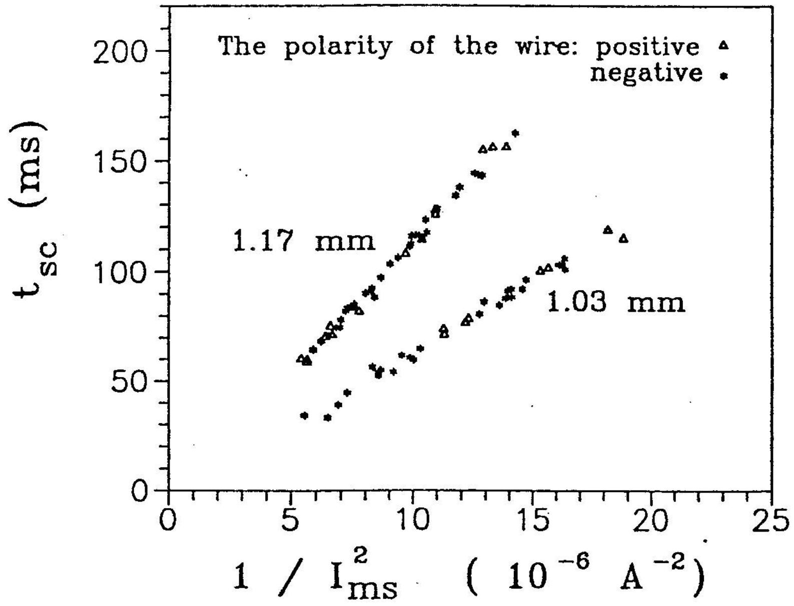

Fig. 3. Dependence of short-circuit duration t_{sc} versus $1/I^2_{ms}$ for both negative and polarities of the wire electrode at two different diameters of the wire (1.03 mm and 1.17 mm).

and $Pr = 0.84$, the corresponding Nusselt number $Nu = 3$ estimates a convective loss as $\pi D\lambda NuT_m = 1.6$ W, where g denotes the gravitational acceleration, d - characteristic length (that of SC bridge, approximately 10 mm) while coefficients of viscosity $\nu = 0.0003$ m^2 s^{-1} and thermal conductivity of air $\lambda = 0.093$ W m^{-1} K^{-1} [6].

If there are no losses the wire element will reach the melting temperature and the bridge will be broken after $\rho CT_mS^2/(\gamma I^2) = 0.13$ s (at density 7500 kg m^{-3}, specific heat 1 kJ kg^{-1} K^{-1} [5].) The estimate is in agreement with Fig. 3. It means that the losses by thermal conductivity of the wire are small enough, otherwise the observed SC duration ought to last longer.

The agreement between the forecasts from Eq.(1) and experimental results on Fig. 3 justifies the used simplifications.

V. CONCLUSIONS

An experimental set-up for sufficiently precise electric measurements in high-current arcs such as, e.g., electric potentials near electrodes or short-circuiting currents, has been designed. It was shown that the precautions taken into account suppressed interference signals induced by quick changes of high currents. A rule describing the duration of short circuits at starts of an arc has been deduced and used for testing the designed equipment. The rule has an advantage in being insensitive the waveform and polarity of measuring arc current.

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