

# Experimental Remote Determination of the Static Characteristic of the Arc in TIG Welding

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**Abstract.** In the conditions of TIG welding, the magnitude of the current is set, but not the voltage of the arc. To determine the arc voltage at a set current, arc length, type of electrode, sharpening angle and others, it is necessary to know the static characteristics of the welding arc. This dependence facilitates the use of simulation modelling methods of welding processes. In the proposed study, the static characteristics of the welding arc in TIG process with 4 types of electrodes were determined experimentally. The magnitude of the current was set in the range of 20 to 200A and the arc voltage was measured. All parameters are measured remotely by a real-time welding monitoring system and transferred to a remote computer via the Internet. Graphs were built based on the recordings, and the numerical results were processed and regression relationships were obtained.

**Keywords:** TIG welding, Static characteristic of welding arc.

## I. INTRODUCTION

The welding arc is a form of gas discharge with a low degree of ionization. Arc voltage has five components – cathode spot, cathode drop zone, plasma, anode drop zone and anode spot. The static characteristic of the arc is the dependence of the arc voltage on the magnitude of the current in an established mode under unchanged conditions of existence of the arc discharge. The anodic (1÷2 [V]) and cathodic (4÷6 [V]) voltage drops are weakly dependent on the magnitude of the current and independent of the arc length. The resistance of the arc (and respectively the voltage drop) changes depending on the temperature [1÷4], the degree of ionization, the current density, etc. For this reason, it is not a constant quantity.

Thus, Ohm's law does not apply to the welding arc. Fig. 1 shows the static characteristics of the arc. At low current [2] (area 1 of the arc), as the current increases, the arc voltage decreases. This is due to the intense increase in the number of charged particles in the arc as a result of increasing the emissivity of the cathode as its temperature increases (Richardson's equation). In the second area of the arc, the characteristic is almost horizontal, which is explained on the one hand by the difficulty of the ionization processes in the arc column, and on the other by the delay in the increase of electron emission [6÷8]. In the third region of the arc, these processes are so hampered that the characteristic of the arc becomes growing - the increase in temperatures is not enough to compensate for the contraction of the arc by its own magnetic field. In this part of the arc characteristic, Ohm's law applies. As the arc length increases, the voltage required to achieve a given current increases.

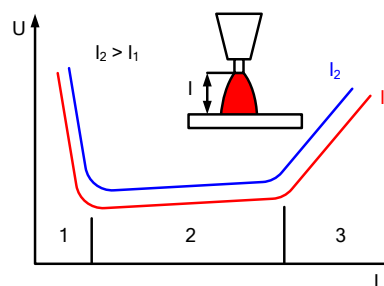


Fig. 1. Static characteristics of welding arc.

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The operation of welding current sources implementing various technological processes is mainly based on the knowledge of the static characteristics of the arc. In MMA, TIG welding, PAW and SAW with low current density, welding is done in the second area of the arc characteristic with a vertical or steeply falling static external characteristic of the current source - the magnitude of the current is stabilized. High current density MIG/MAG and SAW operate in the third region of the arc characteristic with a stiff (slightly drooping) current source characteristic and use of the arc self-regulating process.

In the present publication is reviewed the experimental construction of the static characteristic of the arc of TIG welding process.

## II. MATERIALS AND METHODS

For the purposes of this study, experiments were carried out in accordance with the scheme [9,10] shown in Fig.2 and Fig.3. The used welding current source (Cebora2030m - Fig.4) is designed for TIG welding, with the possibility of setting the current size with step 1 [A]. During the process, the magnitude of the arc current and voltage are visualized. After switching off the power source, the displayed values are saved. In addition, the current source provides a smooth increase of the current when the arc is ignited and a smooth decrease when the process is terminated. The maximum welding current of the power source is 200[A]. The welding torch was set stationary and the arc length  $l = 2.4$ [mm] was the same in all experiments performed. The arc is ignited on a plate with dimensions 6x350x120 [mm] (Fig. 5). The shielding gas (Ar) has a flow rate of 15 [l/min]. During the arc burning process, the instantaneous current and voltage values are recorded using an Arc Tracker welding process monitor (Fig.6). Data are transmitted and recorded in real time on a portable computer on which Power Wave Manager software is installed (Fig.7 and Fig.8). This software allows welding parameters to be monitored and stored in real time. The data is transmitted in real time and over the Internet using the Team Viewer software product to a remote computer where it is visualized and stored. The electrodes used are listed in table 1. The sharpening angle of the electrodes is 15°.

TABLE 1 USED ELECTRODES

№	d, mm	Composition	Colour
1	2.4	W+1.4÷1.6% La	Gold
2	2.4	100% W	Green
3	2.4	W+1.8÷2.2% CeO <sub>2</sub>	Grey
4	2.4	W + 1.7÷2.2% ThO <sub>2</sub>	Red

The experiments were carried out as follows. The magnitude of the current is set, and in the range from 20 to 100[A] the change is in 5[A] steps, and in the range from 100 to 200[A] – in 10[A] steps. Recording of current

values and arc voltage is started. The welding arc is ignited. After switching to the established operating mode, the values of the current source are read. The duration of arc burning for one record is 8÷20[s]. After the arc is turned off and the process is terminated, data recording is stopped (automatically). The procedure is repeated for the set currents with the four different electrodes. No other parameter is changed during the experiment (the arc voltage is varied by the current source to achieve the set current). The pause between individual experiments is such that the duration of ignited arc does not exceed 35%. A sample recording of the process parameters is shown in Fig.6. In Fig. 7 is shown screenshot of captured values with Arc Tracker welding monitoring device.

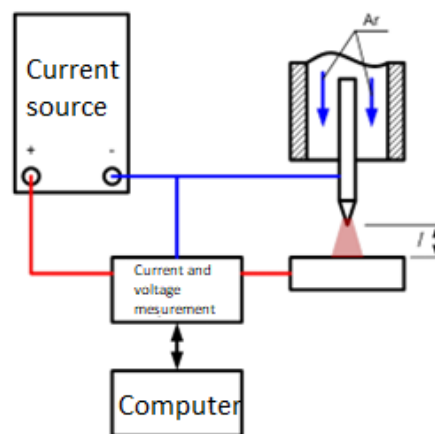


Fig. 2. Scheme of conducting the experiment.

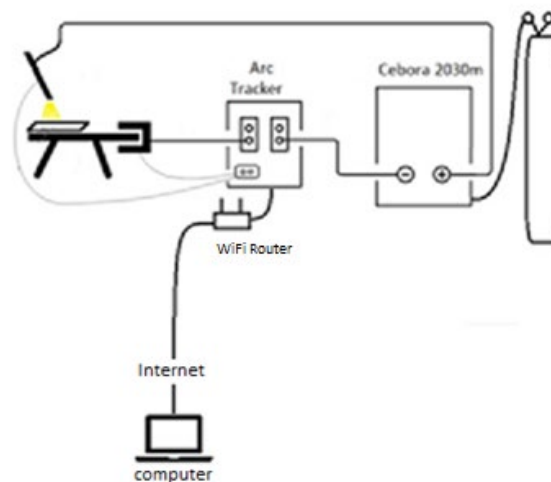


Fig. 3. Experimental set-up.



Fig. 4. Cebora2030m current source.



Fig. 6. Arc Tracker welding monitoring device.



Fig. 5. Welding arc.

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Arc time (s)	Amperage (A)	Voltage (V)	Wire fee
0,000	9,0	10,3	0
0,250	9,8	10,3	0
0,625	11,5	10,3	0
0,828	13,1	10,3	0
1,109	14,6	10,3	0
1,375	16,1	10,3	0
1,703	17,7	10,3	0
1,969	19,2	12,4	0
2,219	20,7	13,5	0
2,484	22,2	13,3	0
2,766	22,5	12,9	0
3,047	22,4	12,9	0
3,297	22,5	12,8	0
3,609	22,6	12,9	0
3,906	22,5	12,9	0
4,172	22,5	12,9	0
4,438	22,6	12,9	0
4,688	22,7	12,9	0
4,938	22,6	12,8	0
5,203	22,7	12,7	0
5,453	22,6	12,7	0
5,719	22,5	12,5	0
5,953	22,5	12,5	0
6,234	22,5	12,5	0
6,500	22,5	12,6	0
6,781	22,5	12,6	0
7,047	22,5	12,5	0
7,328	22,4	12,3	0
7,609	22,4	12,3	0
7,969	22,3	12,3	0

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Fig. 7. Sample recording of the process parameters – Electrode 1 at 25A.





Fig. 8. Screenshot of captures current and voltage values with Arc Tracker welding monitoring device.

### III. RESULTS AND ANALYSIS

Graphs of the dependence of the welding voltage and current on time are made from the captured parameters (in Table 2 are shown results for electrode No1 and Electrode No2). The time interval of an established process is determined from these graphs (Fig. 9). Within this time interval, the average values of the arc current and voltage are determined. The obtained results are shown in Table 3 ÷ Table 4.

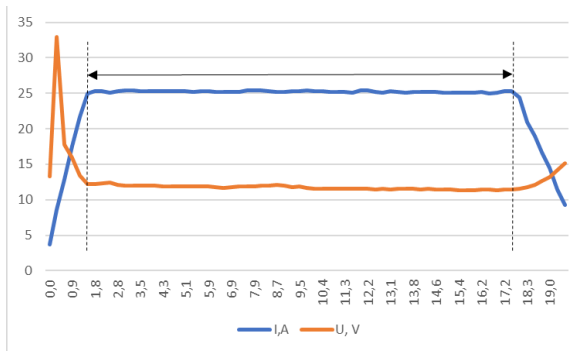


Fig. 9. Determination of time lapse of the established process for electrode No1.

TABLE 2 EXAMPLES OF RECORDED ARC CURRENT AND VOLTAGE VALUES

A	Electrode No1	Electrode N2
25		
55		
160		
200		

TABLE 3 EXPERIMENTAL RESULT FOR ELECTRODE NO1.

Set	Welding current, A		Arc voltage, V	
	Delivered	Measured	Delivered	Measured
20	21	20.1	12.5	11.8
25	25	25.2	11.45	11.7
30	30	30.3	11.25	11.6
35	35	34.9	11.45	11.6
40	39	39.4	11.2	11.3
45	44	44.0	10.5	10.6
50	49	48.5	10.4	10.5
55	54	52.9	10.6	10.4
60	58	58.1	10.5	10.2
65	62	62.3	10.5	10.2
70	68	67.7	10.5	10.1
75	72	72.7	10.45	10
80	77	76.7	10.3	9.9
85	82	80.8	10.4	9.8
90	86	86.1	10.4	9.9
95	92	90.8	10.3	9.8
100	97	96.5	10.25	9.8
110	106	104.9	9.7	9.9
120	115	115.1	10.0	10.1
130	125	124.9	10.25	10.2
140	134	133.6	10.3	10.4
150	143	143.1	10.7	10.7
160	153	152.9	11.1	11.1
170	162	161.8	11.15	11.1
180	172	171.3	11.2	11.2
190	181	181.1	11.6	11.5
200	191	190.8	11.5	11.6

TABLE 4 EXPERIMENTAL RESULT FOR ELECTRODE NO2.

Set	Welding current, A		Arc voltage, V	
	Delivered	Measured	Delivered	Measured
20	21	20.9	10.4	10.3
25	25	25.3	9.8	10
30	30	30.5	9.7	9.7
35	35	34.7	9.7	9.5
40	39	39	9.4	9.2
45	44	44.3	9.3	9.3
50	49	48.6	9.4	9.3
55	53	53	9.4	9.3
60	58	58.1	9.4	9.2
65	62	62.5	9.2	9.2
70	67	67	9.2	9.1
75	72	72.3	9.1	9.2
80	55	76.7	9.1	9.2
85	81	81.1	9.1	9.3
90	86	86.3	9.1	9.3
95	90	90.4	9.1	9.3
100	96	95.6	9.4	9.5
110	106	105.6	9.5	9.7
120	115	115.4	10.0	10.1
130	125	124.9	10.4	10.3
140	134	133.8	10.5	10.4
150	143	143.2	10.5	10.5
160	153	152.7	10.7	10.7
170	162	161.6	11.1	11.2
180	171	171.4	11.3	11.4
190	181	181.1	11.4	11.5
200	191	190.8	11.7	11.6

Static characteristics for the used electrodes were built (fig. 10 ÷ fig. 17) with based on the captured data from the experimental process. The experimental data on the static characteristics of the welding arc were processed by the method of least squares and the corresponding regression equations were obtained. Used type of equation is

$$U_w = \frac{B}{I_w} + C_0 + C_1 I_w + C_2 I_w^2 \quad (1)$$

TABLE 5 COEFFICIENTS IN EQUATION (1)

No	B	C <sub>0</sub>	C <sub>1</sub>	C <sub>2</sub>
1 - down	7.29E+01	6.78E+00	2.33E-03	1.05E-04
1 - up	1.14E+02	7.00E+00	3.14E-02	-4.25E-05
2 - down	6.53E+00	9.79E+00	-2.93E-02	2.11E-04
2 - up	1.15E+02	3.02E+00	8.81E-02	-2.60E-04
3 - down	3.17E+01	7.54E+00	1.30E-02	3.35E-05
3 - up	8.25E+01	3.52E+00	7.72E-02	-2.07E-04
4 - down	4.60E+01	5.95E+00	3.97E-02	-4.23E-05
4 - up	5.55E+01	6.36E+00	4.98E-02	-1.12E-04

The results are illustrated in Fig. 10-17. These results show that during the conducted experiments, the process parameters were such that the welding arc appeared in the first and second parts of its characteristic. Furthermore, it can be seen that the welding arc burns steadily also in the first part of its characteristic.

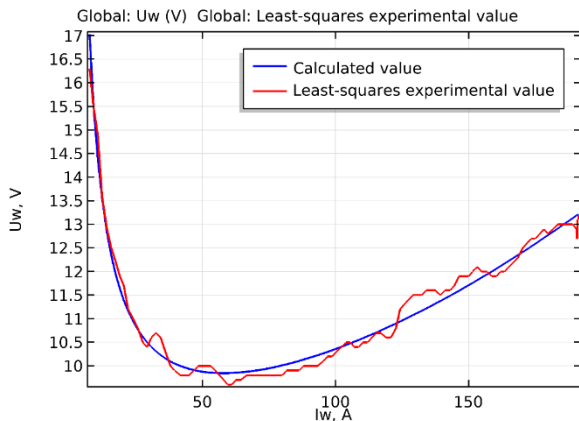


Fig. 10. Static characteristics – electrode No1 (W + 1.4÷1.6% La) decreasing welding current from 200A to 20A.

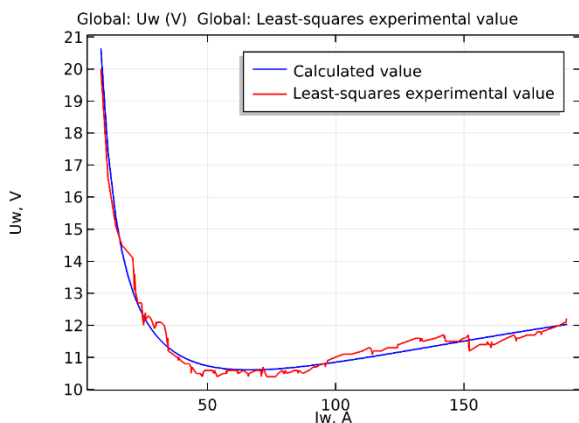


Fig. 11. Static characteristics – electrode No1 (W + 1.4÷1.6% La) increasing welding current from 20A to 200A.

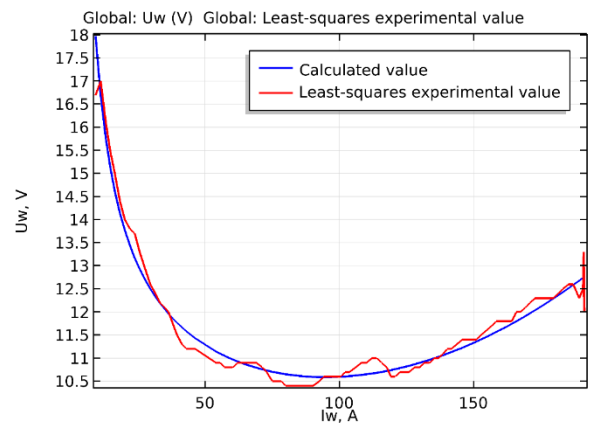


Fig. 12. Static characteristics – electrode No2 (100% W) decreasing welding current from 200A to 20A.

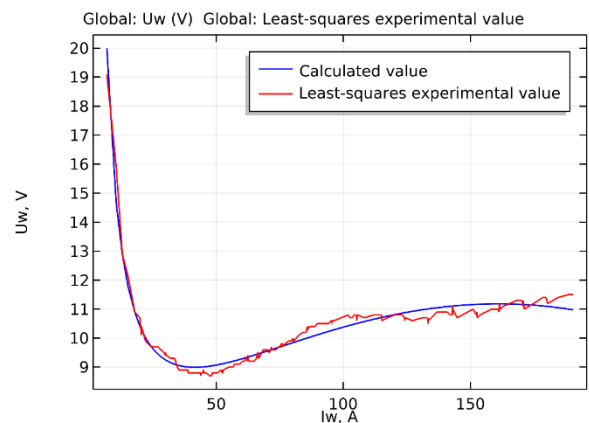


Fig. 13. Static characteristics – electrode No2 (100% W) increasing welding current from 20A to 200A.

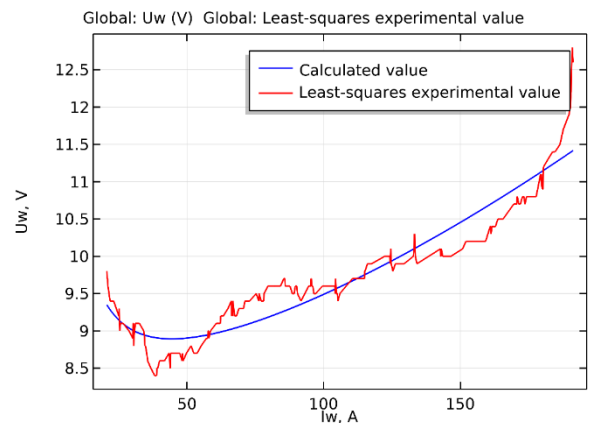


Fig. 14. Static characteristics – electrode No3 (W + 1.8÷2.2% CeO<sub>2</sub>) decreasing welding current from 200A to 20A.

The experimentally constructed static characteristics of the welding arc correspond to its qualitative representation indicated in Fig.1.

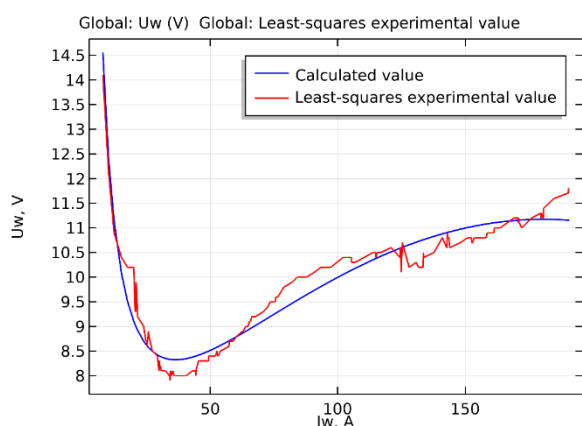


Fig. 15. Static characteristics – electrode No3 (W + 1.8÷2.2% CeO<sub>2</sub>) increasing welding current from 20A to 200A.

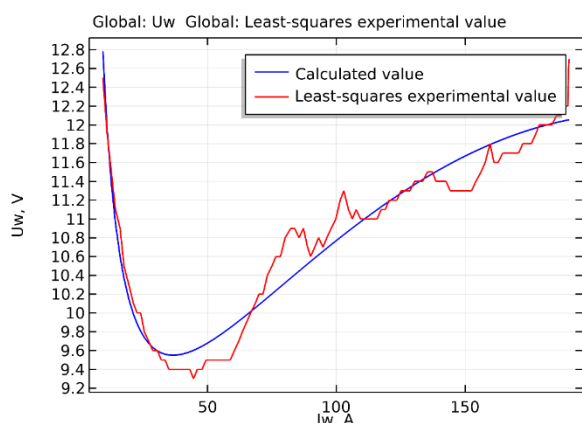


Fig. 16. Static characteristics – electrode No4 (W + 1.7÷2.2% ThO<sub>2</sub>) decreasing welding current from 200A to 20A.

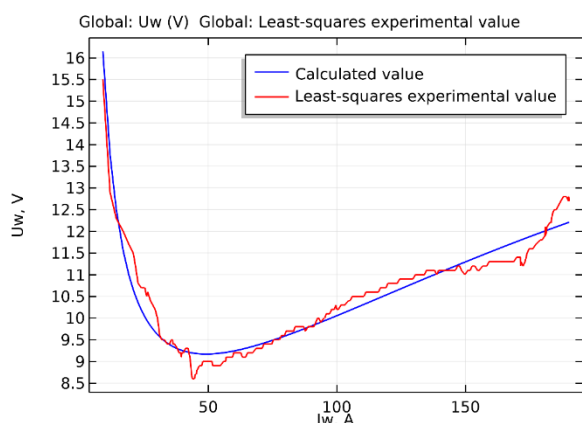


Fig. 17. Static characteristics – electrode No4 (W + 1.7÷2.2% ThO<sub>2</sub>) increasing welding current from 20A to 200A.

Several features can be observed in the presented static characteristics of the arc. First of all, there is no typical expression of the second section of the arc characteristic for electrode No 3 and electrode No 4. The increase in voltage with the increase in the magnitude of the current at electrodes No1 and No2 is observed after reaching a welding current of 90[A]. This is equivalent to a current

density of 19.9 [A/mm<sup>2</sup>]. At electrode No3 electrode No4, the rise in arc voltage begins at a current magnitude of 38.8[A]. This corresponds to a current density equal to 19.3 [A/mm<sup>2</sup>]. Comparison of these data shows that entering the third part of the arc characteristic is realized at a current density in the electrode equal to 19÷20[A/mm<sup>2</sup>].

#### IV. CONCLUSIONS

Determination of the static characteristic of the arc in TIG welding process, was successfully accomplished over the internet on remote computer by measuring welding parameters – welding current and welding voltage with real-time welding monitoring system.

It was determined that within the conducted experiments, the second part of the arc characteristic is not significantly expressed, and at a current density of 19÷20 [A/mm<sup>2</sup>], the arc voltage begins to increase with an increase in the welding current.

Further studies will determine and fill the database of the static characteristic of the arc in TIG welding process with various electrodes varying on both chemistry compound and diameter.

#### V. ACKNOWLEDGMENTS

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