SYSTEM FOR AUTOMATIC REGULATION OF POSITION OF TUNGSTEN ELECTRODE IN NARROW-GAP MAGNETICALLY CONTROLLED ARC WELDING OF TITANIUM

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A system is offered for automatic regulation of position of tungsten electrode in the groove in narrow-gap magnetically controlled arc TIG welding of titanium. The system uses direct measurement of voltage of the arc at its deflection to extreme positions. The experimentally established relationship between displacement of tungsten electrode from the groove centre and amplitude of fluctuations of the arc voltage is presented.

Keywords: *TIG welding, titanium alloys, tungsten electrode, displacement of tungsten electrode from the weld centre, tracking systems*

Narrow-gap TIG welding is a high-productivity and high-efficiency method for joining of titanium more than 16 mm thick. This welding method has certain technological advantages over V- or U-groove arc welding, such as decrease in width of the weld and HAZ, and decrease in weight of the deposited metal, which is particularly important for welding of titanium.

The E.O. Paton Electric Welding Institute developed the technology for narrow-gap magnetically controlled arc TIG welding of titanium and titanium alloys [1]. Application of the external controlling magnetic field provides redistribution of heat input to the welded joint by the arc, reliable fusion of vertical walls of the narrow groove and quality formation of the welded joints.

According to the above technology, welding is performed with the tungsten electrode lowered into the groove, the protective nozzle being located over the weld edges. This allows making the 10 mm wide groove. Magnetic core of the electromagnet is combined with the filler wire feed guide and is placed in the groove ahead of the tungsten electrode. The electromagnet generates the magnetic field, the force lines of which within the arc zone are directed mainly along the welding line. The value of magnetic induction amounts to 12 mT. This magnetic field is transverse with regard to the arc, and its direction changes into the opposite at a certain frequency.

Narrow-gap welding of longitudinal joints is accompanied by undesirable transverse displacements of the tungsten electrode with regard to the calculated central plane of the joint (weld centre). This can be caused by deviation of the actual welding direction from the calculated central plane of the joint, distortions of workpieces during welding under the effect of the welding thermal cycle, etc. These displacements can be substantial, and can lead to short-circuiting of the tungsten electrode to the side wall of the groove. Displacement of the tungsten electrode from the weld centre in narrow-gap welding may cause violation of the uniformity of fusion of the side walls of the groove, which will lead to lacks of fusion and lacks of penetration in the weld, as well as to formation of a defective surface of the deposited layer.

Therefore, when developing a technology for narrow-gap magnetically controlled arc TIG welding, to provide a sound joint it is necessary to estimate the effect of displacement of the tungsten electrode from the weld centre on the welding process, i.e. on the distribution of the electric current in the side walls, arc voltage and weld formation. So, it seemed promising to use the welding arc moved under the effect of the external controlling magnetic field to monitor the electrode displacement from the weld centre.

This, in particular, was the purpose of this study. The authors proceeded from the fact that application of the external controlling magnetic field in narrow-gap welding should lead to redistribution of energy of the welding arc, which is introduced into a metal welded by alternately deflecting the arc to the side walls of the groove under the effect of the Lorentz force resulting from interaction of the magnetic field with the arc current. It causes deflection of the arc and shifts the anode spot to the vertical side wall of the groove. A change in distance between the tungsten electrode and side walls leads to a change in both height of shifting of the anode spot to the vertical wall and values of the electric current flowing through the vertical side walls. The effect of displacement of the tungsten electrode on the electric current flowing through the side walls of the groove, which was measured by the divided anode method [2], was studied to estimate violation of the symmetry of heating of the side walls in displacement of the tungsten electrode from the weld centre.

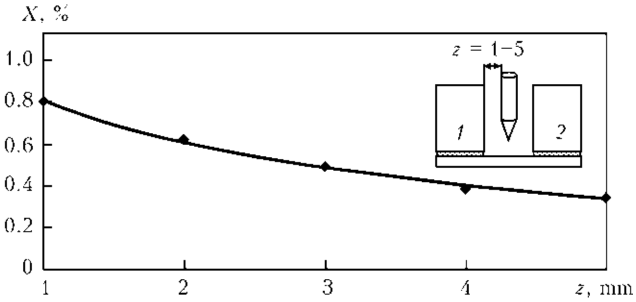

Figure 1. Change in share X of the current flowing through side wall of the groove I_s depending on distance z between the side wall and flat-tip electrode at B_x = 11.4 mT and I_w = 400 A ($X = I_s/I_w$)

It was experimentally determined that a change in distance between the electrode and side walls of the groove is accompanied by a change in the value of the electric current flowing through side walls *1* and *2* (Figure 1). Displacement of the tungsten electrode from the weld centre causes increase of the welding current flowing through near wall *1* of the groove, and decrease of the welding current flowing through distant wall *2*. It was established that displacement of the electrode to 1 mm leads to a 4–5 % decrease in share X of the current flowing through wall *1*, and a 15–25 % increase in the share of the current flowing through wall *2*. Hence, displacement of the tungsten electrode from the weld centre causes violation of the symmetry of heat input into the welded joints, thus leading to a different depth and different height of fusion of the side walls.

Therefore, to maintain symmetrical heat input into the side walls and their uniform fusion in narrow-gap magnetically controlled arc welding, it is necessary to ensure that the electrode be located at the weld centre.

In narrow-gap TIG welding of titanium by applying the external magnetic field, which is transverse with regard to the arc, a decrease in arc voltage U_a is fixed when the arc is deflected to the extreme position. This is related to the fact that distance L_1 between the tungsten electrode tip and side wall is shorter than arc gap length L_0 at the absence of deflection of the welding arc (Figure 2).

Displacement of the tungsten electrode from the weld centre causes decrease of the L_1 values (Figure 2,

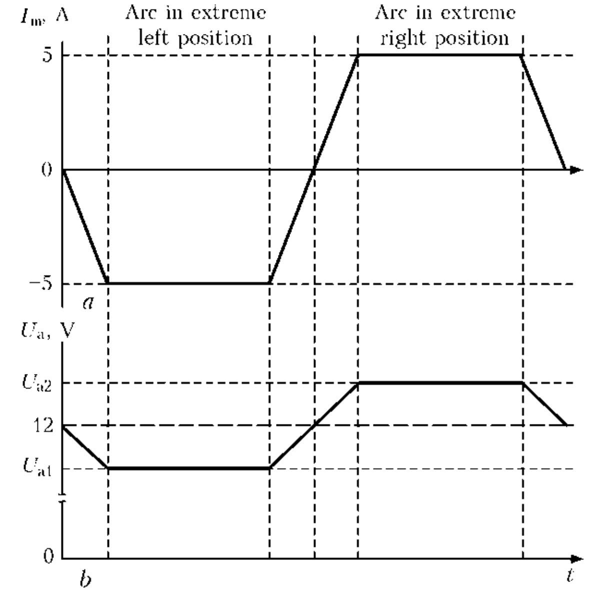

Figure 3. Effect of displacement of tungsten electrode on arc voltage U_a: *a* — diagram of current I_m flowing through the electromagnet coil; *b* — diagram of arc voltage

b) and increase of the L_2 values (Figure 2, *c*). Accordingly, arc voltage U_{a1} measured at deflection of the arc to the nearest wall of the groove (extreme left position) is lower than arc voltage U_{a2} measured at deflection of the arc to the distant wall (extreme right position). With alternate deflection of the arc to the opposite side walls of the groove the arc voltage changes at a frequency corresponding to the frequency of the reversing magnetic field, i.e. the arc voltage is imparted additional pulsations, whose amplitude ΔU is a difference between U_{a1} and U_{a2} (Figure 3):

$$U = U_{a1} - U_{a2}. \qquad (1)$$

It was determined that when welding is performed in a copper water-cooled groove by applying the reversing controlling magnetic field, if the tungsten electrode is placed at the weld centre, then $U_{a1} = U_{a2}$, and their values are proportional to arc gap length L_0. When welding is performed in the copper water-cooled groove by applying the reversing controlling magnetic field, and if the tungsten electrode is shifted from the groove centre, ΔU is directly proportional to displacement of the tungsten electrode from the

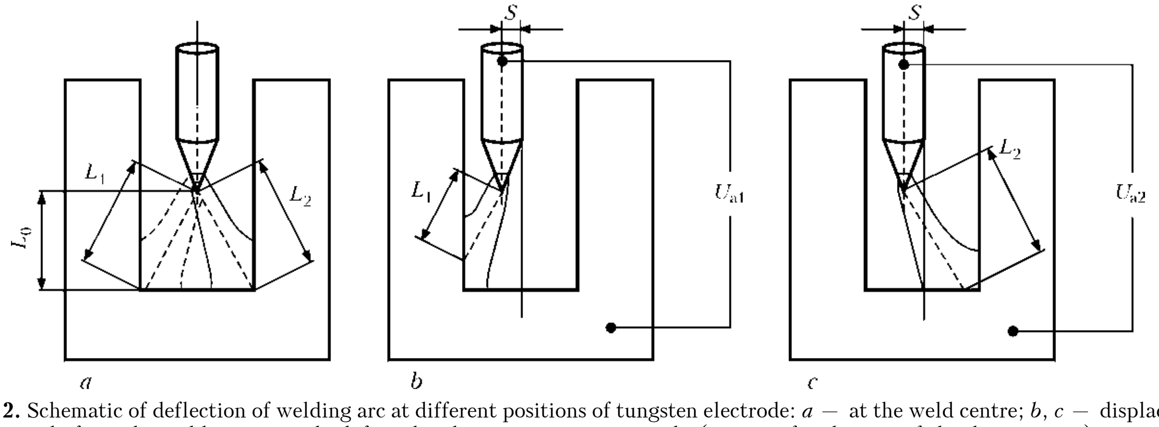

Figure 2. Schematic of deflection of welding arc at different positions of tungsten electrode: *a* — at the weld centre; *b*, *c* — displacement S of electrode from the weld centre to the left and right positions, respectively (see text for the rest of the designations)

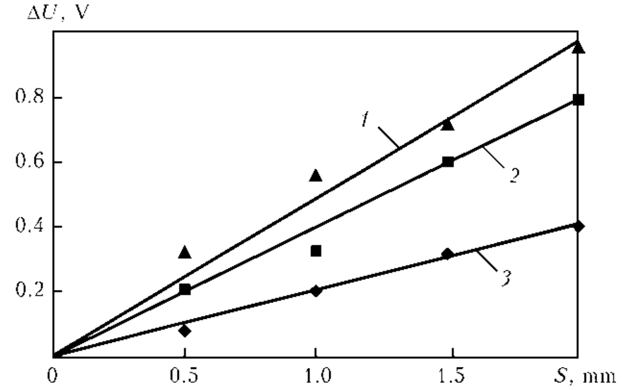

Figure 4. Dependence of arc voltage pulsation amplitude ΔU on electrode displacement S from the weld centre in narrow-gap welding with water-cooled groove: *1* — L_0 = 5; *2* — 4; *3* — 3 mm

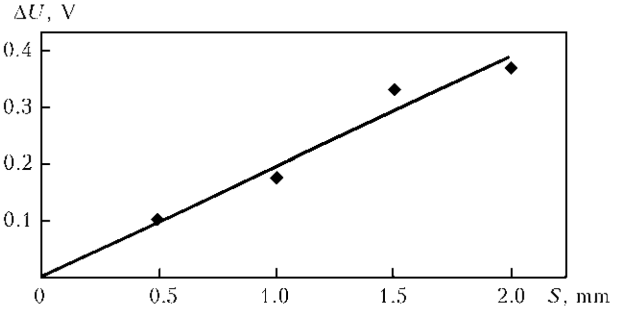

Figure 5. Dependence of ΔU on electrode displacement S from the weld centre in narrow-gap welding of titanium alloy VT1-0 (I_w = = 400 A; U_a = 12 V; welding speed v_w = 8 m/h; 2 mm diameter filler wire feed speed v_f = 120 m/h)

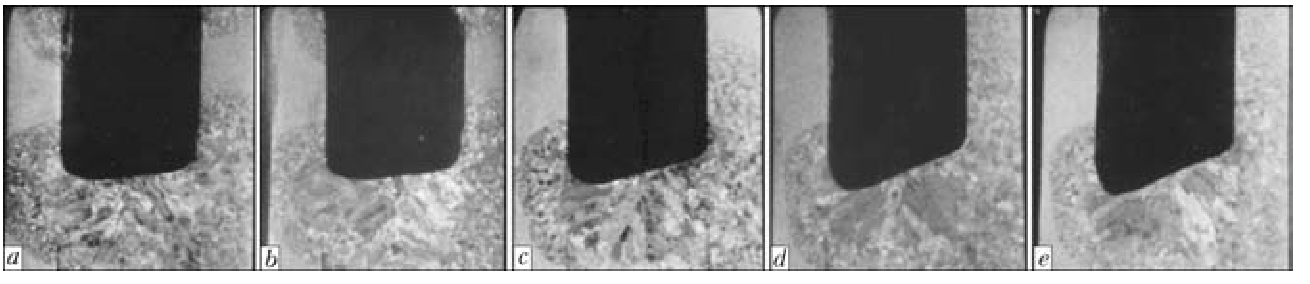

Figure 6. Formation of surface of the deposited layer at displacement of tungsten electrode from the weld centre to a distance of 0.2 (*a*), 0.5 (*b*), 0.7 (*c*), 1.0 (*d*) and 1.5 (*e*) mm

weld centre and depends on the length of the arc gap (Figure 4).

It was established that ΔU also depends on the groove material. For instance, in welding of titanium and titanium-base alloys the material is melted and the shape of the weld pool surface differs from the initial geometry of the groove, the ΔU value being decreased. Dependence of ΔU on the displacement of the tungsten electrode from the weld centre in narrow-gap magnetically controlled arc TIG welding of titanium alloy VT1-0 by using 2 mm diameter filler wire of the VT1-00 grade is shown in Figure 5. Voltage pulsation ΔU amounts to 0.4 V at a 2 mm displacement of the electrode from the weld centre.

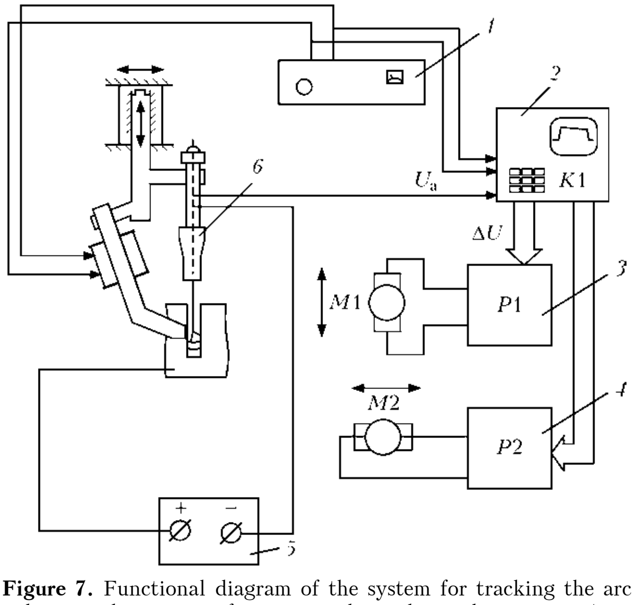

Figure 7. Functional diagram of the system for tracking the arc voltage and position of tungsten electrode in the groove: *1* — electromagnet control device; *2* — programmable controller; *3*, *4* — drives for moving the electrode vertically and across the groove; *5* — arc power supply; *6* — collet with tungsten electrode; *M*1 and *M*2 — electric motors

It was concluded as a result of analysis that in narrow-gap welding of longitudinal joints by applying the controlling magnetic field it is necessary to use tracking systems to correct transverse displacements of the tungsten electrode from the weld centre. Analysis of the welds made with different displacements of the tungsten electrode from the weld centre (Figure 6) showed that the quality formation of the joints can be ensured providing that the electrode displacement is no more than 0.5 mm.

Available are tracking systems based on the use of parameters of the welding arc [3, 4] or mechanical or optical sensors as a source of information on shifting of the line of elements being joined. Because of a small width of the groove, difficulties in viewing the welding zone and a limited access to it, the most promising tracking systems are those where parameters of the welding arc serve as sources of information on the electrode displacement. Study [5] suggested a seam tracking system based on the magnetic deflection of the welding arc and measurement of the instantaneous value of the welding current. As the external magnetic field is applied in narrow-gap magnetically controlled arc welding of titanium to provide reliable fusion of the side walls of the groove, it seemed expedient to use a tracking system based on the magnetic deflection of the welding arc and measurement of one of its parameters — arc voltage.

Investigation of the effect of the external magnetic field on the arc voltage in narrow-gap welding made it possible to offer a tracking system that uses one parameter of the welding arc, i.e. arc voltage, to monitor position of the electrode at the weld centre and length of the arc gap. Functional diagram of the developed system for tracking the arc voltage and position of the tungsten electrode in the groove is shown in Figure 7.

Controller $K1$ measures the voltage which is taken from a current conductor to the tungsten electrode. The signal proportional to $(U_{a1} + U_{a2})/2$ is fed to actuating mechanism $P1$, which provides vertical displacement of the tungsten electrode, filler wire and electromagnet to maintain the value of U_a at a constant level. The signal proportional to ΔU is fed to actuating mechanism $P2$, which provides transverse displacement of the tungsten electrode to keep the latter at the groove centre. To determine direction of the transverse displacement of the tungsten electrode, controller $K1$ measuring the value of ΔU is synchronised with the electromagnet control device.

The experiments conducted showed the efficiency of the offered system for automatic regulation of the arc voltage and position of the tungsten electrode in the groove, and confirmed the high quality of the produced welded joints even at the preliminarily set deviations of the tungsten electrode from the geometrical centre of the weld.

CONCLUSIONS

1. It was established that displacement of tungsten electrode from the weld centre in narrow-gap welding with the external magnetic field is a factor that has a considerable effect on the value of the current flowing through the side walls of the groove, symmetry of heat input into the joint and depth of penetration of the side walls of the groove. Displacement of the electrode to 1 mm leads to a 4–5 % decrease in the share of the current flowing through the distant wall and a 15–25 % increase in the share of the current flowing through the near wall. Also, it causes a change in the penetration depth.

2. It was experimentally proved that displacement of the electrode from the weld centre leads to a difference in levels of the arc voltage with the amplitude of up to 0.4 V at its deflection to the extreme positions, the frequency of oscillations of the arc voltage corresponding to the frequency of reversals of the controlling magnetic field. The value of the coefficient of proportionality between displacement of the tungsten electrode from the weld centre and amplitude of oscillations of the arc voltage in narrow-gap welding of titanium and titanium-base alloys was determined to be equal to 0.2 V/mm. The functional diagram of the system for automatic regulation of position of the tungsten electrode in the groove, using the direct measurement of the arc voltage, was offered.

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