PECULIARITIES OF ARC CONTROL BY EXTERNAL MAGNETIC FIELD (Review)

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Theoretical and practical aspects of methods of effect of variable magnetic field on the arc, burning on a tungsten electrode in argon, to control arc position in space are considered. Analysis of effectiveness of application of arc control by variable transverse magnetic field in welding and its influence on weld formation and quality was performed.

Keywords: *argon arc welding, tungsten electrode, weld pool, magnetic field, arc control, vertical welding*

One of the important disadvantages of argon arc is small number of parameters (welding current, welding speed and length of arc gap), significantly influencing the changes of sizes of produced welds (width, depth of penetration and height of bead reinforcement). This disadvantage somewhat limits the fields of application of this welding method. Influence of magnetic field on such arc can widen its application not only in welding, but also in surfacing, as far as possibilities to control sizes of deposited metal and depth of penetration become more efficient and reliable.

The authors made an analysis of theoretical and practical investigations of regularities of movement of arc, burning at tungsten electrode in argon, under influence of magnetic field on it.

Nowadays two principally different approaches towards investigations of arc burning in magnetic field were outlined: micro- and macrokinetic ones. Some researchers consider the electric arc in magnetic field as a conductor (flexible, gaseous, plasma), the movements of which are governed by the laws of electrodynamics [1, 2]. Others suppose that movement of electric arc in magnetic field is the spreading of ionization state at which the energy is transferred from particle to particle, but not the movement of all totality of particles of conductor plasma [3–5]. One can suppose that micro- and macroprocesses which are proceeding in the arc under the effect of magnetic field are closely connected with each other.

The effect of magnetic field in microprocesses is manifested through a peculiar movement of charged particles under the influence of electromagnetic forces, on which such parameters depend as density of current, change of voltage in active spots of the arc, gradient of potential of arc column, etc. The works are known on study of microkinetic phenomena in welding magnetically-controlled arc with a purpose to explain the mechanism of its movement [6, 7].

The phenomena of macroscopic character are revealed in change of shape, sizes and position of arc in the space. Therefore, it is accepted to consider the welding arc in magnetic field as a single whole.

To establish the regularities of arc deviation in transverse magnetic field the arc was considered in the work [1] as a elastic conductor with current in a magnetic field. Here, the welding arc column is smoothly deformed with increase in magnetic field intensity. The cathode spot remains almost immovable, however the anode spot is moved in the direction of action of electrodynamic force.

To control welding arc by transverse magnetic field is extremely difficult in connection with limited capacity of the arc to be elongated without interruption during its deviation by magnetic field. The interruption of the arc occurs not due to its simple elongation, but as a result of break of the anode spot at some critical value of intensity of magnetic field. In the places of transfer from the arc spot to the column with different density of current the intensity of magnetic field is sharply decreased and, consequently, a negative gradient of pressure along the arc column arises which stipulates the stationary flow of plasma flows from active arc spots. The electrodynamic nature of plasma flow creates a field of speeds where the arc nucleus has a movement speed higher by one-two orders than the speed of a flame [8]. Therefore, in movement of arc in magnetic field, different amplitude of deviation of flame and a nucleus should be expected. Such differentiated character of nucleus and flame deviation is observed in the arcs with a tungsten cathode [9] due to high current densities as compared with other cathodes (for example, carbon).

In all arcs with high density of current in anode spot the plasma flow is observed [8]. Under the conventional conditions of axisymmetric location of active spots the flows from anode and cathode are directed towards each other, but cathode flow suppresses the anode one. At a shift of one active spot relatively to another the pattern of interaction of plasma flows, directed perpendicularly to the surfaces of active spots, is changed: the deformation of arc in magnetic field is defined by deformation of two flows directed at an angle. In the area of contact of two plasma flows the intensive forcing out of charged particles from the arc column takes place, which in the opinion of the authors of study [9] is the main reason of abnormal increase in voltage of arc, deformed by the transverse magnetic field. The violation of thermal balance in the place of contact of two flows, stipulated by this phenomenon, causes the interruption of arc.

The highest effect of increase of arc stability in transverse magnetic field is obtained by stabilization of arc by the gas jet [9]. This is explained by the fact that, at first, short arc, especially in the upper part of the column, is deformed as a single whole, and, secondly, the cathode spot is stabilized at the cathode end.

The stability of arc in transverse magnetic field depends on thermal balance at the area of contact of cathode and anode plasma flows. Having provided thermal balance in any way, one can rely on stable burning of deviated arc or on increase in its deviation angle. On such assumption the method of arc stabilization in transverse magnetic field using «guiding wall» [9] (Figure) is based. The walls, manufactured of graphite or copper, are electrically isolated from the anode and cathode and have a guiding profile of a parabolic shape.

This provides maximum value of the anode spot shifting. The stabilizing wall reflects the anode flow $+A$ and directs it towards the cathode flow C, which causes preserving of thermal balance in arc column during deviations by 2–2.5 times larger than those at the absence of a guiding wall.

The compression of arc column by a natural magnetic field and its stabilization by a plasma jet imparts it properties of a flexible conductor with current, deviation of which in transverse magnetic field occurs due to action of electrodynamic forces. Therefore, the change of current direction at constant magnetic field or change of direction of transverse magnetic field at direct current should lead to change of direction of arc deviation.

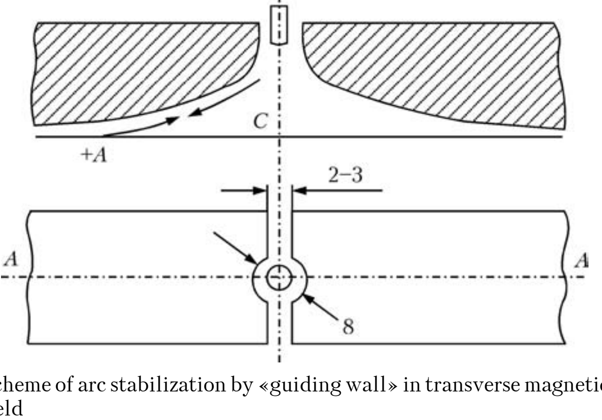
Let us study the behavior of direct current arc in transverse variable magnetic field. The deviation of arc can be defined considering the movement of arc column as oscillation of an elastic conductor of a variable length around a definite point. According to empiric equations the speed of sliding of anode spot depends on amplitude angle of arc deviation, frequency of transverse variable magnetic field and time. At constancy of heat capacity of arc its input energy will change in accordance with the speed of arc movement, which allows controlling heat influence of arc on the base metal. At the areas with a decreased input energy the smaller penetration depth is noticeable.

The welding arc in the variable transverse magnetic field is less stable than in constant one [9]. The less value of critical intensity of magnetic field for the arc in the variable magnetic field is explained by different movement inertia of column and active spots at arc movement. In the moment of change of direction of arc movement the anode spot is stabilized by the plasma flow. The arc column, having high mobility, is tending to shift that leads to remaining the spot behind the column and under certain conditions to arc interruption.

The stabilization of arc by the gas jet leads to increase of its stability in a variable transverse magnetic field. Some effect of improving the arc stability is provided by additional transverse magnetic field, the force lines of which are normal to the lines of variable field. The authors of work [9] explain this by the fact that constant field, acting on the arc column with a constant force, a bit stabilizes the cathode spot. The decrease in amplitude of cathode spot oscillation at the end of electrode under the influence of this force is the reason of increasing the arc stability in the variable magnetic field.

The considered peculiarities of magnetically-controlled arc widen its technological possibilities. As a rule, the depth of penetration is controlled by change of relation between the current value and welding speed. To prevent burn-out of metal at increase of welding current the welding speed is increased that can cause a jumpy movement of an active spot over the surface and, as a consequence, the unsatisfactory weld formation. To prevent burn-out is possible by superposition of constant transverse magnetic field, directed along the weld axis, on the arc. The decrease in penetration depth and some reduction of weld width are observed. The significant change of weld width is attained in welding in transverse magnetic field by adjusting the amplitude of arc oscillation which is directly proportional to magnetic induction in the zone of arc burning [10].

Thus, the application of transverse constant and variable magnetic fields allows welding of metal in different technological variants: with transverse and longitudinal oscillations, angle forwards and backwards, i.e. controlling shape and sizes of welds within wide ranges. Here, the shape of weld pool is changed, which influences the character of weld metal crystallization. The impressive characteristic of change of shape of weld pool is the coefficient of pool shape (relation of weld width to the length of crystallized



Scheme of arc stabilization by «guiding wall» in transverse magnetic field part). This coefficient grows from 1.1–1.4 (in welding without magnetic control) up to 3.0–3.3 at influence of transverse variable magnetic field with amplitude intensity of 4030 A/m. The influence of transverse magnetic field on the movement of weld pool metal in the process of crystallization opens up the possibilities of change of initial structure of crystallizing metal. The molten metal, located under the arc, is moving during movement of arc over the surface of weld pool under the influence of electromagnetic force. The repeated passing of arc across the weld and movement of molten layer of metal results in change of conditions of crystallization and producing of fine-grain weld structure.

The use of magnetically-controlled arc in welding in vertical plane to increase the quality of welds is of a special interest. Producing horizontal welds the molten metal under the influence of gravity is leaking to the lower edge, thus leading to non-uniform bead formation with an undercut at upper edge and overlap at the lower edge. Sometimes this is the reason of formation of such defects as lack of penetration, which are difficult to remove, especially in multi-pass welding. Under the conditions when input energy and welding speed are limited the unsatisfactory result of welding works is imminent.

With the purpose to solve the above-mentioned problem the authors of study [11] developed a method of welding where electric field in weld pool is subjected to influence of additional electromagnetic field caused by passing the electric current through two filler wires. The generated magnetic field influences the molten metal by electromagnetic force, which is directed upwards, balances the gravity force and contributes to prevention of a bead sagging. Thus, it is possible to control the flow of molten metal and bead shape. The value, which defines the quality of bead formation, can be the relation between the density of magnetic flux and contact angle. With the increase in density of magnetic flux the contact angle is decreased.

The given-above method of welding was tested in making horizontal welds of large-size steel structures. Along with the achieved high rate of deposition (up to 100 g/min) it is necessary to note some complication of welding process, as far as presence of two filler wires creates additional difficulties due to increase of amount of adjustable parameters.

To change the spatial position of arc the application of welding using tungsten electrode in argon by magnetically-controlled arc, which was realized both in automatic narrow-gap welding of titanium [12, 13] and also in manual (mechanized) welding under site conditions, is seemed as more challenging [14].

Thus, application of transverse variable magnetic field in welding widens greatly its technological capabilities, as it allows controlling the distribution of heat energy of arc between welded edges, filler wire and metal of weld pool, changing the conditions of crystallization of weld pool metal and, as a consequence, controlling the shape and sizes of the weld.

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