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Study of Electric Arc Welding Using Variable Cross Section Electrodes

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Abstract

The achievements of modern science and technology in the field of arc welding using consumable electrode indicate that the performance of automatic welding under flux reached its limit. Known compression techniques affecting the state of the plasma arc are stabilized by magnetic fields. Motion control arc on the electrode tip, ordering drip transfer by forced discharge mechanical devices, or the imposition of pulses of electrical energy. Other improvements in technology have already been exhausted. In this paper, discrete changes in the heat balance at the end of a continuous consumable electrode under a sudden change in cross-sectional configuration is investigated through experimental studies. At a constant electrical power, arc dramatically change the conditions of heat transfer at the end of the electrode; there is a natural contraction of the hearth melting and stabilization of the active spot of the arc, thereby, increasing the mass and linear velocity of the melting of the electrode without supplying additional electrical energy.

Keyword: Arc Welding, Consumable electrode, Plasma arc

Introduction

In assessing the manufacturability of an arc melting in the case of artificial feeding electrode, attention is given to the importance of the physical relation of linear (mechanical) speed of electrode wire v, cm / s and the mass melting rate g, g / s, which satisfies the physical process of transition of the solid metal material at the end of the electrode liquid state under the influence of arc energy:

v, cm / s = g, g / s (1)

Violation of equality in which v> g leads to short-circuit the arc, therefore, the loss of stability of combustion in the opposite case, when v <g, the arc length increases up to a natural cliff.
Given the cross-section of the electrode S, cm^2 and its density ρ, g/cm^3 rate ratio (1) becomes:

g = v S • ρ (2)

Where: v in (cm / s) is the linear velocity of the electrode, which is the ratio of length h to the departure time t, for which each cross-section of the electrode is the distance from the current supply to the active spot of the arc;

ρ - Density of the metal, g/cm^3.

In the range of normal modes of arc welding electrode melting rate v is usually taken proportional to current strength. Based on the assumption that the mass rate of melting will be greater, the greater the amount of current, introduced another indicator of the performance of melting - melting factor αr = A1, where A1 allows the units of mass in g, the current in A, time - in hours.

However, this assumption is justified only in part, because in the energy balance of melting heat in Joule plays a significant role, which is released in the radius of the electrode (Fig. 1).
The heat is expressed by a quadratic function of the Joule current $q_n = a_2 I^2 R$ and heat capacity of the arc $q_e = \eta e (I \times U)$, the expression for α_r reduces to [1]:

$$\alpha_r = \frac{\eta_э U + a_2 RI}{a_1\left(H_{Tк} - H_{Tн}\right)} \qquad (3)$$

Thus is proved that the rate of melting αr is valued function of current while the current strength is a complex dependence difference $\Delta H_{Tк} - \Delta H_{Tн}$ enthalpy drop and the heat of the Joule heated section, coming into the melting area

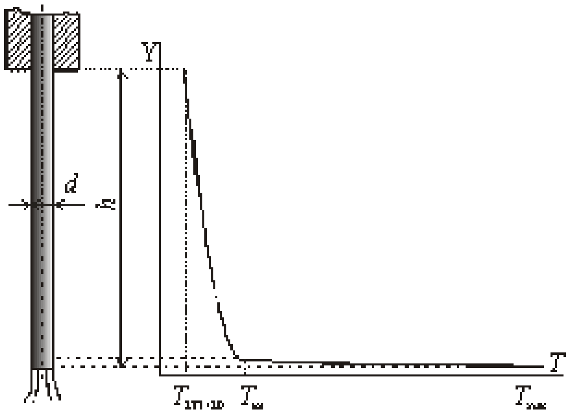


Fig. 1 Scheme of temperature distribution over electrode extension

Factors that determine the kinetics of the melting face of the electrode, considered separately, would not allow us to describe the complex physical processes occurring in a short time interval. In addition to the performance of fusion greatly influenced the formation of a layer of liquid metal on the end of the electrode, after the detachment of the drop, a natural increase of liquid mass to a critical level beyond which, the drop breaks away.

According to the results of numerous experiments in [1] proved the logical scheme of melting of the electrode tip (Fig. 2.) According to which power qe, released by the arc in the active spot at the end of the electrode is transferred to the solid metal electrode rod through a layer of molten metal.

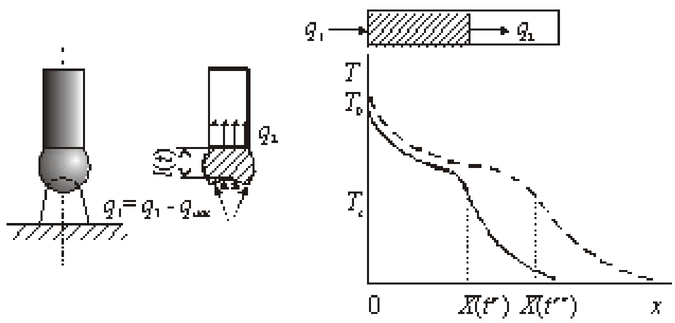


Fig. 2. Heating consumption in echanging within the drop

Part of this power is expended in evaporation of the metal and the liquid layer is introduced heat flux $q_1 = q_e - q_x$. Prior to a rigid metal comes only power q2. The difference (q_1 - q_2) determines the amount of losses on the overheating of the mass of the drop, including the latent heat of melting λ_{pl}. As a result, losses in the drop represented the balance equations, whose structure is illustrated diagram (Fig. 2)

$$(t) = q_1 - q_2 \left[c\rho\left(\frac{1}{X(t)} \int_0^X T(x,t)dx - T_s \right) + \rho\lambda_{\kappa\pi} \right] \frac{dX}{dt}$$

Where X (t) - coordinate of the moving boundary of melting;
c - specific heat of the molten metal.

Despite the obvious and logical completeness of the physical representations of the arc melts the electrode, the solution is not given. According to AA Yerokhina [1], even an approximate solution of Fourier's equation for one-dimensional flow under given boundary conditions and neglecting the convection and heat transfer from the lateral surface, would be unrealistic.
Analysis of the basic theoretical arc melting shows a lack of, what - or the real prospects for accelerating the process of arc-melting, while maintaining a constant arc power.

PROBLEM STATEMENT

In the absence of theoretical assumptions described a heuristic approach to solving the problem of intensification of arc melting without adding additional capacity. Solution of the problem was taken to look through the experimental studies of the effect section S. This is usually constant along the length of metal rod; the parameter is the proportionality coefficient of linear relations and the mass melting rate [3].

The impetus for research in this direction were the results of numerous comparative tests, melting the wire and tape electrodes of equal cross section, which show the performance gains melting tape with equal power arc discharge of about 20% or more [2].

EXPERIMENTAL SETUP

Studies of arc process with discretely varying cross-section of the electrode were carried out on plates of mild steel 20 mm thick. Beading machine marks were DT-1000-4, with a layer of flux AN - 348 A. The weight of the electrode rods of different cross sections were determined by weighing up to 0,1 g, record the current carried recorder H-390, the process was determined by an electronic stopwatch and refined on the chart recorder, feeding speed which was measured directly.

Well-known asymmetry in the distribution of heat of the arc between oppositely charged poles. For example, separate calorimetric arc burning a short time (0, 03 - 0, 7 s), conducted by ID Kulagin and AV Nikolaev, [3] showed that the current strength of about 250 A between the electrodes is a redistribution of power. The authors explained this phenomenon is changing the direction of plasma flows, which at low amperage with products aimed at the electrode, and at large - with an electrode on the product. Accordingly, when a small current of greater amount of heat released at the electrode (40 - 45%) and smaller (30 -37%) - on the product. But at high amperage, conversely, a smaller amount of heat - on the electrode (30-35%) and more - on the product (45-50%).

Nothing like that is not marked on the reverse polarity, when all the forces of the current product gets more heat (55-60%), and the electrode is less (30-20%), the flow of plasma in all cases directed to the product.
Since an alternating current by changing the polarity of 50 times in a redistribution of heat capacity is averaged over time, therefore, the results are more reasonable in terms of the overall problem statement.
Selected for the experiment welding machine is equipped with a closed system of automatic speed control fusion (Fig. 3).

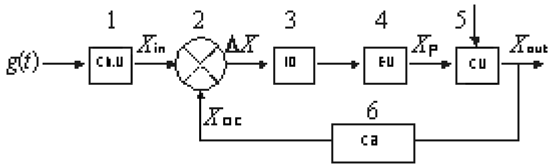


Fig. 3. Key diagram of automatic control system of aregulatory type for milting electrode

Ch.U - Charging unit
ID - Initiating device (Starter)
EU - Executive unit
CU - Controlled unit
Ca - Calculator

The change in the regulatory impact X_p indicating X_{out} change occurs until X_{out} until it reaches the desired value, then the $\Delta X = 0$, and $| X_{in} | = | X_{oc} |$, therefore the system is in equilibrium. If the perturbation X_{out} swings, causing the equilibrium condition which in turn will cause the recovery X_{out}. In essence, a regulator of this type is an analog (less digital) calculator that solves the equation:

$$Xp = K_0 + K_1 \Delta X + K_1 K_2 \int \Delta X dt + K_1 K_3 \frac{d\Delta X}{dt}$$

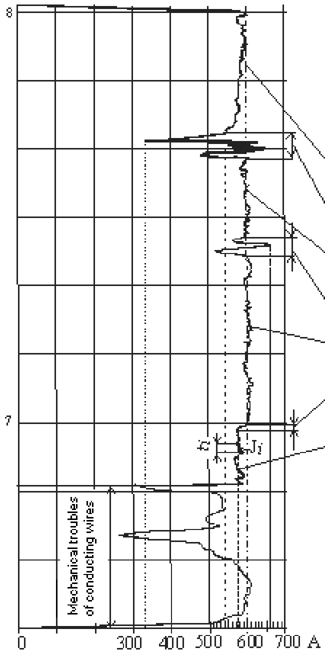
Where, K0, K1, K2, K3 - factors determined the device settings 3 and 4 of the regulator.
The main feature of the experiment - is to use a continuous consumable metal electrode of special design [4]. In the first series of experiments, pre-treated to a square rod S □, after weighing and measuring length, welded to the wire - S ○, well balanced and measured in advance. Basis for comparison electrode was a solid round cross-section of mild steel St - 08A.

The experiment was limited to ensure that a continuous arcing, to make discrete changes in the hearth melting, starting from a circular cross-section S ○ → S □ → S ○ → S □ etc. In this factor, disturbing the steady arc process should take into account the automatic regulation of the arc.
At this stage, the description of each can assume an expected result, but in the final part of the article to check whether justified or not justified his assumption.

RESULTS

To facilitate the analysis of the results we have combined a chart recording of current to the table, which shows the actual characteristics of rods of different cross-section S, mm2, length L, cm and mass m, was Shows the data fusion time t, c of each rod and the transition process by changing the cross section of the continuous electrode and the average value of current, as a result of record processing. On the right side of the table indicate the values of the linear and the mass melting rate of each of the sites, as well as the ratio of melting α_r, r / A · h.

Table 1: Characteristics of rods of variable cross-section



Characteristic of the rod				Time	Weld current		Micro characteristics of melting		
S,мм²	L,см	m,г	m/L	t,c	I,A	j=I/S	v,см/с	g,г/км	α, г/Ач
□9	50	35	0,7	7	575±15	63,8	**5,21**	**3,65**	**22,82**
				3	330...660		1,63	1,18	1,24
○12,6	25	24	0,96	7,8	600+15	47,6	3,2	3,07	18,46
				2	515...662		1,6	,15	1,49
□16	30	40	1,33	15	600+15	37,5	2,0	2,66	16,06
				~0,5	575+25		1,12	1,5	1,43
○12,6	9, 7/30	9,7	0,99	5,4/11	575±15	45,8	1,79	1,77	11,2

In the bottom row of the table shows the data entry area of the electrode of circular cross section, taken as the base. It corresponds to the mode of melting of the electrode, recorded at the initial section of the chart below. Plot chart with a record of current and bottom line of the table joined by a line. Shown is an emergency situation violation of the melting process, which comes at a time when the electrode is a square, the next round, stuck at the entrance to the current supply mouthpiece of the machine. After eliminating the mechanical problems the melting process went normally.

Next on the chart shows the time interval Δt ~ 0, 5 c of the transition process by changing circular electrode on the square (S ○ → S □). This quantum transition is characterized by a slight increase over the average current value I = 575 + 25 A. The corresponding increase in productivity of melting (at 1.12, 1.5, 1.43 times) is shown in the second bottom row of the table.

The melting of the electrode square is characterized by high stability, as evidenced by the almost constant current (600 +15, A). This section of the diagram is connected to the corresponding row of the table, which shows the linear and the mass melting rate, as well as the value of α_r.
Transition process of changing the square to round (S □ → S ○), characterized by a time Δt = 2c, and sinusoidal changes in current magnitude (515 ÷ 662, A) in this period of time. The abrupt increase in productivity of melting when the cross section (S □ → S ○) is shown in the corresponding row.
Then we see a plot diagram of melting a circular electrode connected to a corresponding row of the table, which shows the corresponding performance of fusion.
The following describes the transition process of changing the circular electrode on the square, but smaller cross-section (S ○ → S □), and the corresponding change in the indices of the smelting process. Outcome in the top row of the table in bold, to emphasize the unusual nature of quantum transitions of the heat balance of the arc-melting in the amount enhanced the performance of melting metal electrode is more than twice without any additional cost of electrical energy that fuels the arc.
In the scope of this article does not fit the description of experiments to study the discrete transitions of the heat balance at the end of the electrode by changing various sections of the electrode, described by a broken line contour and curve of the second order [4].

DISCUSSION OF RESULTS

From the analysis of theoretical positions, it can be concluded that the modern theory of the arc melting can not explain the physical essence of discrete changes in energy balance at the sudden change in cross section. For their interpretation we turn to the scheme, explaining the line (S ○ → S □) and reverse (S □ → S ○) the quantum effects (Fig. 5, 6, where 1 - consumable electrode of different sections, 2 - electric arc, 3 - main metal, 4 - a drop of liquid metal, 5 - power supply of the arc).
It is known that the active spot of the arc is characterized by extremely fragile situation on the convex surface of the growing droplets of liquid metal. It may even go on the lateral surface of the round electrode. It is clear that Tm isotherm on a solid surface is described by a smooth, closed curve of second order. It is thus manifested a physical property of surface tension, which is characteristic for the substance in the liquid aggregate state. The question is how to melt the peripheral areas of a square, beyond the circle inscribed in a square hearth melting if the temperature T_m for these inaccessible areas in general? Because the square of the isotherm, or isotherms, described by a broken line in nature do not happen.

Due to limitations in the perimeter of the hearth melting of the convex surface of the drop at the round electrode becomes flat and then concave inward. I_e flat front melting, as shown in Fig. 2, where bends and acquires, for example, the shape of a spherical segment. Volume equals the volume of melted metal cavity spherical segment $V = 1 / 3 \pi h^2 (R-h)$, which generally depends on the radius R and height of segment h. Here, the size of h - is the result of discrete changes in the cross section S ○ → S □. In the physical process of melting the electrode tip, this size seems to increase as the voltage drop across the arc in the electrode region ΔU_e, in $\sim h_e = l_m$. Factor perturbations arc along its length is taken into account by the automatic control machine (Fig. 3, p. (4)), thus, the rate of melting is experiencing a discrete increment.

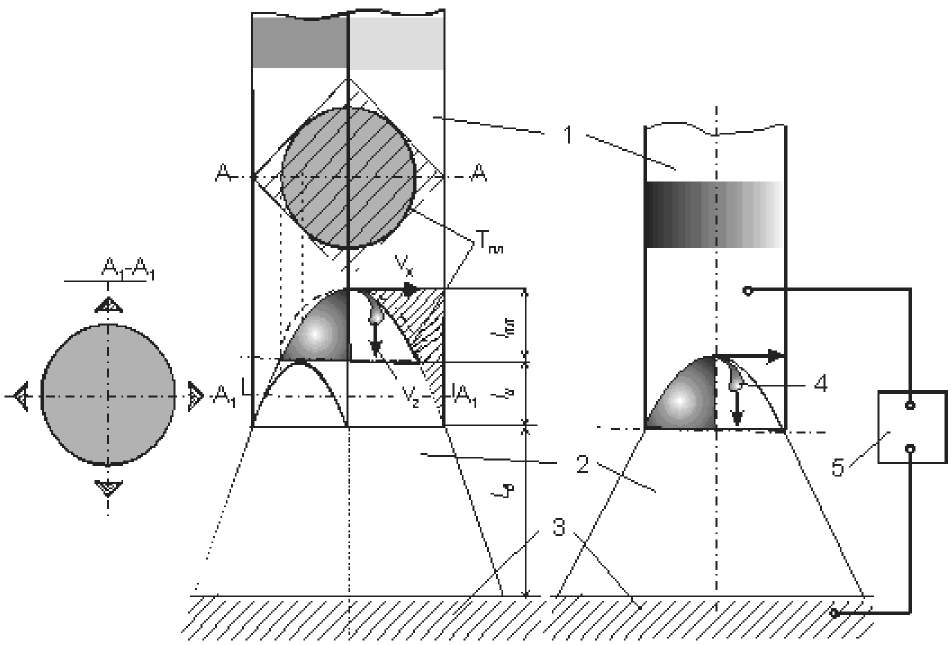


Fig. 5 Fig. 6

Curvature of the melting front leads to the stabilization of the active arc spot in the center of symmetry of the electrode, and the loss of heat in a liquid layer with a decrease in its thickness is greatly reduced. Previously established [5] ,that the height of the concave surface of the velocity of the metal from the base of the arc is an order of magnitude greater than the speed drops dripping on the side surface under gravity. Thus, due to the discrete shift-section conditions improve heat transfer solid metal electrode, changing the kinetics of droplet formation and mechanism of Kapleperenosa.

The second factor explaining the growth performance of the electrode melting square are peripheral areas located outside of the inscribed circle of the isotherm Tm, which lagged behind the base plane of the spherical segment B-B. These sites take the form of pyramids with variable cross section (Figure 5. For A1-A1) with an acute apex, turned to the base metal and the base is close to triangular. This forms another factor that leads to a lengthening of the arc L, and as a result of the metal equivalent of 4 pyramids in the corners of a square electrode is melted by

the radial component of the radiation of the arc column, but not due to heat transfer through the active spot at the end of the electrode.
There are possible objections. Peripheral areas lag behind the flat melting front so that cause short circuits. However, inherent in this current oscillations on a chart recording mode settings are virtually absent; therefore, the objections are not justified.
Solution of the balance equation (3) is not required [6], it is enough to make the calculation of the volume of pyramids and domed concave spherical segment with a known diameter at the base of the inscribed circle in a square. Thus, dividing the calculation, the volume figures, we can find components of a discrete change in the heat balance at the end of the electrode, both individually and in proportion.

Thus completes the description of the direct quantum effect due to the discrete shift-section (S ○ → S □) continuous consumable electrode.

It was expected that a return to the original, unmodified form of the electrode of circular cross section, the heat balance at the end of the electrode is restored, and indicators of mass and linear melting rate will be close to the base. However, the inverse quantum effect was asymmetric in the sense of physical manifestation.

Characteristic of this transient change of the cross section turned out to be a sine curve in the diagram of the current. The sharp decline from the current average level means a sudden increase in the length of the arc gap as a result of complete melting of the peripheral areas of square section, followed by a sharp increase in current to the expected calculated value of 662 A, exactly coinciding with the first three digits of the numerical series of the Planck constant h = 0, 6626 ... · 10-33 · J with.
As a result of the transition process recovered average parameters of the arc I_{cv} and U_d, the mass is melting rate has surpassed not only the initial rates, but significantly higher than those for the square of the electrode due to a direct quantum effect.

In the absence of peripheral regions of the cross section concave shape of the melting was inherited (Fig. 6), moreover, due to increased current density due to smaller cross-section of the electrode S ○ <S □ reconfigure the design dome volume. Ie volume of the spherical shape (segment) increased due to the height and he got the form, described the rotation curve of the parabola, the vertex facing upward. Due to the further concentration of power in the active spot of the arc due to restriction of its mobility, to further enhance the efficiency of heat energy solid electrode. A gain of height of the parabolic of rotation means that the radial component of the arc column now operates not only on separate sites at the vertices of the square, but on the entire periphery of the circle. Similar to the process as the concave surface of the melted region at the long candle wick, quickly filling the recess with liquid wax.

The end result was again due to the direct quantum effect in which the circular cross-section was changed to a square, but the square was inscribed in a circle (S ○ → S □). In this transition process is characterized by a portion of the diagram, does not look like all the previous (second row from the top table 1), and yet, the current in the steady melting of a square smaller area does not differ from baseline during the melting of a circular electrode at the beginning of I = 575 ± 15, A.

Investigated and many other cases of discrete shifts round consumable electrode, a second-order curve is described by the cross section, described a variety of broken lines. As a result, new ways of intensification of a discrete arc melting are protected by patents [4, 7].
Note that a discrete change in the heat balance at the end of the electrode could not affect the kinetics of melting the base metal. The result of these studies are being processed and their publication possible continuation of the article.

CONCLUSIONS

1. Traditional differential-integral mathematical model of heat balance consumable electrode tip is not able to take into account the changing conditions of the discrete input heat of the arc, so physically accurate description of the arc-melting in this case can be built on a fundamentally new theoretical basis [8].

2. Discovered a previously unknown method of macro quantum of the thermal balance at the end of the electrode by a discrete change of cross section of a continuous consumable electrode.

3. Significant role of the energy of the radial arc radiation in the thermal balance of the melting of the electrode is not measured by electrical appliances.

4. Improved performance of fusion of the electrode allows more than 2-fold increase in the mass of deposited metal, thus reducing unit labor costs and energy consumption per unit mass. In addition, an increase in the welding speed, significantly reducing the power per unit length q / v at a constant value of q = UI method can be recommended for welding hard enable, special steels at higher speeds.

5. For the "acceleration" of the arc-melting to the required level of performance is enough to make a change in cross-section only on the initial section (at radius) electrode. It is sufficient to know the time of transients when changing sections.

References

[1] A. A. Yerokhin, Fundamentals of fusion welding, Moscow: Mashinostroenie, 1973, 448.
[2] Y. V. Belousov, Investigation and improvement of methods of arc welding electrodes tape, Candidate of Science, Moscow Higher Technical School, 1979, 15.
[3] I. D. Kulagin, AV Nikolaev, Heat balance of the arc DC gases during the formation of droplets, Izvestia AN SSSR. HMA, 11(1958), 89-91.
[4] Y. V. Belousov, A. V. Karezina, A utility model patent number 22236. UA V23K 35/00. Continuous consumable electrode for welding, 5 (2007), 4.
[5] Y. V. Belousov, The role of a liquid layer in the melting of the electrodes under the influence of the arc, welding proizvodstvo, 7 (1989), 33 - 35.
[6] Y. V. Belousov, Imperfection of the theory arc melting and new possibilities of quantum process intensification. - Technology repair, rehabilitation and strengthening of machine parts, machinery, equipment, tools and tooling: Proceedings of the 9 - the first international conference. SPb. Ed. Polytech. Press, (2007), 16-25.
[7] Y. V. Belousov, Quantum, the natural, causal theory of mass (Quantum theory of physical properties of time - the theory of the universe) - Mariupol, "New World", (2006), 378.

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