

# Effect of the inert gas on the shape of the column and the degree of concentration of the low-ampere arc in a non-consumable electrode

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The shape of the column of the welding arc is determined by the nature of the plasma flows in the arc and depends on the physical characteristics of the arc gas and, to a lesser extent, on the design features of the non-consumable electrode. According to the current views, the column of the arc of the non-consumable electrode in argon has the form of a truncated cone ('bell') with a smaller base on the electrode-cathode and a larger base on the anode.<sup>1,2</sup> As concerns the arc in helium, in this case it is assumed that the arc column is conical<sup>2</sup> or spherical<sup>3,4</sup> and the shape is characterised by compression in the vicinity of the anode. The improvement of the available data and the examination of the effect of arcing parameters and of electrode design on the shape of the arc column in helium make it possible to select the shielding gas from the viewpoint of increasing the degree of concentration of the heat flow from the arc into the welded metal in non-consumable (TIG) welding.

The shape of the arc column is determined by the probing method. The general feature of the methods of measurement of the diameter of the arc column using a probe at present is the recording of the voltage between the probe and the electrode using an oscilloscope, and the velocity and position of the probe in the arc are determined by filming or video recording.<sup>2,3</sup> This requires highly accurate synchronisation of the devices and, consequently, complicates the measurement procedure. These shortcomings are not found in specially developed method of transverse probing of the arc using a double horizontal probe. Two probes, produced from tungsten wire (VRN) with a diameter of 0.3 mm, are situated in the horizontal plane at the distance  $r$  from each other and rigidly secured in a probe holder designed in such a manner as to ensure spatial positioning of the block of the probes in the arc and rotation around the vertical axis (figure 1). The distance  $r$  between the probes and also between the probes and the electrodes in positioning of the block in the arc gap is determined using an MBS-9 stereoscopic microscope fitted with eyepieces with a measurement scale. The arc length was determined on the indicating device with the scale divided in 0.1 mm. The variation of the potential of both probes in relation to the non-

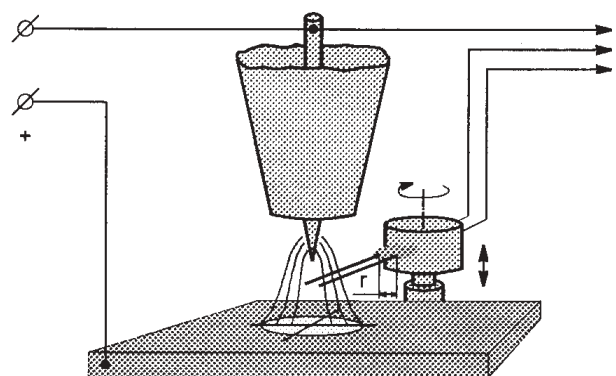
consumable electrode in passage of the probes through the arc was recorded simultaneously using S9-8 two-beam digital memory oscilloscope. The oscillograms of the probing process are shown in figure 2a.

The difference between the moments of passage of the probes through the axis of the current-conducting channel of the arc column is  $t_1$  (figure 2b). Consequently, knowing the distance  $r$  between the probes and the time period  $t_2$  of passage of the current-conducting channel through one probe, it is possible to calculate the diameter of the cross-section of the arc column:

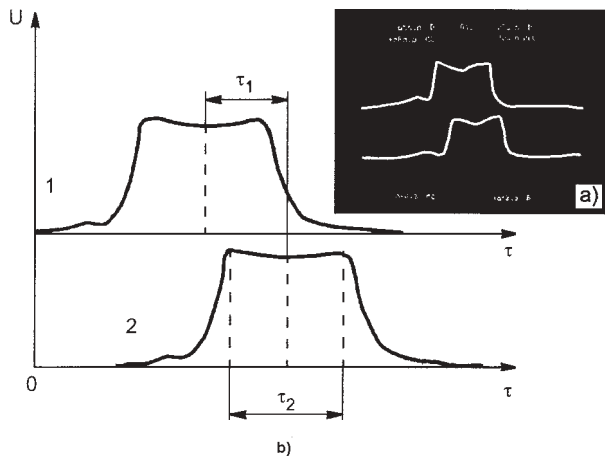
$$d_c = \frac{r t_2}{t_1} \quad [1]$$

The experiments were carried out using tungsten electrodes EVI, with a diameter of 2 mm, the tip angle was varied in the range 15–60°. The shielding gases included helium A and a higher-grade argon.

The results of determination of the shape and dimensions of the column of the low-ampere arc of the non-consumable electrode are presented in figure 3. It



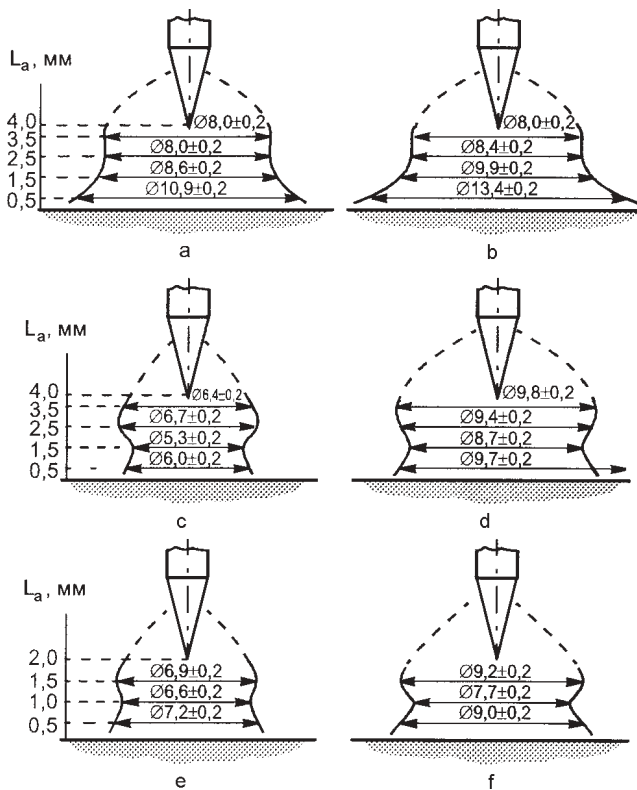
1 The diagram of the transverse probing of the arc using a dual horizontal probe.



2 The characteristic form of the oscillogram (a) and the diagram of determination of the time periods  $\tau_1$  and  $\tau_2$  (b).

may be seen that the arc column in argon is bell-shaped form which is in complete agreement with the data presented in the literature. The increase of the arc current increases the diameter of the column, and the increase in the vicinity of the anode is considerably larger: if in the vicinity of the non-consumable electrode (at a distance of 0.5 mm) the column diameter increases only slightly, then at the same distance from the anode, the increase of the diameter is several times greater.

In the experiments it was found that the shape of the arc column in helium differs from that described in the literature. The arc column is characterised by constriction, but this does not take place in the immediate vicinity of



3 The dimensions and shape of the arc column of a non-consumable electrode ( $\alpha = 30^\circ$ ) in argon (a, b) and helium (c-f):  $I_a$  of 12 (a, c, e) and 20 (b, d, f) A,  $L_a$  of 4 (a-d) and 2 (e, f) mm.

the arc but is detected at some distance from the anode (1.0–1.5 mm).

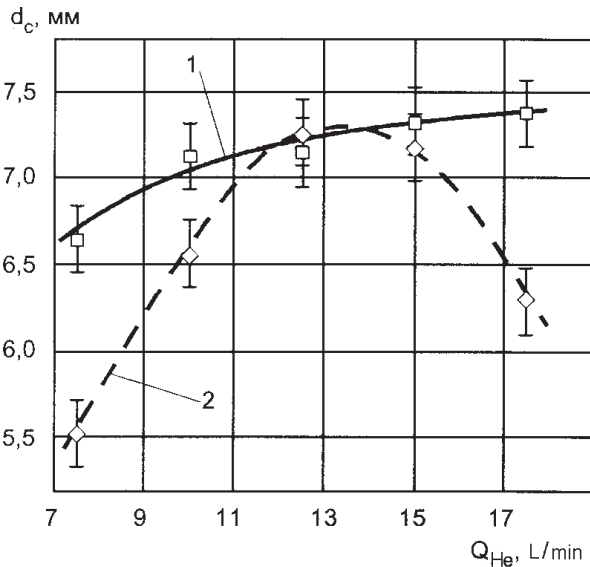
An increase of the arc current in helium from 12 to 20 A results in an almost proportional increase of the column diameter. It is important that the dimensions of the arc column in helium for the same arcing parameters are considerably smaller in comparison with the parameter for the arc in argon, and the difference of the diameters is the largest in the immediate vicinity of the anode. Halving the arc length from 4 to 2 mm has no effect on the shape of the arc column and results only in a change of the column diameter (figure 3e, f). The constriction of the arc column is less marked: the minimum diameter of the 'neck' increases from 5.3 to 6.6 mm (figure 3e). Different results are obtained in the case of high currents ( $I_a = 20$  A). The shortening of the arc in this case results in constriction: the minimum diameter of the arc column (at a distance of 1 mm from the anode) decreases.

The shape and dimensions of the arc column in helium depend on the consumption of the gas and the tip angle of the non-consumable electrode. At a relatively low consumption of helium in the range 7.5–12.5 l/min, the diameter of the arc column increases and this is more marked at a distance of 1.5 mm from the anode (figure 4). At a gas flow rate greater than 13 l/min the controlling role is played by the high heat conductivity of helium resulting in cooling and de-ionisation of the peripheral sections of the column. This is accompanied by arc constriction. In this case, the diameter of the column in the vicinity of the anode changes only slightly, because the shape and dimensions of the column in the section are determined by the convergence of the current lines to the anode spot of the arc.

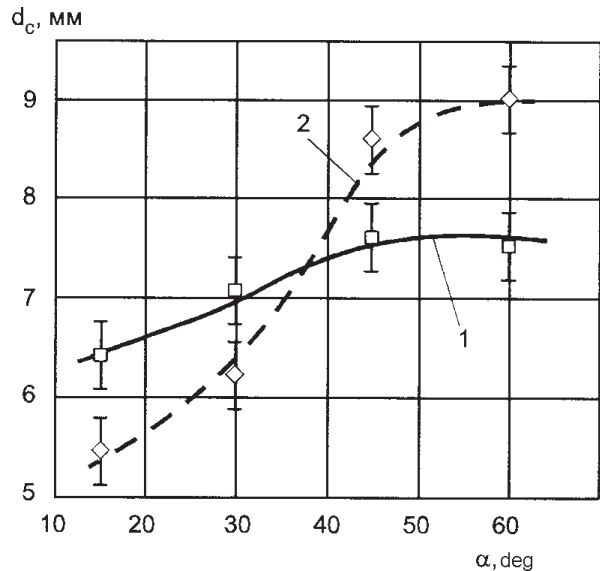
The relationships, presented in figure 4, also indicate that at a specific combination of arc current, the length of the arc gap and the flow rate of helium (in the experiments 16 A, 4 mm, 12.5–13.5 l/min, respectively), constriction of the arc column in helium may not take place and, in this case, the column has a form very similar to cylindrical.

The shape of the arc column is strongly affected by the tip angle of the non-consumable electrode (figure 5). For example, at  $\alpha = 15^\circ$ , the arc column is characterised by distinctive constriction whose maximum is found in the section at a distance of 1.5 mm from the anode (at the arc length of 4 mm). The increase of the tip angle of the electrode reduces the difference of the diameters and at  $\alpha = 35\text{--}40^\circ$  arc constriction is almost non-existent.

At high tip angles ( $45^\circ$  and greater), the increase of the intensity of heat removal into the body of the electrode holder results in a large change of the conditions of existence of the cathode spot of the arc. The need for maintaining the required level of thermal emission results in the constriction of the cathode spot and localisation of the tip of the conical part of the electrode. As regards the effect on the shape and dimensions of the column, this is identical with the decrease of the arc length. The variation of the geometry of the working section results in a change in the conditions of the flow of the shielding gas around the electrode and this greatly influences the dimensions and the shape of the electrode.<sup>4</sup> The arc becomes spherical and is characterised by constriction



4 The dependence of the arc column diameter on the flow rate of helium at a distance of 0.5 (1) and 1.5 (2) mm from the anode ( $I_a = 16$  A;  $L_a = 4$  mm;  $\alpha = 30^\circ$ ).



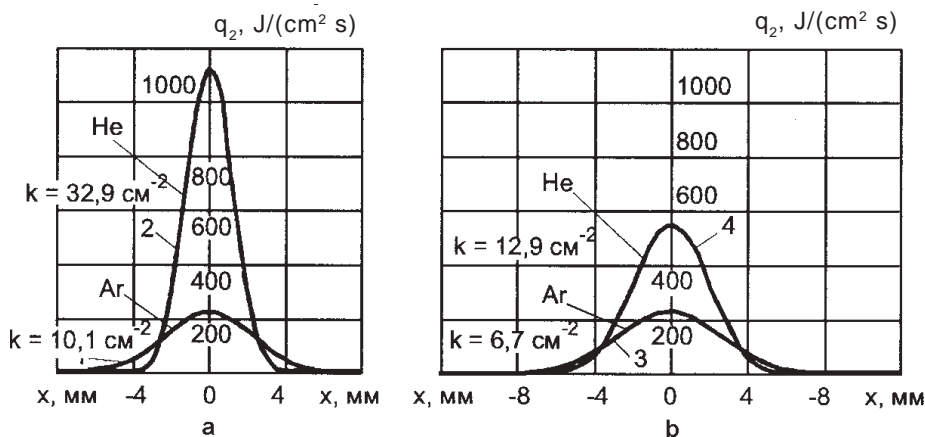
5 The dependence of the arc column diameter in helium on the tip angle of the non-consumable electrode at a distance of 0.5 (1) and 1.5 (2) mm from the anode ( $I_a = 16$  A,  $L_a = 4$  mm,  $\alpha = 30^\circ$ ).

in the immediate vicinity of the anode. However, it is necessary to take into account the relative nature of this constriction because the variation of the shape in this case is accompanied by the increase of the diameter of the arc column.

In the majority of the problems solved in single-pass butt welding of sheets the welding arc is treated as a concentrated linear heat source. Similar schematisation greatly simplifies the calculations, but this approach cannot be used for the low-ampere arc where the heating conditions of the metal make it necessary to take into account the distribution of the heat flow in the heating spot, characterised by the coefficient  $k$  of the concentration of the heat source. The importance of the results in practice is reduced to the possibility of simplified determination of the coefficient  $k$  of the low-ampere arc of the non-consumable electrode. The experimental evaluation of this coefficient is associated with a number of difficulties and requires formulation of labour-

consuming experiments.<sup>5</sup>

It is well known that to calculate the value of  $k$ , it is necessary to know the diameter of the heating spot of the heat source of the welded metal. Evidently, the diameter of the heating spot in DC arc welding with straight polarity is determined primarily by the diameter of the anode arc spot. The heat flow, supplied to the anode from the arc column with the gas flow, and also by the radiation, increases the diameter of the heating spot. In the investigations, the coefficient  $k$  of the low-ampere arc in argon in helium was evaluated assuming that the diameter of the heating spot is equal to the diameter of the arc column in the immediate vicinity of the anode. Obviously, the data obtained taking these assumptions into account, cannot be regarded as quantitatively accurate. However, from the viewpoint of qualitative evaluation, and also for comparative analysis of thermophysical characteristics of arc discharges in different conditions, this approach is fully acceptable.



6 The distribution of the specific heat flow of the low-ampere arc in argon and helium: a, b)  $I_a$  of 12 and 20 A, respectively; 1–4) the value of  $k$  equal to 10.1, 32.9, 6.7 and 12.9  $\text{cm}^{-2}$ , respectively.

The calculated values of coefficient  $k$  and the distribution of the specific heat flow of the low-ampere arc in argon and in helium are presented in figure 6. It is important to note the high degree of concentration of the arc in helium: at a current of 12 A,  $k = 32.9 \text{ cm}^{-2}$ , which is more than three times higher in comparison with the arc in argon burning in the identical conditions. The degree of concentration of the arc in both cases decreases with increasing arc current and this is expressed in the increase of the width of the heating zone. The maximum specific heat flow from the arc in argon remains almost completely constant, whereas in helium it is approximately halved. Figure 6 also shows that the increase of arc current reduces the difference in the width of the heating zone  $B_h$  of the low-ampere arcs in argon and helium.

Thus, the low-ampere arc in helium occupies, as regards the concentration of the heat flow into the welded metal, an intermediate position between the open arc and the plasma process (for microplasma welding in relation to the parameters of the process  $k = 30\text{--}150 \text{ cm}^{-2}$ )<sup>6</sup> and is a highly efficient tool for welding thin sheet materials. The application of helium as a shielding gas ensures stable complete penetration of the weld edges in the welding of structures with a small thickness produced from high-alloy steels and alloys with special properties in combination with the minimum dimensions of the welded joints and the heat affected zone. The effect resulting from the application of helium increases with a decrease of arc current and this shows that helium-shielded arc welding of thin structures should be carried at the minimum current, considering the condition of complete penetration of the weld edges. The additional condition for ensuring the required arc constriction in this case is the rational selection of the angle of the tip of the non-consumable electrode and the flow rate of the shielding gas.

## Conclusions

The arc column in helium is characterised by constriction with the maximum value recorded at some distance from the anode which depends on arc length. With increasing arc current, the dimensions of the column increase proportionately.

The shape and dimensions of the arc column in helium greatly depend on the tip angle of the non-consumable electrode and the gas flow rate. When using electrodes with the tip angle greater than  $45^\circ$ , the arc column becomes spherical with a simultaneous increase of diameter. The experimental results show that in the range of the helium flow rate of 11–15 l/min, there is no constriction of the arc column.

As regards the concentration of the heat flow into the welded metal, the low-ampere arc in helium occupies an intermediate position between the open arc and the plasma process. The concentration coefficient of the arc at the arc current of 10–12 A may exceed  $30 \text{ cm}^{-2}$ . In this case, the high degree of concentration reduces the dimensions of the welded joint and the heat affected zone in welding thin metal sheets.

## References

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