Determination of factors influencing the speed of moving arcs by rectanine electrodes

Az T Gabdrakhmanov, I H Israphilov, A T Galiakbarov and T F Gabdrakhmanova

Kazan Federal University, Naberezhnye Chelny, Russian Federation

E-mail: ATGabdrahmanov@kpfu.ru

Abstract. A mathematical description of the gas motion in an electric discharge moving in the interelectrode gap under the action of the Lorentz force, considers in this paper. The presented model of the electric arc allows one to calculate the magnetic field acting on the charges in the discharge and to explain the occurrence of the arc shunting effect when moving along the electrodes.

1. Introduction
Currently, plasma devices with transverse arc blowing are used, moving between coaxially located electrodes. These devices allow you to create large volumes of plasma and process large areas [1-5]. But for these types of plasmatrons, an engineering method for calculating the main characteristics has not been developed.

One of the main parameters characterizing the railgun type plasmatron is the speed of movement of the electric arc, because the speed of the arc affects the number of pulses per unit time and determines the time of plasma exposure to the part [6-9].

2. Experimental studies
For calculations, the arc is considered as a hot cylinder. In this case, the conductive channel is practically impermeable to particles of the surrounding cold gas and moves, pushing it like a solid body. At the boundaries of the conductive channel there is heat - mass transfer with the surrounding cold gas. Behind the conducting channel there remains a trace of heated gas having a temperature substantially lower than in the arc channel, and practically not conducting current.

An electric arc in a pulsed plasma generator moves as a result of the action of electrodynamic forces on it. These forces (Ampere force \( F \)) arise as a result of the interaction of the arc current with the magnetic field created by the electrodes. It is necessary to determine the magnetic induction at any point in space for different sections of the electrodes.

For this, the induction of a conductor with current can be represented as the vector sum of elementary inductions created by individual sections of the conductor:

\[
\overrightarrow{B} = \sum_{i=1}^{n} B_i \quad \text{or} \quad \overrightarrow{B} = \int d \overrightarrow{B}
\]
Figure 1. An arc moving under the influence of its own magnetic field

From experience it is impossible to separate a section of a conductor with a current, since direct currents are always closed. Only the total induction of the magnetic field created by all current elements can be measured. The Bio–Savart law determines the contribution $d\vec{B}$ to the magnetic induction $\vec{B}$ of the resulting magnetic field created by a small portion $dl$ of the conductor with current $I$ (1).

$$d\vec{B} = \frac{\mu_0 I}{4\pi r^3} [dl \cdot \hat{r}]$$

or

$$dB = \frac{\mu_0 I \sin \alpha \cdot dl}{r^2},$$

where $r$ is the distance from a given section $dl$ to the observation point, $\alpha$ is the angle between the direction to the observation point and the direction of the current in this section, $\mu_0$ is the magnetic constant.

If we integrate the contributions to the magnetic field of all individual sections of the rectilinear conductor with current, we obtain the formula for the magnetic induction of the direct current field (2):

$$B = \frac{\mu_0 I}{2\pi R},$$

and for a conductor of finite length (3):

$$B = \frac{\mu \cdot \mu_0}{4 \cdot \pi \cdot R} \cdot I \cdot (\cos(\alpha_1) - \cos(\alpha_2))$$

where the angles $\alpha_1$ and $\alpha_2$ between the conductor segments of finite length and $r_1$ and $r_2$ connecting the conductor ends of the point.

Using expression (3) and the principle of field superposition created by two electrodes (Figure 2), to be a special case of finding the magnetic field distribution in the interelectrode gap shown in Figure 3.
Figure 2. The magnetic field created by the arc current

Figure 3. The distribution of the magnetic field in the interelectrode space d = 8mm, L = 8mm, I = 300A

The arc moves along parallel electrodes under the action of the Ampere force (4):

$$ F = I \cdot B \cdot \Delta l \cdot \sin \alpha $$

where is the $\Delta l$ length of a direct conductor with current acting on the force $F$, $B$ is magnetic induction, $\alpha$ it is the angle between the direction of the element of the length of the conductor $\Delta l$ and the direction of the magnetic field.

The force $F$ will have an uneven effect on different parts of the arc (Figure 4), similar to the distribution of the magnetic field in the interelectrode space (Figure 3), and different parts of the arc will move at different speeds. Perhaps this is one of the reasons for the appearance of arc shunting.

As a result of experimental studies, it was found that the following factors have a significant influence on the speed of the arc: current strength, electrode diameter, electrode gap, plasma-forming gas flow rate and electrode material. The data obtained as a result of experimental studies are presented in the form of graphs in Figure 5.
Figure 4. Ampere force distribution in the interelectrode space $d = 8\text{mm}$, $L = 8\text{mm}$, $I = 300\text{A}$

Figure 5. The dependence of the speed of the electric arc on external parameters:

a) from the interelectrode distance at $d = 6\text{ mm}$, $G = 0 \text{l/min}$; $ \bullet - R = 0.28 \text{ \Omega}$; $\blacksquare - R = 0.3 \Omega$; $\blacktriangle - R = 0.35 \text{ Ohm}$; $ \bullet - R = 0.525 \text{ \Omega}$; $ \times - R = 1.05 \text{ \Omega}$; b) from the current at various diameters of the electrodes $\blacktriangle - d = 12\text{mm}$, $L = 4\text{mm}$; $\blacksquare - d = 6\text{mm}$, $L = 4\text{mm}$; $ \bullet -d = 4\text{mm}$, $L = 4\text{mm}$, $G = 0 \text{l/min}$; c) from the consumption of plasma-forming gas at $d = 6\text{mm}$, $L = 5\text{mm}$; $ \bullet -R = 0.28 \text{ \Omega}$; $\blacksquare - R = 0.3 \Omega$; $\blacktriangle - R = 0.35 \text{ \Omega}$; $\bullet - R = 0.525 \text{ \Omega}$; d) from the current for various electrode materials $d = 4\text{mm}$, $L = 4\text{mm}$, $G = 0 \text{l/min}$; $\blacksquare$ - copper; $\bullet$ - steel.
3. The conclusion
As can be seen from Figure 5, with increasing current, the speed increases significantly, however, with increasing current, the transverse dimensions of the arc increase, which increases the aerodynamic resistance of the arc and slows down its movement to some extent.

The interelectrode gap also has a significant effect on the speed of the arc. At distances between the electrodes substantially larger than the transverse size of the arc, the speed of the arc is determined by the transverse size of the arc, and it flows around like a cylindrical body. A decrease in the distance between the electrodes leads to a spatial flow around the arc and a decrease in the drag coefficient, which makes the speed increase. A decrease in the distance between the electrodes, apparently, leads to a decrease in the transverse size of the arc, which also contributes to an increase in speed. With an increase in the diameter of the magnetic electrodes, a decrease in the speed of the arc is observed, due to a decrease in the field accelerating the electric arc.

References
[1] Israphilov I H, Israphilov D I, Bashmakov D A, Galiakbarov A T, Samigullin A D 2015 Calculation of thermal processes in bottom electrode Contemporary Engineering Sciences Volume 8, no. 1, p. 13 - 20 HIKARI Ltd, www.m-hikari.com http://dx.doi.org/10.12988/ces.2015.48110.
[2] Rakhimov R R, Saubanov R R, Israfilov I H, Analysis of the impact of informative heat treatment parameters on the properties of hardening of the surface layers 2017 Journal of Physics: Conference Series Volume 789, Is.1, Art. № 012040.
[3] Zvezdin V V, Rakhimov R R, Saubanov R R, Israfilov I H, Akhtiamov R F 2017 Management of laser welding based on analysis informative signals IOP Conference Series: Materials Science and Engineering Volume 240, Issue 1 Article number 012073.
[4] Gabdrakhmanov A T, Galiakbarov A T, Samigullin A D, Galiakbarov R T 2016 The calculation of a thermal field in the surface of a processed part under the influence of a low-temperature plasma IOP Conference Series: Materials Science and Engineering Volume 134, Issue 1, Article number 012040. DOI: 10.1088/1757-899X/134/1/012040.
[5] Samigullin A D, Samigullina A R, Samigullin A D, Gabdrakhmanov A T 2017 Localized thermal cleaning method for pumping and compression pipes from asphalt, resin and paraffin deposits using plasma Journal of Physics: Conference Series Volume 789, Issue 1, Article number 012047. DOI: 10.1088/1742-6596/789/1/012047.
[6] Gabdrakhmanov A T, Israphilov I H, Galiakbarov A T 2014 The study the erosion of the electrodes under the influence moving electric arc Journal of Physics: Conference Series 567, Issue 1, Article number 012013. DOI: 10.1088/1742-6596/567/1/012013.
[7] Gabdrakhmanov A T, Shafigullin LN, Galimov E R, Ibragimov A R 2017 Surface thermohardening by the fast-moving electric arc Journal of Physics: Conference Series Volume 789 Article number 012010. DOI: 10.1088/1742-6596/789/1/012010.
[8] Denisov D G, Kashapov N F, Kashapov R N 2015 The appearance of shock waves in the plasma electrolytic processing Iop conference series: materials science and engineering №012005.
[9] Kashapov R N, Kashapov L N, Kashapov N F 2019 Investigation of parameters of low-temperature gas discharge plasma with liquid electrodes upon receipt of metal powder Journal of Physics: Conference Series Volume 1328, Issue 1, Article number 012104.