On the mechanism of retrograde motion of vacuum arc cathode spot in external magnetic field

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The physical processes that accompany the retrograde motion of the cathode spot of a vacuum arc in an external tangential magnetic field are considered based on the principle of maximum magnetic field. It is shown that the magnetic field causes an asymmetry in the plasma density distribution at the boundary of the plasma jet ejected from the cathode spot, but it has no effect on the physical processes that occur immediately in the spot. Cathode spot extinction is accompanied by ejection of plasma toward the site where the total magnetic field (the external field plus the self-magnetic field of the cathode plasma jet) is a maximum. At this site, a new spot is born. The velocity of the directed motion of a cathode spot in an external magnetic field increases with current mainly due to an increase in geometric size of the spot operation area.

The retrograde motion of the cathode spot of a vacuum arc in an external magnetic field parallel to the cathode surface is one of the most mysterious and difficult-to-explain phenomenon of vacuum discharge physics. The cathode spot motion opposite in direction to the Ampere force was discovered in 1903 by Stark [1].

When constructing a model describing the retrograde motion of the cathode spot of a vacuum arc, we will proceed from the principle of magnetic field maximum formulated by Kesaev[2]. Its essence is that the cathode spot motion is directed predominantly toward the site where the total magnetic field being the sum of the external magnetic field and the self-magnetic field of the cathode plasma jet is a maximum. In reality, the retrograde motion of a cathode spot is the initiation of new cathode spot cells mainly in the direction "retrograde" to the Ampere force. Analysis of the mechanism of initiation of cathode spot cells (that explosively emit ectons [3]) has shown that the main characteristic that determines the development of thermal instability of the cathode surface microscopic irregularities (on reaching a critical temperature T_{cr}) is cathode plasma density n_{pl} [4].

It is shown that immediately in the area of the cathode spot operation, the magnetic pressure is substantially lower than the gas-kinetic pressure and its effect shows up where the jet is compressed and, as a result, the plasma density increases.

When a cathode spot dies out, the current passed through it decreases abruptly, and so does the magnetic pressure produced by this current at the boundary of the plasma jet. This results in plasma ejection in the direction of cathode spot retrograde motion at the site where the total magnetic pressure was a maximum until the spot extinction.

The initiation of new cathode spots is probabilistic in nature and is determined not only by the plasma density, but also by the geometry and temperature of microirregularities whose explosion gives birth to new spots. We introduced the probability density function for the angle by which the cathode spot path deflects from the retrograde direction to the Ampere force:

$$f(\theta) = \frac{1}{2\pi} + \frac{B_e}{\pi B_s} cos(\theta), \qquad (1)$$

The velocity of the retrograde motion of a cathode spot is determined as

$$V_r \approx \frac{4RB_e}{\pi\tau B_s} \propto B_e, \qquad (2)$$

where R and τ are the space and time steps of the motion of a single cathode spot. For a second-type spot, these quantities are approximately equal to the spot crater radius and lifetime, respectively. According to our model, the increase in velocity of the directed motion of a cathode spot with arc current is determined mainly by the increase in crater size.

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