PHOTOGRAPHIC APPEARANCE
OF HIGH-CURRENT VACUUM ARCS
PRIOR TO AND DURING ANODE SPOT FORMATION

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This article presents the results of research on the photographic appearance of a high-current vacuum arc between butt type copper electrodes of 30-80 mm diameter and a fixed gap of 10 mm. Current pulses of up to 30 kA peak amplitude at an initial value of \((\text{di/dt})_0\) from 1-10 kA/ms and a duration of approximately 14 ms were applied. Arcs were photographed with a high-speed framing camera, mostly at 10^4 frames/s. A detailed study of discharge modes in phase transition from a high-current diffuse arc to a constricted arc with an anode spot was conducted. Most of the measurements were obtained at a peak current slightly in excess of 10 kA for electrodes of 55 mm diameter. It was found that at peak current exceeding moderately the threshold value of the onset of anode spot formation, the arc is characterized by the following main features: the formation of an anode spot and an anode plasma jet occurs concurrently with a local concentration of cathode spots; the anode spot is, most often, formed on the electrode edge; the coexistence of very varied structures of spots on the cathode; the lack of considerable constriction of the cathode discharge; the pseudo-periodic shrinking and expansion of the area occupied by cathode spots; the existence of a relatively dark space separates the anode plasma jet from the plasma sheath near the cathode surface; the plasma space distribution in the interelectrode gap is non-uniform and non-stationary.

1 Introduction

As the current is raised in an arc between electrodes in a vacuum, a transition from a low-current mode to one of high-current occurs. Vacuum arc modes are characterized according to the type and location of plasma sources near the electrodes and the distribution of plasma jets within the interelectrode gap. At low and moderate currents the arc plasma is generated by either single or multi-cathode spots. The source of anode plasma appears when the current exceeds a certain value which is dependent, among others, on the shape and dimensions of electrodes, electrode spacing, electrode material, current waveform and the magnetic field itself. The anode spot formed at that time together with the plasma jet exerts a considerable influence on the type and properties of high-current arc. This description of the arc arose as the result of many high-speed framing camera studies on the appearance of the vacuum arc. At this point, the research of Mitchell [1], Heberlein and Gorman [2], Kaltenecker [3,4] and Gellert et al. [5], concerned primarily with the high-current vacuum arc, deserves mention. Despite these investigations, further data are necessary to present a more precise description of the modes and properties of the high current vacuum arc.

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The purpose of this paper is to investigate the modes of high-current discharge between butt type electrodes in transition from a diffuse to a constricted vacuum arc at a very active anode. Here, the term constricted refers to the discharge confined to a small fraction only of the interelectrode space. Of particular importance in this research is an understanding of the conditions under which plasma sources in the anode region and anode plasma jets occur as well as the dynamics of their development. Considerable emphasis is placed on a description of cathode discharge modes just before formation of the anode spot during the period of anode activation.

This article extends available information on the physical properties of vacuum arcs within the application-oriented current range.

2 Experimental setup

The experiments were conducted in a demountable vacuum chamber made of stainless steel at the base pressure of $10^{-5}$ Pa. The chamber was provided with viewing ports which allowed lateral observation and photographic recording of arcs.

The arc behavior was recorded with a high-speed framing camera (Hadland) at 10000 frames/s with a 40 % exposure time. Additionally, waveforms of current and arc voltage were recorded by an oscilloscope.

The experimental circuit is shown in Fig. 1. The capacitor $C_1$ and the transformer $T_{tr}$ form a high-current source, which gives current pulses of 4-30 kA peak, at initial value $(di/dt)_0$ from 1-10 kA/ms and about 14 ms duration. The ignition of the preliminary discharge was achieved by contact separation at a low dc current supplied from the auxiliary circuit $C_2, R, Th$. When the contact gap reached the required length, usually 10 mm, the switches $Z_1$ and $Z_2$ were closed and the high-current source was turned on. The preliminary current was kept low, so that only a single cathode spot existed at the moment of closing $Z_1$ and $Z_2$.

The butt-type electrodes of the diameters 30 mm, 55 mm, and 80 mm were made of OFHC copper. Before each measurement the electrodes underwent thorough arc cleaning using series of dc discharges with both polarities. The process of contact conditioning was finished with a series of high-current arcs.

Fig. 1. Diagram of the experimental circuit. VAC — vacuum arc chamber; $C_1, T_{tr}$ — components of the main current circuit ($i$); $C_2, R$ — auxiliary current circuit ($I_p$); $Th$ — thyristor, $Sh$ — coaxial shunt.