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APPLICATION OF ELECTRIC PROBES FOR MEASUREMENT OF POTENTIAL DISTRIBUTION IN HIGH-CURRENT ARC STABILIZED BY SUPERSONIC FLOW OF SF_6[1)]

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Potential distribution in high-current arc in supersonic flow of SF_6 is measured using electric probes located near the nozzle wall. The conditions of application of probes are analysed. From the probe saturation currents the time dependence of ion concentration near the nozzle wall is estimated. Results of measurements of potential distribution are presented for the arc in nozzle flow and are compared with the results for the arc in the absence of external gas flow.

I. INTRODUCTION

Electric probes are frequently used for the measurement of parameters of low-current electric discharges. The application of probes in the case of the high-current arc in the nozzle gas flow is connected with the specific problems. The arc is usually ignited by separating the electrodes and the probes cannot be located in the centre of the discharge, where the electrode moves. Moreover in the high-current arc the probes located in the arc core intensively interact with the arc plasma. Consequently, the probes have to be located near the nozzle wall outside the arc core. The probes then have not a continuous contact with the arc core and special attention has to be paid to the interpretation of experimental results.

In the paper we discuss the problems of application of electric probes to the measurement of the arc potential and parameters of ionized gas near the nozzle wall. The experiments were carried out for arc in the flow of SF_6 in Laval nozzle in the conditions typical for high-voltage circuit-breakers.

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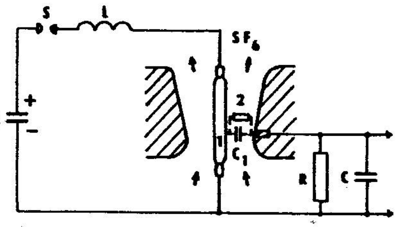

Fig. 1. Principal scheme of electric circuit and probe connections

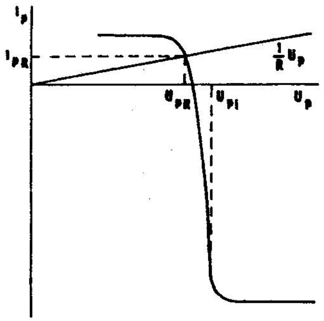

Fig. 2. Determination of probe current I_p and voltage U_p.

II. EXPERIMENTAL SYSTEM

The principal scheme of the electrical circuit is in Fig. 1. The arc current was supplied by an oscillating LC circuit with the capacitor bank 0.88 mF, 20 kV. The amplitude of sinusoidal current was 4 kA, frequency 90 Hz. The arc current was measured with a 5 mΩ coaxial shunt, the arc voltage and the potential of probes were measured using Tektronix dividers P 6015.

Two different types of probes were used. The movable probe made of tungsten wire of diameter 1 mm was radially inserted into the nozzle through the nozzle wall. This probe was located in the nozzle throat. Two ring probes were installed 10 and 20 mm downstream of the throat flush with the nozzle wall. The width of the Cu rings was 1.8 mm.

The gas flow was shaped by the PTFE nozzle with the throat diameter 15 mm. The position of the nozzle with respect to the electrodes and the location of the probes can be seen in Fig. 4. The pressure drop on the nozzle was 0.7/0.3 MPa.

The arc was ignited by the motion of the dewnstream anode and was maintained at a dc current of 100 A during the electrode movement. After the electrode reached the predetermined fixed position, the spark gap S switched on the main sinusoidal arc current. The experiments were performed for two electrode separations of 40 and 50 mm.

The reproducibility of experimental conditions was ensured by an exact synchronization of the arc current injection with the electrode movement and the development of pressure distributionm along the nozzle. The pressure was measured at both ends of the nozzle and in the nozzle throat using Kistler 601 A pressure gauges.

III. ELECTRICAL CONNECTION OF PROBES

The electrical connection of the probes can be seen in Fig. 1. The probes were negatively biased by connecting to the upstream cathode via resistance R. Parallel to R is the capacitance C representing the probe capacity and the capacity of the measuring device, C_1 is the capacitance between the probe and conducting arc core 1.

Between the probe and the conducting arc core is the region of the flowing gas 2 that can be partially ionized by the absorption of radiation from the hot arc core. The width of this region continually changes during the halfwave of the arc current, for high currents in the vicinity of the peak of the current the arc core can take up the whole cross section of the nozzle.

If the time constant of the changes of the probe potential is high compared to the time constants given by the values of R, C and C_1, the potential of the probe is determined by the current flowing from the plasma to the probe and by the value of the resistance R. The dependence of the probe potential on the current is given by the probe characteristic that is schematically presented in Fig. 2 [1]. The prime line in Fig. 2 represents the dependence of the voltage drop on the resistance R on the current. The point of intersection of the two curves gives the values of the probe current I_p and the potential U_p for a given R.

For lower resistances R we obtain the point of intersection in the region of the ion saturation current, which is almost independent of voltage. In this region the resulting probe potential is strongly dependent on R. If the value R is higher, then the value corresponding to the bending of the probe characteristic, the probe potential will be close to the plasma potential U_{p2} and will be almost independent of the value of R. Consequently, by analysing the dependence of the probe potential on the resistance R, we can determine the region of applicability of the probe for the measurement of the arc potential. We can also estimate the ion saturation current and from its value evaluate the concentration of ions near the nozzle wall.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A number of tests were performed under the same conditions with the values of biasing resistance R changing within the range of 10^5 - 10^8 Ω. For each probe the measured signals of the probe potential obtained for a different R were compared. Probe currents were evaluated from the values of R and the probe potential U_p. The shape of the probe characteristic could then be reconstructed corresponding to various times during the arc current halfwave.

Fig. 3 presents values of ion saturation currents evaluated from the results of measurements. Though the experimental conditions were reproduced with great

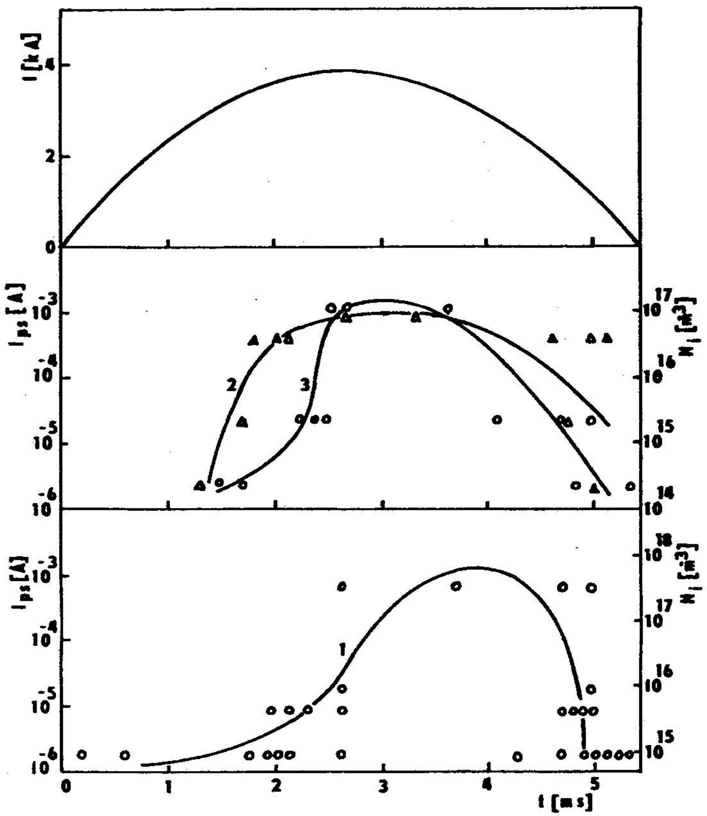

Fig. 3. Arc current I, ion saturation currents I_{pS} for ring probes (2,3) and for wire probe (1), and ion concentrations N_i in dependence on time.

care, the scatter of the evaluated ion currents is relatively high. The greatest scatter was obtained for the wire probe. This fact is probably due to a higher sensitivity of conditions in the probe vicinity to the arc movement in the case of the wire probe. Even though the scatter of the points is high, the time changes of the probe saturation current during the arc current halfwave can clearly be seen in Fig. 3.

The hysteresis in time dependences of the ion saturation currents can be seen in Fig. 3. This is the consequence of a slow decay of the arc plasma near the nozzle wall after the peak of the arc current.

The ion saturation current is approximately equal to the thermal random current [1]

$$I_p = A_p Z_i e N_i \left(kT_i/2\pi m_i\right)^{1/2} , \quad (1)$$

where A_p is probe area, Z_i charge number, N_i ion concentration, T_i temperature and m_i ion mass. The concentration of ions can be estimated from (1), if the type of the ions and ion temperature are known.

We have measured the temperature of the arc from the light emission characteristics [2]. The resulting temperatures in the arc centre were about 20 000 K, near the nozzle walls 13 000 - 14 000 K. Relatively high concentrations of Cu vapours from the electrodes were found in these experiments.

The conducting arc core of the SF_6 arc for temperatures of 13 000 - 20 000 K consist mainly of S^+, S, F and electrons [3]. Owing to the low ionization potential of Cu atoms, a high concentration of Cu^+ can be assumed in our conditions [4]. In the decaying SF_6 arc plasma, the most important positively charged component is S_2^+ [5]. The same situation is in the cooler zones surrounding the arc core [5].

For the estimation of ion concentrations we assumed the ions S_2^+ and Cu^+. The ions have similar masses $m_{Cu^+} = 1.055 \times 10^{-25}$ kg and $m_{S_2^+} = 1.064 \times 10^{-25}$ kg. The concentration N_i was calculated from (1) using the value $m_{S_2^+}$ and the temperature $T_i = 13\,000$ K. The calculated concentrations N_i can be seen from Fig. 3 using the plot on the right-hand side.

The resulting ion concentrations are low comparing to the data given in [3,4,5]. This is probably due to the cooling of the arc plasma near the wall by the flow of ablated material from the wall. A strong erosion of walls was found after demounting the arc chamber.

Fig. 4 presents measured arc potentials for two configurations of the nozzle and the electrodes. Measured values for the arc in supersonic flow are compared with potentials measured in the same configurations without external pressure gradient. The highest potential drop in both cases is near the upstream cathode. This is consistent with the results of theoretical modelling of the arc stabilized by the forced convection [6]. In the case of the arc without external gas flow the high potential drop near the cathode can be explained by induced gas flow due to the magnetic forces connected with the contraction of the discharge near the cathode.

V. CONCLUSIONS

Electric probes located near the walls of the nozzle can be applied for the measurement of the arc potential in a limited range of conditions. The potential of the probe is close to the arc potential if the ion current to the probe is substantially less than the ion saturation current. The ion current is controlled by the value of biasing resistance. By the analysis of the influence of the value of this resistance

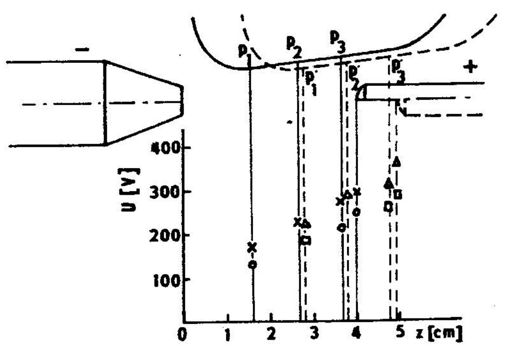

Fig. 4. Measured values of potential along the arc and configuration of the nozzle and electrodes, P_1 - wire probe, P_2, P_3 - ring probes, X, Δ arc in gas flow, SF_6, 0.7/0.3 MPa, o, □ arc without external flow, SF_6, 0.7 MPa.

on the probe potential, the parameters of the plasma near the nozzle wall can be estimated.

REFERENCES

[1] Chung, P. M., Talbot, L., Touryan, K. J.: *Electric probes in stationary and flowing plasmas.* Springer, Berlin-Heidelberg-New York 1975.

[2] Šenk, J., et al.: *Proc. of XVIIIth ICPIG*, Swansea 1987, 692.

[3] Ruchti, C. B.: *Proc. of 5th Int. Symp. on Switch. Arc. Phenom.*, Lodz 1985, 34.

[4] Bartl, J., Coufal, O., Gregor, P.: Tech. el. přístr. a rozv., TEPR *2/3* (1984), 25.

[5] Kopainski, J.: In: *Current interruption in h-v networks* (ed. K. Ragaller), New York 1978, 329.

[6] Hrabovsky, M.: *Proc. of 6th Int. Symp. on Switch. Arc Phenom.*, Lodz 1989, 104.

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ПРИМЕНЕНИЕ ЭЛЕКТРИЧЕСКИХ ПРОБ В ИЗМЕРЕНИИ РАСПРЕДЕЛЕНИЯ ПОТЕНЦИАЛА ВЫСОКОПОТОЧНОЙ ДУГИ СТАБИЛИЗИРОВАННОЙ СВЕРХЗВУКОВЫМ ПОТОКОМ SF_6

Приведены результаты измерения распределения потенциала высокопоточной дуги в сверхзвуковом потоке SF_6. Измерение проводилось с применением электрических проб помещеных в близости стенки сопла. Анализируются также условия применения проб. Оценен их ток насыщения и временная зависимость концентрации ионов в близости стены сопла. Приводятся результаты распределения потенциала обдуваемой дуги и сравниваются с результатами полученными для дуги без обдувания.