ELECTRICAL BREAKDOWN IN AIR IN A TRANSVERSE MAGNETIC FIELD

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The electrical breakdown of gases in a transverse magnetic field is discussed in references [1–16]. Attention has mainly been concentrated on the case of coaxial electrode geometry [1–10]. The existing experimental data on breakdown between plane-parallel electrodes [11–14] relate to a narrow range of variation of the parameters characterizing breakdown (P, d, H, U). The author has made an experimental study of the process of electrical breakdown in air in a transverse magnetic field between plane-parallel electrodes of finite size in the pressure interval from 650 to $5 \cdot 10^{-3}$ mm Hg at gap lengths of from 1 to 140 mm and magnetic inductions from 0 to 10 600 G.

§1. The experimental apparatus is shown schematically in Fig. 1.

The discharge chamber 1 takes the form of a glass tube (inside diameter 55 mm, length 250 mm) containing copper Rogowski electrodes 50 mm in diameter. The working surface of the electrodes was polished.

The electromagnet 11 created in the working space (diameter 200 mm, gap 80 mm) a magnetic field of up to 12 000 Oe with inhomogeneities of less than 1%.

The system of high-voltage sources 17, 18, 19 (VSV-2, UPU-1M, and VS 222a, respectively) made it possible to vary the voltage across the breakdown gap smoothly from 0 to 65 000 volts. The discharge chamber was evacuated by means of two forepumps 2, 3 and one diffusion pump 4 (RR-300, VN-1, and TsVL-100, respectively). The maximum vacuum obtained in the discharge gap was $8 \cdot 10^{-4}$ mm Hg. In Fig. 1, 5 denotes a vacuum valve, 6 an inlet valve, and 7 a receiver.

As the working gas we used atmospheric air.

The pressure in the discharge chamber was measured in the interval from 0.7 to $5 \cdot 10^{-3}$ mm Hg with a thermocouple vacuum gauge 8 (VT-2A), in the interval from 0.5 to 30 mm Hg with a compression manometer 9, and in the interval from 10 to 740 mm Hg with a reference vacuum gauge 10. The magnetic field intensity in the working volume was measured directly for each experiment with a IMI-3 magnetic induction meter (15 in Fig. 1).

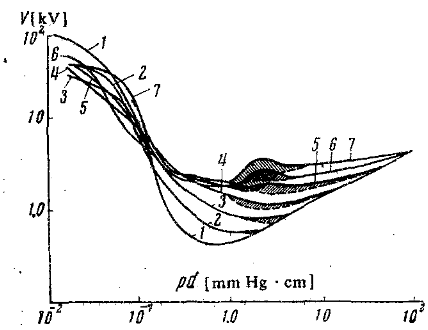

Fig. 2

The object of the experiments was to investigate the dependence of the breakdown voltage on the pressure in the working gap (in the interval from 650 to $5 \cdot 10^{-3}$ mm Hg) and the intensity of the transverse magnetic field (from 0 to 10 600 Oe) at different gap lengths (from 1 to 140 mm).

The breakdown voltage was measured in two ways. First, by means of switch 20 (see Fig. 1) we connected to the discharge gap a capacitor bank C_1, which was first charged from the high-voltage source 17, 18, 19 across resistance R_1. If there was no breakdown (capacitor bank potential $U < U_*$, where U_* is the breakdown voltage), switch 20 returned the capacitor bank C_1 to the starting position, in which it was charged to a higher voltage.

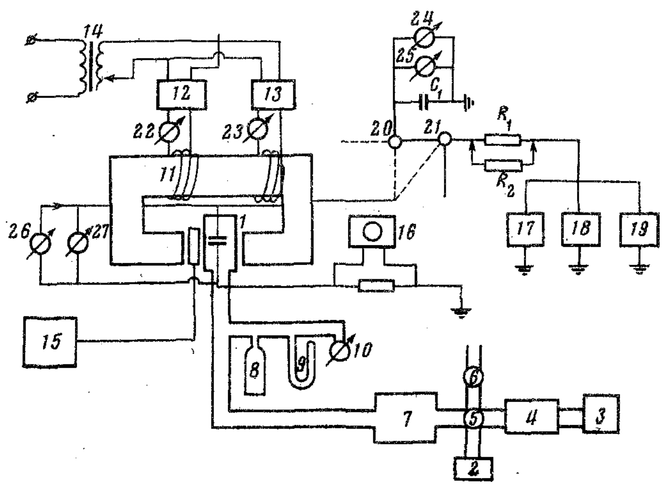

Fig. 1

Breakdown was registered both visually (from the luminescence in the gap) and with a threshold current detector 16, which was triggered only at $I_* \geq 10^3$ A, which made it possible to distinguish an arc breakdown from a glow discharge.

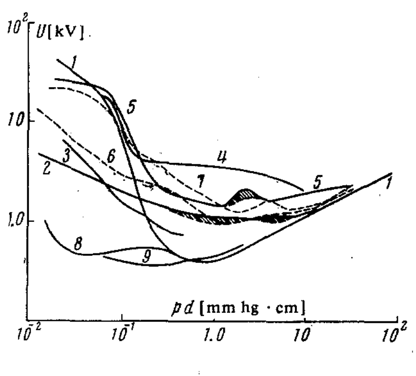

Fig. 3

In the second method, by means of switch 21 the voltage across the discharge gap was supplied directly from the high-voltage source across the resistance R_2. The capacitor bank C_1 was then connected in parallel with the discharge gap. The voltage across the gap was increased smoothly up to breakdown, which was also registered in terms of the value of the discharge current and the voltage drop across the gap.

Typical experimental results are presented in Figs. 2–4. Figure 2 shows the breakdown voltage in the presence of a perpendicular magnetic field U_*^+ (recorded by the second method) as a function of the pressure in the discharge gap (length of gap d = 3 cm) for different magnetic field strengths H: (1) H = 0, (2) H = 188 Oe, (3) H = 375 Oe, (4) H = 750 Oe, (5) H = = 1500 Oe, (6) H = 3000 Oe, (7) H = 6000 Oe. The broken lines denote the voltage $U_*^!$ at which unstable breakdown occurs.

Figure 3 shows the breakdown voltage U_*^+ as a function of pressure, obtained by both methods at a constant magnetic field intensity H = 3000 Oe, for different gap lengths: (1) H = 0, (2) d = 15 mm—second method ($U_*^!$ is denoted by a broken line), (3) d = 7.5 mm—second method, (4) d = 140 mm—first method, (5) d = = 30 mm—second method ($U_*^!$ is denoted by a chain-dotted line), (6) d = 15 mm—second method, (7) d = = 30 mm—first method, (8) d = 1 mm—first method, (9) d = 2 mm, H = 3120 Oe—according to Meyer's data [12]. For comparison, Fig. 4 gives relations for U_*^+ at H = 6000 Oe, d = 30 mm, obtained by two methods: (1) first method ($U_*^!$ is denoted by a broken line), (2) second method, (3) H = 0.

§2. These investigations lead to the following conclusions.

1) As may be seen from an analysis of Figs. 2, 3, the breakdown voltage U_*^+ for air is not a function of the two parameters pd and Hd, as asserted by the equivalent pressure theory [2, 3, 10]. The voltage U_{min}^+ always increases with increase in H and d more than U_{min}^0 and is attained at higher values of pd, i.e., when $pd_{min}^+ > pd_{min}^0$.

2) There exists a region $pd > pd_*$ (H, d), where U_*^+ is greater than U_*^0 and increases with increase in H and d. When $pd < pd_*$ the value of U_*^+ becomes less than that of U_*^0, the intersection of U_*^+ and U_*^0 with increase in H and d occurring at ever lower values of p (Figs. 2, 3).

3) There exists a p' (H, d) below which U_*^+ increases with decrease in H and d (see Figs. 2, 3).

4) With increase in p the quantity U_*^+ approaches U_*^0 from above the more rapidly, the smaller H and d (see Figs. 2, 3).

5) In the pressure interval $p \leqslant 0.7$ mm Hg there is a considerable difference in the discharge voltage U_*^+ depending on how it is supplied to the gap (see Figs. 3, 4). When supplied from the capacitor bank (first method) the breakdown voltage is much higher. The difference may reach 10–15 kV (see in Fig. 3: d = = 15 mm, H = 3000 Oe, $10^{-2} \geq p \geq 5 \cdot 10^{-3}$ mm Hg). With increase in p and decrease in d the difference decreases, and at $p \sim 0.5 - 1$ mm Hg is practically equal to zero for all H.

6) There is a region of pressures in the interval $0.3 \leq p \leq 3 - 5$ mm Hg (shaded in Fig. 2), in which the following effect was observed in experiments based on the first and second methods.

As U was increased, breakdown occurred (capacitor bank C_1 was completely discharged across the gap) at an easily reproducible $U_*^!$ (denoted by a broken line in Fig. 2), after which, even when $U_*^!$ was increased by 200–300 V (to 1700 V), breakdown did not occur again for a long time (5–10 min). With further increase in U ($U > U_*^!$) breakdown reoccurred more frequently (however, the time between successive breakdowns remained much greater than the time required to charge capacitor bank C_1). Then, at U_*^+ stable breakdown occurred; $\Delta U = U_*^+ - U_*^!$ increased with increase in H and d and reached a maximum at $p \sim 0.5 - 0.6$ mm Hg for all H and d.

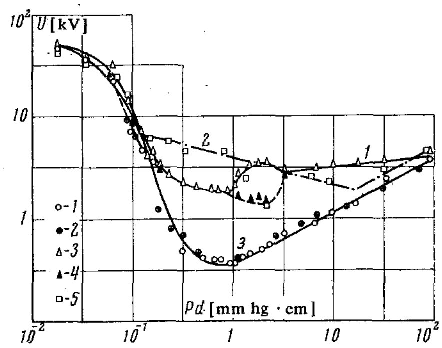

Fig. 4

In the region $2 \cdot 10^{-2} \leq p \leq 7 \cdot 10^{-2}$ Hg (not denoted in Fig. 2, see Fig. 4) a similar picture was observed; however, in this case $\Delta U = U_*^+ - U_*^!$ reached 4–4.5 kV.

It should also be noted that in the pressure intervals $p < 5 \cdot 10^{-2}$ mm Hg and $p > 1$ mm Hg good stability of U_*^+ was observed. In the case of repeat breakdowns without preliminary flushing of the gap with atmospheric air breakdown occurred at the same voltage (correct to experimental errors, i.e., 3–5%). At H = 0 repeat breakdown without flushing always occurred at much lower voltages.

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