CONDITIONING AND MONITORING OF CLEANNESS OF HIGH VOLTAGE SYSTEM WITH GASEOUS INSULATION

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Abstract

New effective technique of conditioning of gaseous insulation of electrostatic accelerator is described. To achieve stable breakdown voltage, accelerator conditioning procedure would take 7-8 hours (volume of pressure tank is 9 m^3). Three methods of monitoring cleanness of gaseous insulation are proposed.

HIGH UNSTABLE VOLTAGE

The paper is devoted to preliminary tests of accelerator without tubes. Cleanness of the system is usually achieved by step-like increasing of gas pressure ("from low to high pressure" method). Breakdowns are repeated until the breakdown voltage rise stops. The method is ineffective since it disregards the second source of instability of breakdown voltage, namely: presence of free solid particles in the vessel space.

Influence of particles was evidently found when testing the EG-2.5 and the EG-3 accelerators without tubes with positive voltage polarity. N_2/CO_2 gas mixture always contained 20% of CO_2. Tests were carried out by step-like decreasing of gas pressure ("from high to low pressure" method). High unstable breakdown voltage first appeared under gas pressure of 1 MPa during fourth breakdown after the start of the experiment. Then the breakdown voltage gradually decreased down to about 0.8 of high unstable value and increased again up to 1.09 of this value in the thirteenth breakdown.

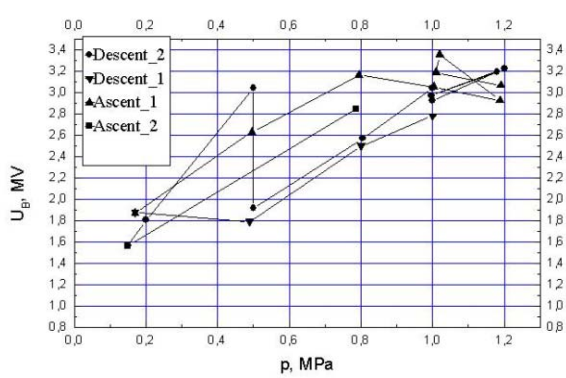

Figure 1: Breakdown voltage of the EG-2.5 accelerator before conditioning versus vessel pressure measured in descending and ascending series of tests. Descent_1 curve corresponds to "low unstable breakdown voltage" mode, Descent 2 curve corresponds to "stable" and "high unstable voltage" modes. Ascent_1 and Ascent_2 curves correspond to "high unstable breakdown voltage" modes.

After that we replaced the whole amount of insulation gas and obtained "four parallel lines" picture (Fig. 1), i.e. four voltage values corresponding to the same pressure. No special gas conditioning was conducted. The first descending series of tests started with 1 MPa pressure in "low unstable voltage" mode and it was converted into "high unstable voltage" mode upon pressure decrease down to 0.17 MPa. In the first ascending series of tests, "high unstable voltage" mode was stopped upon reaching 1.0 MPa pressure and it was converted into "the low unstable voltage" mode starting from 1.2 MPa pressure.

The abrupt change of the average stable breakdown voltage to high unstable value was observed in the second descending series of tests under 0.5 MPa pressure (after the fifth breakdown) with multiplicity of 1.9 relative to its value. It should be noted that high unstable breakdown voltage naturally arose under constant N_2/CO_2 gas pressure maintained within 0.1–1 MPa operating range and it was kept during the second ascending series of tests.

"High unstable voltage" mode is slightly mentioned in [2].

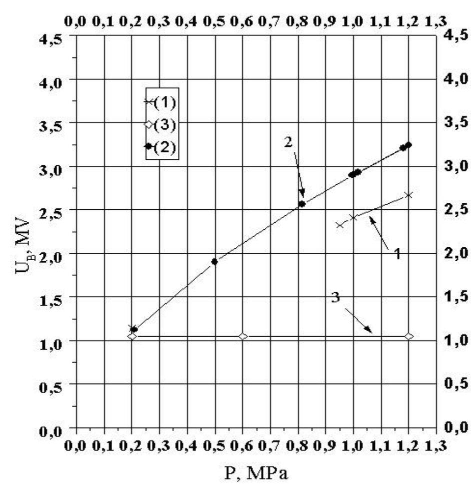

Figure 2: Breakdown voltage of the EG-2.5 accelerator versus vessel pressure before and after "from high to low pressure" conditioning. Curves 1 and 2 correspond to "low unstable" and "stable" modes, and curve 3 corresponds to "conditioning without breakdowns" technique (to remove light particles from the vessel).

NEW CONDITIONING TECHNIQUE

It is experimentally found that polished electrodes have the most relative increase of breakdown voltage, i.e. the highest conditioning effect [3]. Therefore one can consider free solid particles as the main cause of insulation deterioration. The particles arise and start

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moving between the electrodes under high voltage. Besides, accelerators operating experience showed that particle traps installed in the gap were ineffective. As a result of a breakdown trap is shaken and particles are returned to the gap space.

The new technique [4] combines high voltage application to the system electrodes and pumping out insulation gas from the vessel in order to completely remove particles instead of their trapping.

Diagrams in Figs. 3 and 4 are made on the common time scale.

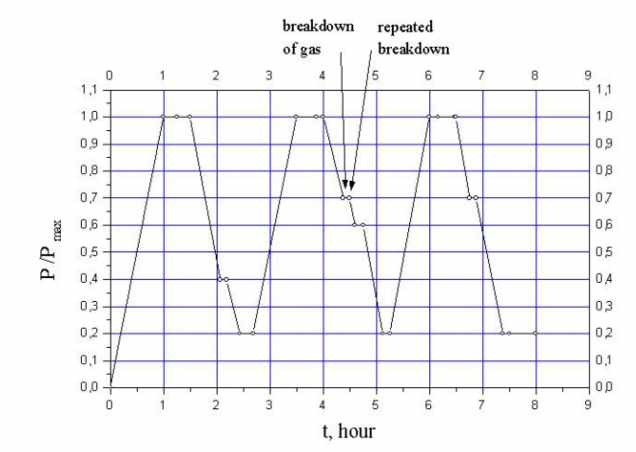

Figure 3: Vessel pressure change versus time.

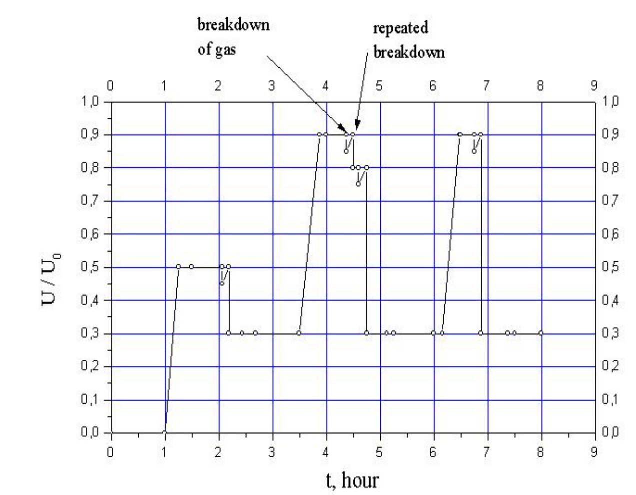

Figure 4: Electrodes voltage change versus time.

In the initial stage, dust filter with pores of 1 μm is installed in the vicinity of the gas main inlet to the vessel, insulation gas is dried to humidity of 30-50 ppm and pumped to the vessel up to the max permissible pressure $p_{\max}$ (Fig. 3).

System cleanness degree is determined by the stable breakdown voltage value for the clean system, e.g. U_{max}. To estimate anticipated $U_{\max}$ voltage the following procedures are conducted as the second step: rise of static voltage on the electrodes to about haft of maximum anticipated breakdown voltage value (Fig. 4); gas pumping out from the vessel to reserve tank until the occurrence of the first breakdown of gas; pressure change stop; voltage decrease followed by its slow increase until repeated breakdown occurs; and calculation of anticipated voltage value using the following relationship:

$$U_{\max} = k_{cl}^{-1} \cdot (p_{\max} / p_{in})^{X_p} \cdot U_{in} , \qquad (1)$$

where $U_{\max}$ is the stable breakdown voltage under maximum pressure in the clean system: $U_{\max} = U_B(p_{\max})$, U_{in} is the breakdown voltage measured under initial gas pressure in the vessel; $p_{\max}$ and p_{in} are, respectively, maximum and initial values of absolute gas pressure reduced to 20°C temperature; X_p is exponent, k_{cl} is an empirical cleanness coefficient: $k_{cl} = U_{in} / U_{stbl}$; and U_{stbl} is gas breakdown voltage under the same pressure in the clean system.

The third step implies decrease of electrode voltage and vessel pressure to the minimum level corresponding to electric field strength on gap electrodes not lower than 0.5 kV/mm value.

The fourth step includes cleaning cycles repeated till the min fluctuations of breakdown voltage under max pressure are achieved. Results of “from high to low pressure” conditioning technique application for rare breakdowns [4, 7] are presented using least-square method as follows:

$$U_B = A \cdot p^{X_p} , \qquad (2)$$

where U_B is breakdown voltage of the gap, MV; p is gas pressure (MPa) reduced to 20°C temperature; A and X_p – constants. Thus Eq. (2) can be used for calculations on, respectively, EG-2.5 and EG-3 accelerators as follows:

$$U_B = 2.901 \cdot p^{0.609}, MV, \sigma = 4.2\%, p = 0.21 - 1.2 \text{ MPa}, \quad (3)$$

$$U_B = 3.613 \cdot p^{0.677}, MV, \sigma = 5.0\%, p = 0.21 - 1.2 \text{ MPa}, \quad (4)$$

where σ – standard deviation of the experimental values from the curve.

The “MNK_one” code written in Pascal for calculation of A and X_p constants in Eq. (2) was published [7]. Absence of high unstable breakdown voltage and coincidence of $U_B(p_{\max})$ values provide the strict proof of cleanness of tested systems.

CHECKING SYSTEM CLEANNESS

Two simple criteria of conditioning completion and three methods of conditioning obtained recently are listed below.

(1) Independence of breakdown voltage of its serial number.

(2) Change of the average breakdown voltage values is insignificant for two successive series of 5-10 breakdowns [3].

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The above two criteria assume the use of "from low to high pressure" testing method and conditioning by successive breakdowns. Both criteria are ineffective in "high unstable voltage " mode.

(3) Conditioning by "from high to low pressure" technique with applied voltage and rare breakdowns provides reliable cleanness checking with small fluctuations of voltage $U_B(p_{max})$ and without high unstable voltage.

(4) Eq. (2) can also be used for verification of experimental data. It is known that pressure increase results in non-linearity of breakdown voltage / pressure dependence due to the rough electrode surface. Condition of $X_p \le 1$ in Eq. (2) with $p_{min} \le 0.2$ MPa corresponds to the "stable" test mode.

Let us calculate parameters of Eq. (2) using code from [7]. For this purpose data file length is varied several times by successive decrease of maximum pressure p_{max} in the data file. If X_p parameter approaches 1 asymptotically, then the breakdown voltages are stable. Otherwise the experimental data contains a systematic error caused by unfinished conditioning.

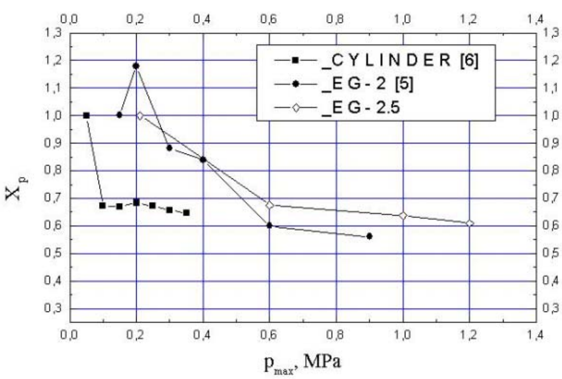

Figure 5: Exponent X_p in Eq. (2) versus maximum pressure in the $U_B(p)$ file.

Thus EG-2.5 curve in Fig. 5 characterizes dependence 2 from Fig. 2 of this paper; it is related to polished electrodes and stable voltages. EG-2 curve shows the presence of low or high unstable breakdown voltage under 0.2 MPa pressure in the preliminary tests of the other accelerator [5] with $N_2/CO_2/SF_6$ gas mixture.

It is in the case of CYLINDER for coaxial cylinders in SF_6 gas [6, Fig.3] that exponent X_p does not approach 1 apparently due to the rough surface of electrodes having arithmetic mean profile deviation $R_a = 10\mu m$.

(5) If conditions of the base experiment and input data of calculation are taken into account, then mathematical model described in [1, 7] extrapolates result of the base experiment to the calculated breakdown voltage of the object. If the base breakdown voltage is stable (e.g. that in MP, EG-2.5 and EG-3 accelerators), then calculated breakdown voltage for the object would also correspond to the stable performance accurate to $\pm(2-3)\%$. Hence the calculated breakdown voltage determines reachable limit of electric object's strength.

CONCLUSION

1. "High unstable" breakdown voltage mode arises within operating range of N_2/CO_2 gas pressure indicating deterioration of the system insulation.
2. In contrast to the unsafe "from low to high pressure" technique based on repeated breakdowns with step-like pressure changes, "from high to low pressure" method with limited number of breakdowns allows to effectively remove free solid particles from the gap.
3. Quantitative criteria of insulation cleanness, namely: maximum voltage $U_B(p_{max})$, exponent X_p, and calculated breakdown voltage U_{B_CALC} make it possible to determine electrical strength of a system, its shortcomings and reserves.

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