



High-Voltage Structure Development for The EGP-15 Tandem (Project)

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Abstract

A comparatively accurate method for breakdown voltage calculation allows to optimize the accelerator geometry for obtaining maximum operating voltage. Due to complex approach, the breakdown voltage can be increased up to 1.5 times or more relative to usual structure. In addition to the EGP-15 project the paper studies how much variation of forms and dimensions of accelerator electrodes is powerful as to the increasing of an insulation gap breakdown voltage.

1. Methods

For simplicity one can consider an insulation structure breakdown voltage as the main function and search its maximum. In IPPE there was developed a procedure of breakdown voltage calculation based on the analysis the insulation system (similar to a high-voltage accelerator) into separate elements and considering all principle breakdown parameters [1-3]. It has made available to compare some accelerators of the same 6–9 MV class.

This algorithm is called the “base” technique, as it supposes performing an experiment at the standard base gap. If the input information of the base breakdown voltage and electrostatic field strength is accurate within 1–2%, then our approach allows to compare different high-voltage structures with the same accuracy.

Electrostatic field is calculated by a special code REP, used the method of finite-differences, the axial symmetry and an accurate description of curvilinear boundaries by Shortley–Weller method. Besides, a special estimation procedure was developed for the systematic error caused by numerical calculation of accelerator weakly nonuniform fields [4,5]. Six factors of net nodes potential errors are considered. Then another six factors inducing error of calculation of electrostatic field strengths are considered. The main factors are the distance between the net nodes and the curvature of field boundaries. The compensation of the 100% of systematic error increases precision and efficiency of numerical calculation.

2. The EGP-15 project

The EGP-15 tandem has the same internal structure as the EGP-10-1 tandem except the tube length (4.8 m counter 4.2 m). The equipotential rings have circular profile with diameter of 30 mm. The EGP-15 tank has a 4 m ID middle part. Diameter of the tank at one-third of the column from the terminal decreases to 3 m (Fig. 1,2).

The calculated breakdown voltage of this structure is equal to 7 MV at 1.1 MPa of gas mixture N_2 – CO_2 pressure, CO_2 volume concentration of 20%, humidity of 50 ppm. A conditioning degree k_{cntn} is proposed to equal

$$k_{cntn} = U_{unstbl}/U_{stbl} = 0.85,$$

as a complete conditioning is difficult to reach and is dangerous for solid insulation. (Here U_{stbl} denotes a mean breakdown voltage which doesn't depend on a breakdown number, U_{unstbl} is a low unstable breakdown voltage).

On the first stage of modernization a *common equipotential ring* of the OGK-type (Fig. 3) shields three elements of support column. The common ring profile is conjugation of two half-ellipses. The profile inclines to the accelerator axis at an angle of 15°.

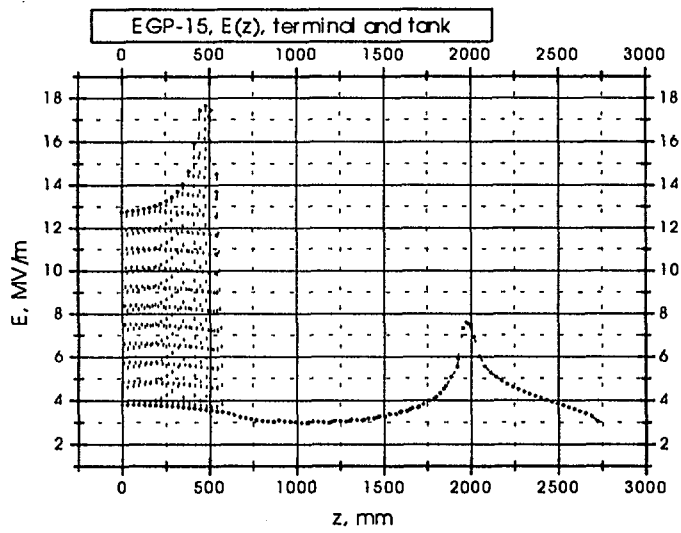


Fig. 1

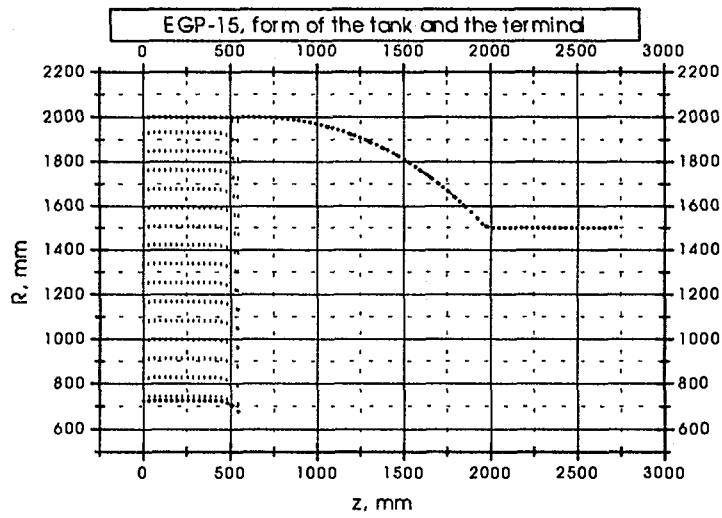


Fig. 2

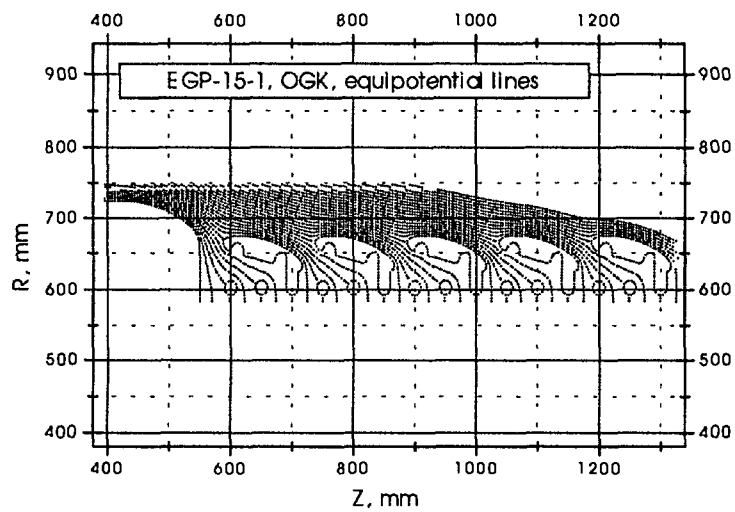


Fig. 3

As a result the column field strength decreases from 19.0 MV/m to 14.8 MV/m [7, Fig.3,4]. However, a breakdown voltage of this insulation system even decreases because the terminal has lower breakdown strength, than a 30 mm OD equipotential ring profile. A notable increasing of a breakdown voltage was obtained only after the terminal profile variation (structure EGP-15CT).

Common equipotential ring forms four insulation gaps: one is outer and three are inner. When the inner insulation is stronger, then

$$U_{syst} = U_{br.term} < U_{br.inn} \times n_{ser}.$$

Relative electrical strength $k_{strn.inn}$

$$k_{strn.inn} = \frac{U_{br.inn} n_{ser}}{U_{syst}}$$

for the EGP-15CT structure is for instance equals 2.1. Here U_{syst} denotes minimum breakdown voltage to tank, $U_{br.inn}$ is that between neighboring rings, n_{ser} denoted a quantity of gaps connected seriesly along the column.

The additional increase of radial breakdown voltage due to common ring inclined oval profile causes decrease of axial one, giving rise to form spark gaps between the equipotential rings. That is why the EGP-15CT column can be made stronger than terminal in the case that $k_{strn.inn} \leq 1$. As it was pointed in Ref. [6], the small probability of the “column–tank” breakdown means lowering of overvoltages and lower energy dissipated on the solid insulators of the column and the tube after the tank breakdown occurs. The operation reliability rises.

Table 1: Efficiency of electrode geometry variation for the purpose of increase the insulation gap breakdown voltage

Structure	R_{tank} (m)	L (m)	$E_{max}/U(1/m)$	L/L_{EN}	E_{EN}/E_{max}	U_{br}/U_{EN}	$U_{br}(MV)$
EN[8]	1.2	0.7	3.4	1.0	1.0	1.0	5.03
EGP-10-1[9]	1.5	0.775	2.75	1.1	1.24	0.99	5.00
FN[8]	1.83	1.33	2.556	1.9	1.33	1.31	6.61
EGP-15	2/1.5	1.35	2.19	1.93	1.55	1.39	7.00
EGP-15C	2/1.5	1.35	2.04	1.93	1.67	1.35	6.8
EGP-15CT	2/1.5	1.35	1.75	1.93	1.94	1.53	7.71
Sh6[10]	1.8	1.193	1.78	1.70	1.91	1.45	7.29

The manufacture technology of the OGK-type common rings and the KRF-type terminal profile was developed at IPPE. Similar terminal is prepared for the EGP-8 tandem.

3. Breakdown voltage of some accelerators without tubes

Breakdown voltages have been calculated at mentioned above in section 2 conditions. In Table 1 EGP-15C (EGP-15-1) has the modernized column, EGP-15CT has both the column and the terminal modernized. R_{tank} denotes a tank radius, L is a terminal–tank distance, E_{max}/U denotes a field strength and an applied potential difference ratio at the field calculation.

It is seen that the geometry optimization increases the breakdown voltage up to 1.5 times. The gap increase not always gives a positive effect (EGP-10-1), as well as decrease E_{max}/U (for example EGP-15C). The EGP-15CT structure has some reserve of electrical strength and reliability.

Conclusion

1. An electrode geometry optimization must be complex.
2. A geometry optimization of a column and of a terminal is competitive with using SF₆ gas and, maybe, is the cheapest way for increasing operation voltage.

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