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CORONATING VOLTAGE DIVIDER OF MEV ACCELERATING TUBE

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This paper describes the methodology of high-voltage testing of the voltage divider of a positively charged ion accelerating tube for energies up to 1000 keV. The test results are presented, and a simple engineering method for calculating the corona voltage divider is proposed.

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INTRODUCTION

Corona discharge is widely used in a number of practical applications. These include electro filtration, separation of materials, generation of ion streams (e.g. ozone), and formation of high-speed gas streams. Various electrode configurations are used to create systems that perform these tasks, for example: needle-plane [1], thin rod-needle [2], cylinder-wire-plate [3], sub millimeter interelectrode gap [4], needless-plane [5]. Such structures have been well studied.

Another application of corona discharge is considered in this paper - corona voltage divider (CVD) of high and ultra-high voltage installations [6]. This is a system of series-connected electrodes of the “needle-plane” type, which provides a specified voltage distribution over the high-voltage structure of the installation.

CVD is a successful alternative to the resistive voltage divider for medium class high voltage installations (up to 1000 kV) operating at insulation gas pressure of the order of atmospheric pressure [6, 7]. The advantages of CVD are high reliability, voltage stability, simplicity of construction and low cost.

Aim of the work: to carry out experimental and computational studies of the electrical strength of the CVD for a proton accelerating tube at energies up to 1 MV.

METHODOLOGY AND RESULTS OF THE STUDY

The accelerating tube CVD for voltages up to 1000 kV was tested. The schematic diagram of the accelerating tube (AT) is shown in Fig. 1. The main parameters of the CVD geometry:

– Needle-plate distance, b = 6 mm;
– distance between the plates, h = 12 mm;
– number of needles of each gap, 3;
– maximum number of gaps, $N_{\max}$ = 20.

Titanium needles with a diameter of 0.5 mm, a length of the conical part of 1 mm, and a radius of curvature of the tip apex of no more than 0.05 mm were used as tips (measurements were performed using an optical microscope МБС-10). The tips and plates were mechanically cleaned from dust and electrocorrosion in such a way that their voltage-current characteristics (VCC) coincided.

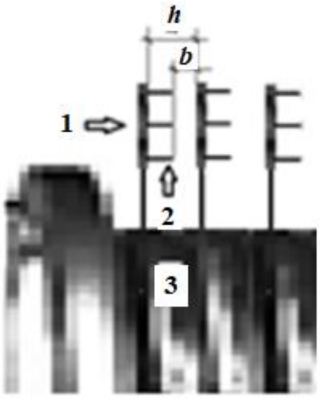

Fig. 1: Corona voltage divider as part of the accelerating tube: 1 – plate; 2 – needle; 3 – accelerating tube

Method: measurement of voltage-current characteristics of the divider. The tests were carried out in the open air without application of insulating gas, at ambient temperature t = +15...20 °C, atmospheric pressure 750...760 Torr and relative humidity 50...90%.

The power supply source of the AT was a high voltage source (HVS) NCN 35-35000 manufactured by Fug (Hamburg, Germany), having the following main characteristics:

– polarity of the high voltage, (+/-);
– maximum output voltage, 35 kV;
– current range, 1 ... 1000 μA;
– residual voltage ripple, 10^{-4} pp.

Next, the VCC of the “negative corona” (minus the high voltage source on the CVD needles) are presented.

VCC OF A SINGLE CVD GAP

The VCC of a single gap (Fig. 2) has a classical form [1, 8]. O1 – discharge ignition section (point “1” corresponds to the discharge ignition voltage U_0 =4 kV), 1–2 – ascending section, $I \sim U^2$, “2” point of corona discharge transition to spark discharge, corresponds to the limiting characteristics for a single gap: voltage U_2 =8 kV and current I_2 = 258 μA.

The VCC of the gap can be represented by the Townsend formula [1]:

$$I = A(U - U_0)^2 . \quad (1)$$

The values of U_0 and A depend on the design of the gap and the electrophysical characteristics of the air.

According to the experimental data (see Fig. 2) by the method of nonlinear regression [9] for the CVD gap (see Fig. 1) it was obtained that if U is measured in kV and I in μA, then $U_0 = 4$ kV, $A = 15,4$ μA/kV^2, $U_2 = 8$ kV). The accuracy of the approximation is of the order of magnitude of the experiment error, not more than 1…5%.

VCC in the ranges of relative air humidity ω = 50...90%, pressure P = 750...760 Torr are identical with the accuracy of measurement error, that corresponds to the literature data [10].

The polarity of CVD electrodes practically does not affect the discharge ignition voltage. The "negative corona" currents are several times higher than the "positive corona" currents.

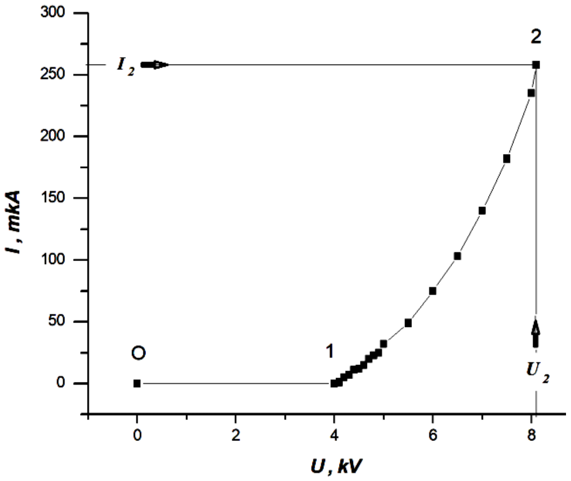

Fig. 2. Voltage-current characteristic of a single gap of the accelerating tube (negative corona). U_2 and I_2 limit values of the VCC corresponding to the transition of the corona discharge to the spark discharge

CALCULATION OF THE MULTI-NEEDLES CVD

Townsend's formula (1) cannot be used to calculate the voltage-current characteristic of a multi-needles CVD, so it must be converted to a generalized form for N gaps. Since for one gap $I \sim (1/b)^2$ [11], a system of N intervals should be equivalent to increasing b by N times and (1) will take the form:

$$I = A[(U - U_0)/N]^2. \quad (2)$$

The error of calculation by (2) is less than 5% compared to the experimental data.

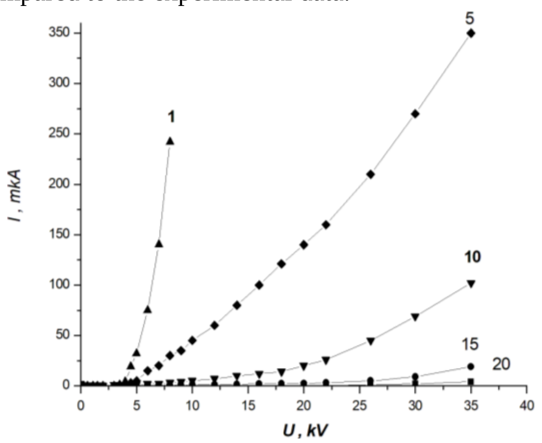

Fig. 3. Voltage-current characteristic of the negative corona. 1, 5, 10, 15, 20 – number of CVD intervals

From (2), the current limits of the divider corresponding to the transition of corona discharge into spark discharge (the beginning of CVD breakdown) can be obtained:

$$I_{br} = A[(U_{br} - U_0)/N]^2, \quad (3)$$

where $U_{br} = N \cdot U_2$ - is the maximum voltage of the system of N gaps, U_2. -is the maximum voltage of a single gap (see Fig. 2).

For example, for a CVD of 5 intervals. $U_{br} = 40$ kV, $I_{br} = 800$ μA . According to the experimental data $I_{br} = 810$ μA.

CONCLUSIONS

The obtained VCCs allow us to predict the performance of any multi-axis corona voltage divider using the results of measurements for a single gap (see Fig. 2, formula (1)), for which expressions (2), (3) are used.

The results of this research are not limited to corona voltage dividers and can be used in other applications of corona discharge in gases, such as ion flux generators.

The coronating voltage divider investigated in this work will be further used in the proton beam lithography facilities of the Institute of Applied Physics National Academy of Sciences of Ukraine.

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КОРОНУЮЧИЙ ДІЛЬНИК НАПРУГИ ПРИСКОРЮВАЛЬНОЇ ТРУБКИ МЕГАЕЛЕКТРОНВОЛЬТНИХ ЕНЕРГІЙ

І.Г. Ігнатьєв, С.В. Колінько

Описано методику високовольтних випробувань дільника напруги прискорювальної трубки позитивно заряджених іонів на енергію до 1000 кеВ. Наведено результати випробувань, запропоновано простий інженерний метод розрахунку коронуючого дільника напруги.