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COMPUTER SIMULATION OF EXPLOSIVE EMISSION ELECTRONS ACCELERATION AND X-RAY QUANTUM GENERATION IN PULSE COAXIAL DIODE SYSTEM WITH INTERIOR ANODE*

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Abstract

Computer simulation of electrons from explosive emission acceleration and X-ray quantum generation in pulse coaxial diode system with interior anode, which is used in accelerating tube of compact X-ray generator [1] with Tesla transformer as high voltage source, was done. The results obtained allow us to choose accelerating tube diode system geometry for different running modes. Comparison of numerical results with experimental data of dose rate dependence on the distance from vacuum tube anode and energy at first circuit Tesla transformer was fulfilled.

INTRODUCTION

National Research Nuclear University (MEPhI) together with Experimental Plant of Pulse Technique (EPPT) developed and create compact pulse x-ray generator [2]. Computer simulation of electron emission and X-ray generation in pulse coaxial diode system with inner anode of this X-ray generator was done with the help of 2.5 dimensional relativistic particle in cell (PIC) code SUMA [3]. Results obtained allow us to optimise geometric parameters of accelerating tube for different operational mode.

THE EXPERIMENTAL SETUP

X-ray source along with small sizes (maximal linear size should not exceed 0.5 m) must produce minimal exposure dose 10 mr on the distance of 0.5 m from the target during 1 sec for minimal target radiating surface. These parameters can be achieved by means of accelerating tubes which operate in pulse periodic mode with amplitude of accelerated electron current ~ kA, pulse duration ~ nsec and electron energy of several hundred kilovolts. To improve image acutance at the same time we should diminish efficient target radiating surface of accelerating tube. In diode systems with axial electron acceleration, it can be done by using projection method where flat surface target is oriented with assigned angle to the tube axis. The similar results may be obtained in diode systems with spherical or coaxial geometry with inner small radius anode-target. The most affective is the system with acicular cathode, which produce explosive-emission cathode plasma. Moving to the anode plasma serve as intensive source of electron. A schematic view of the setup shown in Fig. 1.

Special pulse high-voltage source on the base of transformer with spark gap-peaker used in experimental setup. Transformer run on resonance circuit without ferromagnetic core, installed together with accelerating tube inside sealed pressure-resistant case and filled with isolating gas (mainly SF_6) under pressure 15 – 20 atm.

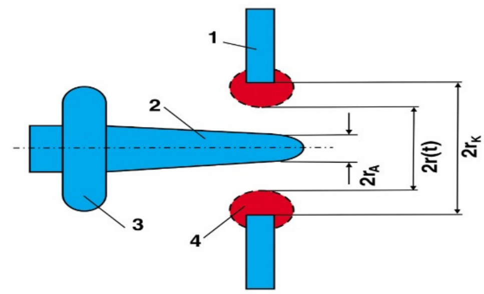

Figure 1: Accelerating tube electrodes for X-ray generation. 1 – cathode, 2 – anode, 3 – protective screen from cathode sputtering, 4 – plasma cloud.

High voltage switching scheme shown on Fig. 2.

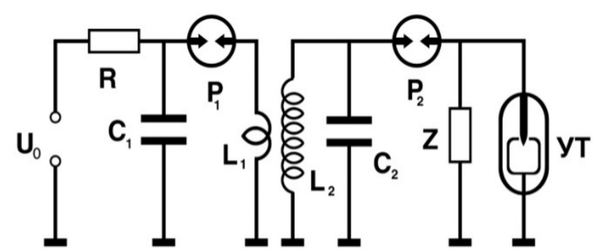

Figure 2: Accelerating tube triggering circuit: R – charging resistance; C_1 – tank capacitor; P_1 – primary circuit discharger; $L_{1,2}$ – Tesla coil primary and secondary winding inductance; C_2 – Tesla coil secondary circuit capacitance; P_2 – discharger; Z – reactance.

The tank capacitor C_1 charges via small-sized source of direct-current voltage. Figure 3 shows the block diagram of generator interface. The distinctive feature of this generator is a high stability, regardless of the line voltage or of the battery charge. This is achieved by the division of a voltage increase into two stages. Due to the feedback there is no-load loss protection and short circuit protection in a generator.

The pulsed-periodic launch of AT could be performed in both the auto generated mode and armed mode with a given frequency. In the latter case instead of an uncontrolled gas-filled double-electrode spark gap P_1 there can be used a controlled vacuum or gas-filled spark gap provided with an additional ignition electrode.

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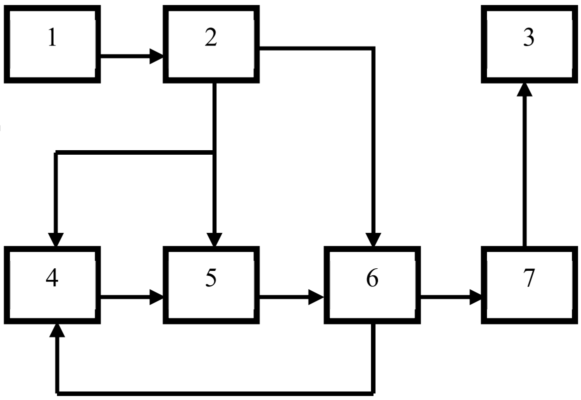

Figure 3: The block diagram of x-ray quants generator. 1- supply-line filter, 2- power supply unit, 3- high voltage unit , 4- control unit, 5- pulse generator, 6- power amplifier, 7-voltage multiplier.

When launching AT in the auto generated mode, the tank capacitor C_1 is being charged. Reaching the breakdown of the spark gap at the voltage capacitor, the circuit is closed and the capacitor is discharged into the primary winding of a transformer. Due to the current flowing through the primary low-inductive winding, in the secondary winding there arises a high voltage, which increases to the response voltage (U_M) of a spark gap - peaker P_2. As a result, the anode of AT acquires potential U_M. To ensure the galvanic coupling of the right electrode of the spark gap - peaker with the ground in a circuit, the resistance Z is introduced which also ensures to maintain the voltage on the anode of AT during the generation of x-ray quants owing to the inductive component. In addition, parameters of resistance are selected to provide the optimal conditions for power transmission to the accelerated electron stream.

The enhancement of a primary discharge circuit in the part of the tank capacitor and the spark gap was carried out during the development of the instrument. The original design of the capacitor with three plates was suggested, i.e. consisting of two combined capacitors in series.

Tests of AT working model have shown that with the amplitude of accelerating voltage of 300 kV the amplitude of electron current and the pulse duration at half maximum comprised about 2 kA и 2 nsec respectively that is in agreement with estimated data and the dose at 0.5 m away exceeded 1 mR per pulse.

Figure 4 shows experimental dependencies of the dose rate in the air on the distance R between the target and the observation point on power W stored in the tank capacitor.

To obtain more detail information about probability to improve generator parameters, computer simulation of electron emission and accelerating processes in accelerating tube were fulfilled by 2.5 dimensional relativistic particle in cell (PIC) code SUMA [3].

The code is a time dependent model that describes self consistently the dynamics of charged particles in rectangular, cylindrical, and polar systems of coordinates. The system of equations used in mathematical model consists of the Maxwell equations, the equation of the medium, and the equation of motion.

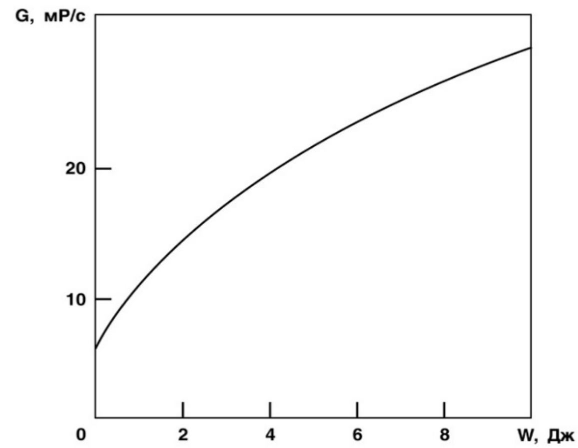

Figure 4: The measurement results of the dose rate of generated radiation G on power W stored in the tank capacitor.

Typical electrons and field distributions in the accelerating tube shown on Fig. 5.

Computer simulation and physical modelling at a demountable vacuum stand give us on optimal geometrical dimensions of a diode acceleration system [4] that formed the basis for designing accelerating tube.

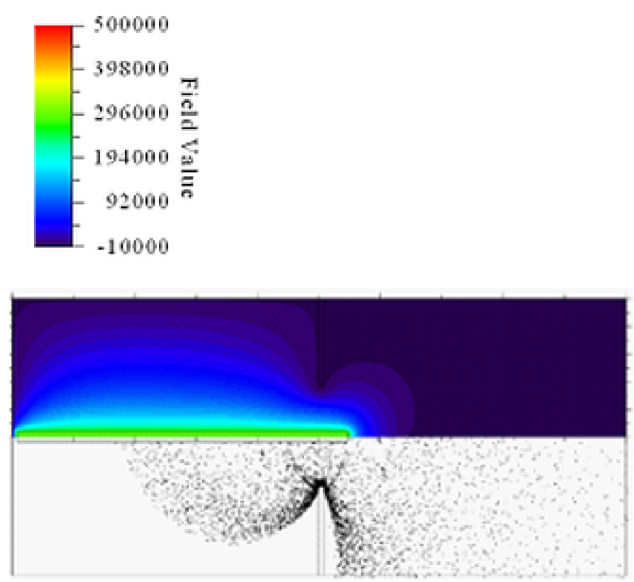

Figure 5: Field potential (upper part) and electrons (lower part of each picture) distribution in accelerating tube.

Obtained relations of geometric dimensions for a diode system are defined by the following system of inequalities [1]: $5.10^{-4}\text{m} \le \rho \le 10^{-3}\text{m}$, $5\rho \le r_K \le 10\rho$, $0.2\ r_K \le r_A \le 0.5\ r_K$, $0.4\ r_K \le h \le 1.4\ r_K$, where ρ- the rounding radius at the anode end, r_K– the radius of a hole in the cathode, r_A- the radius of an anode circular section with the plane passing through the front end of a cathode, h- the distance from the front end of a cathode disk to the front end of an anode.

Computer simulation results for optimising generator dimensions shown on Fig. 6 and Fig. 7.

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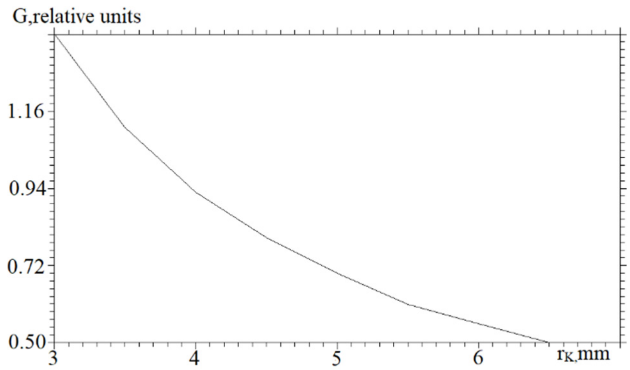

Figure 6: Dose rate of generated radiation G on cathode radius r_K.

Figure 6 shows dose rate of generated radiation G in relative units dependence on cathode radius for the 300 kV accelerating voltage. Generated radiation G decreases rapidly with anode-cathode distance increased because of accelerating field reduction.

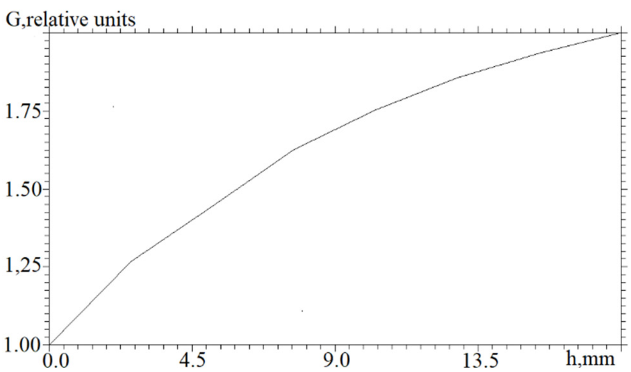

Figure 7: Dose rate of generated radiation G on distance from the front end of a cathode disk to the front end of an anode.

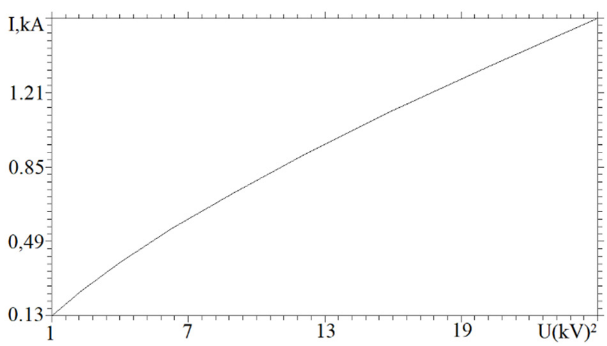

Figure 8: Anode current dependence on square of accelerating field.

Figure 7 shows dose rate of generated radiation G in relative units dependence on distance from the front end of a cathode disk to the front end of an anode for the 300 kV accelerating voltage.

Anode current dependence on square of accelerating field which value proportional to power W, stored in the tank capacitor, shown on Fig. 8.

According [5] instant dose rate on the distance R from the radiating anode area may be estimated as:

$$P(r_A, r_K, U_0, t) \approx k(R)\sum_i j_r(r_A, \mathbf{r}_i, t)\Delta S_i U(t)^2$$

where t – time, ΔS_i – square of radiating anode area with number i, r_i – radius vector of this area, $U(t)$ – accelerating pulse and U_0 – it's amplitude.

Calibration factor $k(R)$ determined from relation

$$k(R) \approx < P(R) > / \int_0^\tau dt \sum_i j_r(r_A, \mathbf{r}_i, t)\Delta S_i U(t)^2$$

where $< P(R) >$ – mean dose rate from dosimeter.

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