200 KV PULSE GENERATOR FOR A POWER SUPPLY OF THE ELECTRON GUN FOR THE COMPLEX VEPP-5 PREINJECTOR

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A 200 kV DC power source on the base of a high-voltage cascade generator [1] is used for a power supply of the electron gun for the VEPP-5 complex preinjector. Advantages of the circuit with DC power supply are its relative simplicity and small power consuming from an AC line. However, a fixed voltage applied to the gun at a beam current of 10 A causes frequent vacuum insulation breakdowns, which decrease its electrical strength. Therefore a problem was stated to develop a high-voltage pulse generator, which will allow us to increase an electrical strength.

Furthermore, a small capacitance of the pulse transformer and so less stored energy reduce probability of failure of the gun's electrodes during its breakdown.

HIGH-VOLTAGE INSULATION CHARACTERISTICS IN A PULSE MODE

SF_6 gas under pressure of 1.7 atm is used as an external insulation of the electron gun and main insulation of the pulse transformer (PT). It is not dangerous to operate vessels at such pressure and the legal requirements are reduced in Russia. This choice of gas insulation is based on its small dielectric permeability, which provides minimum capacity of high-voltage elements of the generator. The gas insulation is easier at repair and setting up in comparison with liquid (for example, with oil, especially – at vacuum volume opening), and the ecological problems of SF_6 use are still under discussion.

The choice of operating pulse duration as well as operating gradients of SF_6 and vacuum insulation was made in view of electrical strength as a function of pulse duration.

Empirical voltage applying time t [2] dependence of a product of breakdown intensity E into a voltage V was used for vacuum:

$$E \cdot V = 100 \big/ t^{0.34}, \left(kV^2 \big/ mm\right),$$

then for a gap of 100 mm breakdown intensity dependence looks like (see also Fig.1):

$$E = 10 \big/ t^{0.17} \, \frac{kV}{cm}.$$

The data on electric strength for SLAC klystrons [3] turn out to be close to an estimated curve.

Thus, reducing the voltage applied duration down to 1 µs and less, it is possible to increase a breakdown voltage in vacuum at least twice in comparison with a constant voltage. Vacuum electric strength along the surface also depends on the applied voltage duration. According to [4] the electrical strength for a 20 mm long fluoroplastic insulator grows fourfold at reduction of a applied constant voltage duration down to 0.2 µs.

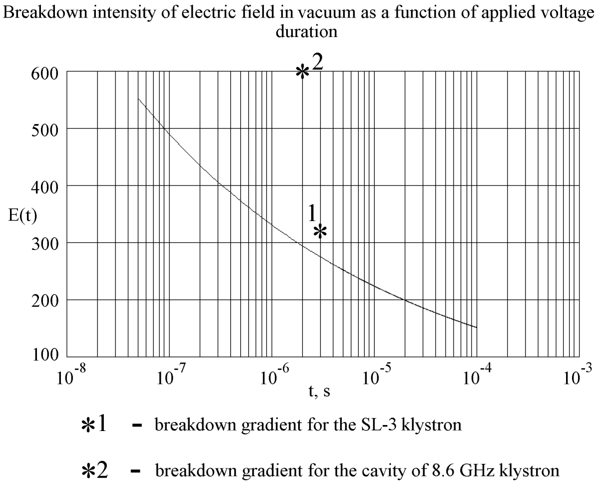

Fig. 1: The breakdown electric field strength in vacuum versus applied voltage duration.

Time dependence of SF_6 insulation electrical strength for small pressures and gaps is less distinct.

Thus, changing to forming the pulses with duration up to 1 µs allows us to sharply increase vacuum insulation gradients or reduce the breakdown probability for chosen operating gradients.

CIRCUIT OF THE PULSE FORMER

The initial data for a choice and simulation of the generator's circuit are pulse and load parameters:

Gun cathode voltage of 200 kV;
Beam current of 10 A;
Beam current pulse duration (at half-height) of 2 ns;
Gun capacitance of ~50 pF;
Voltage pulse duration at a gun cathode not longer than 1 µs.

Because the gun capacitance is discharged during a beam current pulse not more than by 0.2 %, the action of a beam current on the voltage shape may be ignored, considering capacitance of the gun and high-voltage elements of the device as a load of the generator.

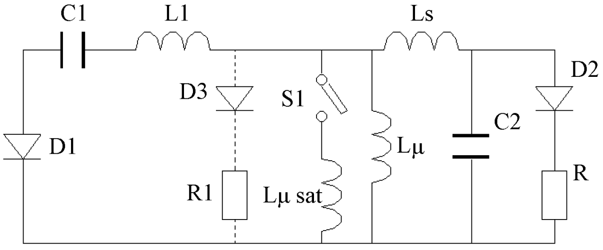

Fig. 2: Simulation circuit of the pulse former.

The basic criteria for the choice of the pulse former circuit were:

Possibility to obtain a pulse with duration no longer than 1 µs;
Simplicity of manufacturing and compactness of the generator.

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Given above, a simple circuit of capacitance resonant charge through the step-up PT has been taken as a base.

Fig. 2 represents the circuit of the pulse former used for simulations. All circuit parameters are referred to a secondary winding of PT. C1 is a capacitance of the primary circuit storage, C2 represents the total capacitance of the gun, PT, and other high-voltage elements of the generator. For complete energy transfer from C1 to C2 their values should be equal: C1=C2~80 pF. Ls is a PT leakage inductance, L1 is an inductance of the primary contour. The primary circuit switch is replaced by the diode D1. Parameters of the contour (Ls, L1, C1) were simulated and chosen so that the capacitance C2 charge time t did not exceed 0.5 µs, i.e.

$$\tau = \pi \sqrt{(L1 + Ls) \cdot C2/2} \le 0.5\,\mu\text{s}.$$

An operating feature of this circuit is generation of a pulse fall time by a saturated PT. Both PT core section and number of turns as well as a reset current are chosen so that the induction in the core is average out to the saturation induction in a moment of pulse top. Then at once after pulse top generation the capacitance C2 begins to discharge through the magnetization inductance of a saturated PT $L_{\mu\,sat}$, and pulse fall is generated. In the simulation circuit on Fig.2 the phenomenon of saturation is simulated by placing the inductance $L_{\mu\,sat}$ in parallel with PT magnetization inductance L_{μ}. A circuit formed of the resistor R and diode D2 placed in parallel to the load is used to limit the subsequent inverse overvoltage on a load. A power of 100 W is dissipated in resistor R. Its resistance was chosen such that inverse overvoltage was not more than 40 % from the peak value.

The current and voltage curves in the circuit are shown on Fig.3a. These drawing show that the amplitude of a current (referred to the secondary winding) through the switch makes about 55 A. For PT with transformation ratio ~20 it will make about 1.1 kA. Thus, allowing for small duration of a pulse, it is possible to use thyratron TGI1-1000/25 as the primary switch. Charging voltage on C1 capacitor will make not more than 10 kV. The capacitance storage was assembled from 6 ceramic capacitors K15-10 10000/40, and the high-voltage diode assembly from 4-th SDL-type diode stacks was used.

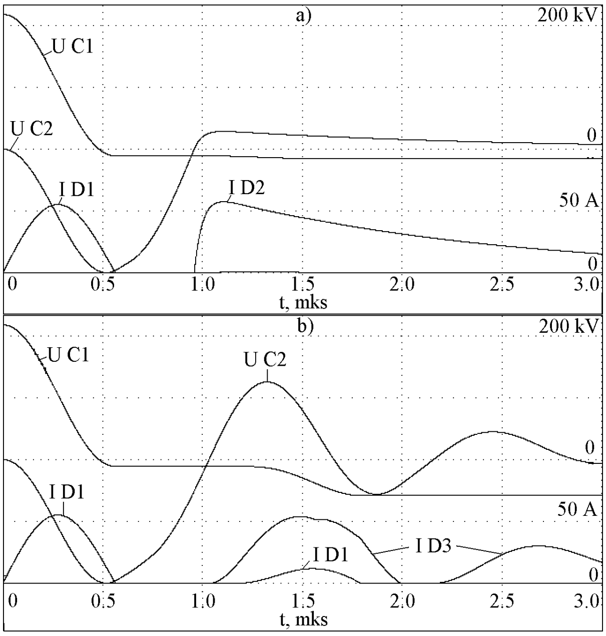

Fig. 3: Current and voltage shapes for the circuit presented on Fig.2. a) – with D2-R circuit, b) – with D3-R1 circuit.

Besides the considered circuit with high-voltage D2-R circuit there was analyzed the similar pulse former circuit, but with an absorber circuit at the primary side of PT (on Fig. 2 this circuit (D3-R1) is represented by a dotted line). In this case high-voltage design of the generator becomes essentially simpler due to absence of any elements in the secondary circuit of PT except for the actual electron gun. Simultaneously capacitance C2 of the secondary circuit decreases in some degree that reduces capacitance of the generator. However, due to rather large value of PT leakage inductance Ls, comparable with PT inductance in a saturated mode $L_{\mu\,sat}$, the energy dissipation processes in a circuit D3-R1 are delayed, and inverse overvoltage on a load is increased. The simulated curves of voltage and currents in elements of the circuit are shown on Fig.3b. The transient process after pulse fall generation is of oscillating type and it cannot be changed by choosing R1 resistance. The effective pulse duration in view of the oscillations can be adjusted by changing a core reset current. Therefore it is possible to obtain a rather short pulse at an acceptable inverse overvoltage by making trade-off. The given variant of the generator is supposed to be tested hereinafter after manufacturing the high-voltage high-current diode for the circuit D3-R1.

DESIGN OF THE GENERATOR

Structurally the generator is carried out from 2 parts: a high-voltage part including PT and diode circuit and low-voltage block, consisting of charge device, capacitance storage, and of a primary circuit switch. Location of the PT and electron gun in the same tank allows us to simplify high-voltage performance of elements of the generator and cathode of a gun.

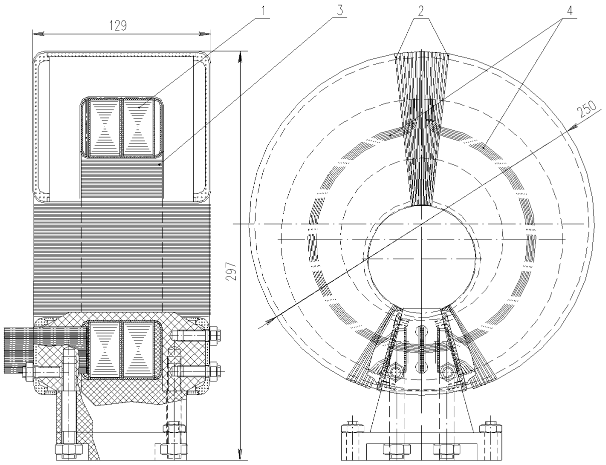

Fig. 4: PT design.

The basic part of the generator is PT. The sketch of the transformer is shown on Fig.4. Structurally PT is carried out similarly [6]. The core (1) is of continuous type and carried out from a tape of amorphous alloy 2NSR by thickness of 25 microns. The toroidal shape of the core allows us to receive the minimum PT leakage inductance at given length of an average line of the core at the expense of the best use of its length. The design of the continuous core with a sound magnetic material allows us to reduce to a minimum magnetization losses in PT. The PT secondary winding is carried out from two symmetric parallel parts (2). The high-voltage edges of windings rejoin each other, therefore the electrical field between windings is practically homogeneous in such design. Using two parallel branches of a secondary winding allows us to use them for a feed of a heat circuits of the cathode and grid control. For reduction of leakage inductance the secondary winding is of cone type (only in a radial direction). For the same purpose the primary winding (3) is carried out of lump of parallel conductors with return leads (4), which run under lateral cheeks of a skeleton. Both primary and secondary windings were reeled up with conductor having polyethylene isolation by a diameter 1.4 mm for increase of their electrical strength. The absence of a skeleton on an internal generating line of the secondary winding excludes an opportunity of breakdowns along the surface. Fastening the secondary winding and PT itself is provided with bars from glass-reinforced dielectric material.

TEST RESULTS

To the present days the nominal parameters of a pulse were obtained on a dummy load: 200 kV at a pulse repetition frequency of 50 Hz. The PT output voltage (Fig.5) was registered by a capacitor divider. Capacitance of a divider made ~60 pF and played a role of equivalent capacitance of the gun. PT, diode circuit, and capacitor divider were located in a SF_6 filled tank under pressure of 1.7 atm.

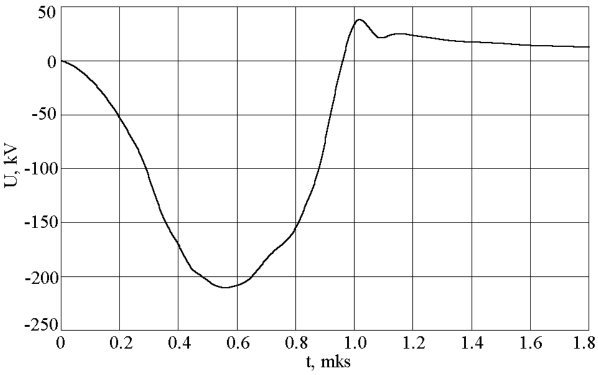

Fig. 5: Voltage pulse shape on a dummy load.

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