PRINCIPLES FOR DESIGN OF HIGH POWER PULSED MICROWAVE DEVICES AND DEVICES WITH LOW OPERATING VOLTAGE FOR ACCELERATORS

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Abstract

The principle of obtaining the extra-high pulsed power at significantly lower operating voltages by creating klystrons with magnetron gun; location of several such klystrons in a single solenoid with a homogeneous magnetic field and summing their output capacities is proposed. The principle of designing of high-power klystron with multi-beam magnetron gun with anode modulation and several energy outputs is proposed. The principle of designing of high-power klystron magnetron gun with multi-beam magnetron gun with control electrode modulation and several energy outputs is proposed. Are given the results of theoretical studies demonstrating the feasibility of such devices and high-power microwave systems based on them. During development of principles of obtaining an extra-high power were used the design of single-beam klystron with magnetron gun with control electrode modulation created at RPC "Istok".

INTRODUCTION

When creating modern high-power microwave systems it requires using of low-voltage electrovacuum microwave devices with an output pulse power of 50-100 MW. In single-beam klystrons pulse power of this order are achieved with anode voltage of hundreds of kilovolts (320-450 kV), so application of such klystrons are problematic due to the problems associated with the bulkiness of their supply sources, presence of hard x-ray radiation and the need to create bulky special protection. In this connection acute problem of obtaining the indicated microwave output pulse powers at much lower anode voltages, not requiring complex x-ray security systems. Low anode voltages will allow creating microwave system, having a high dielectric strength and high reliability during their operation.

This problem can be solved on the basis of principle [1-3] proposed by JSC "RPC “Istok", consisting in the following:

- in creating of the single-beam klystrons with magnetron gun with anode modulation and modulation of the electron beam on the control electrode, placing several such klystrons in a single solenoid with uniform magnetic field and to combine their output powers. Besides, the microwave energy input is realized from a single microwave source by dividing the common input channel into several paths for the microwave power supply to each klystron, and the input of each klystron is equipped with phase-shifter;
- in creating of multi-beam klystrons with magnetron gun with anode modulation of electron beam;
- in creating of multi-beam klystrons with magnetron gun with modulation of electron beam on control electrode.

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SINGLE-BEAM KLYSTRONS WITH MAGNETRON GUN IN SINGLE SOLENOID

Single-beam klystrons with magnetron gun of megawatt power levels with control electrode modulation were created in Russia by “Istok” [3] and abroad by Litton, USA. In these the DC voltage are applied to anode and pulsed voltage to control electrode.

Figure 1: High-power klystron with magnetron gun.

On Fig. 1 is shown the high-power klystron with magnetron gun, created at “Istok”, on Fig. 2 is shown the magnetron gun for such klystron.

Figure 2: Magnetron gun.

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The emitting cathode surface of the klystron the cathode has the shape of side face of blunted cone, i.e. the cathode has extended emitting surface in the longitudinal direction of the klystron with a relatively small outer diameter of the cathode, and the electron gun.

The application of magnetron gun in the klystron allows:

- to form full electron beam with high perveance of $(2.4 \ldots 3.0)\cdot 10^{-6}$ A/B$^{3/2}$ (instead of $(1.5 \ldots 2.0)\cdot 10^{-6}$ A/B$^{3/2}$ in typical klystrons);
- to significantly reduce anode voltage and hence increase the electric strength of the klystron;
- to decrease current density from the cathode and thus to increase the device durability;
- to significantly reduce lateral klystron dimensions in the electron gun area;
- to reduce lateral dimensions of focusing solenoid.

Placing four such klystrons in a single solenoid with a homogeneous magnetic field and summing their output powers using dual adders (Fig. 3), it is possible to achieve high values of microwave power at significantly lower anode voltages. For example, at voltages of 170-180 kV it is possible to obtain an output pulse power of 50 MW

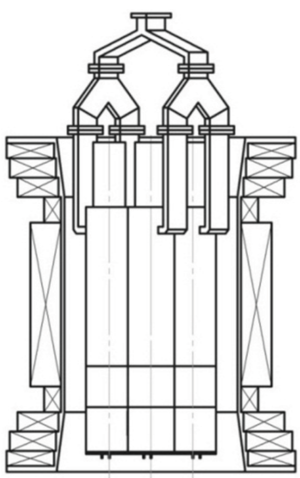

Figure 3: Four single-beam klystrons with magnetron gun in one solenoid.

However it should be noted that the klystron modulated by the control electrode is stable even at constant anode voltages up to 200 kV, at the voltage more than 200 kV it is hard to protect the unit from powerful high-voltage breakdowns that makes it less reliable.

In this connection, we considered the possibility of creation of super-power klystrons as well with the electron beam modulation. In this case, the voltage can be increased above 200 kV.

To estimate the output parameters of super-power klystrons with magnetron gun with a hollow electron beam, were calculated the devices for the anode voltage of 200 and 250 kV. Calculations were performed for four-resonator klystron at frequency of 1818 MHz with the distance between the gaps of input and output resonators of 330 mm.

The dependences of klystron efficiency from the quality factor of output resonator are shown in Fig. 4.

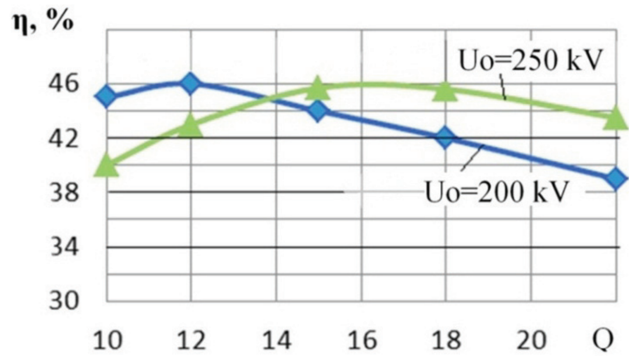

Figure 4: Dependence of efficiency of klystrons from quality factor of output resonator for voltages of 200 and 250 kV.

The calculations determined that in klystrons with magnetron gun with anode modulation it is possible to obtain the output power from 19 to 34 MW at voltages of 200 to 250 kV. In the summation of four such klystrons located in a single solenoid, you can achieve the output power of 70-120 MW.

Figure 5 shows the results of theoretical calculations of electron-optical system of such klystron with an anode voltage of U_0 = 200 kV, the magnetic field of the solenoid with a maximum induction B_Z = 0.2 Tl, an electron beam perveance $2.4 \cdot 10^{-6}$ A/B$^{3/2}$, a current density of 3.5A/cm^2 at the cathode, the drift channel diameter 36mm.

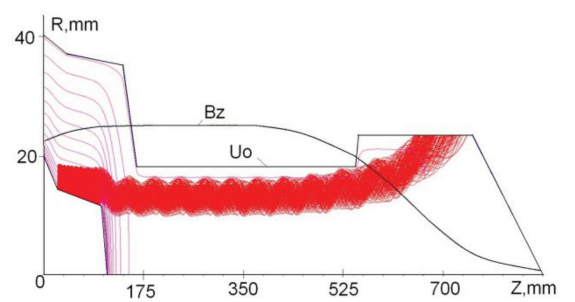

Figure 5: Klystron electron-optical system with magnetron gun and anode modulation.

The theoretical results demonstrate the feasibility of creation of klystrons with magnetron gun with anode modulation: the required values of magnetic fields can be realized, the electron beam is stable, electrodynamic and electro-optical systems can be also realized.

MULTI-BEAM KLYSTRONS WITH MAGNETRON GUN WITH ANODE MODULATION OF ELECTRON BEAM

Using multi-beam klystron design can significantly reduce the anode voltage, which is especially important for super-power devices. The coaxial resonator on the 4th mode was selected as the active resonator in multi-beam

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klystron. Four drift channels (Fig. 6) are located in maximums of the electric field of this resonator. Characteristic impedance of the resonator is 33 Ohms. The main geometrical dimensions of the resonators are:

Internal diameter of resonator	212 mm
Central diameter of conductor	40 mm
Distance between drift channels	85 mm
Height of resonator	62 mm

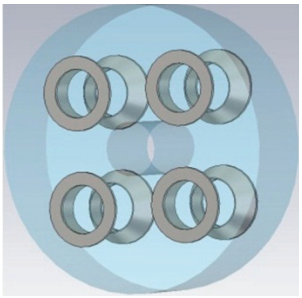

Figure 6: General view of coaxial resonator on the 4th mode of oscillations.

The results show that at an accelerating voltage of 170 kV can be achieved an output pulse power of 50 MW, and at a voltage of 230 kV - 100 MW.

In the klystron with anode voltage of 230 kV, microwave energy output is supposed to be done using four waveguides connected to the output resonator. In the klystron with anode voltage of 170 kV, it is enough to use two microwave energy outputs. Using of several microwave energy outputs allow symmetrical loading of the output resonator and thus - efficient energy extraction from the electron beam.

Thus, our calculations showed principle possibility of creation of super-power klystrons with level of the output pulse power of 100 MW at a record low anode voltage of 230 kV.

MULTI-BEAM KLYSTRONS WITH MAGNETRON GUN WITH ELECTRON BEAM MODULATION ON CONTROL ELECTRODE

On Fig. 7 is shown a 4-beam klystron with magnetron gun. In klystron coaxial resonators are used, the input power to the klystron is fed via coaxial, located in the wall between the first and second resonators and apples into the first resonator via its central coaxial. This allows initiating the input resonator symmetrically. From the output resonator the power is displayed using two waveguides for more uniform load of resonators.

According to the calculations at a constant anode voltage of 100 kV and impulse voltage of control electrode of 30 kV the output pulse power of the klystron is 14 MW.

In the long wave range (30 cm) in the klystron can be accommodated 6 beams, and then output pulsed power will be 21 MW (in the common one-beam klystrons we will require voltage of 250 kV to obtain such power).

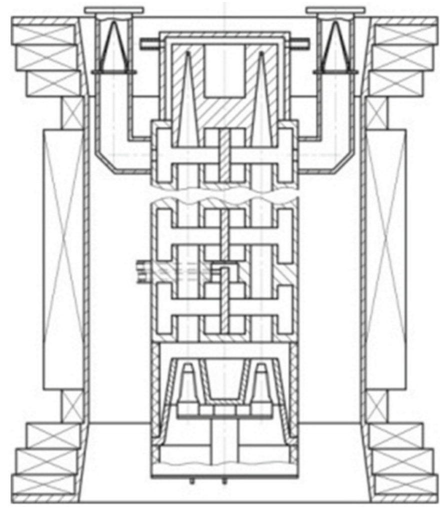

Figure 7: Multi-beam klystron with magnetron gun.

A 6-beam klystron with anode voltage of 70 kW and control electrode voltage of 20 kV is also very promising. In this klystron can be achieved an output peak power of 10 MW. At such relatively low voltages, klystron and power source and can be operated without oil insulation of their high voltage elements. This allows using the compact power sources and ensuring reliable operation of a klystron and power sources.

CONCLUSION

Were considered the principles of designing of high-power microwave systems with significantly lower anode voltage, which consists in creation of klystrons with magnetron gun, placing them in a single solenoid with a homogeneous magnetic field and the sum of their output powers.

Were considered the ways of creating of super-power multi-beam klystrons with magnetron gun with anode modulation of the electron beam.

Were considered the ways of creating of super-power multi-beam klystrons with electron beam modulation on control electrode.

As a result of these calculations was shown that in the klystrons with magnetron gun can be achieved an output pulse power of 50-100 MW at significantly lower anode voltages of 170-230 kV.

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