20 MW PULSE AMPLIFIER KLYSTRON WITH MULTIPLE FREQUENCY TWO-GAP BUNCHING RESONATORS FOR LINEAR ELECTRON ACCELERATORS

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Abstract

A klystron design is considered with a two-gap bunching resonator which provides interaction with electron beam by fields of multiple frequencies of two-gap resonator fundamental oscillations for increasing the klystron efficiency. That the two-gap resonator is tuned to anti-phase oscillation at operating frequency f and to in-phase oscillation at the doubled frequency $2f$.

Such choice of frequency oscillation types allows to compact the resonator and provide optimal conditions for electron beam interaction with microwave fields of the two-gap resonator both in anti-phase and in-phase oscillation types. The relations are given for choosing two-gap resonator interaction area size providing klystron operation stability without self-excitation.

The compactness of the realized two-gap resonator with multiple frequencies allowed to locate it into klystron drift tube between the main resonators without increasing the klystron overall dimensions.

Experimental investigation of klystron with the two-gap resonator demonstrated significant increasing of klystron efficiency.

INTRODUCTION

In modern linear electron accelerators high-power sources of microwave energy are widely used which contain high stability driving oscillator, driver amplifier (solid-state or vacuum) and output device – klystron.

Klystrons provide high output power in a pulse (several dozens of MW), possess high gain and long life and to a large degree define main technical and operational characteristics of linear electron accelerators.

The present contribution gives the results of research in increasing the efficiency of the klystrons for accelerators using compact two-gap resonators operating at double frequency or at multiple frequencies of its fundamental oscillation modes –anti or in-phase ones.

TWO-GAP RESONATORS OPERATING AT MULTIPLE FREQUENCIES

The idea of designing a klystron with two-gap resonators operating at multiple frequencies of its fundamental oscillation modes was proposed in [1, 2].

A two-gap resonator is made in such a way that its anti-phase mode of oscillation is tuned to the klystron operating frequency f, and in-phase mode - to double frequency $2f$.

Such design allows:

– to make the resonator and the klystron itself rather compact;
– to provide at the chosen field of interaction, optimal for one mode of oscillation, optimality for the other mode of oscillation as well;
– to get high wave resistance at the double frequency.

Actually realized such two-gap resonator has a diameter significantly smaller than the diameter of the main one-gap resonators of the klystron which allows to locate it into the klystron drift tube without changing the klystron overall dimensions and mass.

Figure 1 shows a segment of the klystron resonator system in which a two-gap resonator in the drift tube 3 is located between two main bunching one-gap resonators 1, 2 of the klystron. The two-gap resonator contains two one-gap resonators 4, 5 which are connected with each other by a connection slot 6. The two-gap resonator has interaction gaps of d size which are located at s distance from each other.

The two-gap resonator has two fundamental modes of oscillation – in-phase and anti-phase. At in-phase mode of
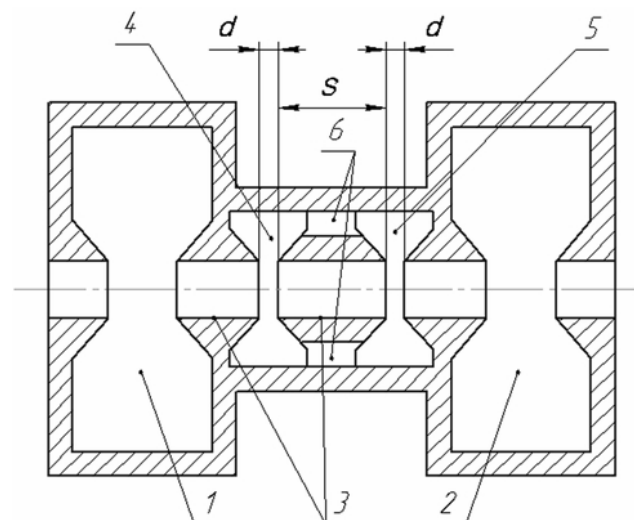

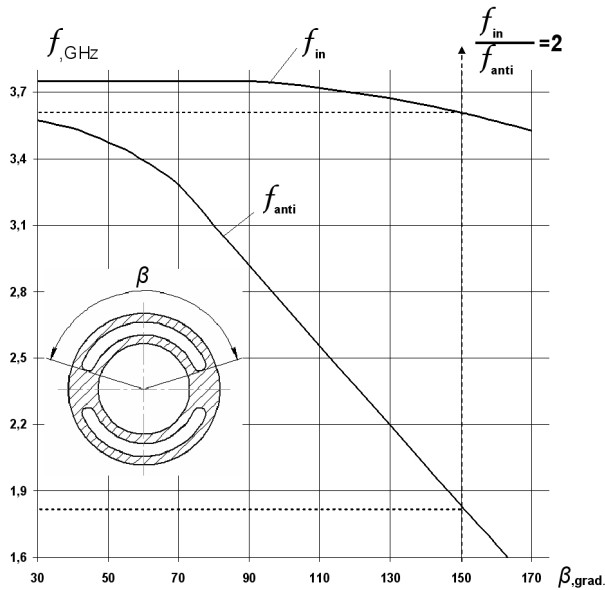Figure 1: A segment of the klystron resonator system.

Figure 2: Frequencies of in-phase and anti-phase modes of oscillations versus connection slot angle.

oscillation the fields in resonator gaps are directed to one and the same side, at anti-phase mode of oscillation – to meet each other.

Figure 2 gives the dependencies of frequencies of in-phase f_{in} and anti-phase f_{anti} modes of oscillation at angle β of the connection slot between the resonators. From fig.2 one can see that the in-phase oscillation mode frequency depends weakly on connection slot whereas the anti-phase mode frequency changes greatly depending on connection slot angle. At the connection slot angle $\beta = 150°$ it is possible to provide the multiplicity of frequencies of anti-phase and in-phase oscillation modes, i.e., $f_{in} = 2f_{anti} = 2f$.

Note, that the overall dimensions for two-gap resonator are chosen to obtain double operating frequency $2f$ for in-phase mode of oscillation, that makes klystron becomes compact. Such resonator can operate in the klystron in two modes:

- at double frequency of in-phase mode of oscillation;
- at multiple frequencies of in-phase and anti-phase modes of oscillation.

KLYSTRON WITH TWO-GAP BUNCHING RESONATOR AT DOUBLED FREQUENCY AND AT MULTIPLE FREQUENCIES.

Let's consider why the frequency selection of oscillation mode is the optimal one for effective bunching of electron flow when in-phase mode is tuned to double operating frequency $2f$ and anti-phase mode of oscillation is tuned to frequency f.

To simplify the analysis consider gap factors [3, 4] for in-phase M_{in} and anti-phase M_{anti} modes of oscillation

(fig.3 a,b) depending on complete transit angle $\theta_s + 2\theta_d$ in two-gap resonator at different transit angles between gaps θ_s ($\theta_s = \frac{2\pi fs}{v_0}$, $\theta_d = \frac{2\pi fd}{v_0}$ – a transit angle in the gap, v_0 – electron flow rate). Figure 3 demonstrates that the value scale for in-phase oscillation mode was chosen twice as larger as compared to that of anti-phase oscillation mode.

Figure 3 shows that gap factors for in-phase and anti-phase oscillation modes have maximal values simultaneously only when in-phase oscillation mode is tuned to double operating frequency $2f$ and anti-phase oscillation mode – to operating frequency f.

The dependencies of electron load conductance for in-phase $\frac{G_{in}}{G_0}$ and anti-phase $\frac{G_{anti}}{G_0}$ (G_0 – dc electron flow conductance) oscillation modes on complete transit angle in two-gap resonator given in fig.4 a, b show that at the selection of transit angles on the basis of relations

$$\theta_s + 2\theta_d = (1.35 \div 1.50)\pi$$

and

$$\theta_s = 1.8 \div 2.4$$

electron load conductances $\frac{G_{in}}{G_0}$ and $\frac{G_{anti}}{G_0}$ have positive values and electron gap factors are close to maximal ones (dashed areas in Fig. 3, 4). It means that the optimal interaction of electron flow with the fields of two-gap resonator multiple frequencies at the stable operation of the device is provided.

Note that one could choose modes with negative values of electron load conductances and maximal values of gap
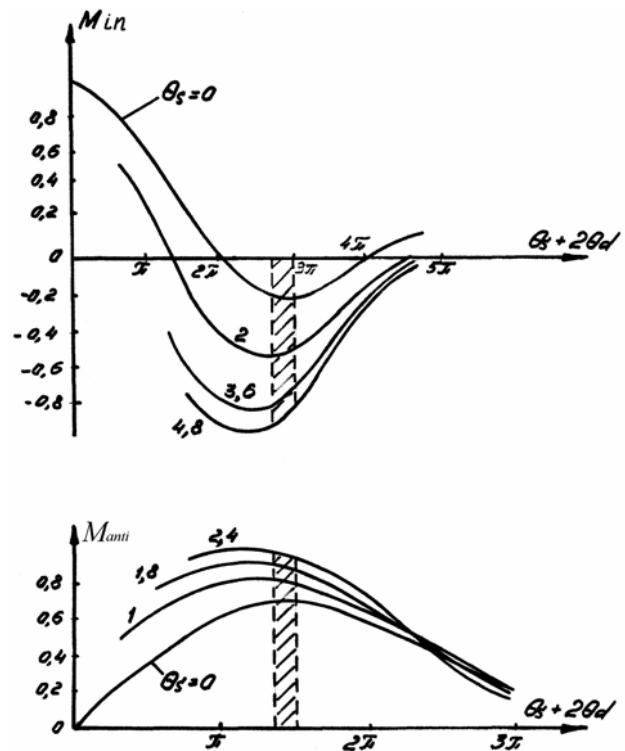

Figure 3: Gap factors M_{in} and M_{anti} versus transit angle $\theta_s + 2\theta_d$.
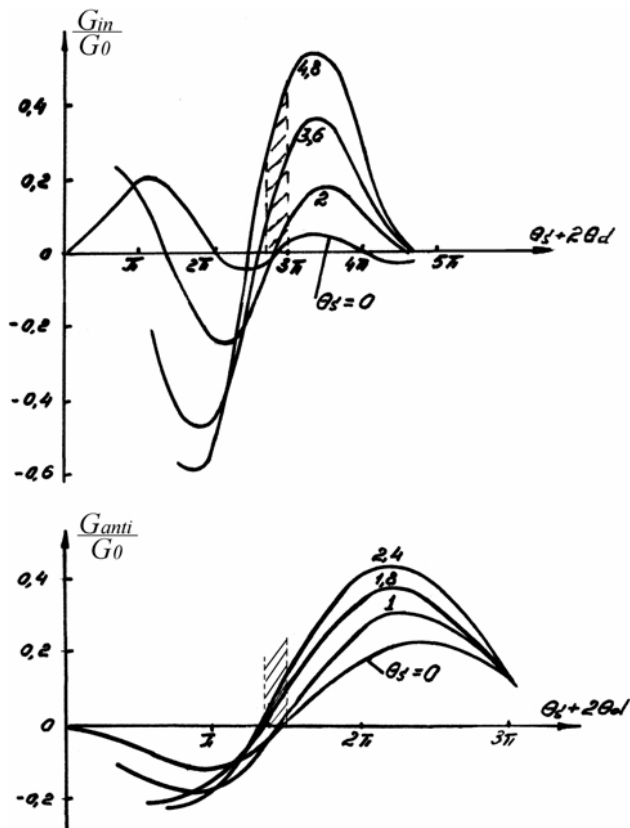
Figure 4: Electron load conductance G_{in} and G_{anti} versus transit angle.

factors, but in that case measures would have to be taken to avoid self-excitation of two-gap resonator.

Now let's consider the case when two-gap resonator operates only in in-phase operation mode at double operating frequency $f_{in} = 2f$.

It is known that the klystrons use one-gap resonators at double frequency which allow to improve the klystron parameters.

As compared to the known solutions, more effective bunching of electron flow is realized in the considered two-gap resonator. It is connected to the fact that the bunching takes place in two interaction gaps and a two-gap resonator has a high wave resistance at doubled frequency $\rho \approx 100\ \Omega$.

Such two-gap resonator was located in a drift tube between the second and the third resonators in existing 20 MW four-resonator klystron.

The results of experimental research showed that the efficiency increased from 36% to 45%.

Moreover, the overall dimensions, mass and focusing magnetic field remained without any changes. It is very important as the klystron is used in many accelerators and alterations of the customers' installations are not desirable.

Main klystron specifications:

Operating frequency	1818 MHz
Output pulse power	20 MW
Output mean power	18 kW
Anode pulse voltage	240 kV
Pulse duration	6 μs
Pulse repetition frequency	150 Hz
Efficiency	45%
Gain	37÷40 dB

At present the work on using a two-gap resonator with multiple frequencies in the klystron is under way. Preliminary investigations showed that it is possible to reach 50% efficiency.

CONCLUSIONS

The design of a compact two-gap resonator in which the interaction with electron flow is realized by fields of multiple frequencies of its fundamental oscillation modes is presented. It is shown that in-phase oscillation mode should be tuned to the double operating frequency and anti-phase oscillation mode – to operating frequency for effective bunching of electron flow.

The results of experimental investigations of the klystron showing the possibility of significant increase of the efficiency (from 36 to 50%) due to compact two-gap resonator with multiple frequencies in the klystron are given.

Two-gap resonator with in-phase oscillation mode at the double operating frequency allowed to increase the efficiency of the existing 20 MW klystron from 36 to 45% without changing the mass and overall dimensions of the klystron and focusing solenoid.

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