Distributed Output of Microwave Radiation from Relativistic Magnetron

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Abstract – This report concerns the issue of output and generation of microwave radiation of relativistic magnetron. A modified magnetron is a subject for examination. Coupling channel with a system of load-radiators is inserted between the elements of the modified magnetron in question. Different options of coupling channel set-up are experimentally examined. It is proved that it is possible to model a specific gain-phase oscillation pattern and ensure high spectral and time stability of radiation.

1. Introduction

When creating high power microwave sources on relativistic devices, it is essential to solve problems of spectral stability increasing and directional output of high-power radiation. The most significant cause of relativistic magnetron instability, as well as of its classical analog instability, is a relatively dense range of resonance system oscillation mode. Usually π-mode acts as operating mode. Processes of mode competition and spectral instability of oscillations develop under conditions of power fields' nonstationarity and emission processes in short-pulse devices [1, 2]. Other destabilizing factors include distortion of azimuthal symmetry of fields caused by the output capacity elements, output feeders' mismatch, anode pack and anode-cathode gap functional deviations. In total these factors deteriorate the synchronism conditions and lead to low energy efficiency of a generator. Application of classical methods of oscillations separation and frequency control [3, 4] is limited due to the risk of breakups at relativistic power levels.

There is also a problem of beam radiation generation aimed at increasing the density of microwave radiation. The possibilities of output from the high-level resonance system are limited by the electric strength of the control elements and waveguides. It complicates the direct usage of well-known methods of electromagnetic radiation generation.

In this report a technique capable of simultaneously solving the problems of stabilization and distributed output of relativistic magnetron oscillations is presented. A modified magnetron oscillator with external coupling channel containing the system of load-radiators is examined. Coupling channel set-up options for different oscillation modes are discussed, as well as principles fundamental for its synthesis.

2. Magnetron with Common Load in Coupling Channel

In the modified model of magnetron oscillator the opposite cavities of the anode block are connected by the waveguide coupling path [5, 6]. The path is constructed using symmetric and asymmetric circuits [7, 8]; it contains common dissipative elements – loads. The most simple path circuit contains one symmetrical loading and can be presented as follows (Fig. 1).

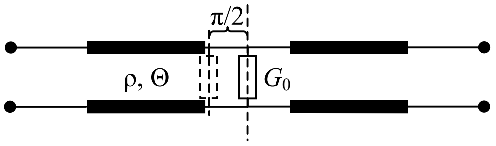

Fig. 1. One-load coupling circuit

Where ρ and Θ are impedances and electrical length of transmission line sections, G_0 – conductivity of common load. Oscillation summation in the common load $G_0 = 2/\rho$ takes place in this circuit under condition of in-phase excitation. Under condition of antiphase excitation oscillation subtraction takes place.

Inserting this circuit between magnetron cavities leads to microwave fields' interaction in cavities, which in turn leads to reciprocal leveling of amplitudes and phases of the electromagnetic field in certain sectors of the interaction space. For π-mode in magnetron with a number of cavities the following requirements should be met: $N/2$ – odd number, oscillations of the opposite cavities when calculating in azimuth are antiphased, and in relation to output waveguides – in-phased. Phase distribution of the electromagnetic field for all other oscillation modes differs from that of the π-mode. Accordingly, if full electric length Θ_Σ of the coupling path meets the following requirement: $\Theta_\Sigma = 2k\pi$, then cavity oscillations interact in the phase. It leads to π-mode stabilization and suppression of all other oscillation modes.

Antisymmetric circuit is obtained from a symmetric one by shifting the common load in relation to the electric symmetry axis of the system by π/2 (Fig. 1). In comparison with a symmetric model the circuit possesses inversion properties: it provides for oscillation subtraction under condition of in-phase excitation of inputs and for oscillation summation under antiphase excitation.

Experimental studies of the circuits in question were based on the example of a 6-cavity relativistic S-band magnetron with power outputs from two opposite cavities. The description of the research facility is given in the report [9] of this symposium.

Magnetron coupling circuit (Fig. 2) is implemented by the sections of a rectangular waveguide *1*, *2* with a cross-section of 72×34 mm. Common load is presented as a waveguide 3-dB T-junction *3*. Radiator – horn antenna *4* – is connected to the output of this T-junction. Waveguide inserts *5*, *6* are inserted in the cirsuit. They allow changing its length and loading switch-on symmetry discretely.

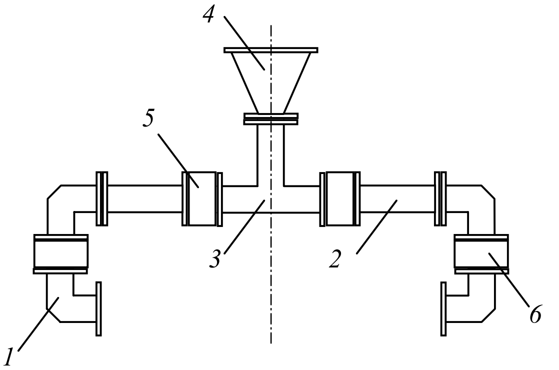

Fig. 2. Coupling circuit of the magnetron cavities with one load-radiator

A magnetron with outputs, which are not connected to each other, is characterized with the following parameters. Power and energy level in pulse from each output equals to ~ 190 MW and ~ 4.8 J respectively. Radiation frequency – to ~ 2740 MHz. Spectral bandwidth at the 3 dB level – to ~ 120 MHz [9]. Combined oscillographs of ten microwave radiation pulses are demonstrated on Fig. 3.

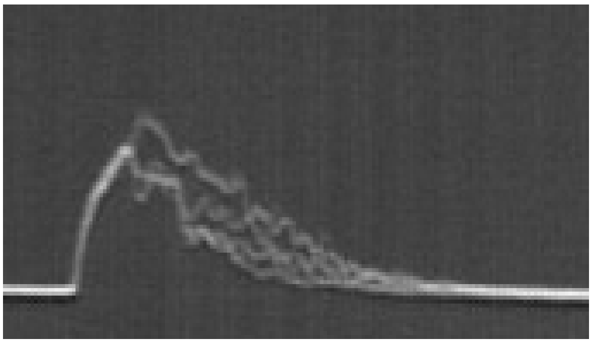

Fig. 3. Pulse oscillographs of the magnetron with independent cavities

They differ in shape and are characterized with relatively deep indentation, which reflects the instability of the generation process.

After connecting the magnetron outputs by symmetric circuit, an optimal coupling circuit length for π-mode is investigated. In the course of experiments spectral and energy parameters of radiation were measured [9]. In the range of optimal adjustment the following results were obtained. Peak pulse power reached 425 MW, which equals to ~ 112% of the power of a magnetron with independent outputs. Pulse energy has risen to 17.6 J, i.e. ~ 80 %. Radiation frequency equaled to 2730 MHz, and spectral bandwidth at the 3 dB level decreased to ~ 35 MHz. These results unambiguously prove the positive effect of coupling circuit on generation processes. Increase of the stability of microwave radiation pulse envelops has been also observed. Fig. 4 shows the oscillographs of 20 shots following one another.

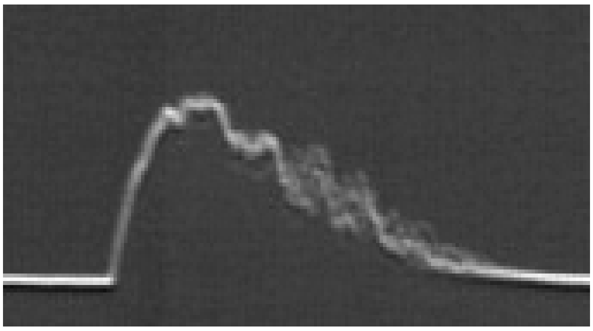

Fig. 4. Oscillographs of the magnetron with external cavity connection

In the relativistic magnetron in question major competitive oscillation modes are π-mode and 2π/3-mode (or its -1^{st} harmonic), that are characterized with comparable ceiling voltage. π-mode, as already mentioned, is characterized with phase coincidence of oscillations at path input terminals, and 2π/3-mode – with phase opposition. The power level recorded in the course of experiment equaled to 425 MW, which proved the summation of oscillations in the load, i.e. the existence of π-mode. Spectrum layout proved it as well.

Similar experiments were carried out for a system with asymmetrically located radiator. The oscillations of π-mode should be subtracted in this case, and in case of 2π/3-mode excitation they should be summated. It allowed to unambiguously define the generation mode in the course of experiment. In fact, power level did not exceed 30 MW, which proved the existence and uniqueness of π-mode oscillations in this system. Emission bandwidth equaled to ~ 45 MHz.

Thus, the suggested circuit may be used for power output from several magnetron cavities and for increasing amplitude and spectral stability of generator radiation.

3. Distributed Output of Magnetron’s Microwave Radiation

Taking the above models as basic, we will try to construct a more complicated system with distribution of power among a number of load-radiators [8, 10] (Fig. 5).

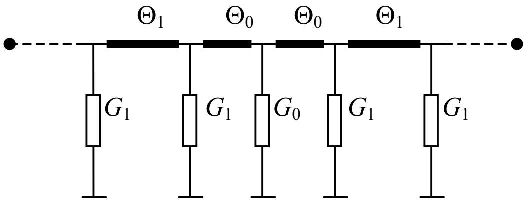

Fig. 5. Multi-load coupling circuit

Opposite cavities of magnetron's anode block are joined by the transmission line with parallel loads connected to it lengthwise at regular intervals. From now on let us consider the coupling circuit symmetrical in relation to central load G_0. If supposed that cavity oscillations on circuit input terminals are strictly antiphased and equal in amplitude, then dynamic short-circuiting takes place on G_0 load. Also, if $\Theta_0 = \pi/2$, then the loads G_1 closest to it do not shunt. Finally, if $\Theta_1 = 2\pi$ (or π), then the loads G_1 of the left and right groups are connected "in parallel". For equal-amplitude distribution of oscillations among the loads, identity of their conductivities is required. In-phase distribution is implemented if the distance between loads in groups is divisible by 2π, and one of the load groups is shifted in relation to the central one by π.

The same operation takes place in the antisymmetrical circuit at in-phase excitation of its inputs.

A magnetron with three load-radiators in the coupling circuit was examined in the course of experiment. Coupling circuit layout is presented on Fig. 6. Central load G_0 is connected antisymmetrically, left and right loads are located at the distance of 2.5π and 3.5π in relation to it.

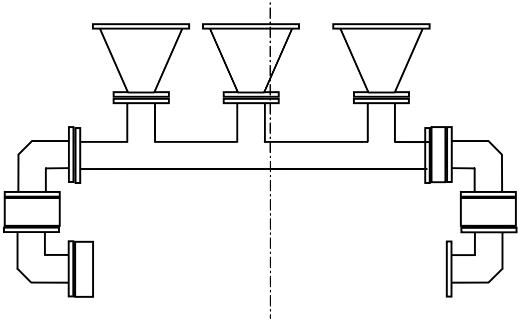

Fig. 6. Coupling circuit of the magnetron cavities with three load-radiators

The length of the coupling path was chosen according to the results of the previous experiments, and equaled to 34π.

The recorded power and energy levels from the central radiator terminal did not exceed 25 MW and 1.5 J respectively, which proved the existence of π-mode oscillations in the system. This fact was also implied by the results of spectral measurements of the signal emitted by one of the side radiators. These results are absolutely identical to those obtained in the course of examination of a one-load system. Magnetron's radiation frequency in this experiment equaled to 2720 MHz, the spectrum was relatively narrow with width of ~ 40 MHz. Power levels of side radiators did not differ by more than 10% and equaled to ~ 200 MW.

Stability of phase distribution of oscillations in the system of horn antennas was visually demonstrated in the specifically conducted microwave radiation distribution experiment. The results of this experiment are demonstrated on Fig. 7. Minimum points on the diagram show the presence of oscillatory conditions with stable gain-phase profile in the system.

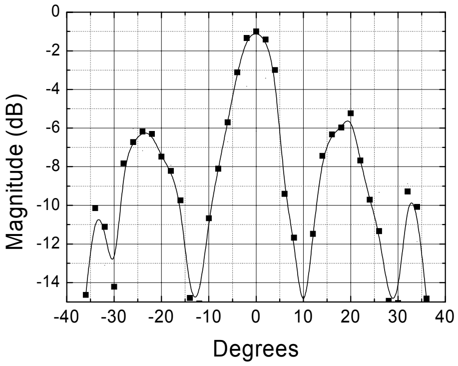

Fig. 7. Radiation diagram

Coupling circuit of the magnetron cavities can be presented as four-pole. Thus, for symmetrical circuit with three loads (Fig. 5) for $\Theta_1 = \pi$ and $\Theta_0 = \pi/2$ we can find Y-parameters:

$$Y_{11} = Y_{22} = \frac{1+\rho^2 G_0 G_1}{\rho^2 G_0},$$

$$Y_{12} = Y_{21} = \frac{1}{\rho^2 G_0}.$$

At equal-amplitude excitation of circuit the input conductance can be found as

$$Y_{in} = Y_{11} + Y_{12} e^{j\Delta\varphi},$$

where $\Delta\varphi$ – input voltage phase difference.

In operative mode of antiphase oscillations $\Delta\varphi = \pi$, as may be seen from the equations, input conductance $Y_{\text{in}} = G_1$.

In case of in-phase oscillations $\Delta\varphi = 0$ we have

$$Y_{\text{in}} = \frac{2+\rho^2 G_0 G_1}{\rho^2 G_0}.$$

From this equation it follow that conductance G_0 reducing when the coupling value Y_{12} increasing, the input conductance Y_{in} increasing too. This means that central load causes high dissipative losses in magnetron's oscillation system by competitive oscillation modes. And this leads to fast damping of oscillations. These arguments explain the mechanism of operating oscillation mode selection.

5. Conclusion

Different models of coupling circuits of relativistic S-band magnetron cavities are presented in this report. Depending on their set-up in the generator, various operating modes with summation, subtraction or oscillations power distribution can be obtained. It is demonstrated that introducing external communication significantly improves energy and spectral characteristics of emitter's radiation. Thus, spectral bandwidth obtained in the course of experiment equaled to 1–1.5%, compared to 3% for magnetron with independent terminals. Modified magnetron's performance is characterized of high mode stability.

The obtained results may be useful for development and construction of high-power microwave radiation supplies with various relativistic generating devices.

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