Radiation Spectrum Dynamics of Relativistic Microwave Magnetron with Coupled Cavities[1]

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Abstract – In this work, the results of research on the relativistic magnetron oscillator, in which two opposed cavities are connected by the external coupling section, is presented. Data about formation and behavior of spectrum during the pulse were obtained. The results were compared with the spectrum of magnetron with uncoupled outlets.

1. Introduction

Spectral stability of microwave radiation and repeatability of its characteristics is one of the most important requirements to modern high-power sources, in particular, to relativistic magnetrons, which are characterized with a high generation efficiency and capability of high repetition rate operation.

Authors suggested the modification of magnetron oscillator [1], which is based on introducing a controlled mutual coupling of cavities into the oscillation system. By varying coupling characteristics, it is possible to change substantially radiation characteristics. Coupling channel construction methods as well as its influence on radiation characteristics were already considered in the works [2-4].

The results of experimental investigations of the spectral parameters of the modified relativistic magnetron radiation are presented in the report. The phenomenon of frequency pulling by cavities' coupling section is described.

2. Experimental scheme

Structural scheme of coupling channel with one radiant load and radiation parameter measurement scheme are presented on Fig. 1. Magnetron *1* which was used during the work has 6 resonators of vane type. Power outlets of opposed cavities *2* are joint with coupling section, which consisted of the following elements: waveguide H-shaped turning *3*; a set of straps *4*, which provide the change coupling section length in range 16.5 – 17.7 wave length of working mode of oscillation; 3-dB waveguide H-tee *5*, which is situated on the circuit electrical symmetry axis. Radiating horn antenna *6* is plugged to the H- tee.

The magnetron is supplied by the section of linear induction accelerator (LIA 04/6) [5] with the output parameters: voltage U≈400÷500 kV, beam current I≈2.5÷4 kA. Static magnetic field is creates by magnetic system with induction up to 0.55 T. Experimental setup provides microwave pulses generation with repetition rate up to 320 Hz and has high stability of working characteristics.

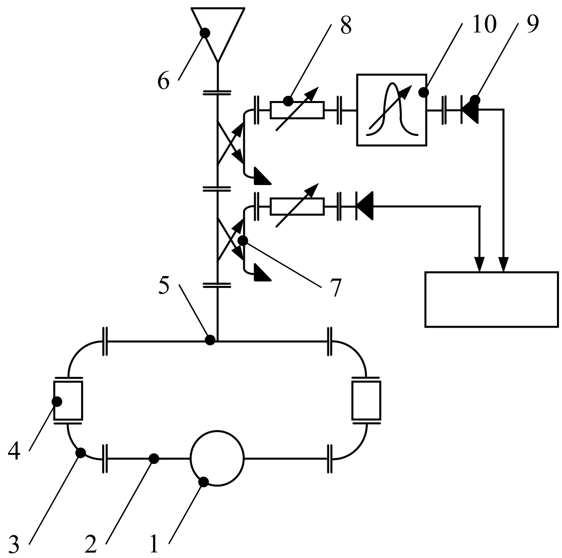

Fig. 1. Schematic of the experiment.

Working mode of oscillation in magnetron is π-mode, during which the oscillations of opposed cavities are cophased and are summing up into symmetric load. The nearest competitive 2π/3-mode is characterized by coupling cavities antiphase oscillations.

In order to diagnose microwave radiation parameters two waveguides directional couplers *7* connected in series with each other were installed between H-tee and antenna. Waveguide attenuators *8* and microwave detectors *9* were plugged into channels of derived energy. In order to measure radiation spectrum reconfigurable band-pass filter *10*, installed in one of instrument channel was used. Filter resonance frequency was changing with pitch of 5 MHz in range 2550-3000 MHz. On each filter position up to 10 pulses were carried out.

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Spectral processing method of signals is the following. The ratio between signal power after filter P_F in every tuning f_i and power of reference signal P_0 in certain moment of time τ were analyzed:

$$S(f_i, \tau) = \frac{P_F(f_i, \tau)}{P_0(\tau)}.$$

The analysis of change in this relation in a sequential detuning of filter frequency in selected moment of time of pulse allows us to estimate spectrum dynamics. Normalization on power of reference signal P_0 allows eliminating instability of pulse shapes. During the research more then 10000 pulses were processed; inaccuracy of measurements was brought down and results verification was enhanced thanks to data statistical treatment.

3. Results and discussion

Microwave radiation measurements of relativistic magnetron with uncoupled cavities, which were loaded on matching radiators – horn antennas, were the initial ones. Typically magnetron oscillation pulse is presented on Fig. 2. Pulse power level and pulse energy at each output is ~200 MW and ~7 J respectively.

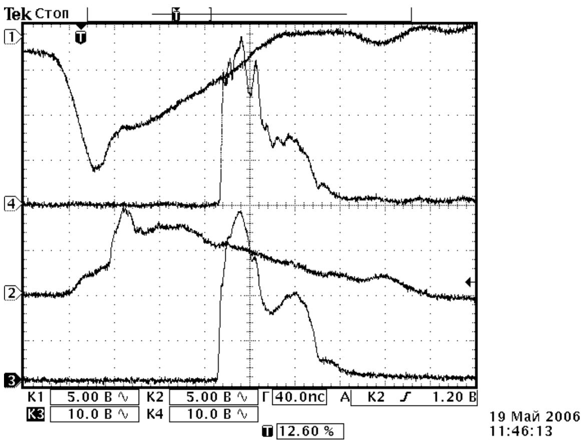

Fig. 2. Oscillograms of voltage (1), current pulses (2) and signals from microwave detector (3 and 4) for 6-cavity relativistic magnetron.

Magnetron spectral characteristics (Fig. 3) are determines in 4 pulse points: on the rise-up edge (τ≈10 ns), in point of maximum power (τ≈20 ns), and in two point on the falling edge of pulse (τ≈50 ns and τ≈75 ns).

The analysis of presented spectrums shows their complicated noisy character. Rise-up edge spectrums and in the point of maximum power are almost identical; spectrum width on level -3 dB is ~80 MHz with center 2775 MHz. Then spectrum undergoes modification and in τ≈50 ns two more peaks appear, which stand ~70 MHz from the central one. Central peak frequency is shifting in 40 MHz. In the end of pulse (τ≈75 ns) regular components are almost lost and noisiness becomes more intense.

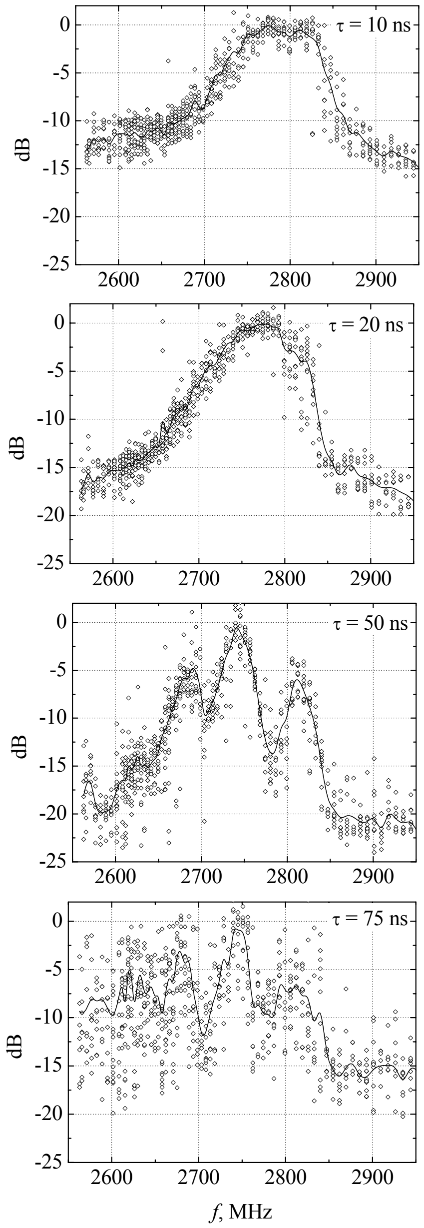

Fig. 3. Oscillation spectrum of relativistic magnetron with uncoupled outlets in different moments of time τ.

Magnetron oscillation modes of different kind may corresponds to discovered spectral components. Their simultaneous existence is caused by pulsed supplying fields instability and radial widening of cathode plasma during pulse. In aggregate these factors cause synchronism conditions disturbance and changes in system resonance characteristics. Presence of several competitive modes of oscillations within pulse, which differ in various grouping of space charge cause spectrum noisiness and pulse amplitude instability [2].

Magnetron microwave radiation characteristics depend substantially on phase delay of oscillations in section. This delay is determined by its whole length. Therefore after joining relativistic magnetron outputs, a search of optimal coupling section length L for π-mode oscillations was performed. Criterion for optimal tuning was narrow monofrequent and microwave oscillation spectrum. Position of spectrum peaks at different coupling section length is shown on Fig. 4. It can be clearly seen that there are area of one-frequency oscillations (type b spectrum) was changed of areas where magnetron excitation occur randomly, from one pulse to another, on one of two frequencies (type a spectrum). Therefore the phenomenon of generation frequency pulling with cycling within section length takes place.

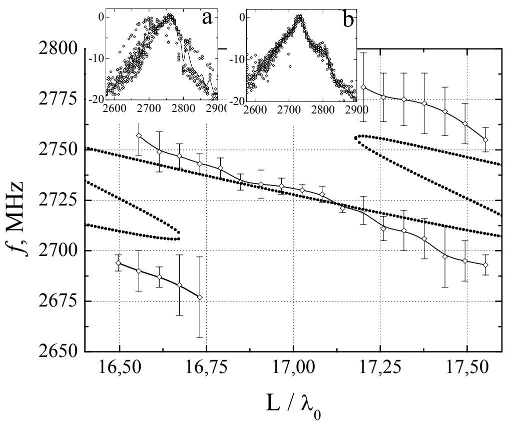

Fig. 4. Changes of spectral peaks in magnetron with external cavities coupling.

Magnetron oscillation spectrums in one-frequency oscillations area are shown on Fig, 5. Rise-up edge pulse spectrum resembles analogous magnetron spectrum with uncouples cavities. Peak of frequency is ~2728 MHz. Pulse spectrum in maximum power point (τ=20 ns) differs greatly. If τ≈50 ns an spectrum is shaping into a peak with frequency ~2728 MHz with spectrum bandwidth ~30 MHz. Oscillation spectrum shape and peak positions remain unchanged up to the end of pulse.

In the area of optimal coupling the magnetron energy parameters are ~425 MW (~112 % of magnetron with uncoupled cavities total power) and 15 J. It testifies about oscillation synchronism in load, i.e. about π-type excitation. Oscillations of competitive 2π/3-mode do not excite.

The work of magnetron on the frequencies in the band of spectrum bifurcation according to the level of generated power (~400 MW) correspond to cophased condition, i.e. excitation of π-mode oscillation subtypes.

The generation of subtypes of the basic oscillation mode, as well as the oscillation frequency pulling should be related with mismatching of the common load [2]. Such phenomena are inherent to classical magnetron oscillators loaded with long mismatched feeders [6]; in this case, mismatching has dynamic character. Dotted line in Fig. 3 shows the calculated dependence of resonance frequencies of equivalent magnetron circuit [2]. Section parameters were chosen close to those used in the experiment. The calculation satisfactorily reflects the effect of frequency pulling and development of frequency instability [7].

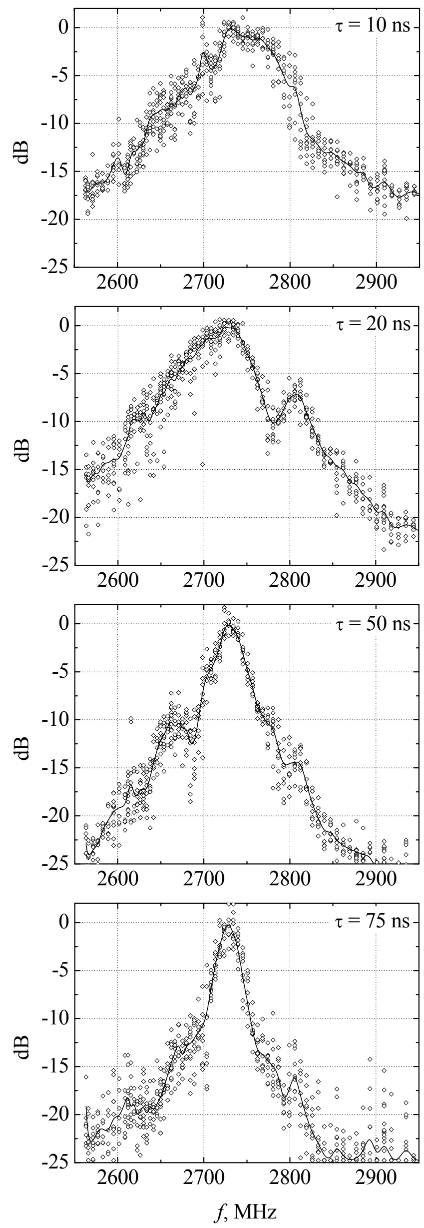

Fig. 5. Oscillation spectrum of relativistic magnetron with external resonator coupling in different moments of time τ.

4. Conclusion

Thus, based on the results of conducted experiments, we can draw a conclusion that the external coupling channel has substantial influence on the generation process in the relativistic magnetron. The conditions of forming electronic beam are obviously improving, the microwave fields in the interaction space become more balanced, that, in spite of considerable signal delay (~17 periods), results in rapid formation of oscillation spectrum, its stability during the pulse, and high reproducibility of output pulses parameters.

References

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