Relativistic Magnetron with Distributed Output of Microwave Radiation [1]

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Abstract – Theoretical and experimental results are presented for researches on the method of distributed extraction of electromagnetic radiation from the relativistic magnetron aiming at generation of coherent radiation of high directivity. Modified magnetron oscillators are distinguished with external coupling of their resonant systems. Into the coupling channel, the slot-waveguide array is introduced.

1. Introduction

Such advantages as high efficiency, amplitude and frequency stability, long lifetime, low weight, dimensions, and cost typical for classical magnetrons and magnetron-based devices pre-determined the interest to them in relativistic microwave electronics. The relativistic magnetron, like known classical vacuum tubes, falls to the category of so-called resonant-type devices with short-time interaction of an active medium (electron flow) with electromagnetic field. The magnetron oscillation system is a distributed multimode electrodynamic structure.

For the frequency separation of oscillation modes and stabilization of the main operating mode, different methods based on arranging additional couplings are used. The classical and most widely used method is employing anode straps. Another enough effective method is based on using an external high-Q cavity and phenomenon of generation frequency pulling.

For relativistic magnetrons, using straps is impossible because of the high level of generated power. A short duration of microwave radiation pulse limits possibilities of using an external high-Q cavity.

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 [2–6].

The practical goal of the investigations being performed is the development of the microwave radiation source capable of high directivity and efficient energy extraction from the system at high stability of output pulse parameters.

2. External coupling channel in the form of slot-waveguide array

In previous experiments, horn antennas were installed into the external channel of cavities coupling [4]. In order to reduce the size of the radiating system, it was proposed to make it as a slot-waveguide array. The distance between the near by slots were chosen equal to $\lambda_w/2$. In this case, the inphase excitation of longitudinal slots located at the opposite sides from the centerline at the distance of $\lambda_w/2$ is provided by means of additional 180° phase shift, which is conditioned by the oppositely-directed transverse currents.

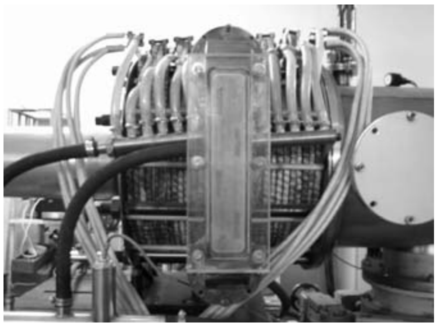

Fig. 1. Appearance of the antenna array

The external view of the slot-waveguide array is shown in Fig. 1. The only slot-waveguide array appropriate for installing between the outputs of the relativistic magnetron microwave radiation is that with the 4 alternating phase slots made in the wide wall of the waveguide. The slots are covered by the plexiglass window with the groove for the vacuum O-ring.

The normalized conductivity of the longitudinal slot employed in our array design is equal to:

$$g = 2,09\frac{a\lambda_w}{b\lambda}\cos^2\left(\frac{\pi}{2}\frac{\lambda}{\lambda_w}\right)\sin^2\left(\frac{\pi x_1}{a}\right) = 0,357, \quad (1)$$

where $\lambda = 10$ cm is the oscillator wavelength; $\lambda_w = 13.7$ cm is the wavelength in the waveguide; $a = 7.2$ cm and $b = 3.4$ cm stand for the waveguide inner dimensions; $x_1 = 1,5$ cm is the slot displacement related the waveguide axis. For the slot-waveguide array with 4 slots, the total load conductivity $G_\Sigma = 4 \cdot 0.357 = 1.428$.

Since the regime of matching corresponds to the conductivity $G_\Sigma = 2$ (because the channel is fed from

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two sides), in our case, underloading takes places that is recommended by theoretical estimations [7].

Investigations of the slot-waveguide array were carried out with the relativistic magnetron driven by the LIA 04/6 voltage source at several values of the charging voltage. The radiation patterns of the array were measured in the vertical and horizontal planes. The scheme of measurements included two receiving microwave units consisting of the rectangular horn antenna with known characteristics, calibrated attenuator, and microwave detector; one unit was fixed and another one was moved along the surface of imaginary sphere. The fixed detector provided the reference signal for monitoring the radiation.

The results of the radiation pattern measurements evidence that the length of the coupling channel significantly influences on the pattern and location of electromagnetic beam in the free space. At a non-optimal channel length, the radiation maximum was observed at an angle of 15 ° with respect to the axis of the slot-waveguide array. Therefore, for adjusting the coupling channel, two detectors were used: one was installed at the array axis and another one at an angle of 15 °.

The adjustment of the waveguide channel length using the insertions installed by pairs into each arm of the channel with the step of 5 mm allowed us to form the narrow electromagnetic beam (angular width of ~ 5 °, FWHM). Within the range of optimal coupling channel length, at 10 and 15 mm insertions, we observed the increase of the signal from the microwave detector at the array axis and decrease of the signal from the detector installed in the side lobe direction (see Fig. 2).

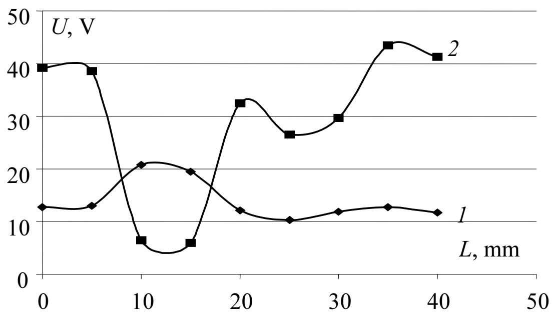

Fig. 2. Amplitude of the detected microwave signals U versus the length L of insertions into the waveguide channel. Detectors are at the axis of the array (*1*) and at the angle of the side lobe direction (*2*)

In addition, the adjustment of the coupling channel length affects the amplitude stability of output pulses (see Fig. 3). In the course of experiments, a large amount of measurements of the microwave signal amplitude (100 for each insertion) was performed for estimating the mean-square dispersion. As is seen from Fig. 3, at the optimal length of the coupling channel, more stable generation of the relativistic magnetron microwave radiation is observed.

As a result of optimization of the coupling channel length, it became possible to form a narrow microwave beam in the system of slot radiators, so that the angular width was of about 5 ° FWHM. The radiation spectrum of the adjusted magnetron corresponded to the spectra obtained with the 6-cavity magnetron at optimal adjustment of its channel [6]. The comparison with the calculation results for the anode block frequency spectrum and with the previous experiments (system with a single load) shows that the operating oscillation mode excited in the magnetron is the π-mode.

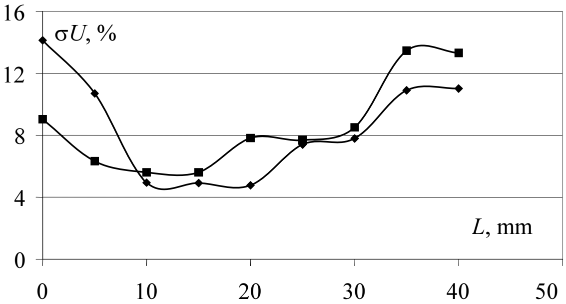

Fig. 3. Mean-square dispersion δU of the signal from the microwave detector at the array axis versus the length L of insertions for two values of the LIA charging voltage

3. Conclusion

As a result of the investigations performed, the laboratory prototype of relativistic magnetron-based directed microwave radiation source with high stability of energetic and spectral characteristics has been developed. One should emphasize such specific feature of the source as the effective system of power extraction, which is the integral part of its design having the direct stabilizing influence on the magnetron. The important technical result should also be noted: we did not observe in the experiments any microwave breakdown of slots that confirms prospects of the proposed method of distributed output of high-power radiation from the relativistic magnetron.

References

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