Reflectors Influence on MWCG Efficiency and Radiation Stability

V.I. Koshelev, M.P. Deichuly

Institute of High Current Electronics, RAS, 4 Akademichesky Ave., 634055 Tomsk, Russia
Phone: +7(3822)491915, Fax: +7(3822)492410, E-mail: koshelev@lhfe.hcei.tsc.ru

Abstract – The investigations that were carried out have demonstrated possibility to increase stability and efficiency of radiation generation at using a distributed reflector.

1. Introduction

Use of reflectors is natural for a backward-wave oscillator not only for microwave radiation removal to the collector direction [1] but for mode transformation [2] as well. Use of the beam-field interaction near the π-type oscillations of the operating mode E_{01} in the overmoded ($D/\lambda >> 1$, D is the diameter, λ is the wavelength) slow-wave structures (SWS) results in direction of some part of radiation power backwards to the cathode side. To optimize a Cherenkov generator with one-sectional SWS having $D/\lambda \approx 3$ by power, it is suggested in [3] to use a flat reflector. At the diode voltage $U_d \approx 500$ kV, radiation pulses with the power of ~ 0.5 GW at the efficiency of ~ 15% have been obtained in the experiments. Microwave pulse length was essentially less than the beam current one.

In the experimental investigations [4, 5] of multiwave Cherenkov generators (MWCG) at $U_d \approx 1$ MV, $I_b \approx 10$ kA we used a diffraction (distributed) reflector placed between the cathode and SWS. The reflector presented a SWS section with three diaphragms; π-type oscillation frequency of the E_{01}-mode of the reflector was less than MWCG generation frequency. Use of a diffraction reflector allowed increasing efficiency and stability of the generator. At the peak radiation power of ~ 2.5 GW and efficiency of ~ 30% a microwave pulse length was equal to the beam current length. At the diode voltage decrease to $U_d \approx 500$ kV and conservation of the beam current $I_b \approx 10$ kA, high ~ 30% efficiency and stability of radiation were realized in MWCG [6] only due to the use of a diffraction reflector.

This paper presents results of detailed comparative experiments studying influence of flat and diffraction reflectors on the MWCG operation.

2. MWCG with Flat and Diffraction Reflectors

Figures 1 and 2 present the schemes of the slow-wave structure with flat and diffraction reflectors, respectively.

The slow-wave structure consisted of two equal sections. Each section contained 5 diaphragms divided with a drift tube.

A diffraction reflector presents a piece of a diaphragmatic waveguide. Slowdown and period were chosen so that the operating frequency of generation should be in the nontransparency band of the E01-mode of the reflector. Resulting from rapid attenuation (at the length of 3–4 periods), the power entering the reflector input of the E01-mode is transformed into the growing inverted waves.

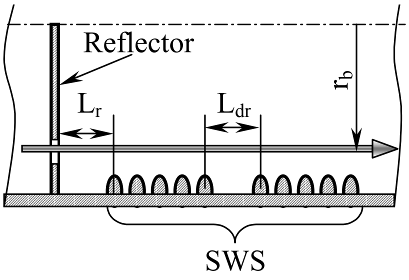

Fig. 1. Scheme of slow-wave structure with flat reflector

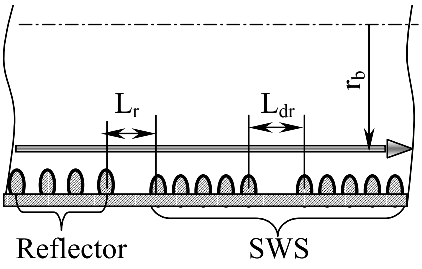

Fig. 2. Scheme of slow-wave structure with diffraction reflector

3. Experimental Investigations

The experimnts were carried out at the Sinus-7M accelerator. A hollow beam with the average diameter $D_b = 2r_b = 104$–116 mm and thickness of 1.5–2 mm was formed at the diode voltage $U_d = 400$ kV. The current pulse of the value $I_b = 13$ kA had the length $\tau_p \approx 40$ ns. The waveguide magnetic field was changed in the limits of $B = 12$–15 kG. Radiation power was determined by measured patterns for two polarizations. A radiation pattern was measured with the probes placed three meters apart the generator. Generation efficiency was determined relative to the diode power $U_d \cdot I_b$.

Figure 3 presents the starting radius of the electron beam versus the distance between the SWS and flat reflector. Figs. 4 and 5 present, respectively, the power and the central wavelength of the output radiation spectrum versus the distance between the SWS and flat reflector L_r.

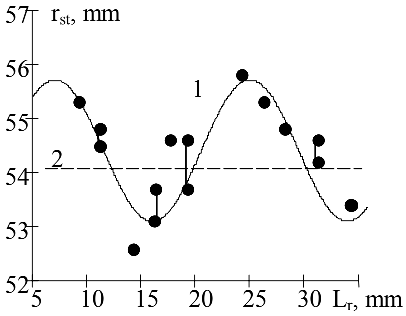

Fig. 3. Starting radius of electron beam versus distance between SWS and flat reflector (1), starting radius without reflector (2)

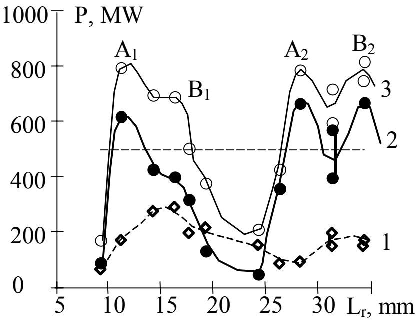

Fig. 4. Radiation power of cross-polarized (1), radially polarized (2) components and their sum (3) versus distance between SWS and flat reflector

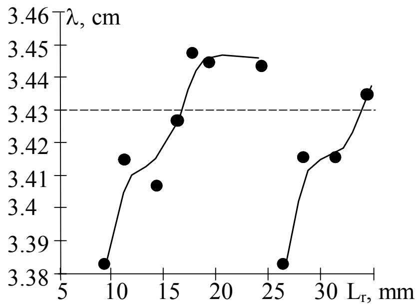

Fig. 5. Central wavelength of radiation spectrum versus distance between SWS and flat reflector

Periodicity is observed in the indicated dependences. The changing period is approximately equal to a half wavelength of the E_{01}-mode of a circle waveguide at the generation frequency $\lambda_w/2 \approx 17.4$ mm. Results of analogous investigations for MWCG with diffraction reflector are shown in Figs. 6, 7 and 8.

In radiaton power dependence on L_r some periodicity is observed as well as in case of using a flat reflector. But in the change of the wavelength and starting radius there is no periodicity. Investigations were carried out for both types of reflectors at large distances between the SWS and reflector ($L_r \sim 15\ \lambda_w$) in the field of expected minimum and maximum by radiation power. It was found out that degree of reflector influence is decreased. For convenience, maxima in the regions of increased power are denoted with the letters A_i and B_i, where i is the number of the region (Figs. 4 and 7). Radiation generation in the maxima A_i and B_i essentially differs by the radiation pattern. The patterns in case of A_1 and B_1 maxima for a diffraction reflector generator are shown in Figs. 9 and 10, respectively. In the maxima A_2 and B_2 the patterns are the same.

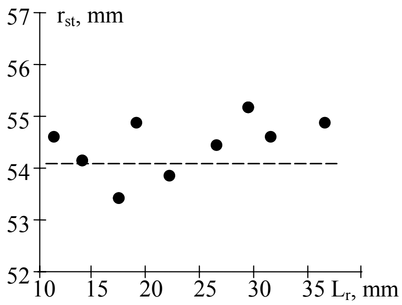

Fig. 6. Starting radius of electron beam versus distance between SWS and diffraction reflector

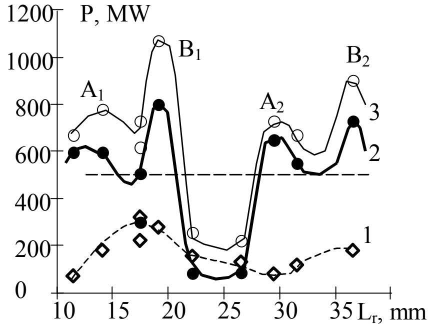

Fig. 7. Radiation power of cross-polarized (1), radially polarized (2) components and their sum (3) versus distance between SWS and diffraction reflector

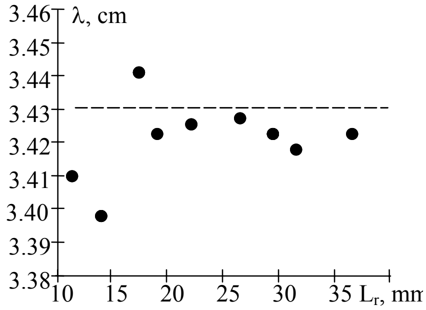

Fig. 8. Output radiation wavelength versus distance between SWS and diffraction reflector

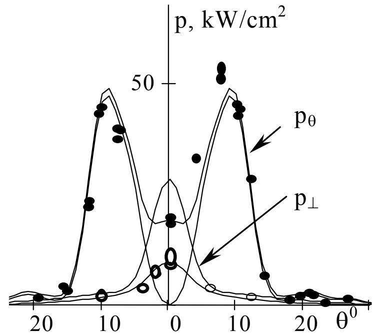

Fig. 9. Pattern of radial (1) and cross-polarized (2) radiation components for diffraction reflector generator at $L_r = 11.4$ mm

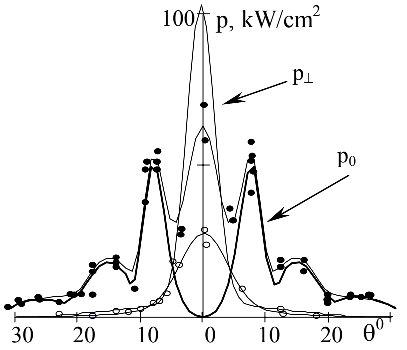

Fig. 10. Pattern of radial (1) and cross-polarized (2) radiation components for diffraction reflector generator at $L_r = 19$ mm

In case of B_i maxima, 20÷30% of radiation power is contained in a cross-polarized radiation component. The power in a radial component is distributed in three lobes. For a flat reflector generator the patterns in the maxima A_i and B_i are the same but they are less stable from pulse to pulse. One can note that in case of $B_{1,2}$ maxima, in the central part of a flat reflector the traces of a high-frequency breakdown appear. Dependences of radiation power on the beam radius for the maxima A and B differ as well (Figs. 11 and 12, respectively).

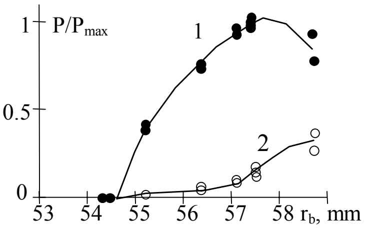

Fig. 11. Power of radial (1) and cross-polarized (2) radiation components versus beam radius for diffraction reflector generator at $L_r = 11.4$ mm

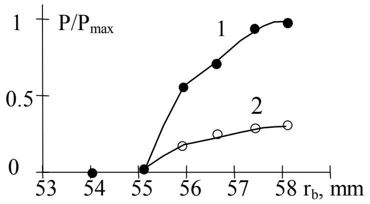

Fig. 12. Power of radial (1) and cross-polarized (2) radiation components versus beam radius for diffraction reflector generator $L_r = 19$ mm

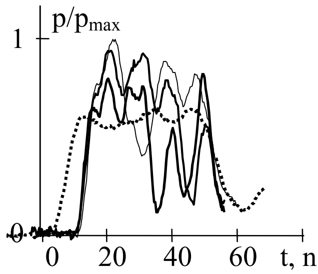

Fig. 13. Waveforms of the radiation envelopes for MWCG without reflector

Waveforms of radiation envelopes for MWCG without reflector, with flat and with diffraction reflectors are shown in Figs. 13, 14 and 15, respectively. Beam current waveform is shown here with a dashed line.

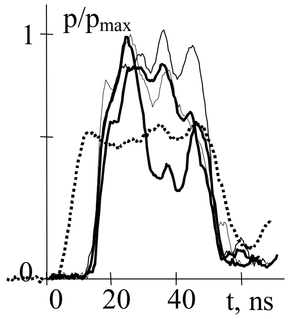

Fig. 14. Waveforms of radiation envelopes for MWCG with flat reflector

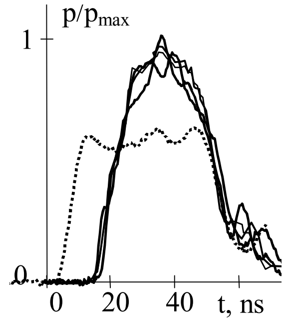

Fig. 15. Waveforms of radiation envelopes for MWCG with diffraction reflectors

We suppose that when a diffraction reflector is used, then the mechanism of the amplitude-phase distortion correction is realized by means of the inverted wave from the reflector [7] and this case explains more stable pattern and output radiation power in comparison with the plane reflector MWCG.

In the region of low powers in the dependences presented in Figs. 4 and 7 a nonsymmetric mode prevails in radiation. Fig. 16 shows a pattern for a flat reflector generator at $L_r = 24$ mm.

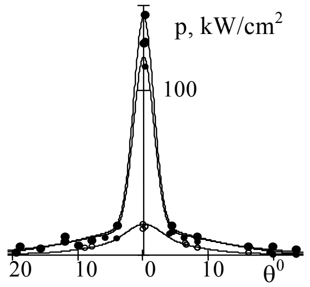

Fig. 16. Distribution of radiation power density for flat reflector generator at $L_r = 24$ mm

4. Conclusion

It is shown that the presence of both flat and diffraction reflectors in front of the slow-wave structure essentially affect the radiation parameters. Influence of a reflector on the radiation generation depends on the distance between the SWS and reflector. It is determined that there are two sets of values of the optimum distance between the SWS and reflector $L_r \approx n \cdot \lambda_w/2 \pm \lambda_w/8 + \delta$, where n is the whole number, λ_w is the wavelength of the E_{01}-mode in a circle tube, and δ is the constant depending on the reflector design features and choice of a reference point. Observance of this condition results in radiation power increase and waveform smoothness. When reflectors are used, radiation power increases by 1.3÷1.4 times and makes up ~1 GW at the diode voltage of 400 kV and electron beam current of 13 kA. Application of a diffraction reflector results in the more stable pattern high radiation power.

References

[1] S.D. Korovin, S.D. Polevin, A.M. Roitman, V.V. Rostov, Pis'ma Zh. Tekh. Fiz. **20**, 12 (1994). (Rus.)

[2] E.B. Abubakirov, A.N. Denisenko, N.F. Kovalev, E.A. Kopelevich, A.V. Savelyev, E.I. Soluyanov, M.I. Fuks, V.V. Yastrebov, Zh. Tekh. Fiz. **69**, 102 (1999) (Rus.).

[3] A.N. Vlasov, A.S. Shkvarunets, J.C. Rodgers, Y.Carmel, T.M. Antonsen, Jr., T.M. Abuelfadl, D. Lingze, V.A. Cherepenin, G.S. Nusinovich, M. Botton, V.L. Granatstein, IEEE Trans. Plasma Sci. **28**, 550 (2000).

[4] M.P. Deichuly, V.I. Koshelev, A.A. Petkun, *in: Proc. 11th Int. Conf. on High Power Particle Beams*, 1996, pp. 221–224.

[5] V.I. Koshelev, M.P. Deichuly, *in: AIP Proc. High Energy Density Microwaves*, 1999, pp. 347–359.

[6] M.P. Deichuly, V.I. Koshelev V.M. Pikunov, V.A. Popov, A.A. Petkun, *in: Proc. 14th Int. Conf. on High Power Particle Beams*, 2002, pp. 287–290.

[7] B.Ya. Zeldovich, V.I. Popovichev, V.V. Rogulsky, F.S. Faizullin, Pis'ma Zh. Eksp. Teor. Fiz. **15**, 160 (1972) (Rus.).