GENERATION AND ACCELERATION OF HIGH-CURRENT ANNULAR ELECTRON BEAM IN LINEAR INDUCTION ACCELERATOR AND MICROWAVE POWER FROM CHERENKOV TWT.

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Abstract: The section of linear induction accelerator (LIA) with a strong guiding magnetic field (up to 1.5 T), with output beam power up to 2 GW and impulse duration 100 ns is created and experimentally investigated. The beam energy gain is equal to 10 keV/cm with the beam current up to 1.5 kA. In LIA it is used annular magneticaly insulated cathode with explosive emission; the large length of the beam propagation (1.5 m) without spoiling of the beam with high beam energy gain is established. The power microwave radiation about 30÷100 MW was achieved from relativistic cherenkov travelling wave tube with high expo-nentional gain on basis of LIA and high-current diode.

1. Introduction

Last time in connection with the problem of linear colliders and compact high gradient accelerators building the great successes were achieved in power microvawe radiation amplifiers of centimetre and millimetre wavelength range with relativistic electron beams application. A linear induction accelerator beams were used in the experiments with the microwave power amplifiers in FELs - [1,2] and in the relativistic klystrons [3,4].

The relativistic cherenkov TWT is attractive in the considered wave range by its simplicity and efficiency. In comparison with FEL the relativistic TWT has a considerable advantage in space exponentional gain (it has a large electron-wave coupling coefficient) and it does not demand large electron energies (space exponentional gain is inversly proportional to the electron energy).

2. Relativistic TWT on the base of SINUS-5.

Our first experiments with the relativistic cherenkov TWT have been done at the Institute of Applied Physics of Academy of Sience USSR (Gorky) with "SINUS-5" [5] -a short pulse accelerator. In this experiments the annular electron beams with 350÷600 keV kinetic energy, 1.5÷2 kA currents and 5 ns duration were used. The beams were formed by annular magnetically insulated cathode with explosive emission. For beam focusing it was used homogeneous longitudinal magnetic field with strength 10 ÷ 20 kG. The slow symmetric electrical wave $E_{0,1}$ of the oversized round waveguide with corrugated side wall have been chosen as an operating one. The input signal at RF wavelength λ=8.24 mm was drived into the operating waveguide through the quasi-optical mirror (Fig.1).

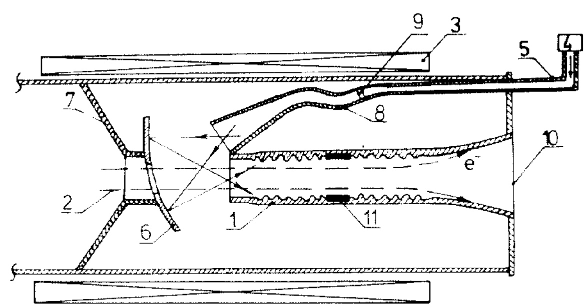

Fig.1. Scheme of the experiment:
1-decelerating corrugated cylindrical -surface waveguide;
2-annular electron beam;
3-magnetic field coils;
4-magnetron;
5-waveguide transmission line;
6-quasi-optical mirror;
7-mirror fastening system;
8-mode transformer;
9 and 10-vacuum windows;
11-microwave absorber.

The space exponentional gain in a linear regime is obtained by the formula

$$K_\ell = \alpha \cdot \frac{\pi\sqrt{3}}{2} \cdot \frac{C}{\gamma_0^2} \cdot \frac{1}{\lambda} \tag{1}$$

where α (in the experiment $\alpha \sim 1$) is determined by particle-wave synchronism detuning and the beam space charge, γ_0 is electron relativistic factor. Parameter C is an analogue of the claccical Pierce's parameter:

$$C = \left(\frac{4 \cdot \gamma_0^3 \cdot Z \cdot e \cdot I}{mc^2}\right)^{1/3} \tag{2}$$

where I is a beam current, Z is an electron-wave coupling impedance. The parameter values were varied in the experiment in the range C=0.4÷0.55 by varying Z when the electron beam diameter was changed. The exponentional gain gradient and efficiency calculated values were equal to 3÷4 dB/cm and 20 % accordingly. In the experiment when the Pierce's parameter had the smaller value C = 0.4 the output power had a linear dependence as a function of the input power, but when C =0.55 the output power saturation was observed (Fig.2).

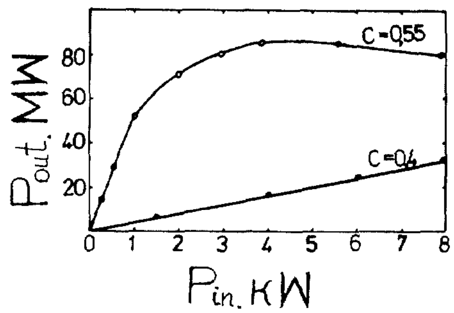

Fig.2. Output power as a function of input signal.

The measured exponentional gain gradient corresponded to the calculated values. The total exponentional gain was equal to K_1=48±2 dB in a linear regime and K_s= 44±2 dB -in a power saturation regime. The peak power was equal to 70 ÷ 100 MW with input signal power 4 kW and beam efficiency 8 ÷ 11 %. The radiation pulse duration was close to the current pulse duration 4 ns. The efficiency value obtained by experiment was two times less than calculated one, that can be evidently explained by EH_{11} mode admixture at the level 5÷10 % with the basic power that is coursed by imperfection of radiation input into the oversized waveguide.

The second run of the experiments that is specified by its greater electron beam pulse duration, have been done at JINR using one section of the linear induction accelerator that had been modified from the section intended for electron-ion ring acceleration.

3. Linear induction accelerator of the annular beam.

The block diagram of the installation is shown in Figure 3.

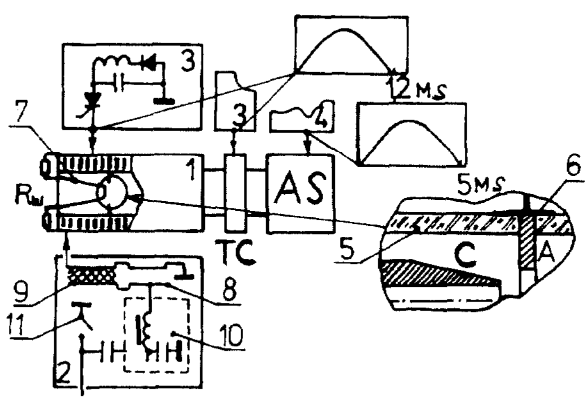

Fig.3. Scheme of the experimental plant.

A modulator (2) drives one section (1) 180 cm long, consisting of 18 inductors. There are two permalloy cores in each of inductor having the dimensions 460 x 230 x 25 mm^3. The guiding magnetic field forming system (3) permits to produce the pulse magnetic field with strength B_z up to 15 kG and 1.2 ms pulse duration in the accelerator aperture 170 mm in diameter practically without inductor cores magnetizing.

The accelerator section with help of transition chamber (TC) is adjusted to additional solenoid (AS) where diagnostics devices and different electrodynamic structures for experiments on microwave relativistic electronics may be placed. The magnetic field strength in AS is up to 15 kG with 5 ms pulse duration. The modulator contains a forming line with linear (8) and non-linear (9) sections, three magnetic generator pulse chains for power compression (10) and comutator-thyratron (11). The peak modulator power working on the equivalent load is equal to 7.5 GW.

The electron-emitting source having magnetized annular cathode with explosive emission is situated in a first third of the accelerator section. The graphite cathode (C) and anode (A) location in the dielectric accelerating tube 120 mm in diameter are shown in Figure 3. The voltage summation with respect to 1/3 of the section is provided by metallic cathode-holder.

We have attained 1.7÷1.8 MV summary accelerating voltage with 1.3÷1.5 kA beam current, the impulse voltage plateau is equal to 60 ns (Fig.4).

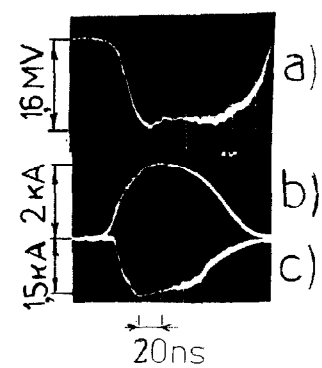

Fig.4. a) summary accelerating voltage pulse; b) diode current pulse; c) current pulse observed at the section exit.

The measured peak energy of accelerated electrons is equal to 1.5 MeV, peak beam power of 2 GW has been achieved, maximum electric field strength in accelerating regime that was achieved on the last 2/3 of the section length (ignoring diode) is 10 kV/cm.

It have been shown experimentally that the kinetic energy of the accelerated in the section beam differs from the corresponding voltage approximately by an amount of potential difference between the beam boundary and accelerating tube wall.

The beam cross-section dimension have been measured in TC and AC with the help of images on tin-plate. A characteristic image at the distance 120 cm from the cathode corresponding to the cathode diameter is shown in Figure 5a. The beam compression in AS have been accomplished by changing magnetic field strength on the cathode. In Figure 5b) and c) the beam images in AS obtained in identical conditions exept the acceleration rate in the accelerating section part (b-acceleration rate is 3 kV/cm c -7 kV/cm) are snown. This images are illustrating the decrease of the diocotron instability space increment under the beam acceleration and possibility of the annular

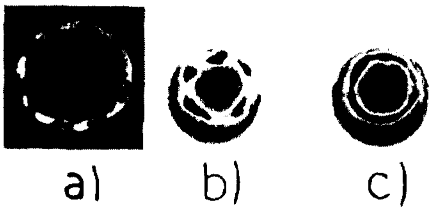

Fig. 5. Electron beam images on the target.

electron beam transportation at a great distance when acceleration rate is large.

4. TWT amplifier on the LIA.

The using LIA experiments on microwave power amplification have been done with the following beam parameters: beam energy 500 ÷ 800 keV, current 0.5 ÷ 0.7 kA, pulse duration about 60 ns.

The energy increase and electron current decrease as compared with the first run of the experiments led to the Pierce's parameter lowering. However, inspite of this, the possibility of the system self-exitation was higher in the second run of the experiments because of the greater current pulse duration. Therefore for parasitic self - exitation suppression one was forced to use in consisted of two sections TWT microwave absorber providing greater than in the first run of the experiments wave damping up to 10 ÷ 20 dB. In accordance with calculation in the experiment it have been obtained exponentional gain 1.5 dB/cm. If the electron energy have been within the amplification band the microwave pulse duration was close to the current duration. As in the first run of the experiments the output emission on the whole consisted of $E_{0,1}$ wave and small addition of the nonsymmetrical types of waves. Soon after the microwave filter made in the form of cylindrical-surface waveguide section having the longitudinal slots, letting $E_{0,1}$ wave pass and suppressing $H_{m,1}$ waves (in which the slow waves are converted on the matched transition from the corrugated waveguide to uniform one) have been set into the output waveguide transmission line, the radiation power diminished not more than on 5 ÷ 10 % but the field structure and its polarization began to correspond to the "pure" $E_{0,1}$ wave (Fig.6). The peak radiation power was 25 ÷ 30 MW with the exponentional gain 35 ÷ 38 dB and efficiency 10 %.

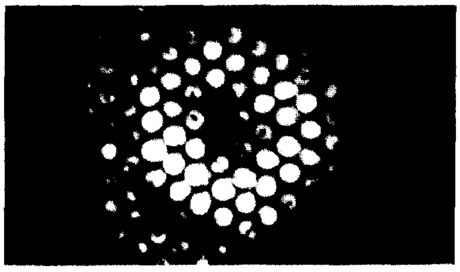

Fig.6. Picture of the neon-filled lamps annunciation panel glow under the action of the output microwave radiation.

The made experiments have demonstrated the possibility and relative simplicity of achieving in relativistic cherenkov millimeter wavelength range TWT of large pulse power (up to 100 MW) with the great exponentional gain (close to 50 dB).

References

[1] T.J.Orzechowski et al., "Microwave Radiation from a High - Gain Free-Electron Amplifier", Phys. Rev. Lett., vol.54, pp. 889-892, March 1985.

[2] Yu.B.Victorov et al., "The Experiments on Amplificatin of Millimetre Wavelength Radiation in Undulator", in Proceedings of the XI All-Union Conf. on Charged Particle Accelerator, Dubna, USSR, vol.II, 1989, pp. 95÷98.

[3] A.M.Sessler and S.S.Yu, " Relativistic Klystron Two-Beam Accelerator, Phys. Rev. Lett., vol.58, pp. 2439-2442, June 1987.

[4] M.A.Allen et al., " Relativistic Klystron Research at SLAC and LNL", in Proceeding of the VII Intern. Conf. on High Power Beams, Karlsruhe, Germany, vol.II, 1988, pp. 1429-1434.

[5] I.E.Botwinnik et al., " Experimental Investigation of the Convectiv Cherenkov Relativistic electron Beam Instability", in Proceedings of the VII All-Union Conf. on High Current Electronics, Tomsk, USSR, vol. II, 1988, pp. 191÷193.