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

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Last time in connection with the problem of linear colliders and compact high gradient accelerators building the great successes were achieved in power microwave radiation amplifiers of centimetre and millimetre wavelength range with relativistic electron beams application. A linear induction accelerator (LIA) 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 inversely proportional to the electron energy).

Our first experiments with the relativistic Cherenkov TWT have been done at the Institute of Applied Physics of Academy of Siences 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_{01} of the oversized round waveguide with corrugated side wall has been chosen as an operating one. The input signal at RF wavelength λ =8.24 mm was driven into the operating waveguide through the controlled attenuator by the quasi-optical mirror (fig.1). The space exponentional gain in a linear regime is obtained by the formula

$$K_e = \alpha \cdot \frac{\pi \cdot \sqrt{3}}{2} \cdot \frac{C}{\gamma_0^2} \cdot \frac{1}{\lambda}, \qquad (1)$$

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 classical Pierce's parameter:

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

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

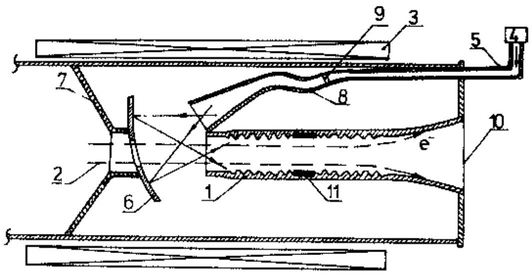

Fig.1. Scheme of the experiment: 1-decelerating corrugated cylindrical -surface waveguide; 2-annular electron beam; 3-magnetic field coils; 4-magnetron; 5-waveguide transmission line; 6-quasi-optical mirror; 7-mirror fastening system; 8-mode transformer; 9 and 10 -vacuum windows; 11-microwave absorber.

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). 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 sigual 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 the 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.

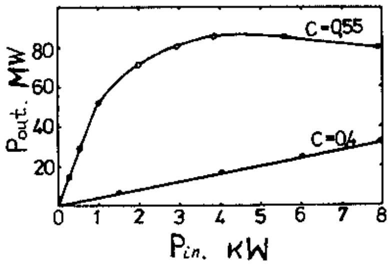

Fig.2. Output power as a function of input **signal**.

The second run of the experiments that is specified by its greater electron beam pulse duration, **has** 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. The block diagram of the installation is shown in Figure 3. A modulator (2) drives one section (1) 180 cm long, consisting of 12 inductors. There are two permalloy cores in each of inductor having the dimensions 460 x 230 x 25 mm^3 . The guiding magnetic

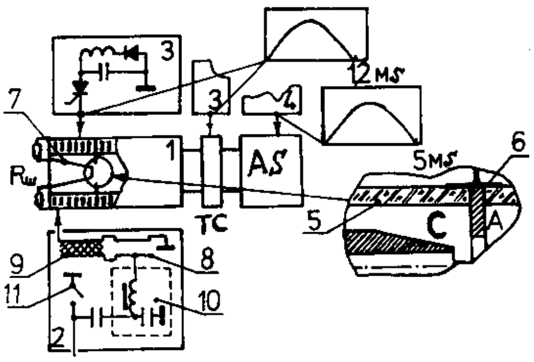

Fig.3. Scheme of the experimental plant.

field forming system (3) permits one to produce the pulse magnetic field with strength B_z up to 15 kG and 1.2 ms pulse duration in the accelerator apperture 170 mm in diameter practically without inductor cores magnetizing.

The accelerator section with the 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 commutator-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 in the LIA section. The impulse voltage plateau is equal to ~60 ns (Fig.4). 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 has 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 has been measuared 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

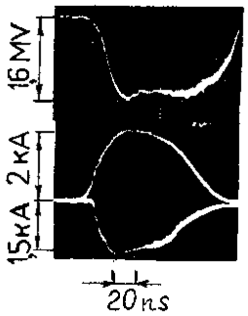

Fig.4. a) Summary accelerating voltage pulse; b)diode current pulse; c)current pulse observed at the section exit.

is shown in Figure 5a. The beam compression in AS has bean accomplished by changing magnetic field strength on the cathode. In Figure 5 b) and c) the beam images in AS obtained in identical conditions except the acceleration rate in the accelerating section part (b-acceleration rate is 3kV/cm, c-7 kV/cm) are shown. These images are illustrating the decrease of the diocotron instability space increment under the beam acceleration and possibility of the annular electron beam transportation at a great distance when acceleration rate is large.

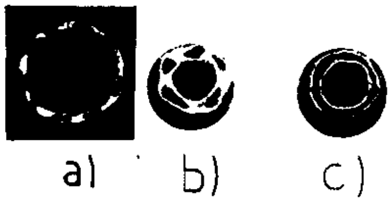

Fig.5. Electron beam images on the target.

The 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-excitation suppression one was forced to use consisting 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 has been obtained exponentional gain 1.5 dB/cm. If the electron energy has 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 the uniform one), has 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 %.

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)

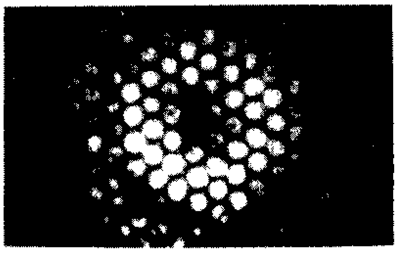

Fig. 6. Still picture of the annunciation panel glow of neon-filled lamps under the action of the output microwave radiation.

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Формирование и ускорение сильноточного трубчатого пучка электронов в ЛИУ и получение мощного СВЧ-излучения миллиметрового диапазона в черенковской ЛБВ

Создана и экспериментально исследована секция ЛИУ с сильным ведущим магнитным полем (до 1,5 Тл), с выходной мощностью в пучке до 2 ГВт при длительности импульса 60 нс. Темп набора энергии составляет 10 кэВ/см при токе пучка до 1,5 кА. В ЛИУ использован трубчатый взрывоэмиссионный замагниченный катод, экспериментально установлена большая длина транспортировки (1,5 м) пучка без ухудшения качества пучка при высоком темпе набора энергии. На базе ЛИУ и сильноточного диода при высоком пространственном коэффициенте усиления в релятивистских черенковских ЛБВ миллиметрового диапазона достигнуты мощности 30 ÷ 100 МВт.

Работа выполнена в Лаборатории сверхвысоких энергий ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1990

Abubakirov E.B. et al. E9-90-407
Generation and Acceleration of High-Current Annular Electron Beam in Linear Induction Accelerator and Generation of the Power Microwave Radiation from Cherenkov TWT

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 beam pulse duration 60 ns is created and investigated by experiment. The beam energy gain is equal to 10 keV/sm with the beam current up to 1.5 kA. In LIA the annular magnetically insulated cathode with explosive emission is used; the large length of the beam propagation (1.5 m) without spoiling of the beam with high beam energy gain has been established. The microwave radiation power about 30 ÷ 100 MW has been achieved from relativistic Cherenkov travelling wave tube (TWT) with high exponentional gain on the basis of LIA and high-current diode.

The investigation has been performed at the Laboratory of Superhigh Energies, JINR.

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