CW LINEAR ACCELERATOR WITH HIGH BEAM CURRENT

A.Alimov, A.Chepurnov, O.Chubarov, K.Gudkov, D.Ermakov, V.Shvedunov
Institute of Nuclear Physics, Moscow State University
RU-119899, Moscow, Russia

Abstract

The results of the experimental investigation of CW linear accelerator at the energy of 600 MeV and beam power up to 5 kW are presented. A simplified RF power supply system for driving the accelerator section and the buncher is described. The results of the experiments on capturing a DC electron beam of an electron gun are presented. The results of these investigations make it possible to design a CW powerful electron accelerator for industrial applications.

Introduction

For a long time the main sources of electrons with high mean power at low energies were DC accelerators and pulsed linear accelerators. The development of new technologies requires an increase of a penetration capability of electron beams by means of increase of their energy and average beam power. For these purposes a CW mode of operation is more preferable than a pulsed one or a DC acceleration. Transition to a CW acceleration enables, in principle, to cover a new field of energies and beam powers (up to 10 MeV and 1 MW).

Development of powerful CW linacs requires solution of a number of problems connected with effective capturing of particles into acceleration, design of powerful and reliable CW klystrons, and simple RF power supply systems.

The present paper deals with experimental investigation of electron capturing into acceleration and RF power system design.

Accelerator description. Accelerator structure parameters

Block-diagram of a prototype one-section accelerator is shown in Fig.1.

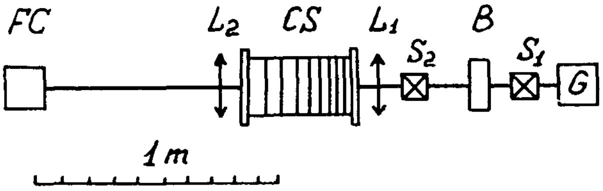

Fig.1. Block-diagram of the accelerator.

A DC electron beam of the gun (G)[1] with the energy from 70 to 100 keV, the current from 0 to 16 mA, and normalized transverse emittance 5 mm*mrad enters the buncher cavity (B). As a buncher we use a cylindrical copper cavity with TM_{010} mode at a frequency of 2450 MHz. The buncher has a probe for power supply and a probe for field control. Fine frequency tuning of the buncher is made by a tuning plunger, which makes it possible to vary the resonant frequency of the buncher in the range of 2450 ± 2 MHz. Loaded quality factor of the cavity $Q_l = 3500$ with a coupling constant 1.0. The calculated value of intrinsic quality factor $Q_0 = 9000$, shunt impedance $R = 1.4$ MΩ. After the buncher the beam enters the accelerator section with graded-β (capture section, CS). Beam current and power at the accelerator output are measured by the Faraday cup (FC). To focus the beam, solenoidal lenses L_1 and L_2 are used. Beam alignment is carried out by steerers (S_1 and S_2).

The investigation was carried out with capture section with graded-β designed for the injector linac of Moscow CW RTM [2]. The capture section is made on the basis of on-axis coupled accelerator structure with effective shunt impedance 78 MΩ/m (for ß = 1) and operation frequency 2450 MHz. It consists of 9 accelerating cells, which are similar to ß = 1 cells [3] and differ only in the length of the central part and in the width of the accelerating gap. The capture section construction, position of cooling channels, and pumping are similar to the accelerator section with ß = 1 described in [3].

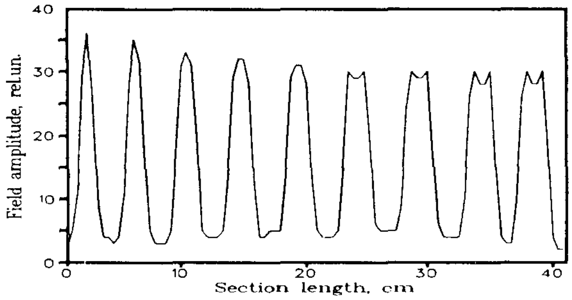

Fig.2. Accelerating field distribution on the section's axis.

Fig.2 shows the results of bead-pull measurements of the field distribution on the section axis. The capture section loaded quality factor Q_l = 7000, and the coupling with a feeding waveguide is 1.2 (overcoupling).

RF power supply system

One of the problems of CW operation of accelerator structures is a shift of a resonant frequency as a result of thermal deformations of the structure during start-up. This frequency shift depends on a level of RF power losses and on cooling efficiency. For our accelerator structure with circumferential cooling only, the frequency shift can exceed the bandwidth of a resonant curve at moderate values of RF losses (20 kW, at RF frequency 2450 MHz) [3]. Dependence of the structure resonant frequency on the dissipated RF power results in an asymmetry of a resonant curve and can be interpreted as a non-linear resonance.

In these conditions the most simple and reliable method of operation of one-section accelerator is a self-excited mode in a positive feedback loop between klystron and accelerator section. In this mode of operation the system oscillates at a section's resonant frequency and is automatically followed by the klystron's frequency.

Block-diagram of the accelerator RF system is shown in Fig.3. A 22 kW CW klystron (K) at the frequency of 2450 MHz [3] is used to drive the accelerator section (CS).

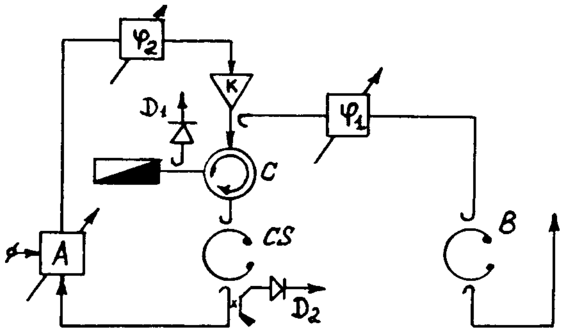

Fig.3. Block-diagram of the accelerator RF system.

The klystron is isolated from the section by a T-circulator (C). The signal of the section which is taken from the RF probe passes through the electrically driven coaxial phase-shifter (φ_2), p-i-n attenuator (A) and enters the klystron. Phase conditions of self-excitation are chosen by the phase-shifter. The feedback p-i-n attenuator regulates the output power of the klystron, and, hence, the amplitude of the accelerating field. Reflected power level is controlled by a diode D_1 ; the accelerating field amplitude, by a diode D_2 . D_2 -signal is used by the system of amplitude stabilization, which controls the p-i-n attenuator current, stabilizing the amplitude of the accelerating field in the section. Such a stabilization is very essential for our system with high beam loading.

Part of the klystron power (~ 60 W) is used to drive the buncher. This signal is taken from a probe in the output waveguide of the klystron; it passes through the isolators and phase-shifter (φ_1) and enters the buncher.

We also control a flow and temperature of inlet and outlet water passing through the section and Faraday cup in order to measure the power dissipated in section walls and the power of electron beam.

Beam acceleration experiments

Beam acceleration experiments were carried out in three stages. At the first stage we chose the phase and amplitude of the buncher to obtain the maximum capture efficiency. Dependence of the output beam current on the buncher phase (respective to the section phase) is shown in Fig.4.

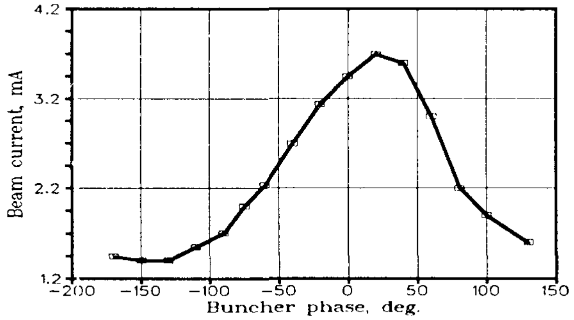

Fig.4. Dependence of the output beam current on the buncher phase.

The buncher phase was being adjusted by a phase- shifter φ_1 (see Fig.3). The dependence has the expected sinus form and enables to choose the optimal phase of the buncher. It was measured at gun voltage V = 80 kV, cathode current I_{cath} = 7 mA, section power P_{cs} = 10 kW, and buncher power P_B = 60 W. The output beam energy was 600 keV.

Fig.5 shows the dependence of the output beam current on the power, dissipated in the buncher. The measurements were made at the optimal value of buncher phase. The buncher power was regulated from 0 to 66 W by means of rotating the RF probe in the output waveguide of the klystron. This dependence was measured at gun voltage U = 80 kV, cathode current I_{cath} = 6.8 mA, output beam energy 600 keV.It is seen that the output current is constant in the range of buncher power 40 - 66 W.

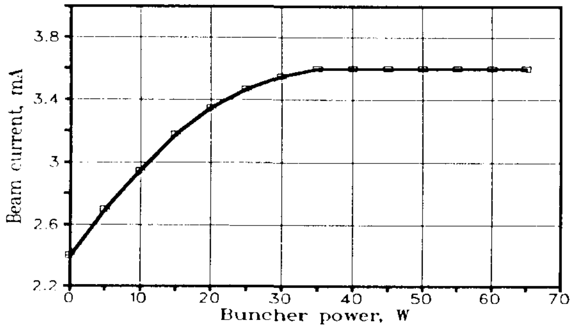

Fig.5. Dependence of the output beam current on the buncher power.

Capture efficiency, which can be defined as a relation of the output beam current to the cathode current, is equal to 35% when the buncher is switched off, and increases up to 53% at the optimal level of buncher power 40 - 66 W.

At the second stage, after choosing the parameters of the buncher, we measured the dependence of the output beam current on the power, dissipated in the section walls (Fig.6).

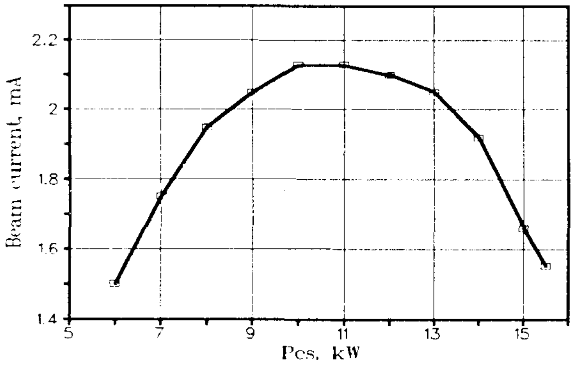

Fig.6. Dependence of the output beam current on the power dissipated in the section walls.

The measurements were carried out at gun voltage U = 80 kV, cathode current I_{cath} = 4.0 mA. The optimal value of dissipated RF power is 10.5 kW, which corresponds to the level of RF losses 26 kW/m. Output beam energy is 600 keV at the injection energy of 80 keV.

At the third stage of the investigation we tried to obtain maximum beam current and beam power to see whether the accelerator operation is stable or not. The maximum value of beam current was limited by the parameters of the gun power supply and amounted to 16 mA. Dependence of the beam power on the cathode current up to 16 mA was linear. This means that space charge effects have no influence at these currents. With the capture efficiency of 53% the output beam current was equal to 8.4 mA at beam energy of 600 keV. This corresponds to the beam power of 5 kW. The accelerator operated under these conditions for 48 hours without additional tuning of its parameters.

Summary

The prototype one-section CW linear accelerator with a simple RF power supply system was constructed. The electron beam with the energy of 600 keV and beam power of 5 kW was obtained at this accelerator.

Next steps in this work are the following:

1) construction of a two-section accelerator at the energy 1.2 MeV and beam power 10 kW;

2) modification of the electron gun power supply system and increase of the beam power up to 10-11 kW for one-section accelerator (E=600 keV) and to 20-22 kW for two-section accelerator (E=1.2 MeV).

References

[1] B.S. Ishkhanov et al. "100 keV Electron Gun for Moscow CW RTM", Pribori i Technica Experimenta, 3 (1987), pp. 24-26 (in Russian).

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[3] A.S.Alimov et al. "Operational Experience with Room Temperature Continuous Wave Accelerator Structures", Nucl.Instr. and Meth. A328 (1993) pp. 385-397.