Two Section CW Electron Linac

for Industrial Applications

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Abstract

The results of the experimental investigation of one and two section linacs with the energies of 600 keV and 1.1 MeV and beam power up to 3 kW are presented. The variants of RF power supply system for multi-section accelerator are described. The results of these investigations make it possible to design a powerful electron accelerator for industrial applications.

1. INTRODUCTION

Up till now the main sources of electrons with high average power at low energies were DC accelerators and pulsed linear accelerators. The development of new technologies requires an increase of the penetration capability of electron beams by means of increase of their energy and average beam power.

The transition to a CW mode enables to work in a new field of energies and beam powers (about 10 MeV and 1 MW) which are inaccessible for other types of accelerators.

The development of powerful CW linacs faces a number of problems.

1. Because of a relatively low values of accelerating fields in a CW mode and a high average power of the electron beam, effective capturing of the particles into acceleration and acceleration without losses presents a serious problem.
2. Powerful accelerators require RF klystrons with high average power and, as a rule, can be designed as multi-section accelerators, each section being supplied by a separate klystron.
3. The characteristics of the existing room-temperature accelerator structures do not allow to reach the maximum characteristics of CW linacs.

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

2. ONE SECTION ACCELERATOR

2.1 Parameters of the Accelerating Section

A prototype one section accelerator was designed to carry out investigations on electron capturing. A DC electron beam of the gun [1] with the energy from 70 to 100 keV and a current from 0 to 12 mA, normalized transverse emittance 5 mm*mrad, entered the accelerating section with graded-β (capture section). A 45° magnet at the output of the section served to measure the accelerated beam energy and spectrum. Beam current and power at the accelerator output were measured by Faraday cups placed at 0° and 45° to beam direction. To focus the beam solenoidal lenses were used. Parasitic magnetic fields were compensated by steerers.

The investigation was carried out with two capture sections designed for the Moscow CW RTM injector [2]. Both sections were made of on-axis coupled accelerator structure with effective shunt impedance 78 MOhm/m (β=1) and operation frequency 2450 MHz. In the first variant the accelerating section consisted of 17 cells, in the second of 9 cells of graded-β. Accelerating gradient for both sections was about 1 kW/m, corresponding RF losses 9 kW for short section and 17 kW for long one.

2.2 RF Power 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 startup. This frequency shift depends on a level of RF power losses and on cooling efficiency. For our accelerator structure with circumferencial cooling only, the frequency shift can exceed the bandwidth of a resonant curve at moderate values of RF losses (20 kW/m 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 which can be interpreted as a non-linear resonance.

In this 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 accelerating section. In this mode of operation the system oscillates at a section's resonant frequency and the klystron frequency follows it automatically [3].

The block-diagram of the RF system of one section accelerator is shown in Fig.1. A 22 kW CW klystron at the frequency of 2450 MHz was used to drive the accelerating section. The klystron was isolated from the section by a T-circulator. The signal of the section which was taken from the RF probe passed though the phase-shifter, attenuator and entered the klystron. Phase conditions of self-excitation were regulated the output power of the klystron, and, hence, the amplitude of the accelerating field.

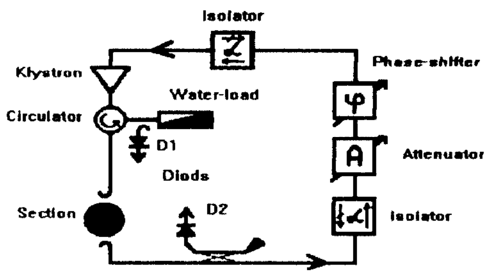

Fig.1 Block-diagram of
the RF system for one section accelerator.

The accelerating field amplitude was controlled by a diode D2. The level of reflected power was controlled by a diode D1. We also controlled a flow and temperature of inlet and outlet water, passing through the section and Faraday cup. This made it possible to measure the power dissipated in section walls and the power of electron beam.

2.3 Measurements of Energy Spectra

The aim of the experiment was to define the conditions of maximum capturing of the electrons into acceleration, without additional bunching of a gun beam. Voltage of the gun and RF power in the section, proportional to the amplitude of the accelerating field, were varied during the measurements. The capture efficiency was estimated by measuring energy spectra of the output beam. Fig.4a and Fig.4b show high energy parts of beam spectra measured at 9- and 17-cell sections for different values of electron gun voltages, RF power losses in the walls (curves 1, 2, 3).

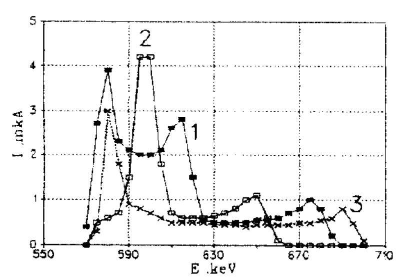

Fig.2a High energy part of the spectrum measured at 9-cell section

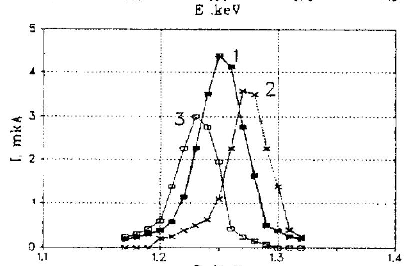

Fig.2b High energy part of the spectrum measured at 17-cell section

The optimal level of RF losses for both sections was 1 kW per cell and injection energy 100 keV. Maximum capture efficiency for short section was 27%, for long section - 21%.

3. TWO SECTION ACCELERATOR

3.1 Block-diagram of the Accelerator

Block-diagram of two section accelerator is shown in Fif.3. This accelerator included the same electron gun, described in section 1, a buncher, placed at the output of the gun, capture section consisting of 9 cells with graded-β, the electrically isolated aperture with cooling and the second accelerating section consisting of 7 accelerating cells. First three cells of this section had β=0.945 and next four cells had β=0.975. Beam was focused by two solenoidal lenses, placed at the input and output of the first section.

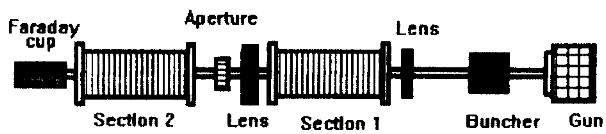

Fig.3 Block-diagram of two section accelerator

As a buncher we used a cylindrical copper cavity with TM010 mode at a frequency of 2450 MHz. The buncher had a probe for power supply and a probe for field control. Fine frequency tuning was made by a tuning plunger. Loaded quality factor of the cavity was Ql=3500 with a coupling constant 1.0. The calculated value of intrinsic quality factor Qo=9000, shunt impedance R=1.4 MOhm.

3.2. RF Power Supply System

A transition from one to two section accelerator considerably complicates the structure of the RF system. This complication is connected with a necessity to phase the sections and with a presence of different frequency shifts of the sections as a result of RF losses in the walls of the structures. Block-diagram of the RF system for two section accelerator is shown in Fig.4.

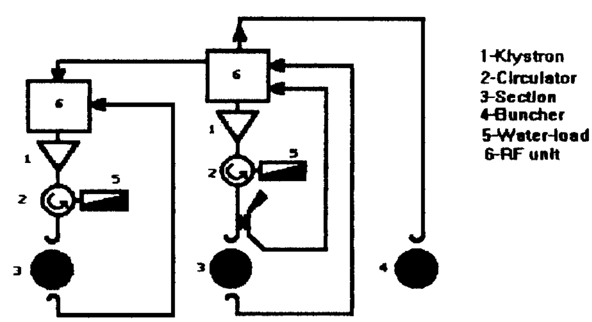

Fig.4 Block-diagram of the RF system for two section accelerator

The first section operated in a self-excited mode and formed a reference signal for the second section and for the buncher cavity. To increase frequency stability of this mode of operation the field amplitude was stabilised with a help of p-i-n attenuator at the level of 10^{-3}. Other sources of frequency instability, such as water temperature and flow, changed practically in the same way for both sections.

3.3. Beam Acceleration Experiments

Beam acceleration experiments with two sections were carried out in two stages. At the first stage the buncher was switched off and we chose phases of sections 1 and 2 to obtain maximum current and maximum beam power at the Faraday cup. At the second stage we switched the buncher on and in the same way chose the phase difference between the first section and the buncher. At two section accelerator the electrons which were not captured into acceleration by the first section could not reach the Faraday cup because the focusing length of the lens L2 for low energy electrons was several centimetres and these electrons could not pass through the aperture. Hence, the capture efficiency could be estimated as a relation of the current at the Faraday cup to the cathode current of the gun. The estimation of the beam energy using the relation E = P/I is a good approximation for the energy of the output bunch.

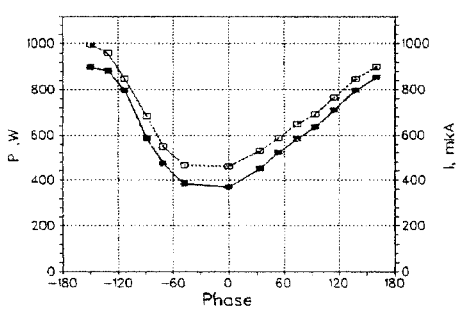

Fig.5 Phase dependence of the beam energy(open) and beam power(dashed)

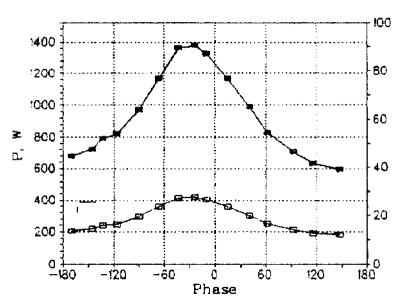

Fig.6 Phase dependences of the beam power(dashed) and capture efficiency(open)

Fig.5 shows dependences of the beam power and beam energy on the phase between the sections when the buncher is switched off. The maximum capture efficiency was 20%, maximum beam power 900 W. Changing the phase between the sections it is possible to vary the beam energy in the range 0.4 - 1 MeV with the corresponding capture efficiency 16 - 20%. The value of cathode current was 5 mA.

The buncher action on the beam is shown in Fig.6, where dependences of the beam power and capture efficiency on the phase between the first section and the buncher are presented. In these experiments the gap voltage of the buncher because of technical reasons was limited by the value of 4.7 kV - two times lower than the optimal value. Nevertheless, the influence of the buncher is clearly seen from the figure. The beam power changes in the range 650 - 1400 W, corresponding capture efficiency is 14 - 28% and the beam energy is practically constant : 950 ± 75 keV. The value of cathode current was 5 mA.

The maximum cathode current was limited by the parameters of the gun power supply and amounted to 12 mA. With the increase of the cathode current the beam power increased linearly and at the cathode current of 12 mA was equal to 3.0 kW.

4. SUMMARY

The prototype of two section CW linear accelerator with a simple RF power supply system, which makes it possible to increase the beam energy and power by increasing the number of the accelerating sections without considerable complication of the system was constructed. The electron beam with the energy of 1 MeV and beam power of 3 kW was obtained at this prototype accelerator. Beam energy can be regulated in the range 0.4 - 1.0 MeV by changing the phase difference between the sections.

The next step in this work will be optimisation of the buncher, the electron gun power supply system and increase of the beam power up to 8 - 10 kW.

5. 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).

[2] A.S.Alimov et al. "Performance of the 6 MeV Injector for the Moscow Racetrack Microtron". Nucl. Instr. and Meth. **A326**, 1993, pp. 391-398.

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