EXPERIMENTAL RESEARCHES OF HIGH-POWER ELECTRON BEAM CHARACTERISTICS PERFORMED ON A RESONANCE ACCELERATOR OF CONTINUOUS OPERATION

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Abstract

A resonance accelerator [1] is being created in RFNC-VNIIEF to generate a beam with electron energy from 1.5 to 7.5 MeV and average beam power up to 300 kW. The accelerator basis is half-wavelength coaxial cavity. Electrons gain required energy after multiple passes through accelerating cavity.

The present paper gives the results of electron dynamics computer simulation in terms of space charge effect. Electrons injection parameters into the accelerating cavity, which allows beam production with sufficient electron energy, were defined.

Novel experiments on the facility were carried out at the RF power level up to 180 kW. The measured electron energy after the first pass of acceleration is 1.5 MeV. Then the beam turns back to the accelerating cavity with the aid of the beam recirculation system. The measured electron energy after the second pass is 3 MeV. Energy spectrum of electrons in a bunch also was determined and the average beam current was measured on each acceleration stage.

INTRODUCTION

The produced accelerator is designed to operate both in pulse-periodic and continuous mode of radiation production. The design and principle of such accelerator operation are minutely described in paper [1].

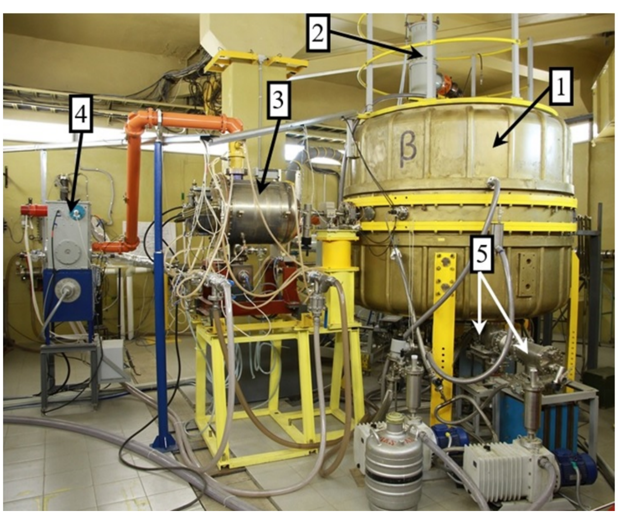
At present the accelerator complex (Fig. 1) involves a coaxial accelerating cavity (100 MHz), RF injector (100 keV, 40 mA), RF generator (180 kW), RF power input unit, vacuum system, cooling system, automated control system as well as some elements of beam transport, delivery and extraction systems.

Acceleration process is based on multiple passes of electron beam through the accelerating gaps of coaxial half-wavelength cavity (type of oscillations T_1) on the level of median plane where the magnetic component of RF field is entirely absent

Electric field distribution in accelerating gaps arised in the cavity at RF power of ~ 165 kW is sufficient for electron energy gain up to 1.5 MeV per one pass in the accelerating phase of RF field.

BEAM DYNAMICS CALCULATION

The calculation of electron beam dynamics was performed using program ASTRA [2]. The basic task at this stage is to define the criteria of electron beam injection to the accelerating cavity at which the sufficient conditions for electron energy gain by 1.5 MeV per one pass with minimum current losses at all sections are realized.



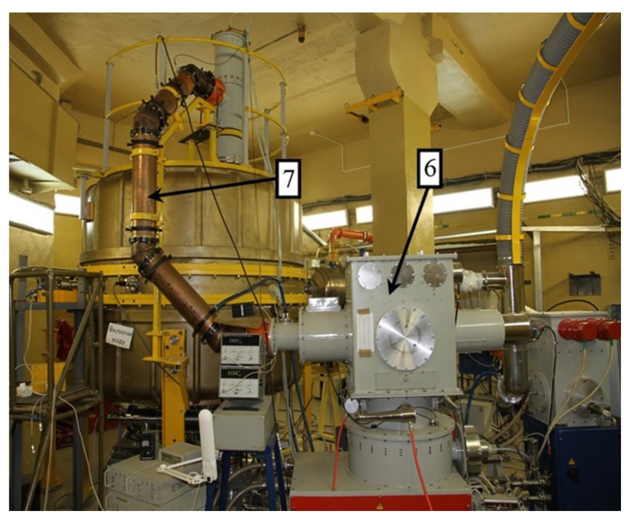


Figure 1: Accelerator external view: 1 – accelerating cavity; 2 – RF power input unit; 3 – RF injector; 4 – generator of RF injector 16 kW; 5 – vacuum pumps; 6 – RF generator 180 kW; 7 – coaxial feeder.

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The calculation was performed using scheme, shown in Fig. 2. At single pass through the accelerating cavity (4) the electrons get the energy of 1.5 MeV. Then, the electron beam turns back to the cavity by bending magnet (5) where electrons are accelerated up to the 3 MeV energies.

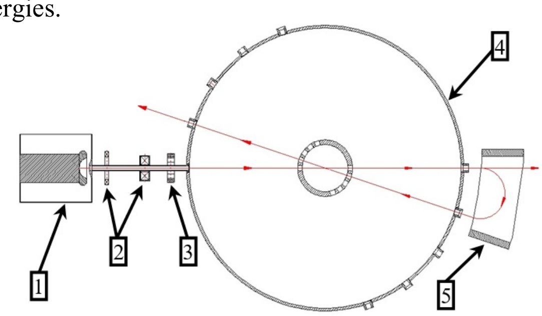
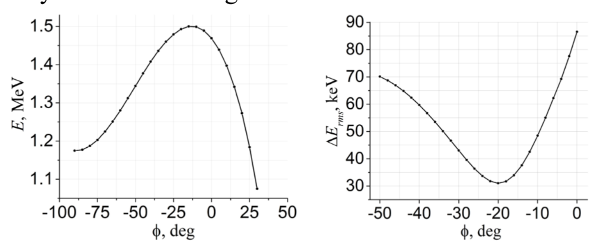


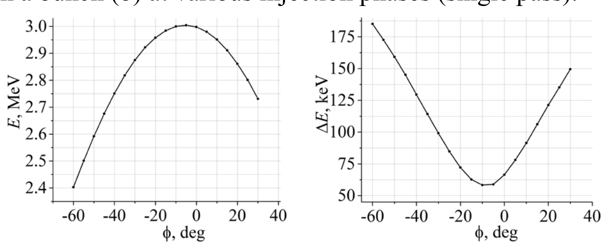
Figure. 2: Acceleration scheme: 1 – RF injector; 2 – focusing solenoids; 3 – quadrupole lens; 4 – accelerating cavity; 5 – bending magnet.

The calculation data of accelerated electrons energy characteristics after each pass through the accelerating cavity are shown in Fig. 3 and 4.



(a) (b)

Figure 3: Average electron energy (a) and energy spread in a bunch (b) at various injection phases (single pass).



(a) (b)

Figure 4: Average electron energy (a) and energy spread in a bunch (b) at various injection phases (two passes).

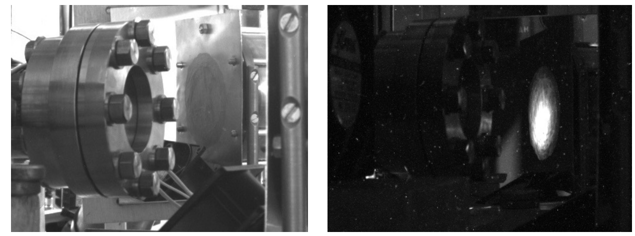
According to Fig. 3a the 1.5 MэB electrons can be obtained at the injection phase range from - 20 to - 5 degrees. The optimal range of electron injection phases at the second pass (3 MeV) is from - 10 to 5 degrees (Fig. 4 a). The electron energy spread in a bunch after each acceleration stage is presented in Fig. 3 b and 4 b.

EXPERIMENT

The experiment was carried out at the pulse-periodic operational mode of RF power generation. The RF pulse duration was 2 ms, the pulse repetition period was 40 ms. The average beam current varied from 10 to 100 μA.

To identify availability of the beam an aluminum plate with the luminescent coating was installed opposite to the beam output device (Fig. 5 a).

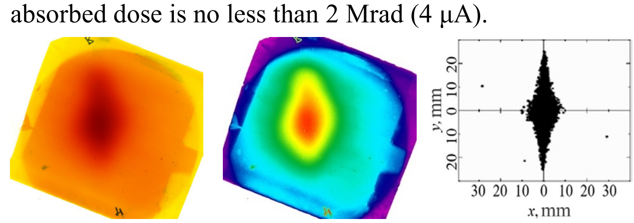
The registration of the integral glow pattern was fulfilled with the aid of videocamera [3]. Thus, the availability of accelerated electrons at the output of the accelerating cavity was registered (Fig. 5 b).



(a) (b)

Figure 5: Image of the plate with luminophor: with no beam (a), with a beam (b).

Then, a colored radiation monitoring film was installed at the 25 mm distance from the beam output device. After 20-second irradiation the darkening appeared at the film (Fig. 6 a). The reconstructed gradient image of the glow is shown in Fig. 6 b. For comparison Fig. 6 c presents the calculated transverse electron beam profile. The transverse bunch dimension is 40×20 mm. The absorbed dose is no less than 2 Mrad (4 μA).

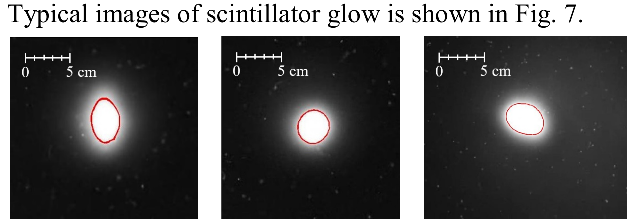


(a) (b) (c)

Figure 6: Beam image (a), reconstructed gradient image (b) and calculated transverse beam profile (c).

Anisotropic electron distribution in the bunch cross-section (Fig. 6) is conditioned by various effect of electric field components inside the accelerating cavity. [1]. Magnetic quadrupole lens installed in the injection channel is intended to compensate this diversity (Fig. 2, pos. 3).

In the next experiment a scintillation screen based on the polystyrene was installed opposite the beam output device. The scintillator formed the image in visible-light spectrum which characterized distribution of electrons in the beam cross-section. To register the integral pattern of the screen glow a digital videocamera was used [3]. Typical images of scintillator glow is shown in Fig. 7.



(a) (b) (c)

Figure 7: Scintillator glow image: 1.5 MeV with no quadrupole lens (a), 1.5 Mev with quadrupole lens (b) and 3 MeV (c).

More isotropic beam profile was obtained with the use of quadrupole lens in the injection channel (Fig. 7 b).

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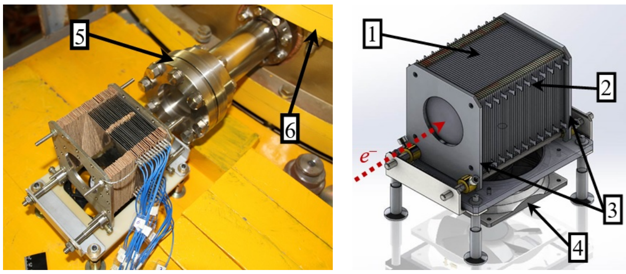
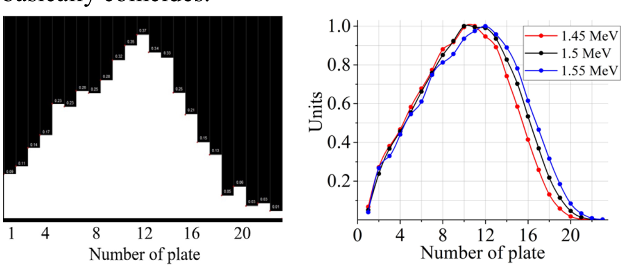
The measurement of the accelerated electrons energy characteristics was performed with the aid of a measuring assembly (Fig 8 a) using a method of absorbing filters [4]. The measuring assembly is composed of 23 isolated from each other aluminum plates with air gap between them (Fig. 8 b). The thickness of plates for 1.5 MeV electrons is 0.15mm, for 3 MeV electrons – 0.5 mm.



(a) (b)

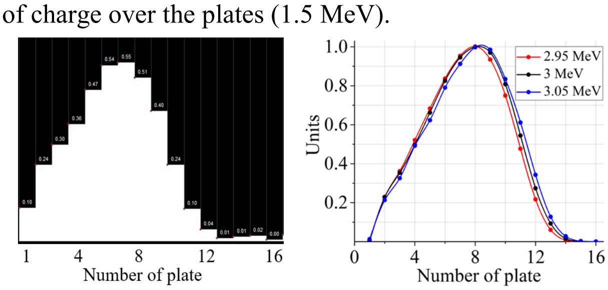
Figure 8: Experiment scheme (a) and measuring assembly (b): 1 – aluminum plates; 2 – current pickups; 3 – retention flanges; 4 – fan; 5 – output device; 6 – accelerating cavity.

The electron energy spectrum reconstruction was implemented basing on charge absorbed distribution in the assembly plates. The typical experimental charge distribution over the plates for a 1.5-MeV beam is presented in Fig. 9 a, for a 3 MeV beam – in Fig. 10 a. The calculated distributions for 1.5-MeV and 3 MeV beams are shown in Fig. 9 b and 10 b, respectively. The calculated data were obtained using the procedure from [5]. It is obvious that experimental and calculated data basically coincides.



(a) (b)

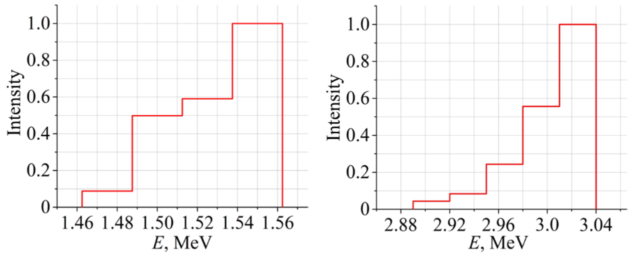
Figure 9: Experimental (a) and calculated (b) distribution of charge over the plates (1.5 MeV).



(a) (b)

Figure 10: Experimental (a) and calculated (b) distribution of charge over the plates (3 MeV).

Furthermore, using calculated and experimental charge distributions the energy spectrum of accelerated electrons was reconstructed (Fig. 11). The average electron energy after one pass is 1.52 MeV, after two passes – 3 MeV.



(a) (b)

Figure 11: Reconstructed electron energy spectrum after one pass (a) and two (b) passes.

CONCLUSION

Parameters of electron injection to the accelerating cavity were determined by calculation.

As a result of the conducted experiments electron beam was obtained at the designed accelerator. The measured electron energy was 1.5 and 3 MeV. Average beam current attained ~ 100 μA.

It is significant to note that current losses were minimized with the aid of magnetic focusing elements.

The experimental spectrum-energy characteristics of accelerated electrons correlate satisfactorily with the calculated data.

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