INJECTION SYSTEM OF CONTINUOUSLY WORKING RESONANCE ACCELERATOR WITH HIGH POWER OF ELECTRON BEAM

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Abstract

The paper presents a modified variant of injection channel for electron accelerator augmented by diagnostic equipment and additional magnetic optical elements.

To optimize operation modes of a new injection channel elements a computer simulation of electron dynamics was performed.

An experimental bench with a capability for electron beam diagnostics was developed on the basis of conducted calculations. Composition and geometry of the upgraded injection channel are fully reproduced on the experimental bench.

By the results of calculation and experimental studies an optimal variant of the injection channel is proposed. Such modified channel is supposed to be introduced into the acceleration complex.

INTRODUCTION

Designed resonance accelerator is intended for the electron beam production with discrete values of energy 1.5, 4.5 and 7.5 MeV and average power up to 300 kW [1]. The accelerator is based on the coaxial cavity, operating at the frequency 100 MHz.

Parameters of beam injection into the accelerating cavity possess a vital importance in approaching design characteristics of the output electron beam. Therefore, it is necessary to efficiently control the electron beam characteristics on the injection stage during accelerator operation. As of today there is lack of beam diagnostic devices in the existing injection channel. The presented paper proposes a variant of channel modification by diagnostic equipment and additional beam-focusing elements. The implemented equipment was tested on the experimental bench. Performed tests will also allow to optimize working parameters of RF injector and focusing elements.

ACCELERATOR INJECTION CHANNEL

The accelerator's electron injector is a grid-controlled hot-cathode gun based on the RF quarter-wavelength coaxial cavity (100 keV, 40 mA, 100 MHz) [2]. An advantage of such injector is a capability for longitudinal beam bunching by emission phase variation.

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The external view of the active injection channel is shown in Fig. 1. A list of magnetic optical elements involves two focusing solenoids (2) and (4) and a magnetic quadrupole lens (5), required for compensating various effects of transverse components of electric field along of the beam trajectory in accelerating cavity [1].

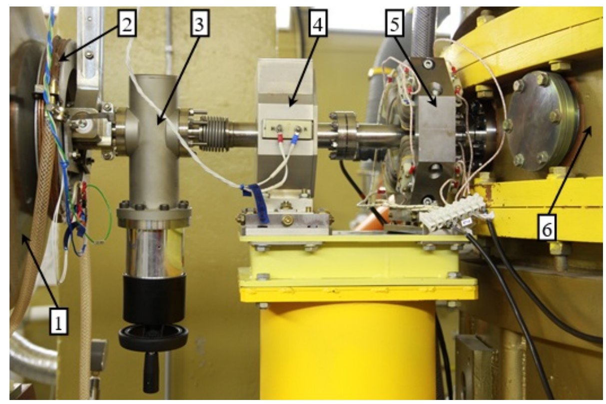

Figure 1: External view of injection channel: 1 – RF injector; 2 – focusing solenoid №1; 3 – high vacuum valve; 4 – focusing solenoid №2; 5 – magnetic quadrupole lens; 6 – accelerating cavity.

DIAGNOSTIC EQUIPMENT

Two space-divided resistive current pickups are planned to use in electron energy, pulse current and bunch length measurement (Fig. 2).

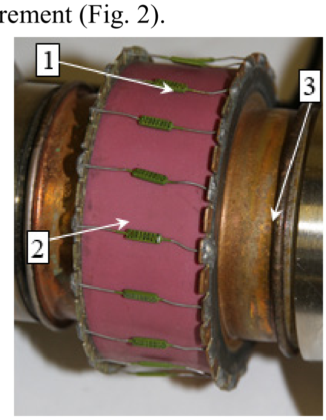

Figure 2: External view of resistive pickup: 1 – resistor 50 Ohm; 2 – ceramic insulator; 3 – beam transporting channel.

Diagnostic system based on the beam position monitor (BPM) and electromagnetic beam corrector (EBC) was developed to control a transverse beam position in the injection channel. BPM is a cylindrical chamber and four capacitive pickups in the form of disks, mounted

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diametrically opposite and electrically insulated from chamber walls (Fig. 3).

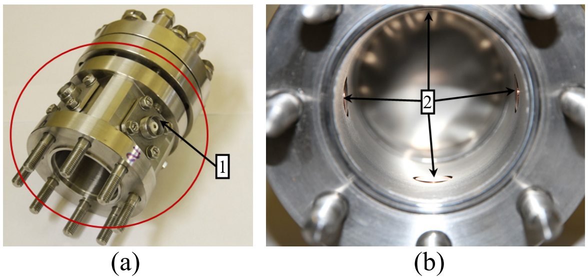

Figure 3: External view of BPM (a) and location of capacitive pickups (b): 1 – RF vacuum socket; 2 – capacitive pickups.

NUMERICAL CALCULATION OF BEAM DYNAMICS

To optimize operation modes of new injection channel elements electron dynamics calculation was performed in program ASTRA [3]. Simulation was carried out for the injection channel geometry, shown in Fig. 4.

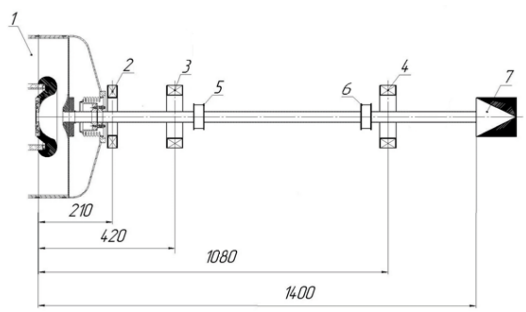

Figure 4: Diagram of injection channel: 1 – RF injector; 2, 3, 4 – focusing solenoids; 5, 6 – resistive current pickups; 7 – Faraday cup.

According to performed calculations, the operating range of electron emission phases is from 30° to 55°. Where boundary values correspond to a longitudinal electron bunching mode (30°) and maximal electron energy mode (55°).

As a result of simulation, the emission phase dependence of radial beam dimension is shown in Fig. 5. Peaks on the plot is caused by effect of focusing solenoid fields (Fig. 4, pos. 2, 3, 4).

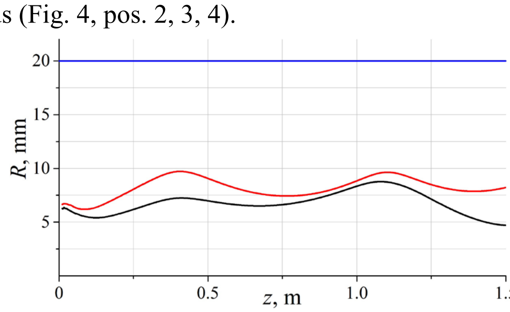

Figure 5: Calculated evolution of radial beam dimension on the drift section 1.5 m (red line – 30°, black line – 55°, blue line – channel aperture radius).

EXPERIMENTAL RESULTS

The experimental bench has been developed to test new diagnostic equipment (Fig. 6).

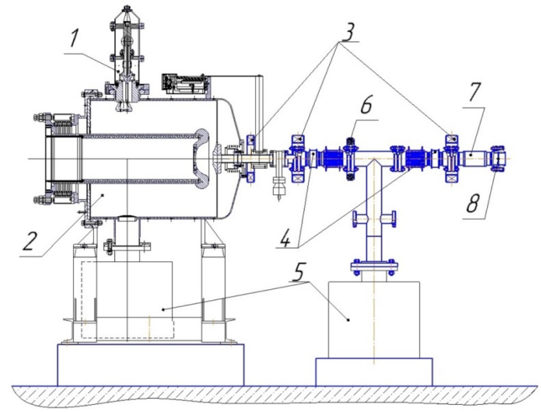

Figure 6: Scheme of experimental bench for electron beam diagnostics: 1 – RF power input unit; 2 – RF injector; 3 – focusing solenoid; 4 – resistive current pickups; 5 – vacuum pumps; 6 – EBC; 7 – BPM; 8 – vacuum-atmospheric window.

Electron energy was determined by a time-of-flight method with the aid of resistive current pickups (Fig. 6, pos. 4). The pulse beam current was measured and pulse widths at various emission phases were also estimated (Table 1). Typical signal oscillograms are given in Fig. 7.

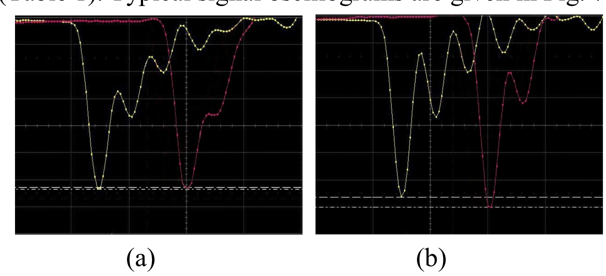

Figure 7: Typical signals from resistive current pickups (horizontal axis resolution 2 ns): (a) – 30°, (b) – 55°.

For equal signal amplitudes emission phase is about 55° (Fig. 7a). Otherwise if the second signal is larger and shorter than the first one the emission phase is 30° (Fig. 7b).

Transverse beam position relatively to the channel axis was defined by the BPM. Typical signals, obtained from capacitive pickups of BPM, is shown in Fig. 8.

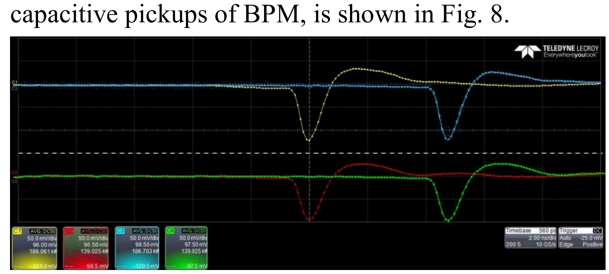

Figure 8: Typical signals from capacitive pickups of BPM.

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Furthermore, two upper signals correspond to vertical pickups, two lower signals – to horizontal pickups. The equality of signal amplitudes indicates that beam path coincides with the injection channel axis.

In order to check up the BPM operability the beam was deflected from the central axis by EBC. The produced deflections were registered on oscilloscope in the real-time mode.

Moreover, to verify BPM operability independent method was employed. Bremsstrahlung, appearing as a result of electron interaction with a foil, was registered on the scintillator (CsI) using videocamera (Fig. 9) [4,5].

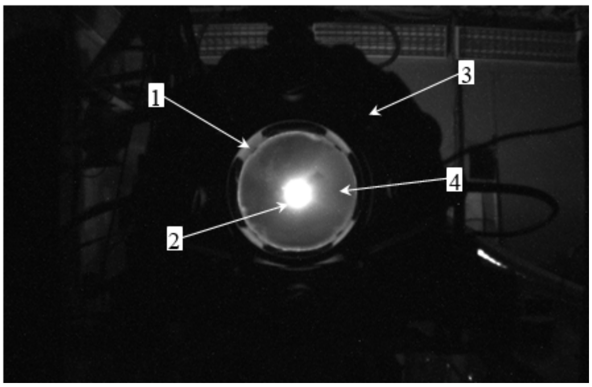

Figure 9: Scintillation screen glow pattern: 1 – scintillation screen attachment; 2 – crystal CsI glow pattern; 3 – flange with fixed titanium foil; 4 – scintillation screen.

Additionally, this method allows to estimate the experimental transverse beam profile and to compare it with calculated one.

Calculated and experimental beam characteristics for two ultimate values of electron emission phases (30° and 55°) is shown in Table 1.

Table 1: Characteristics of Electron Bunches

Parameter	Calculation		Experiment	
Emission phase	30°	55°	30°	55°
Transverse dimension (rms), mm	7.5	6	8	6.5
Electron energy, keV	100.9	96.1	100	96
Bunch length, ns	0.9	1.1	0.9	1
Charge in bunch, nC	0.4	0.42	0.4	0.42

CONCLUSION

The paper reports about additional capabilities of injection channel modification to improve beam diagnostic devices in designed accelerator. Electron beam dynamics has been calculated taking into account enlarged channel extension. Its geometry has been changed due to diagnostic equipment implantation. As a result of performed calculations, RF injector operation modes injector and focusing element parameters have been adjusted.

Implanted equipment has been tested on the experimental bench. Time-of-flight electron energy determination method has been practically implemented with the aid of resistive current pickups. Also the bunch lengths have been measured (~ 1 ns), the electric charge in single bunch has been specified (~ 0.4 nC). As shown in Table 1, measured beam characteristics correlate well with calculation data.

It has been shown that transverse beam position can be monitored with the aid of the developed BPM. Based on BPM and EBC automated control system for accelerator magnetic beam transport complex is planned to be developed in future.

REFERENCES

[1] A.V. Telnov *et al.*, “Progress in CW Mode Electron Resonance Accelerator BETA-8 Development”, in *Proc. XXV Russian Particle Accelerator Conference (RUPAC’16)*, 2017, pp. 185-187.

[2] V.N. Volkov *et al.*, “CW 100 keV Electron RF Injector for 40 mA Average Beam Current”, in *Proc. XXIV Russian Particle Accelerator Conference (RUPAC’2014)*, 2014, pp. 309-311.

[3] Floettmann K. Astra User`s Manual. http://www.desy.de~mpyflo/Astra_documentation.

[4] N.V. Zavyalov *et al.*, “Experimental Try-out of Guiding Radio-frequency Injector Electron Beam for BETA-8 Resonance Accelerator”, in *Proc. XVIII Int. Conf. Khariton’s Topical Scientific Readings. High Energy Density Physics*, Sarov, Russia, 2017, pp. 121-127.

[5] I.V. Zhukov *et al.*, “Intellectual Visual Event Sensor”, *Proceedings of RFNC-VNIIEF*, issue 15, pp. 506-513, 2010.

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