PERFORMANCE OF COMPACT ELECTRON INJECTOR ON EVANESCENT OSCILLATIONS*

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Abstract

An injector on the basis of a resonator structure with exponentially increasing amplitude of the electric field along an axis was developed at NSC KIPT. The injector is supplied with RF power through a rectangular-to-coaxial waveguide transition to provide axial symmetry of the accelerating field. The injector was designed to provide the output current up to 1 A at particle energy up to 1MeV. Results of the injector test are presented in the work. Results obtained are compared with calculated ones.

INTRODUCTION

RF linac beam characteristics are mostly formed in an injector where short electron bunches are generated. Application of a relatively low voltage electron gun (a few tens of kilovolts) in an injector allows of diminishing injector and high voltage equipment dimensions as well as increasing linac reliability. The bunching system on a base of evanescent oscillation (see, for example, [1]) is suitable both for effective grouping of continuous electron beam emitted from a cathode of such gun and for acceleration of generated bunches to relativistic velocities. Feature of the bunching system is exponentially increasing amplitude of the electric field along an axis due to special choice of cavity dimensions. The injector described in [2,3] is advanced modification of such device type that differs from the prototype by optimized resonance structure and on-axis coupling with a source of RF power supply though waveguide-to-coaxial adaptor. The bunching system can be equipped with one of two diode electron guns: 25 kV, 250 mA and 25 kV, 1.1 A. The electron injector on the base of such bunching system was fabricated and tested. Calculated beam parameters as well as design features and the test results are presented below.

CALCULATED BEAM PARAMETERS

The POISSON/SUPERFISH [4] group of codes was used to calculate characteristics of resonance and magnetic systems of the injector. Simulation of electron motion in the diode guns and the buncher was performed using the EGUN [5] and PARMELA [6] codes respectively. To enhance efficiency of bunching on-axis field distribution was optimized using technique [2]. Optimization was carried out for gun current of 250 mA without external magnetic field. Beam parameters at an injector exit for final field configuration calculated using [7] for the both guns are listed in Table 1.

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Table 1: Beam Parameters

Gun current, A	0.25	1.1
Output beam current, A	0.23	0.89
Bunch repetition rate, MHz	2797.15	2797.15
RF power supply, MW	1	1.5
Normalized emittance (1 σ), $\varepsilon_{rms\ x,y}$, π·mm·mrad	9	35
Beam size ($4\sigma_{x,y}$), mm	2.5	9.2
Bunch phase length (70% of particles), degree	7.7	14.7
Energy spread (70% of particles), %	3.9	4.4
Energy, keV	980	970

INJECTOR DESIGN

The injector consists of the following main parts (see Fig. 1): diode electron gun 1, buncher 2, short solenoid 3, coaxial coupler with coaxial to waveguide transition (CWT) 4, beam current transformer 5, axially symmetric magnetic lens 6 and tuning plunger 7.

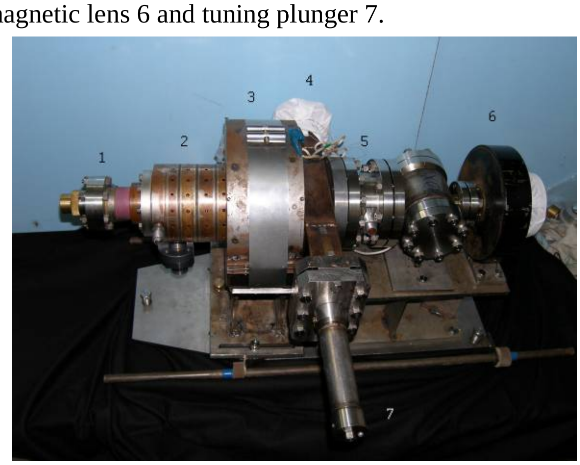

Figure 1: Injector view.

Impregnate cathodes are used as electron sources in the both guns. A spherical cathode with diameter of 5 mm provides of 250 mA beam current and a flat cathode with diameter of 14 mm provides of 1.1 A beam current.

The resonance system of the buncher is made of oxygen-free copper by "disk-ring" technology that is every cell consists of the ring and two disks with apertures for beam passing. Disks and rings were diamond turned and jointed by vacuum brazing. There are 16 ducts at peripheral part of the buncher for water cooling. The first cell of the buncher is equipped with a RF probe to measure amplitude of accelerating field. To decrease transients and to provide effective acceleration of beam with current up to 1 A, the buncher resonant system coupling coefficient with RF feeder was chosen equal to 5. Application of on-axis coupling with RF feeder has some advantages compare with side coupling. For example it ensures field symmetry in a resonance system [8,9]. Besides such coupling allows to design the buncher using 2D electromagnetic solver, for instance, SUPERFISH. Coaxial coupling also gives more flexibility in choice of external magnetic field configuration in the injector to enhance beam transportation.

To provide axially symmetrical field pattern in the buncher it is necessary to suppress propagation of high modes of the feeding coaxial line [8]. The 22.5 Ohm coaxial line with diameter of an inner conductor of 22 mm and length of 75 mm was chosen. This length of the line provide 30 dB attenuation of the nearest high order mode at working frequency. RF power goes to the coaxial line through the “door knob” transition in the WR-284 waveguide. Matching of the transition is adjusted by waveguide sliding short.

Beam transportation is provided by a short solenoid placed along the buncher and a magnetic lens at the entrance into acceleration section. To decrease value of solenoid fringing field near the cathode of the gun the solenoid is equipped with “clipping” coil.

Beam current at the exit of the buncher is measured by a beam current transformer with sensitivity of 2 V/A.

RESULTS OF EXPERIMENTAL STUDY

We began manufacturing of the injector from tuning CWT. For this purpose coaxial transformer was calculated and fabricated to match 22.5 Ohm coaxial line with 50 Ohm matched load. CWT was tuned by changing height of “door knob”. Dependence of power transition coefficient of CWT on distance L from axis of coaxial line to shorting plane in waveguide is shown in Fig. 2.

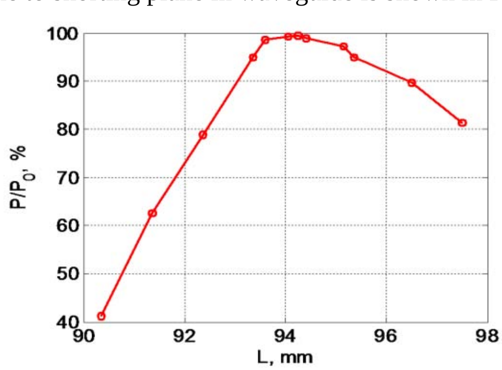

Figure 2: Power transition coefficient of CWT.

The buncher was tuned using POISSON/SUPERFISH data on cavity dimensions. After tuning the buncher was brazed in vacuum furnace. Measurement of buncher eigen frequencies in the lowest pass band showed that calculated and measured values agreed in the range of 100 kHz. Bead pull measurements of on-axis field distribution (Fig.3) were carried out with technique [10].

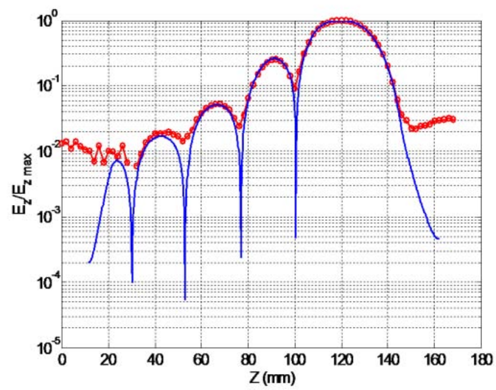

Figure 3: Field distribution for working mode of the buncher: measurement – curve with open circles; simulation – smooth curve.

One can see that measured and simulated distributions are in a good correspondence. There are good agreements between measured and simulated field distributions for all five modes in the lowest pass band.

Measurement of coupling coefficient of the buncher with waveguide shows that it is possible to change this value from 3.3 to 6 by adjusting the shorting plane position in the waveguide without considerable change of resonant frequency.

Simulated and measured buncher parameters are listed in Table 2.

Table 2: Buncher Parameters

Operating frequency, MHz	2797.15
Operating temperature, °	37
Unloaded quality factor	10500
Coupling with waveguide	3.3 - 6
RF power supply, MW	≤ 1.5
Maximal on-axis field (simulation), MV/m	38
Maximal surface field (simulation), MV/m	60

Study of injector performances has been carried out at a testing stand that provided needed supply for injector operation as well as allowed measuring main beam characteristics.

RF conditioning was finished after 6 hour of injector operation at pulse repetition rate of 1 pps. During this period RF power supply was increased from 100 kW to 1500 kW at RF pulse duration about 1.8 μs. It is necessary to note that at RF conditioning we did not observe any phenomena of field instability as it was at RF conditioning of the injector prototype [11]. However, after conditioning the gun cathode and applying high voltage to the gun, amplitude of a signal from the RF probe installed in the first cavity increased in several times. At some values of a solenoid current there was oscillation on the top of the signal pulse. These phenomena were accompanied with some worsening of vacuum conditions. The phenomena ended after a half of hour injector operation at 12 pps. In our opinion this is evidence of secondary emission discharge development in the resonance system of the buncher due to possible pollution of the cavity interior surface by materials evaporated from the cathode during its conditioning.

At a high power test of the injector such main characteristics were measured as output current, energy spread and transversal emittance.

Characteristic contour plot of energy spread is shown in Fig. 4.

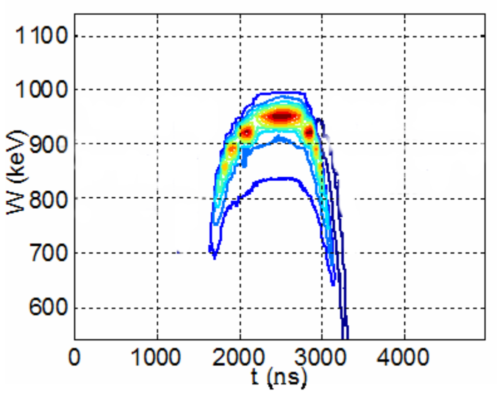

Figure 4: Contour plot of energy spread.

According to the value of coupling one could expect much less transients we can see in Fig. 4. Study of this effect showed that it was caused by resonance property of the RF feeding line. To decrease transients it is necessary to enhance isolation of the buncher from the feeding klystron.

Transversal beam emittance was measured by quadruple scan (see Fig. 5). Results of obtained data processing as well as some other injector parameters are listed in Table 3. Compare Table 3 and Table 1 one can see that measured injector parameters correspond to simulated ones. Simulation of emittance measurement has shown 40% underestimation of the emittance value using full width at half of maximum (FWHM) profile data comparing with root-mean-square emittance.

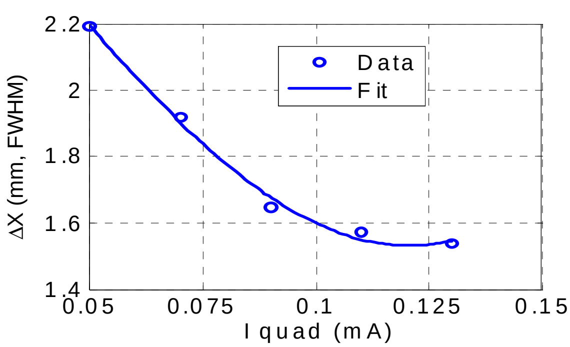

Figure 5: Quadruple scan.

Table 3: Injector Parameters

Gun current, A	0.18
Injection energy, keV	25
Beam current, A	0.14
RF power, MW	1
Normalized emittance, $\varepsilon_{rms\ x,y}$, π·mm·mrad	9
Energy spread (FWHM) for full current pulse, %	9
Minimal instant energy spread (FWHM), %	3.8
Beam energy, keV	950

CONCLUSION

Compact S-band electron injector has been created. Carried out tests have shown that parameters of the injector correspond to design demands. At the moment injector provides 0.14 A beam current at beam energy of 0.95 MeV. Injector test with the 1.1 A gun is under way.

REFERENCES

[1] M.I. Ayzatsky et. al., “Bunching systems of electrons on base evanescent waves”, PAC’03, Portland, 2003, p 1605-1607.

[2] S.A. Perezhogin et. al., “The optimization of the electron injector resonant system based on the evanescent oscillations”, PAC’05, Knoxville, 2005, p. 3170.

[3] M.I. Ayzatsky et al. Problems of atomic science and technology, Ser. Nuclear Physics Investigation, 2, 2006, p. 94–96.

[4] J.H. Billen and L.M. Young, “POISSON/SUPERFISH on PC compatibles”, PAC’93, Washington, 1993, p.790–792.

[5] W.B. Herrmannsfeldt, “EGUN: Electron Optics Program”, Preprint Stanford Linear Accelerator Center SLAC-PUB-6729, Stanford, USA, 1994.

[6] L.M. Young, “PARMELA”, Preprint LANL LA-UR-96-1835, Los Alamos, USA, 1996, 93p.

[7] V.V. Mytrochenko, A. Opanasenko. NIM A558, 2006, p. 235 – 239.

[8] A.I. Zykov et. al. “Device for an input and output of RF power for the disk loaded waveguide”, Proc. of the VI Conference of Nuclear Research Center, Kharkov, 1969, p.27 (in Russian).

[9] F.B. Kiewiet, “Generation of ultra-short, high-brightness relativistic electron bunches”, PhD Thesis: ISBN 90-386-1815-8 NUR 926 Eindhoven, Technische Universiteit Eindhoven, 2003.

[10] V.A. Kushnir and V.V. Mytrochenko. Instruments and Experimental Technique, 1998, Vol. 41, No.2, pp. 206-209.

[11] M.I. Ayzatsky et. al., The investigations of the beam characteristics in the electron injector based on resonance system with evanescent oscillations”, RuPAC XIX, Dubna, 2004, p. 444 - 446.