THE INJECTOR OF HIGH POWER ELECTRON LINAC FOR INDUSTRIAL APPLICATION

M.I. Ayzatsky, E.Z. Biller, A.N. Dovbnya, I.V. Khodak, V.A. Kushnir, V.V. Mitrochenko, D.L. Stepin, V.F. Zhiglo
National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine; E-mail: mitvic@kipt.kharkov.ua

In the paper the results of the experimental study on forming the electron bunches in the injector of a high current S- band linac are presented. The injector consists of a low voltage electron gun, bunching cavity and accelerating cavity. The influence of different factors on the beam spatial and energy characteristics is analyzed.

PACS: 29.25.BX, 41.75.FR

1 INTRODUCTION

Injectors of powerful linear resonance electron accelerators for technological applications should be easy serviced and reliable. Therefore the injector systems based on the low-voltage (U_0 =20...30 kV) electron guns are promising. Usage of the injector consisting of a bunching cavity and an accelerating cavity with a strong field can reduce influences of a space charge on bunch formation. In the accelerating cavity besides of continuation of bunch formation there is an acceleration of particles up to the energy, which provides their capture in the accelerating section with a phase velocity equal to the velocity of the light. The injector system, which implements this principle, was created in the NSC KIPT and has performed itself well during long term service of the technological linac KUT [1]. Therewith the experience of the service indicated the ways of improving the injector. To do these improvements the research of beam dynamics in the injector was carried out with more perfect codes than these used for development of the injector system of the linac KUT. According to research results [2], the configuration of the injector was optimized. First of all it differs from the prototype by an improved electron gun [3]. This gun provides a current behind an anode of 2.3 A at a cathode voltage of – 25 kV. Besides, in the new injector the position of magnet gaps in focusing lenses was changed as well as the length and geometry of a drift pipe between the second lens and the accelerating resonator were changed to improve beam transportation in the injector.

The paper presents the experimental study of beam performance at the exit of the upgraded injector.

2. EXPERIMENTAL RESULTS

Experimental study of the injector was carried out on a special test bench, providing RF power supply of the resonators and power supply of the electron gun as well as measurement of the beam characteristics. Experiments consisted of two stages and included measuring the energy spectrum and the emittance evaluating the phase length of bunches.

At the first stage the above-mention measurements were carried out when the bunching cavity was detuned to decrease substantially the influence of the feedback on a beam on bunching [4]. At the second stage the bunching cavity was tuned more precisely on the operating frequency.

The method of evaluating the phase length of bunches was based on a supposition that the phase portrait of particles at the phase-energy plane can be represented in the form of a line. The phase spread of particles at a given energy is substantially less than the phase length of the bunch. The line thickness depends, in our case, only on the energy spread that occurs due to the action of the space charge force and the electric field force in the bunching cavity. As it follows from the simulation results this spread is rather insignificant.

To evaluate the phase length of bunches we have used a E_{010} cavity at the exit of the magnetic analyzer. It permitted to measure the phases of the centers of particle bunches that passed through the magnetic analyzer aperture at different magnetic field values, and thus to plot the phase-energy relation of particles. Fig.2 shows the measured phase-energy relation and the beam energy spectrum for one of realizations of injector performances. The data for the plot were taken in the time point corresponding to the middle of the current pulse. In this case the microwave power supply was 1.26 MW, the current at the injector output was 1.25 A.

As is seen from Fig.1, the beam has a core. The FWHM energy spectrum is 13%, the phase length of bunches is near 25°. Nevertheless, the beam contains the particles with sufficiently lower energy than energy of the core and their phases differs, at least, by 150°. Since the accelerator is not large and the field strength in the beginning of sections is high enough, the particle from the bunch "tail" can lead to forming the low-energy halo at the linac exit.

The energy spectrum width at the injector output depends on the phase shift between the bunching and accelerating cavities, while the output current depends slightly on changing this parameter in wide ranges (see Fig.2). The value of the integral energy spectrum width was determined with taking into account the particle energy changing during transitional processes in the injector cavities.

The transversal emittance was measured by the three gradients method. The result of quadruple scan is presented in Fig.3. A beam current at the injector output was equal to 0.8 A in this case.

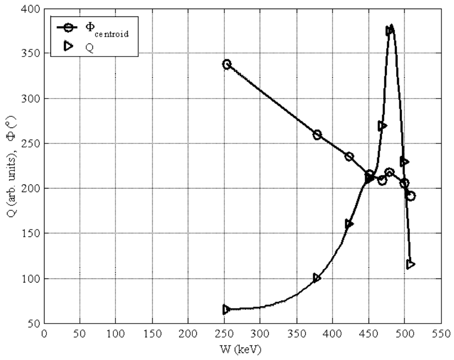

Fig.1. The phase-energy distribution of particles at the injector output and the energy spectrum

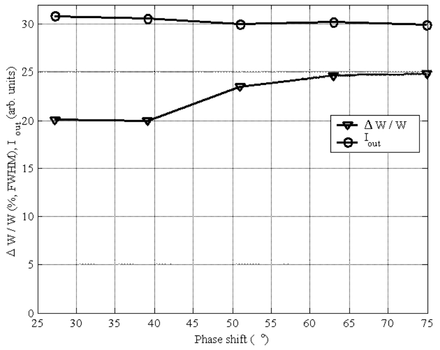

Fig.2. The beam current and the integral energy spectrum width as a function of the phase shift between the bunching and accelerating cavities

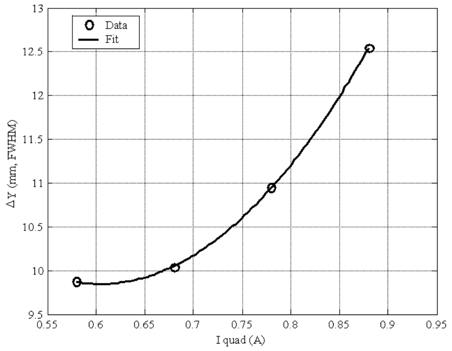

Fig.3. The half-width of the vertical particle density distribution as a function of the quadrupole current

The normalized emittance evaluated from the curve in Fig.4 was 22 π·mm·mrad. It should be noted, that with increasing the current at the injector output the transversal emittance increases insignificantly and equals to 30 π·mm·mrad at output current of 1.4 A. In the course of injector testing, a beam self-bunching was observed. The RF field in the bunching cavity was excited even if the RF power was not supplied into the cavity from an outside source. For example for the tuning condition of the bunching cavity being characteristic for the first stage of measurement the RF power radiated from the cavity into the RF feeding system was 0.6 W for the injected current of 2.2 A. In this case the current at the injector exit was only 0.88 A. To get 1.4 A of the output current it was necessary to supply the bunching cavity with 2.2 kW of RF power. At the next stage of researches the bunching cavity was tuned closely to the operating frequency. At this tuning condition the radiated RF power was 34 W when the supplying power from the outside source was at last 180 W. It is obviously that the bunching voltage excited by electrons accelerated in the reverse direction was negligible as compared with the bunching voltage excited by the outside source in the both cases.

The Fig.4 and 5 show the dependences of the output beam current and the width of the integral energy spectrum, respectively, as a function of the phase shift between the bunching and accelerating cavities.

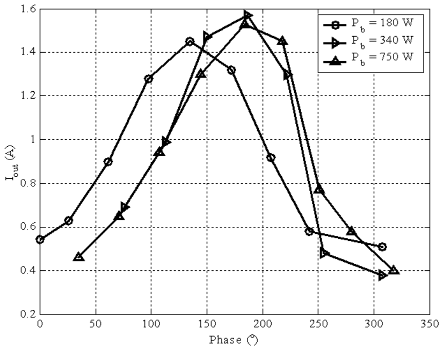

Fig.4. The output beam current v.s. the phase shift between the bunching and accelerating cavities

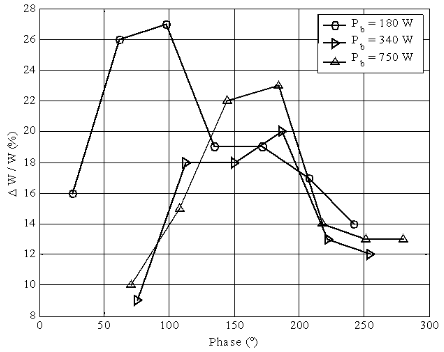

Fig. 5. The width of the integral energy spectrum v.s. the phase shift between the bunching and accelerating cavities

One can see that there is the sharp current dependence on the phase shift between the bunching and accelerating cavities unlike the case of the detuned cavity. Herein, in the case of a maximum current the energy spread width does not differ considerably from that observed under the buncher detuning. Thus, the energy spread formation is defined mainly by the particle dynamics in the accelerating cavity. The beam emittance measurements showed that for the beam current of 1.4 A the emittance does not exceed 21 π·mm·mrad.

Fig. 6 shows the energy spread and the phase-energy distribution of particles in the case of the accurate tuning-on of the buncher. One can see that the accurate tuning-on of the buncher improves the beam phase performances – the interval of phases corresponding to the FWHM energy spread of 11% is 15°.

The analysis of behaviour of an output current of the injector within a RF pulse has not found out spurious oscillations. Dependences of beam characteristics versus a phase shift between bunching and accelerating resonators are rather smooth, that indicates on the absence of instability, which could be caused by the influence of feedback on the beam in the injector.

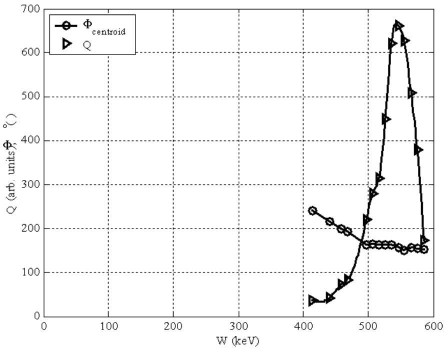

Fig.6. The phase-energy distribution of particles at the injector output and the energy spectrum

After finishing the experimental investigations the injector was installed at the accelerator [5]. The view of the injector joined with the accelerator is shown in Fig.7.

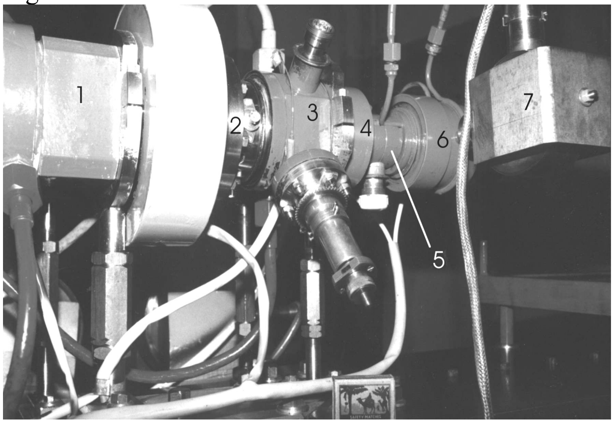

Fig. 7. View of the injector joined with the accelerator

The numbers in Fig. 7 denote the following: 1 - accelerating section, 2 – beam current transformer, 3 – accelerating resonator, 4 – second magnetic lens, 5 – bunching resonator, 6 – first magnetic lens, 7 - ion pump.

3. CONCLUSION

Experimental researches of the injector on the special bench have shown that the parameters of a beam met the requirements, specified at development and were improved as compared to that of the prototype. The measured and calculated data correspond to each other.

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ИНЖЕКТОР МОЩНОГО ТЕХНОЛОГИЧЕСКОГО ЛУЭ

Н.И. Айзацкий, Е.З. Биллер, А.Н. Довбня, В.Ф. Жигло, В.А. Кушнир, В.В. Митроченко, Д.Л. Степин, И.В. Ходак

Приведены результаты экспериментального исследования процесса формирования электронных сгустков в инжекторной системе сильноточного технологического ускорителя электронов десятисантиметрового диапазона. Инжектор состоит из низковольтной электронной пушки, группирующего и ускоряющего резонаторов. Приведен анализ влияния различных факторов на пространственные и энергетические характеристики пучка.

ІНЖЕКТОР ПОТУЖНОГО ТЕХНОЛОГІЧНОГО ЛПЕ

М.І Айзацький, Е.З. Білер, А.М. Довбня, В.Ф. Жигло, В.А. Кушнір, В.В. Митроченко, Д.Л. Стьопін, І.В. Ходак

Приведено результати експериментального дослідження процесу формування електронних згустків в інжекторній системі сильнострумового технологічного прискорювача електронів дисятисантиметрового діапазону. Інжектор складається з низьковольтної електронної гармати, групувального та прискорювального резонаторів. Приведено аналіз впливу різних факторів на просторові та енергетичні характеристики пучка.