THE 150 MeV PULSE ELECTRON LINAC WITH 1 mA AVERAGE CURRENT*

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Abstract

The project of the accelerator driven subcritical assembly facility is under development in the National Science Center "Kharkov Institute of Physics and Technology". The important component of the facility is an electron linac with the particles energy of 100…200 MeV and average beam current of 1 mA. In this paper we focus on the S-band electron linac design. The accelerator scheme includes the injector based on evanescence waves, RF chopper, five accelerating structures and energy compression system. The calculation results of accelerating structure performances and linac systems are considered in the paper.

INTRODUCTION

The developing facility consists of the linac, the system of the beam transport to the target complex, the neutron-producing target and the subcritical assembly of the fuel elements.

Using of the linac as the subcritical assembly driver makes a number of demands. The electron energy at the linac exit must be 100-200 MeV. On the one hand, it provides rather high yield of the neutrons, and on the other hand - the volume of the neutron target will be large enough for the energy density decrease and the target cooling conditions improve. The existing high-frequency linac power supplies and the injector systems allow obtaining the average current at such linac exit in the necessary electron energy range near 1 mA. Considerable average beam power (about 100 kW) obviously demands minimizing the high-energy particles loss during their acceleration and transport.

THE FACILITY POSITION AND STRUCTURE

The linac will be placed in the building of the linac LU-2000 in NSC KIPT. Such placing of the complex doesn't need the new fundamental construction, allows using the existing engineer infrastructure after its major reconstruction. The existing power system allows power supplying of all systems of the linac. New equipment placing is possible after the demounting of the existing equipment. The accelerating sections of the developing linac will be placed after the 36th section of the linac LU-2000. The layout of the linac main parts is presented in Fig. 1.

The accelerator itself consists of the electron source, injector (I), five S-band accelerating sections (1s-5s) and the system of energy compression (SEC). The system of energy compression includes the debuncher (D) and the compensation accelerating section (CS). At the accelerator exit there are placed the magnetic electron energy analyzer (M1) and the dipole magnet (M2), providing the electron beam injection into the transport system to the target complex. The main elements for the beam focusing are the short solenoid on the first section (S) and the doublets of the quadruple lenses, placed on each section. The beam current transformers and the beam position monitors will be placed after the injector and each section exit.

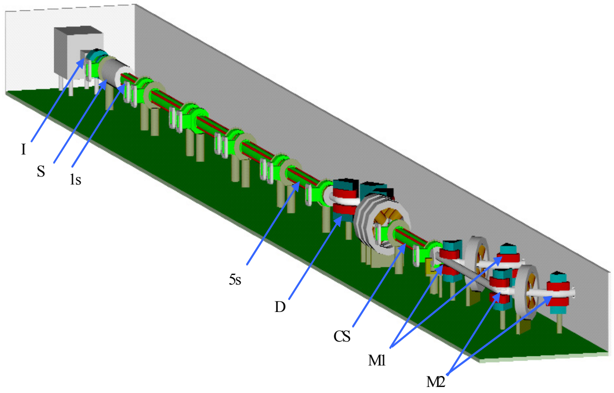

Figure 1: Placing of the accelerator main elements.

The accelerator RF power supply system is planned to be created at the base of six klystrons SLAC 5045 (produced by SLAC, USA). Proceeding from the average beam power 100 kW, the current pulse repetition rate and the pulse duration are chosen 300 pps and 3.0 µs respectively. In this context the standard mode of the klystron SLAC 5045 will have to be changed (see Table 1).

Table 1: Klystron parameters

Parameter	Standard mode	Required mode
RF frequency, MHz	2856	2856
Pulse repetition rate, pps	≤ 180	300
Max. pulse RF power, MW	67	29.9
RF pulse duration, µs	3.5	3.2
Average RF power, kW	37	31.2

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INJECTOR

One of the main conditions of obtaining the minimal energy electron spread at the accelerator exit is the demand of the length and form of the electron bunch, formed in the initial part of the facility – in the injector. We suppose to use the bunching system on the evanescent oscillations [1]. The prototype injector for the developing linac is the accelerator electron injector for the storage ring H-100M [2]. According to the calculations and the preliminary testing of the injector prototype such system allows to form effectively the electron bunches at the pulse current up to 1.5 A and at energy of particles of about 1 MeV.

The code POISSON/SUPERFISH [3] has been applied for the calculations of the injector resonance and magnet system characteristics. The particle dynamics in the bunching system has been simulated using PARMELA code [4]. The electron injector (see Fig.2) with operating frequency 2856 MHz provides the minimal bunch phase size at the minimal energy spread and the electron current up to 1.5 A at the injector exit.

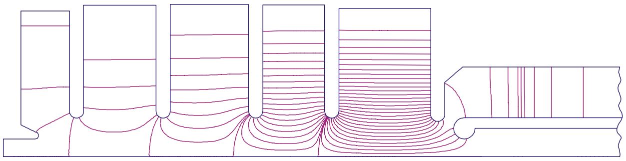

Figure 2: The injector resonance system geometry and the longitudinal RF electric field distribution.

The simulation has been held taking into account space charge forces for the electron beam with the initial energy 25 keV and the current 1.2 A. To decrease the radial beam size the injector is equipped with a solenoid. At the pulse current 1.07 A at the bunching system exit the beam has the following parameters: normalized emittance (1σ), $\varepsilon_{\text{rms } x,y}$=21 mm·mrad; phase spectrum width $\Delta\varphi$=9.8° (for 70% of the particles); energy spread $\Delta W/W$=6.3%, (for 70% of the particles); energy at the spectrum maximum W=1.2 MeV; beam size d=1.55 mm. The phase-energy electron beam distribution at the injector exit is shown in Fig. 3.

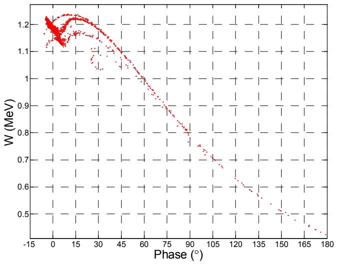

Figure 3: The phase-energy particle distribution at the injector exit.

However, in the interval between the bunching system and the accelerating section the bunch phase duration is increased. At that the phase distribution of the particles has the extended "tail". As the numerical simulation has shown, those periphery particles form the energy halo. That's why it is important in this case to apply the additional methods for the phase compression or phase selection. After the analysis we have considered the possibility to use the chopper system [5, 6]. This system is composed of a RF cavity, a drift tube and a collimator. The most simple is to use the cylindrical cavity with the TM_{110} mode. We have carried out the numerical simulation of the particle motion in the injector system with such chopper. It is shown (see Fig. 4) that using of that device allows to decrease substantially extension of the "tail".

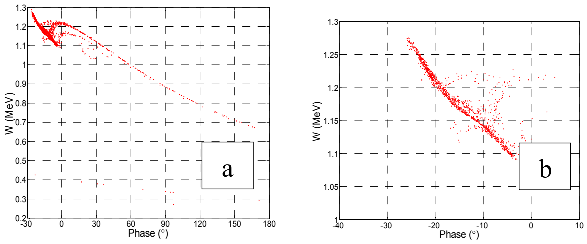

Figure 4: The phase-energy particles spread at the input of the first accelerating section without chopper (a) and with chopper (b).

In general, the main disadvantage of this method is the increase of the transverse beam emittance. However, if during the bunch forming the particles motion in different phase planes is connected, the inverse picture can be observed – in the chopper the particles with bad radial characteristics are also chopped off. Thus, in our case, the particle losses are 29.4% of the particles at the injector exit and the decrease of rms emittance of the chopped beam in a beam scanning plane up to 12 mm·mrad is observed.

ACCELERATING SECTIONS

The accelerating system of the accelerator includes five accelerating sections, where the electron beam with the pulse current up to 1 A, pulse duration 3 μs and the repetition rate 300 pps should gain energy about 150 MeV. When choosing the section parameters the simulation of the particle dynamics in the injector and the sections in the steady state mode has been carried out with the PARMELA program. On the base of simulation the homogenous travelling wave accelerating structure with the π/2 phase advance per cell has been chosen. The length of each of five accelerating sections and the filling time are 4.15 m and 0.368 μs respectively, shunt impedance is 52.8 MOhm/m, attenuation is 0.088 1/m, Q-factor is 11200. For suppression of BBU the radial slots in the accelerating wave-guide irises will be used. The length of the slots and their orientation will vary along the accelerating section. At the supplying RF power for each section of 28.8 MW the electrons energy at the fifth section exit is 154 MeV at the pulse current 0.75 A. The other parameters are shown in Table 2.

To decrease the energy spread there has been settled the system of energy compression at the fifth section exit. It consists of the «magnetic chicane» type debuncher and the additional accelerating section. For the correct operating of such device at the accelerator exit there has been formed a special phase-energy electron distribution. The preliminary calculation of the system of energy compression (SEC) has been carried out with the MADX program [7]. The final calculation of SEC and the accelerator as a whole has been carried out with the PARMELA program. The simulation results are presented in Fig. 5.

Table 2: Beam parameters at the fifth section exit

	d, mm	**ε_n mm·mrad**	**Δφ°**	**ΔW/W %**
70% of particles	1.4	15	14	4,9
99% of particles	3.3	170	24	8

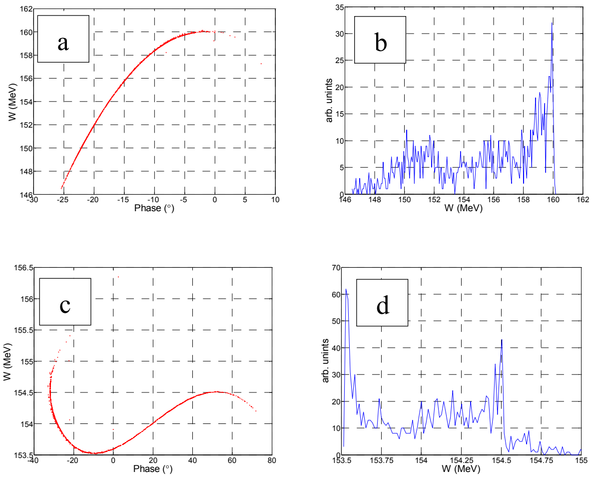

Figure 5: Phase-energy distribution and the energy spectrum at the fifth section exit (a, b) and the SEC exit (c, d).

It is seen, that SEC allows to decrease the energy spread of 99% of the particles from 8 % to 0,7% . At that the normalized emittance of the beam doesn't exceed 180 mm·mrad, and the beam loss are absent in that system. At the same time it should be noted that the work of that system taking into account the beam loading of the compensating accelerating section needs further study.

BEAM MONOCHROMATIZATION IN THE TRANSIENT MODE

The beam energy spread as a whole is determined by both the acceleration steady state mode (considered above) and the beam loading effect. Decrease of influence of transient has been achieved by the selection of the optimal current pulse delay relative to RF pulse. As the results of the calculations we have obtained the optimal values of the pulse delay time for each of five sections: 0.399 μs, 0.323 μs, 0.23 μs, 0.139 μs, 0.045 μs. From the calculation results (see Fig.6) it follows that the particles accelerated during the transient (about 15% of all particles) have the energy spread at the linac exit less than 1%.

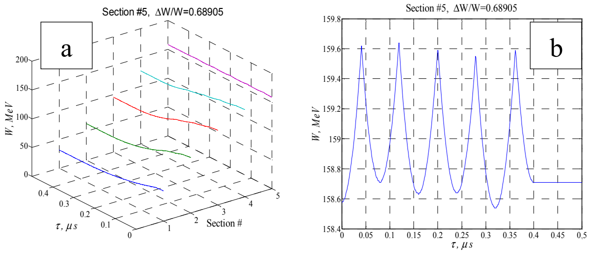

Figure 6: Electron energy during the transient at each section's exit (a) and at the accelerator exit (b).

SUMMARY

Researches on design of the high power pulse linac for the neutron source on the base of a subcritical assembly is under way in NSC KIPT. The simulation results show that the chosen accelerator scheme allows obtaining the beam with the required for the facility work parameters: W=154 MeV, ΔW/W<1%, P_{cp} =104 kW.

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