CALCULATION OF ELECTRON BEAM DYNAMICS OF THE LUE−200 ACCELERATOR

A.P. Sumbaev#, V.S. Aleksandrov, N.Yu. Kazarinov, V.F. Shevtsov,
JINR, Moscow region, 141980, Dubna, Russia

Abstract

The results of calculations of the focusing and transportation systems of the electron beam of LUE-200 accelerator – the driver of a pulse source of resonant neutrons IREN [1], JINR (Dubna), are presented. Simulations of the beam dynamics in the traweling wave accelerator were carried out by means of PARMELA code [2]. The calculations have been fulfilled for various parameters of the focusing magnetic field in the accelerator and the channel, various currents of the beam and various initial distributions of electrons.

INTRODUCTION

The intense resonant neutron pulse source IREN is a traditional JINR combination of a driver (an electron LINAC) and a converter - target with a booster multiplier. The LINAC is designed at the Budker INP of the Siberian Branch of the Russian Academy of Sciences. The design prototype is the preinjector of the VEPP-5 accelerator complex [3]. For ensuring the design parameters of the IREN, the average power of the electron beam must be about 10 kW that defines the electron energy to be 200 MeV if the pulse duration is 250 ns, the electron current is 1.5 A, and the repetition frequency is 150 Hz. The mean rate of the energy gain in the accelerating structures should not be less than 35 MeV/m because the restrictions related to the placement of the accelerator in the available building.

LUE-200 ACCELERATOR

The accelerator (Figure 1) consists of an electron gun (C−A), an accelerating system, and an electron beam transport channel up to the target (T).

The accelerating system consists of a buncher (B) and two accelerating sections (AS1, AS2).

The *buncher* [4] is four coupled resonators (3 cells and a converter of wave type) with an operational frequency 2855.6 MHz and 4π/3 operating mode. Figure 2 shows the distribution of the longitudinal electric field along the axis of the buncher.

The accelerating sections are round disk-loaded waveguides of constant impedance. The major parameters of the section are given in [3]. Each section is fed by RF power from independent klystron amplifiers based on the 5045 SLAC klystron operating at the frequency 2856 MHz.

The *focusing system* consists of a solenoid focusing channel and a quadrupole focusing channel.

The *solenoid focusing channel* is used at the bunching step and at initial acceleration from the energy 200 keV to 100 MeV. It consists of magnetic lenses AS, ML1 and ML2 of the electron source, and of a solenoids system of the buncher (BC) and the first accelerating section (S1). During the design, the configuration of the solenoid focusing channel was evolved. In the first version of the design [3], focusing of the beam in the first accelerating section was performed by two solenoids S1 (length ~0.75 m, field strength ~1.5 kG) and S2 (length ~2.1 m, field strength ~4.0 kG) with opposite directions of the field. After optimization of the fields, the system of two solenoids was replaced by a single sectioned solenoid S1 (16 coils).

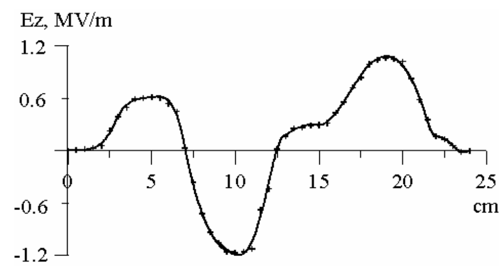

Figure 2: Distribution of the longitudinal electric field strength along the axis of the buncher.

The *quadrupole focusing channel* is used after the exit of the first accelerating section. The channel consists of nine quadrupole lenses Q1–Q9. The correcting lens Q1 is combined with the beam displacement corrector. Two doublets Q2–Q3 and Q4–Q5 are mounted on the second accelerating section and aimed at guiding the beam through the small-aperture channel inside the section.

Two more doublets Q6–Q7 and Q8–Q9 aimed at guiding and focusing the beam to the target (T).

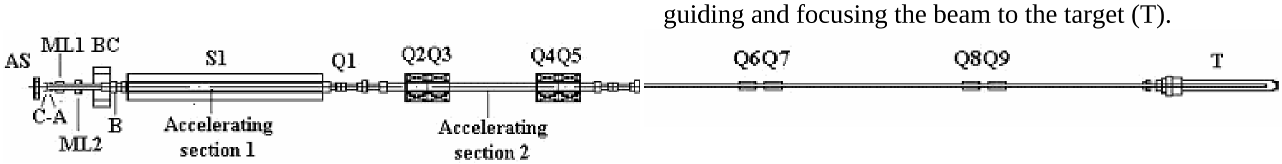

Figure 1: Layout of LUE-200 accelerator.

#sumbaev@nf.jinr.ru

SIMULATION OF THE BEAM DYNAMICS

Simulation was aimed at the following objectives:

- optimization of the values and distribution of the longitudinal magnetic field in the neighbourhood of the cathode unit and buncher;
- testing the possibility to decrease the magnetic field in the solenoids and to avoid reversion of the field in the neighbourhood of the first accelerating section;
- optimization of the parameters for the quadrupole focusing channel that should provide the required beam parameters.

Beam dynamics was computed with the PARMELA code. Initial beam parameters are contained in Table 1.

Table 1: Initial beam parameters

Electron energy	200 keV
Maximum beam current in a pulse	3 A
Duration of a beam current pulse	250 ns
Beam transverse size (radius)	4 mm
Beam emittance (upper bound)	≤ 0.01 π cm rad
Energy spread	≤ 2 keV

Required beam parameters on the target are contained in Table 2.

Table 2: Required beam parameters

Electron energy	200 MeV
Beam current in a pulse	1.5 A
Duration of the beam current pulse	250 ns
Beam radius on the target	10 mm

In the computation, the following input electron density distributions were used:

Vladimirsky–Kapchinsky distribution in the transverse phase space and uniform distribution in the initial phases (from 0 to 2π) and in the energy spread;

Gaussian distribution in the transverse cross section of the beam and uniform distribution in the initial phases at zero emittance and energy spread.

Amplitudes of the Fourier coefficients for the electric field shown in Figure 2 were used in the simulation of particle motion in the buncher by the PARMELA code. The second section was divided into five domains to take into account the quadrupole focusing. Accelerating electric fields in the domains were tuned to gain the required energy on the length of the section.

In the simulation of acceleration and transportation of various bunches of the electron beam, the electric field was decreased according to [5] to obtain the mean energy of a bunch with the beam-loading effect taken into account.

SIMULATION RESULTS

Computations with the POISSON code used the geometry (shown in Fig. 1) of the elements forming the magnetic field in the domain from the cathode to the end of the first accelerating section.

Simulation has demonstrated that the parameters required from the beam on the target can be achieved at the longitudinal magnetic field in the first accelerating section ≲ 2 kG and without change of its direction.

The distribution of the magnetic field on the axis obtained at the optimal parameters of the elements is shown in Figure 3.

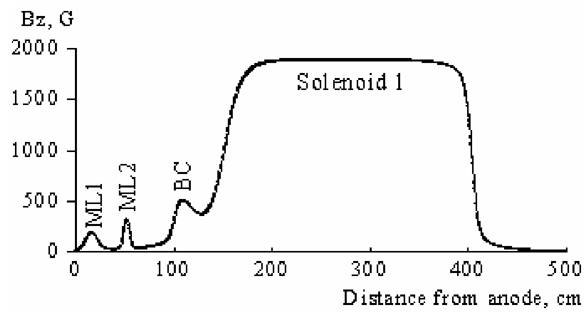

Figure 3: Distribution of magnetic field in the solenoid focusing channel.

The capture efficiency in the acceleration regime was ~80% with the magnetic field formed in the neighborhood of the cathode and the buncher. Modification of the relative positions of the quadrupoles Q6–Q9 required by the placement of the channel in the available building required optimization of the gradients of quadrupoles on the beam parameters on the target. The optimization was performed with the method and code described in [6].

The beam current transmittion along the accelerator line and in the transport channels as well as the energy gain in the acceleration process obtained in the computation, are shown in Figs. 4 and 5.

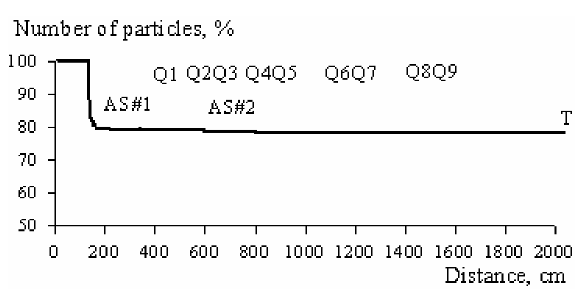

Figure 4: Beam current transmittion through the line.

The total beam losses are about 25% for the initial beam current 2 A. Most of the beam losses are taking place in the neighborhood of the buncher. For the first bunch of the current pulse, the maximal energy of electrons at the target is 204 MeV and the mean energy is 192 MeV.

The same parameters for the last (715th) bunch are 145 and 137 MeV, respectively. The standard deviation of the energy from its mean value is 23 MeV, the minimal electron energy (>65 MeV) is in the required domain, where the neutrons are produced efficiently in a phototarget (> 60 MeV [1]).

Figure 6 shows the distributions of the particles in the transverse cross section of the beam at the target for the microcanonical and Gaussian initial distributions of the electrons. As seen, half-size of the beam at the target does not exceed 5 mm within three standard deviations for the microcanonical initial distribution and 4 mm - for the Gaussian distribution. The beam current transmittion drops till 5% with respect to the microcanonical initial distribution.

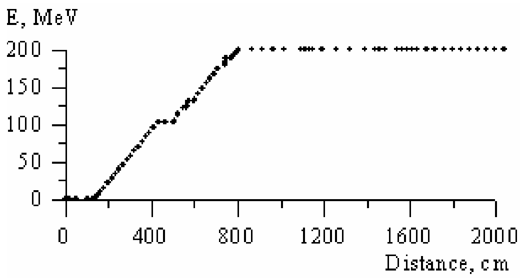

Figure 5: Energy gain along the line.

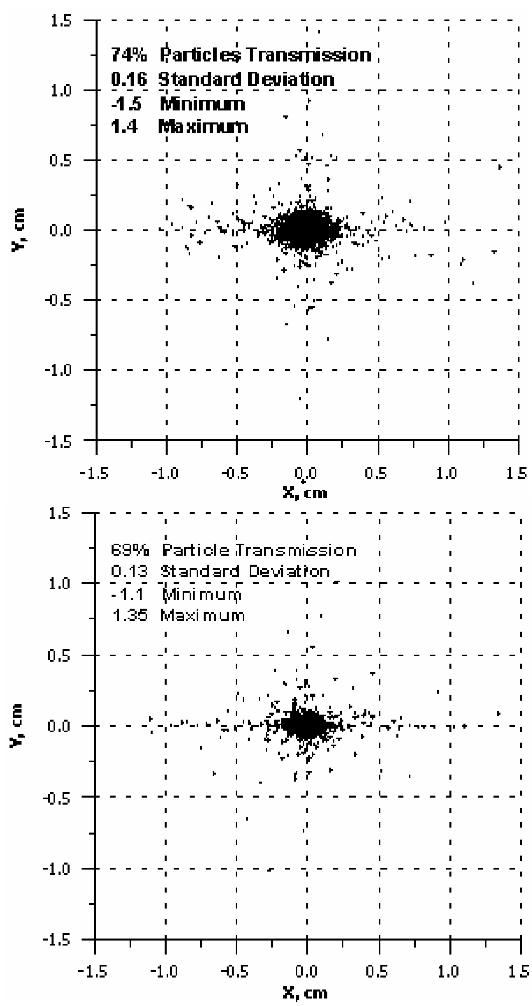

Figure 6: Beam spot at the target for the initial micro-canonical (above) and Gaussian (below) distributions.

CONCLUSIONS

1. The suggested scheme for the accelerator and transport channel is viable at the nominal parameters as well as at various configurations of the focusing magnetic field in the accelerator line, at various currents and initial distributions of electrons in the beam. The following parameters of the accelerated current were obtained: the half-size at the target is less than 10 mm, a final mean energy of 165 MeV, minimal energy >65 MeV, maximal energy of 204 MeV, and beam current transmittion is equal to 70–75% at the initial beam current 2 A. These parameters meet the requirements of the design [1–2].

2. Changing the polarity of the magnetic field in a solenoid does not influence the dynamics and the final parameters of the beam. Using an external magnetic screen for the solenoid results in a 3% increase of the magnetic field strength maximum on the axis, and does not influence the ultimate parameters of the beam.

3. Decreasing the magnetic field in the accelerating section down to 2 – 2.5 kG does not complicate production of the required beam spot on the target if the gradients of the quadrupole lenses are optimal and the beam current transmittion in the line is satisfactory.

4. For the considered range of initial currents (2–5 A) and configuration of magnetic fields of the accelerator (the maximal field of the solenoid S1 ranging from ±2 to ±5 kG) and at the given initial electron energy, placement and parameters of the transport channel lenses, and at various initial distributions, the own field of the beam (without wake field effects) does not considerably influence the dynamics of the beam. We conclude that it is possible to carry the beam while maintaining electron losses as planned (~25%) at fixed gradients of the lenses.

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