ELECTRON BEAM DYNAMICS IN LINAC OF KURCHATOV SOURCE OF SYNCHROTRON RADIATION WITH ENERGY DOUBLING

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Abstract

According to new injection scheme projected for the Kurchatov synchrotron radiation source a full energy booster synchrotron is planed to be the injector of the main storage ring SIBERIA-2. An existing linear accelerator will simultaneously serve as 80 MeV injector for storage ring SIBERIA-1 and as injector for the booster synchrotron with the electron energy of 160 MeV. The energy doubling scheme will be realized by magnetic mirror at the end of linac structure and second passage of electrons through accelerator structure of the linac.

This paper describes the possibility of electron energy doubling. The results of computer simulation of electron beam dynamics during the double passage linac structure are presented.

INTRODUCTION

Linac structure operates with standing wave mode pulse power. The pulsed diode gun with hot cathode is the electron beam source [1]. The main parameters of electron beam at the exit of a gun are given in Table 1.

Table 1: The main parameters of electron beam at the exit of a gun.

Parameter	Value
Beam current	4 A
Pulse duration	18 ns
Beam energy	40 keV
Microperveance	0.5 μA/V$^{3/2}$

Linac acceleration structure is made as biperiodic series of coupled cavities (DAW acceleration structure) [1]. It has 112 regular accelerating cells and 2 accelerating one half length cells. Along accelerating structure the aperture for the beam is small – a diameter of a diaphragm is 8.7 mm. The electrons are accelerated due to stored energy which is reduced by ~10% after electron beam passage through acceleration structure. The main parameters of linac are given in Table 2.

Table 2: The main parameters of linac.

Parameter	Value
RF frequency	2.8 GHz
Shunt impedance	95 MΩ/m
Q factor	28000
Time constant	1.8 μs
Length	6 m
Repetition rate	1 Hz

The unbunched electron beam pulsed by diode gun is injected into first cell of the linac. The shaping of electron bunches occurs mainly during the fly through first two accelerating cells. At the exit of linac structure the current pulse represents a series of bunches following each other with 2.8 GHz frequency. Energy of accelerated electrons is 80 MeV, beam current is about 600 mA.

UPGRADE OF FORINJECTOR

The working principle of upgraded forinjector (see Fig. 1) is as follows: after single pass of linac accelerating structure the electron beam (80 MeV) either is injected into small storage ring SIBERIA-1 to carry out further experiments or is made U-turn with the help of magnetic mirror and is injected into linac for second passage of acceleration structure in opposite direction. After double passage of linac ~160 MeV electron beam is transferred by ETL and injected into booster synchrotron.

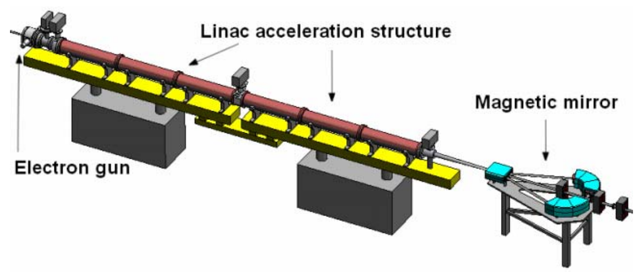

Figure 1: Upgraded forinjector.

To eject electron beam from linac after double passage, electron gun axis has to be deflected relative linac axis at the angle of 30-45 degree. So, electron beam moving just after electron gun with energy 40 keV is deflected by low field bending magnet. This low magnetic field influence will be negligibly small upon high energy (160 MeV) electron beam moving through.

But due to such relative position of electron gun and linac, the dispersion and chromatic bend are arisen for 40 keV electrons injected. This bend complicates the forinjector work and reduces beam capture efficiency in linac structure.

To avoid this problem more preferable version of electron gun and linac relative position is discussed. In this version linac and electron gun are coaxial. The gun cathode has a ring shape with a hole in own center for free passage of electrons after double acceleration. The main difficulty of this location is a creation of a gun itself with hollow cathode. At present time the design of such gun is developed.

To turn the electron beam on 180 degree, magnetic mirror has to provide simultaneously the following: a) achromatic and isochronous bend, b) the saving spatial and angular beam size, c) the correction of beam position and angle.

With the help of a computer modeling program OPTIC, the optical structure of magnetic mirror was designed. The optical functions of one half of magnetic mirror length are shown in Fig 2. The chosen mirror-symmetrical optical lattice of magnetic mirror provides an equality of the initial and final betatron functions and their derivatives. Also the optical structure provides achromatic (dispersion function at the entrance and at the exit of magnetic mirror are equal to zero, $D_{initial} = D_{final} = 0$) and isochronous (momentum compaction factor is equals to zero, $\alpha = 0$) 180-degree turn.

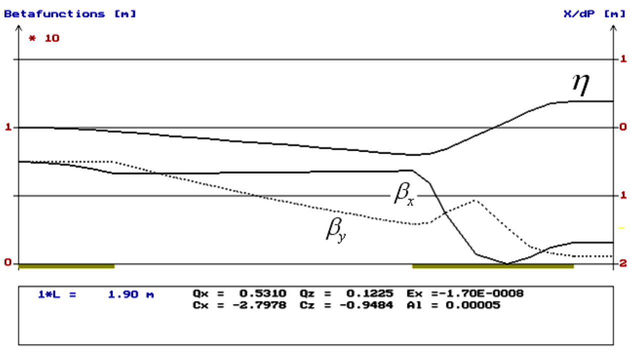

Figure 2: Optical functions of one half of magnetic mirror length.

The magnetic mirror aperture will be accepted the electrons with ±3.5% energy spread from the equilibrium value. The cleaning of electron beam from electrons with small energy will be realized with collimators.

One horizontal and one vertical electron trajectory corrector magnets will be installed in each shoulder of magnetic mirror. These two corrector magnets will be combined into one magnetic yoke.

ELECTRON BEAM DINAMICS

In our model of electron beam we used several limitations: a) coasting beam is injected into linac, b) electrons into the beam don't interact with each other, c) space charge effect is absents. Also we take into account energy interchange between electrons and accelerating structure cavities. We used the following electron beam parameters at the entrance of acceleration structure: electrons energy $W_s = 40\,keV$, beam current duration $T_g = 18\,ns$, beam current $I = 4\,A$, beam radius $R = 3\,mm$.

With ANSYS program code we calculated electromagnetic fields in acceleration structure. Amplitude distribution of this fields in one cell one can see in Fig. 3 (longitudinal electric field E_s) and Fig. 4 (radial electric field E_r and transverse magnetic field multiply by speed of light $B_\theta \cdot c$).

In the first two cells of linac a continuous electron beam is grouping into bunches. This process is shown in Fig 5. About 50 bunches in one train are produced from continuous 18 ns electron beam.

After single passage of linac the 80 MeV electron beam decreases the stored energy in acceleration structure by ~10%. This provides energy spread between head and tail bunches. Head bunches have the energy greater by 10% then tail bunches (see Fig. 6). Energy distribution at the linac exit is shown on Fig. 7.

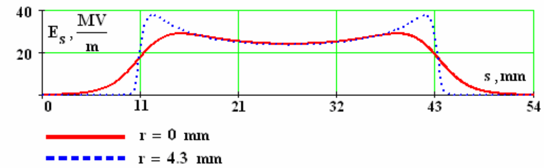

Figure 3: Amplitude of longitudinal electric component E_s at the axis of linac $r = 0$ and close to linac aperture, $r = 4.3\,mm$.

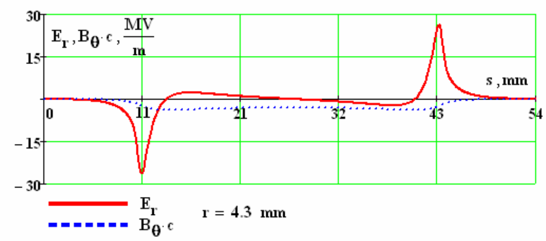

Figure 4: Amplitude of radial electric component E_r and transverse magnetic component multiply by speed of light $B_\theta \cdot c$ close to linac aperture, $r = 4.3\,mm$.

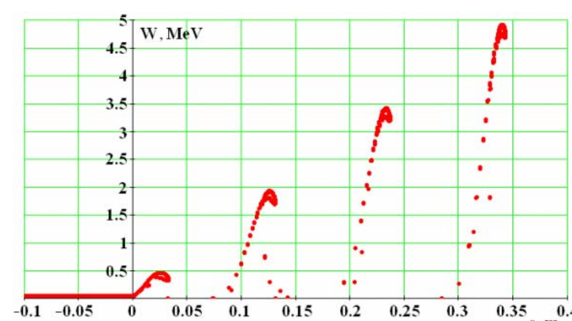

Figure 5: Electrons grouping process and bunches acceleration in a few first cavities of linac.

In the beam 42.5% electrons remain after single passage through acceleration structure. This corresponds to 1.7 A beam current in 18 ns pulse duration. The whole beam from the linac exit for further purposes (injection into storage ring SIBERIA-1 or injection into magnetic mirror and U-turn for second acceleration structure passage) can not be used. Today the energy acceptance of SIBERIA-1 storage ring at injection is as such as ±0.5% from equilibrium value. In this case maximum beam current is achieved at 79-81 MeV beam energy and a number of remain electrons is 3%. Beam current is 120 mA in 18 ns pulse duration.

But into booster synchrotron and magnetic mirror one can inject the electrons with ±3.5% energy spread. Maximum beam current is achieved at 80 MeV beam energy and a number of remain electrons is 19%. Beam current is 770 mA in 18 ns pulse duration.

When electron beam is injected into linac from the gun, less then 50% electrons are captured in accelerating phases. One part of electrons is lost at linac walls and another part of electrons are accelerated in opposite direction and hit into gun cathode.

Low velocities, space charge and radial linac fields will promote faster projection of electrons, accelerating in opposite direction, and most of electrons will be lost on the walls.

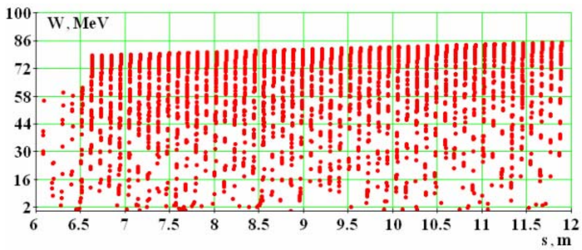

Figure 6: Electron bunches after single linac passage.

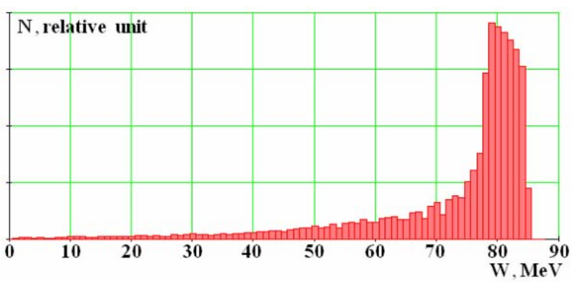

Figure 7: Energy distribution after single linac passage.

We performed some estimation of electrons number "reflected" from linac, their spatial and energy distribution. This estimation was performed without spatial charge influence. Maximum number of electrons will have energy of 40-50 keV and maximum energy will be at 250 keV. Due to 40 kV voltage in electron gun the most part of electrons will be lost. The electrons which will achieve the gun cathode will be located close to gun axis.

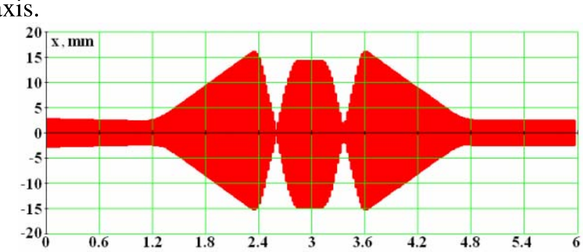

Figure 8: Electrons trajectories in horizontal plane of magnetic mirror.

Electron trajectories in horizontal and vertical planes of magnetic mirror are shown in Fig. 8 and Fig. 9 respectively. The aperture needed for electron beam passage with 7% energy spread into magnetic mirror is of 35 mm $\times$ 8 mm.

After magnetic mirror passage the electron beam with 80 MeV energy and 7% energy spread enters into linac entrance for second acceleration. Electron energy distribution after doubling passage of linac is shown in Fig. 10. An average energy of electrons in the beam is 156 MeV, an energy spared is 5% and a beam current is 770 mA in pulse duration 18 ns. Energy distribution is shown in Fig. 11.

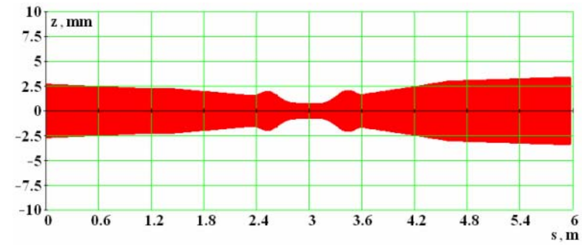

Figure 9: Electrons trajectories in vertical plane of magnetic mirror.

Since electrons are already grouped before second acceleration and electron beam size is saved into magnetic mirror, then electrons are not lost during second linac passage.

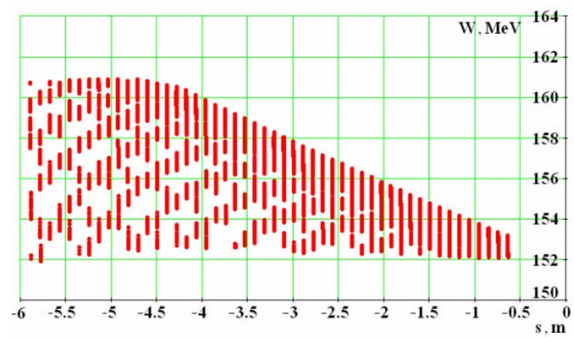

Figure 10: Electron bunches after double linac passage.

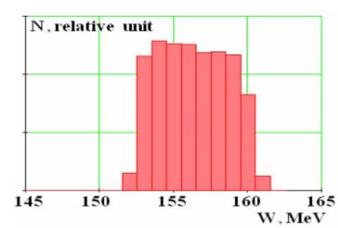

Figure 11: Energy distribution after double linac passage.

By changing the phase of electrons input into first linac cell at second passage, one can change longitudinal energy distribution in the beam. There are several different phases: a) maximum energy phase, b) minimum energy spread phase and c) the saving longitudinal energy distribution phase. In each case we will see a little varying maximum beam energy and energy spread. Therefore a final selection between the different injection phases will be defined in operation.

REFERENCES

[1] A.G. Valentinov et al., Linac – forinjector of the dedicated synchrotron radiation source in RRC "Kurchatov Institute", Preprint BINP, 2002-29, Novosibirsk, 20p. 2002.