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THE LOW ENERGY INJECTOR DESIGN FOR THE SOUTHERN ADVANCED PHOTON SOURCE*

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Abstract

The Southern Advanced Photon Source (SAPS) is a project under design, which aims at constructing a 4th generation storage ring with emittance below 100 pm.rad at the electron beam energy of around 3.5 GeV. At present, two injector options are under consideration. One is a full energy booster plus a low energy injector, and another is a full energy linac injector. In this paper, a preliminary design of the low energy injector is presented, which consists of an DC thermionic electron gun, a bunching section and an accelerating section. The beam energy at the end of the injector is about 150 MeV.

INTRODUCTION

The Southern Advanced Photon Source (SAPS) is a mid-energy fourth generation synchrotron light source which is proposed to be built in Guangdong Province [1], the south of China. The aim of this project is to provide extremely high quality photon beam to promote the progress science and technology. So the natural emittance of the SAPS is designed to be below 100 pm.rad.

At present two kinds of injectors options are considered for the SAPS storage ring. One option is a low energy linac system plus a full energy booster and another one is a full energy linac system. The first injector option has been adopted by many existed and under construction light source, like ALBA [2], DLS [3], Soleil [4], TPS [5], HEPS [6] and so on, due to its robustness and lower cost (compared to full energy linac option and the energy ramping storage ring option). The full energy linac has the ability to provide electron beam with very high quality and it is very attractive for the extremely low emittance storage ring. The option has already been in use by MAX IV [7].

In this paper, the preliminary design of the low energy linac system for the first injector option is presented.

THE LAYOUT OF THE LINAC SYSTEM

The low energy linac system consists of three sections: one DC electron gun section, one bunching section and one accelerating section. The layout of the Linac system is shown in Fig. 1. The DC gun will provide electron bunches with kinetic energy 150 keV at 50 Hz. Then these bunches are longitudinally compressed in the bunching section. Finally, those bunches are boosted and further compressed in the accelerating section.

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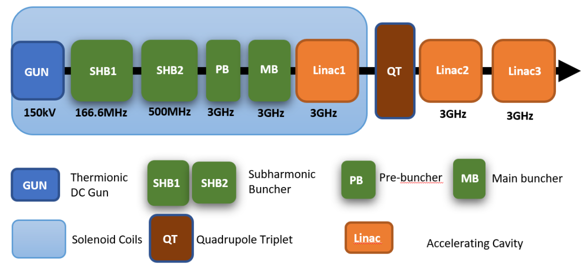

Figure 1: The layout of the low energy linac system.

THE DC ELECTRON GUN

The DC gun of the SAPS will base on the HEPS DC gun [8]. It is assumed that the SAPS DC gun should provide electron bunches with charge about $Q = 4.5$ nC. The DC voltage of the gun is the same as the HEPS gun, i.e. $V = 150$ kV. Given the radius of cathode $r = 8$ mm and distance between cathode to anode $d = 0.1$ m, the Child-Langmuir law will give the current in the electron gun as:

$$I = 2.33 \times 10^{-6} \times \frac{\pi}{r^2} V^{3/2} d^2 = 2.72\,A$$

Then the bunch length is $\Delta t = Q/I = 1.65$ ns. In this case the longitudinal time distribution is simulated by a plateau function with FWHM=1.2 ns and $rt = 0.2$.

The transverse normalized emittance is set as 4.6 mm · mrad which is the same as the HEPS one as a conservative estimation.

These parameters are summarized in Table 1.

Table 1: Parameters of the High Voltage DC Gun

Parameter	Units	Value
Charge	nC	4.5
Energy	keV	150
Pulse length	ns	1.65
Cathode radius	mm	8
Trans. norm. emittance	mm · mrad	4.6

The program ASTRA [9] is used to generate particle distributions at the surface of the electron gun.

THE BUNCHING SECTION

As shown in Fig. 1, the bunching section includes subharmonic cavities, one 3 GHz standing wave pre-buncher cavity, one short 3 GHz traveling wave main-buncher cavity and one 3 meter long 3 GHz traveling wave linac. All these

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components are surrounded by focusing solenoids to control the beam emittance. ASTRA is used for this section.

The Subharmonic Cavities

The first subharmonic (SHB1) cavity is located about 1 m away from the end surface of the electron gun. This distance allows us to arrange several beam diagnostic elements, like ICT, BPM and beam profile monitor. The frequency of the SHB1 is 166.6 MHz, which is 1/18 of 3 GHz. The electron bunch from the electron can occupy 26.7% of the RF period of the SHB1, which is sufficient for the first stage bunch compression. The maximum electric field of the SHB1 is 2.1 MV/m and the phase of the SHB1 is −67 deg (zero degree is RF crest). With these parameters, the longitudinal phase space at the end of the SHB1 is shown in Fig. 2. These electrons on the tail of bunch will have energy higher than those on the head, so the bunch length will be compressed after some drift space.

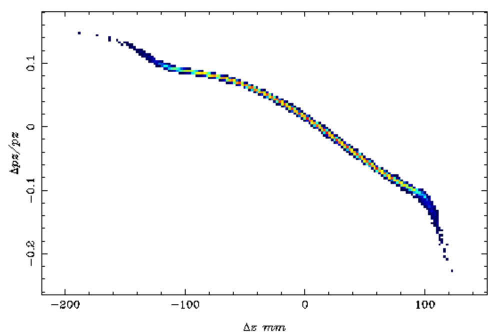

Figure 2: The longitudinal phase space of the electron bunch at the end of the SHB1.

The second subharmonic (SHB2) cavity is located at 2.13 m (the end surface of gun is 0). The frequency is 500 MHz. The simulation shows that the full bunch length before the SHB2 is about 150 mm, which is about 25% of the wave length of the SHB2. The maximum electric field of the SHB2 is 2.18 MV/m and the phase is −82.7 deg. With these parameters, the longitudinal phase space at the end of the SHB2 is shown in Fig. 3. After the SHB2, the energy chirp is increased in order for further velocity bunching.

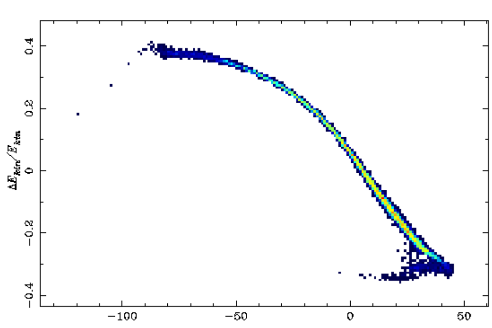

Figure 3: The longitudinal phase space of the electron bunch at the end of the SHB2.

Pre-buncher

The pre-buncher has the same frequency as the main-buncher and the linac, so it will determine the final bunch structure of the system. The simulation shows that the full bunch length of the beam is about 100 mm which is the same as the wave length of the RF cavity, so there will be some particle losses due to the RF field. It also shows that most of particle still locate in the region of half RF wave length. Those particles will be properly collected by the pre-buncher and the following main-buncher.

The pre-buncher is put at 2.43 m with maximum electric field 1.34 MV/m and phase −140.8 deg. With these parameters, the longitudinal phase space at the end of the pre-buncher is shown in Fig. 4. It can be seen that most of the electrons locate in the region of [-30:20] mm. The electrons on the tail still have energy larger than the ones on the head, so the bunch length will be reduced after some drift space.

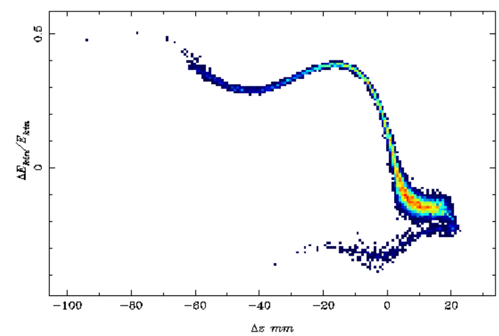

Figure 4: The longitudinal phase space of the electron bunch at the end of the pre-buncher.

Main-buncher

The main-buncher is a 3 GHz traveling wave cavity and works on the $2\pi/3$ mode. The function of the main-buncher is to further compress the electron bunch length and also accelerate the bunch a little. The main-buncher is located at the position 2.60 m. At this position the simulation shows that most of the electrons are in the range [-20:20] mm.

The maximum electric field of the main-buncher is 10 MV/m and the phase is −134.0 deg. With these parameters, the longitudinal phase space at the end of the main-buncher is shown in Fig. 5. It can be seen that the center of the bunch begin to accumulate around a small region [0:10] mm. At the same time, some particles drift far away from the center of the bunch and they will finally be lost.

Accelerating Cavity

The accelerating cavity is a S-band cavity, working on the $2\pi/3$ traveling wave mode. In this cavity the electron energy will be boosted to about 55 MeV and the bunch length will be further reduced through the velocity bunching process. This cavity is located at the position 2.84 m with maximum gradient 26 MV/m and phase -60 deg. The longitudinal phase space at the end of the accelerating cavity is shown in

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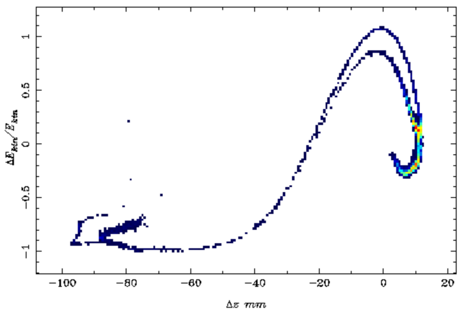

Figure 5: The longitudinal phase space of the electron bunch at the end of the main-buncher.

Fig. 6. More than 80% particles can survive at the end of the this cavity (i.e., the end of the bunching section). The ratio of particle in a range of 10 ps is 73.2% and the r.m.s bunch length in this range is 0.62 mm. The average energy of particle in the 10 ps range is 55.3 MeV and the relative energy spread is 1.8%.

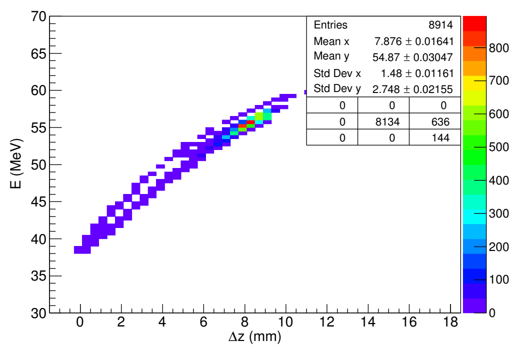

Figure 6: The longitudinal phase space of the electron bunch at the end of the accelerating cavity

Solenoids

In the subsection above, the longitudinal configuration of the bunching section is presented. In the transverse plane, about 20 solenoids are used to control the transverse beam emittance. The on-axis solenoid field is shown in Fig. 7. The maximum solenoid field in this plot is 0.43 T.

Using such a solenoid system, the transverse beam emittance along the bunching section is shown in Fig. 8. The final emittance is about 36 mm · mrad.

THE ACCELERATING SECTION

The main components of the accelerating section are two 3 m long S-band accelerating cavities. Before the cavities, three quadrupoles are used to match the beam parameters. Beam instrumentation elements, like BPM and ICT are also put before the cavities.

The program ELEGANT [10] is used to simulate the beam transmission along the accelerating section. The output beam parameters (in the range 10 ps) from the bunching

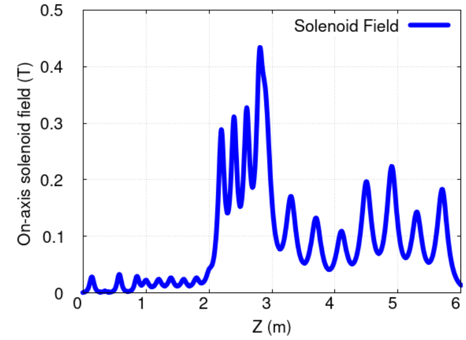

Figure 7: The on-axis solenoid field along the bunching section.

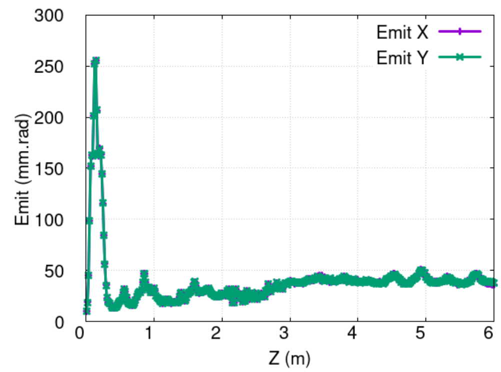

Figure 8: The transverse emittance along the bunching section.

section are used as input for the ELEGANT. The beam energy after this section is about 150 MeV and the energy spread is 0.9%. The normalized emittances are 34.8 and 35.2 mm · mrad in the horizontal and vertical plane, respectively. The beam phase space at the end of the linac are shown in Fig. 9. There is no particle loss in this accelerating section from the simulation.

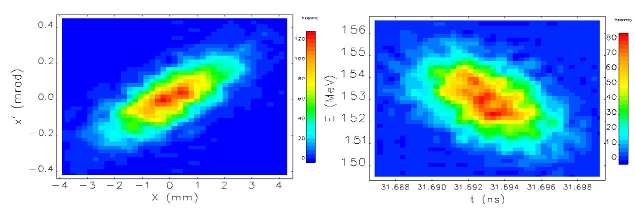

Figure 9: The transverse and longitudinal phase space at the end of the accelearating section.

SUMMARY

In this paper, a preliminary design of a low energy linac system for the project SAPS is presented. This system includes an electron gun, a bunching section and an accelerating section. The program ASTRA and ELEGANT have been used to perform the entire beamline simulation. The simulation shows that there are more 70% particles can be transferred to following booster ring with beam emittance below 40 mm.mrad. More work has to be done in the future.

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