ELECTRON BEAM SIMULATIONS ON THE SCSS ACCELERATOR

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Abstract

The SCSS (SPring-8 Compact SASE Source) is an X-ray SASE-FEL project with a 6 GeV electron beam accelerator. In the year of 2005, the construction of a 250 MeV facility will be started as a preliminary step towards the X-ray radiation. One of the unique features of the SCSS is the use of a pulsed high-voltage electron gun with a thermionic cathode. Meanwhile, the electron bunch should be compressed properly at the injector in order to obtain sufficiently high peak currents. In this paper, a layout of the 250 MeV accelerator is presented with the expected parameters of the electron beam.

INTRODUCTION

The SCSS (SPring-8 Compact SASE Source) is an X-ray SASE-FEL project based on a linear accelerator [1]. The full facility is planned to be constructed next to the 1 km beamline of SPring-8. In order to obtain 0.1 nm radiation, a low emittance electron beam with 6 GeV energy is necessary in combination with 15 mm period in-vacuum undulators [2]. As a preliminary step, we are planning to construct a 250 MeV facility to demonstrate SASE radiation in a VUV region and test the accelerator components in the year of 2005.

One of the unique features of the SCSS accelerator is the use of a pulsed high-voltage electron gun with a thermionic cathode [3, 4]. Main reason for this choice is its high stability and well developed technology relating to the gun. However, the emission current of a theomionic DC gun is small, typically a few amperes, comparing with the RF photo-cathode guns employed in most of the X-ray FEL projects such as LCLS or TESLA. Therefore the electron beam should be properly compressed in the injector to obtain sufficiently high peak currents at the undulator section [1]. Figure 1 is the layout of the SCSS at the 250 MeV stage. In the following sections, the electron beam parameters are estimated using the beam simulation code ”PARMELA”.

INJECTOR

The injector predominantly determines the quality of the electron beam in linear accelerators. In order to make operate the SASE process, the electron beam with high brightness is required, meaning that low emittance, a high peak current and a small energy spread. When the electrons pass through the undulators, only the electrons in a slice of the bunch can contribute to the amplification process of the SASE. The size of this slice is transversely determined by a diffraction limit of emitted light and longitudinally by a slippage length at a maximum. Therefore the beam parameters of the sliced electron bunch are important rather than total integrated or projected parameters of the whole bunch.

The initial condition of the simulation is given based on the results of the emittance measurements carried out on the electron gun. The measured profile in the phase space is shown in fig. 2 (a) and its normalized emittance was 1.1 π mm-mrad with a emission current of 1 A [3, 4]. The ends of the measured profile have slightly curved tails due to the space charge effect at the edge region of the round beam, and these tails increase the emittance in fig. 2 (a). When the electron gun is installed in the injector, these tails will be eliminated using a slit without loosing a major part of the charge. After eliminating the tails, the emittance of the core beam can be estimated from the beam size and the divergence at the beam center and it is about 0.6 π mm-mrad in fig. 2 (a).

Since ”PARMELA” can not treat a DC electron gun, the simulation can not fully reproduce the conditions of the emittance measurement. In the simulation, 500 keV energy is immediately given to the electrons at the start and no DC acceleration process is considered. Therefore, the initial condition of the electron beam is determined so that the electron beam reproduces the core emittance of 0.6 π mm-mrad and the same divergence at the beam center under the identical layout of the beam optics. The obtained phase space profile by ”PARMELA” is shown in fig. 2 (b), in which the effect of the space charge is different from the measured one (fig. 2 (a)) due to lack of DC acceleration in the simulation. The measured and simulated divergences at the beam center (x=0) are compared in fig. 2 (c).

A schematic layout of the SCSS injector is shown in fig. 1. The emission current of the cathode is assumed to be 3A in the simulation. The μsec cathode emission is immediately accelerated by a 500 keV pulsed DC voltage. At the chopper, an electron pulse with 1$\sim$2 ns duration is sliced out from the μsec emission as shown in fig. 3 (a). Then in the 238 MHz SHB (Sub Harmonic Buncher), the energy of the electrons is modulated as a function of their longitudinal position in the bunch (fig. 3 (b)). Since this energy modulation causes the velocity difference between the electrons, it turns into a density modulation as they fly through a drift space. The bunched electrons are accelerated to 1 MeV in a 476 MHz booster cavity and the length of the bunch is further compressed before arriving at the first S-band LINAC (fig. 3 (c)). In the first S-band LINAC, the electrons are again compressed by placing the bunch at off crest of the RF field. Finally at the exit of the injector,

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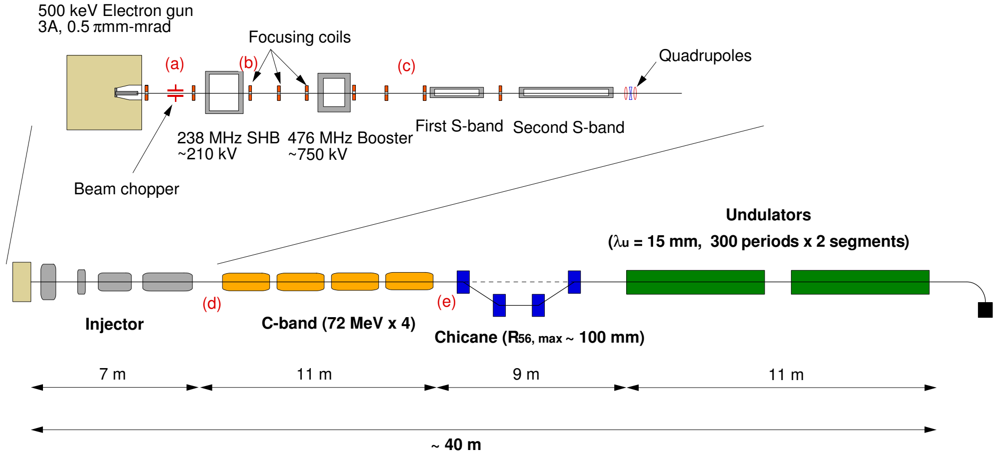

Figure 1: Layout of the SCSS at the stage of 250 MeV beam energy. (a)∼(e) corresponds to the locations used in figs. 3 and 4

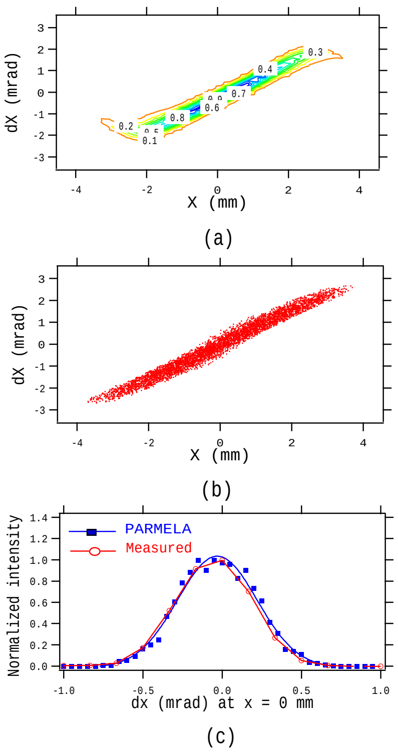

Figure 2: Phase space profiles of the electron bunch, (a) measured [3] and (b) calculated by "PARMELA". The measured and simulated divergences at the electron beam center (x = 0 mm) is plotted in (c).

the peak current close to 100 A can be obtained with the beam energy of 23 MeV (fig. 3 (d)).

In the simulation, APS (alternating periodic structure) standing wave cavities are used for the S-band LINACs and traveling wave disk loaded structure is assumed for the C-band LINACs. The RF fields of the cavities are calculated by "SUPERFISH" and 2-D axisymmetric fields are given to "PARMELA".

Figures. 4 (a)∼(d) are the slice RMS emittance at the locations same as fig. 3. The length of the slice is 1 ps for fig. 4 (a)∼(d), which is larger than the slippage length by rougly one order. The electron beam is focused by using solenoid lenses in the injector and quadrupole magnets after the injector. The parameters of the focusing elements are determined so as to minimize the slice emittance. With the current injector parameters used in figs. 3 and 4, the bunch compression is stopped at each components so that the electrons are not over bunched to keep the emittance small. With the same configuration of the components as in fig. 1, higher compression ratio can be obtained by slightly changing the parameters of the SHB. However, the increase of the peak current at low energy results in the degradation of the emittance due to the space charge effect.

EXPECTED PARAMETERS OF THE ELECTRON BEAM

After the injector, the electron beam is accelerated to 250 MeV by four 1.8 m long C-band accelerator tubes. The expected acceleration gradient is 35∼40 MV/m. Figures 3 (e) and 4 (e) show the profile and slice emittance of the electron bunch at 250 MeV. Expected paremeters of the 250 MeV electron beam are summarized in table 1.

In order to cut out a dark current from the accelerator tubes, a chicane is installed between the C-band LINACs and the undulators. The chicane is composed of four bending magnets and X-Y collimators will be installed between the second and third magnets in the chicane. This chicane is also necessary to inject laser light for the purpose of the undulator alignment [1] and FEL operation with seeding light [6, 7].

A saturation length corresponding to the parameters in table 1 is about 18 m. In order to obtain a shorter saturation length, the peak current should be increased in the injector at the expense of the emittance, or in the chicane. The current design of the chicane has the maximum $R_{56} \approx 100$ mm and it can be used as a bunch compressor. The emittance growth due to the CSR effect (Coherent Synchrotron Radiation) is discussed in ref. [5] in case of a similar bunch compressor design.

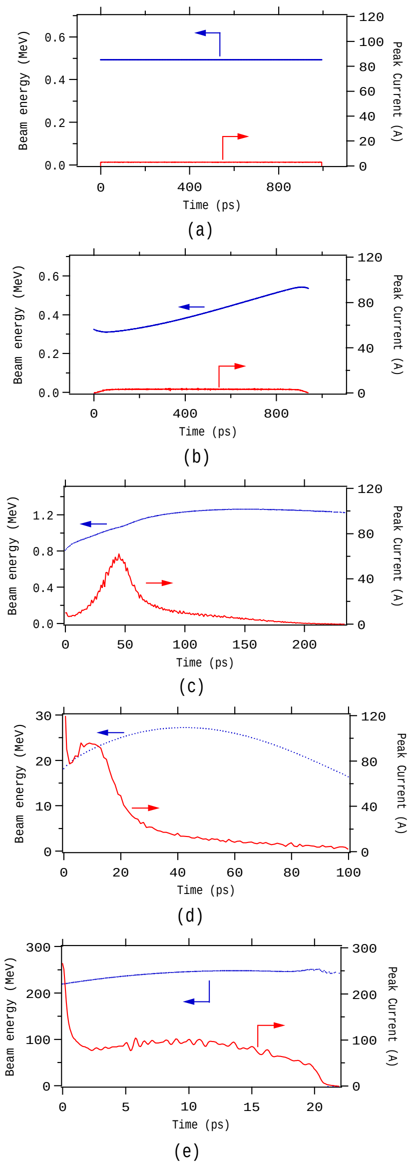

Figure 3: Electron beam energy (blue lines) and peak current (red lines) as a function of longitudinal position (time) in the bunch. (a)∼(e) corresponds to the location marked in fig. 1, at (a) chopper, (b) after SHB, (c) before first S-band LINAC, (d) injector end (before first C-band LINAC) and (e) accelerator end (before chicane). The emission current of the gun is set at 3A and the head of the electron bunch corresponds to the time zero.

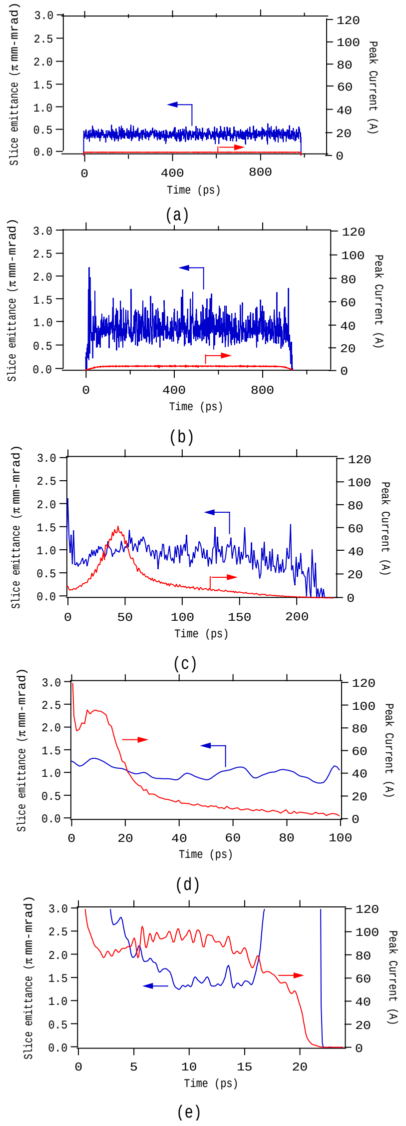

Figure 4: RMS normalized slice emittance (blue lines) and peak current (red line) as a function of longitudinal position (time) in the bunch. (a)∼(e) corresponds to the location marked in fig. 1, at (a) chopper, (b) after SHB, (c) before first S-band LINAC, (d) injector end (before first C-band LINAC) and (e) accelerator end (before chicane). The length of the slice is 1 ps for (a)∼(d) and 0.1 ps for (e). The emission current of the gun is set at 3A and the head of the electron bunch corresponds to the time zero.

Table 1: Expected parameters of the electron bunch at the undulator of SCSS.

Electron Energy	250 MeV
Normalized Slice Emittance	$\sim$1.5π mm-mrad
Peak Current	100 A (before chicane)
Slice energy spread	$\sim 2 \times 10^{-4}$
Undulator period	15 mm
Nominal operation gap	3.5 mm
K parameter	1.3
Radiation wavelength	60 nm

SUMMARY

As a preliminary step to the X-ray SASE-FEL, a 250 MeV facility is planned to be constructed in the SCSS project. The purpose of the 250 MeV facility is to demonstrate the SASE-FEL and test the accelerator components, since the SCSS has unique features in its design, such as the thermal DC electron gun and in-vacuum undulators. The electron beam parameters of the 250 MeV facility are estimated using the code ”PARMELA”. The design performance of the accelerator will be compared with measurements after the completion of the facility including a bunch compressor.

Regarding the SASE operation at 60 nm with 250 MeV electrons, we need to obtain a shorter saturation length than the expected one in this paper. After further optimization of the beam parameters, particularly with the higher peak current, the saturation length of $\approx$ 10 m is expected.

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