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PRELIMINARY DESIGN OF THE FULL ENERGY LINAC INJECTOR FOR THE SOUTHERN ADVANCED PHOTON SOURCE*

X. Liu†, B. Li, Y. Jiao, S. Wang
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
Spallation Neutron Source Science Center, Dongguan 523808, China

Abstract

A 4th generation mid-energy range diffraction limited storage ring, named as the Southern Advanced Photon Source (SAPS), is under consideration to be built at the same campus as China Spallation Neutron Source (CSNS), providing a charming one-stop solution for fundamental sciences and industrial applications. While the design of the ring is still under study, a full energy Linac has been proposed as one candidate option for its injector, with the capability of being used as an X-ray Free Electron Laser (XFEL) in the near future. In this paper, an overview of the preliminary design of the Linac is given and simulation results are discussed.

INTRODUCTION

The Southern Advanced Photon Source (SAPS), a fourth-generation light source featuring a mid-energy range diffraction limited storage ring (DLSR), has been proposed to be built near the China Spallation Neutron Source (CSNS). While a conventional booster has been considered as its injector, recently a full energy Linac option has also been proposed at the prospect of being used for other applications such as an X-ray Free Electron Laser (XFEL).

There are other DLSRs adopting the full energy Linac as the injector. For example, MAX-IV extracts the electron beam at 1.5 GeV and 3 GeV respectively, feeding its two storage rings [1]. At the end of the Linac, short pulse facility and XFEL extension are planned. Another example can be seen from the upgrade of Spring-8, which originally was an 3rd generation synchrotron radiation light source. With its main ring being upgraded to the 4th generation featuring smaller emittance, the old booster with FODO lattice cannot provides such a low emittance beam. Therefore, along with considerations like reducing the power consumption and operation cost, the Linac of SACLA, which is an XFEL, has been proposed to work as an injector [2]. In addition to existing facilities, some on-going projects also choose this option. For example, in Japan, there is a new 3 GeV light source project using full energy Linac as the injector, with a near-future XFEL extensibility in scope [3].

DSLR and XFEL are both categorized as the fourth generation light source. To have them work along with each other is a charming scheme. As a new project, we are aiming to design both the DSLR and the XFEL with the state-of-the-art technologies which are available now or near future. As the XFEL typically requires higher beam quality than the storage ring, the Linac for SAPS is designed similar to that for an XFEL. Meanwhile, as a very recent and still on-going project adopting normal conducting structures, CompactLight Project [4, 5] provides a very good frame which benefits our Linac design.

A general overview of SAPS and the current status of the design studies can be found in [6]. This paper will focus on the description of the preliminary design of the full energy Linac.

DESIGN STUDIES

General Design Settings

The energy of the SAPS ring [7] is presumably 3.5 GeV which determines the beam energy at the exit of the Linac. According to the studies in CompactLight [8], at this energy, with the undulator settings for CompactLight, the photon energy can enter into the hard X-ray regime, as high as 5 keV (0.2 µm beam emittance and 0.05% sliced energy spread are assumed). The corresponding current intensity is 2 kA, as shown in Fig. 1.

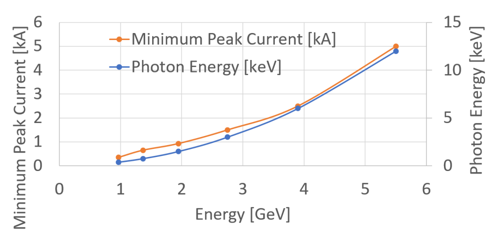

Figure 1: Relationship among the current intensity, beam energy and the photon energy.

Like many other XFEL facilities and also in CompactLight, two-stage compression is often chosen to longitudinally compress the beam. At present, the first bunch compressor (BC1) and the second one (BC2) are simply located at 300 MeV and 1.5 GeV respectively. A simple layout of the Linac injector is shown in Fig. 2.

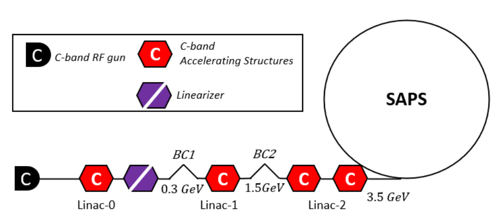

Figure 2: Layout of the Linac injector for SAPS.

* Work supported by Guangdong Basic and Applied Basic Research Foundation(2019B1515120069)
† liuxg@ihep.ac.cn

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RF Considerations

As a spin-off project of Compact Linear Collider (CLIC) [9], CompactLight adopts high gradient X-band structures to accelerate the beam in the main Linac sections, which makes the whole Linac very short compared with other XFEL facilities. However, given the fact that C-band structures are more mature than X-band and the power source is much cheaper, thus in our case for SAPS, we prefer to use C-band structures for the main Linac at this stage. In addition, electron beam will feel smaller wake fields in C-band structures than X-band, which will make the beam commissioning easier.

In order to obtain ultra-low emittance beam, we choose the C-band structures for the gun and the low energy part, similar to CompactLight. As a result, the whole injector for SAPS is a "full C-band" Linac except for the linearizer which is considered as K-band. Main parameters of the C-band and K-band structures are assumed as in CompactLight [10] and are listed in Table 1.

Table 1: Main Parameters of the RF Structures

Parameters	C-band	K-band	Unit
Frequency	5.712	35.98	GHz
Phase advance	2/3		π
Cell length	17.495	2.776	mm
Number of cells	115	108	
Total length	2	0.3	m
Average iris radius	6.6	2	mm
Repetition rate	100		Hz

RF Photo Gun and Low Energy Section

Though C-band RF photo guns are not so mature as S-band guns, they are gaining popularity in recent years. Except for the CompactLight Project, C-band gun has been considered for the SwissFEL [11] and also in a recent study for XFEL and other compact light sources [12].

In this paper, we are assuming the beam at 100 MeV with the parameters as listed in Table 2 in our preliminary design. Simulation on the gun and the low energy part is reserved for another study.

Table 2: Bunch Parameters at 100 MeV

Parameters	Values	Unit
Beam energy	100	MeV
Emittance (norm.)	0.15	um
Total charge	75	pC
Initial energy deviation	5	keV
Bunch length (RMS)	100	um

Module Based Design

Typical power of the commercial high-power C-band Klystrons is 50 MW. With the power compression technique like SLED, we assume that 80 MW can be delivered to the accelerating structure, same as that in the Linac injector for the 3 GeV light source project in Japan [3] which also adopts C-band structures. Additionally, according to the study in CompactLight [13], for the C-band structures shown in Table 1, 20 MW is enough to support a gradient of 40 MV/m. As a result, in this paper, we assume that one klystron can drive four C-band structures. Figure 3 shows a layout for the RF power delivery and also the alignment for accelerating structures and quadrupoles. Since a single C-band structure is 2 m long, we are assuming two structures will be mounted on a girder along with two quadrupoles which are integrated with beam position monitors (BPMs) and correctors. The same arrangement will be kept through Linac-0 to Linac-2, only the length of the quadrupoles is modified slightly at different energy stage.

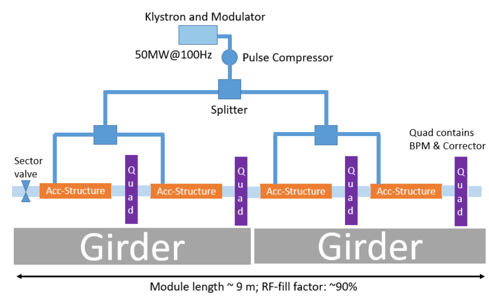

Figure 3: RF power distribution and the module design.

Design Process and Results

The design process is conducted in the following steps:

1) Longitudinal beam design with the help of the tracking code Track1D [14], which is a simple and fast 1D code including short-range longitudinal wake initially developed for CompcactLight

2) Extend the design to 3D by adding the quadrupoles and match sections between Linac sections. Elegant [15] is used for the tracking.

Figure 4 shows an overall layout of each sections and key parameters obtained in the design after Step 1. The Twiss parameters are shown in the upper corner. We found that the longitudinal motion is relatively decoupled from the transverse direction. The transverse phase space plots at the exit of Linac-1 and Linac-2 are shown in Figs. 5 and 6 while Figs. 7 and 8 are for longitudinal direction. We compressed the beam to 2 kA. Collective effects like space charge (SC), coherent synchrotron effects (CSR) and micro-bunch instability (MBI) have also been evaluated based on the design shown here. Please refer to [16] for details.

Injection Scheme

For a modern DSLR like SAPS, the dynamical aperture (DA) is usually small which makes the off-axis injection a challenge. For SAPS, the DA is only 5 mm [7]. On-axis

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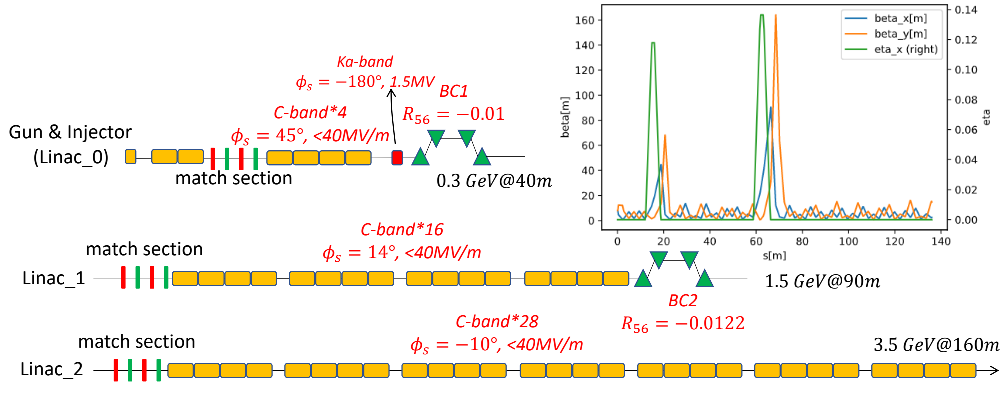

Figure 4: Design parameters for the SAPS injector.

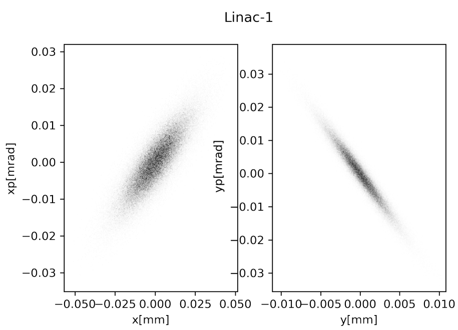

Figure 5: Transverse phase space at the exit of Linac-1.

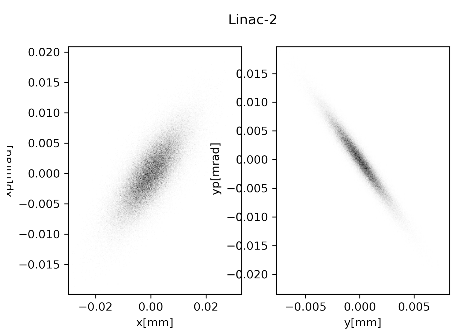

Figure 6: Transverse phase space at the exit of Linac-2.

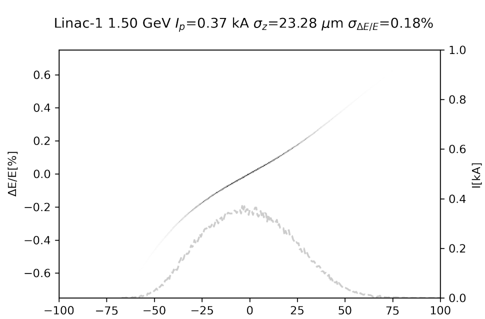

Figure 7: Longitudinal phase space at the exit of Linac-1.

transverse injection can be used for the conventional booster

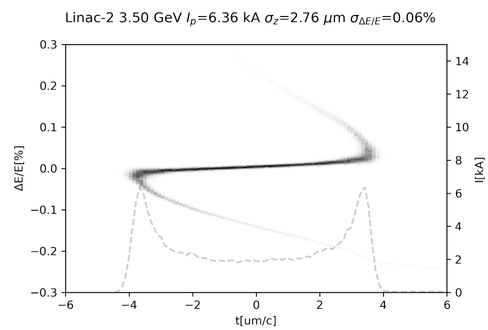

Figure 8: Longitudinal phase space at the exit of Linac-2.

option [17]. The beam can not be accumulated with this method. In case of the full energy Linac option, the charge in a single bunch is typically small so beam accumulation is a must. Therefore, we are looking at the longitudinal injection scheme. Another issue related to the injection is that beam with a current intensity of several kilo-amperes is not suitable for beam transport and injection to the SAPS ring due to large radiation loss. One possible solution is putting BC2 after the final energy like MAX-IV or bypassing the second BC during injection during the injection process. Another is making the bunch longer in the transport line from the Linac to the ring, like that in SACLA [2].

SUMMARY

In this paper, a general overview of the full energy Linac option for the SAPS injector has been given. Our preliminary results show that a compact design can be realized with ultra-low emittance C-band photo gun and high-gradient C-band structures. In addition, it is ready to work as an XFEL at the same time. In the next step, we will add the simulation study for the RF photo gun and more studies will focus on tuning the design, considering the collective effects like SC, CSR, MBI and IBS. In addition, beam transport and injection scheme will be studied to fulfil the requirement for the SAPS ring.

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