An injector of Super SOR

Hiroshi Sakai*[1], Norio Nakamura[1], Hiroyuki Takaki[1], Tadashi Koseki[2], Hiroyuki Hama[3], Tetsuo Shidara[4], Masanori Satoh[4]
[1]*Institute for Solid State Physics, Univ. of Tokyo (ISSP), Kashiwa, Chiba, 277-8581, Japan*
[2]*The Institute of Physical and Chemical Research (RIKEN), Wako, Saitama, 351-0198, Japan*
[3]*Laboratory of Nuclear Science, Tohoku Univ., Mikamine, Sendai, 982-0826, Japan*
[4]*High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, 305-0801, Japan*

Abstract

We present a design of the injector part for the Super-SOR ring of the University of Tokyo, which is a 3rd generation type vuv light source and is aimed to operate with top-up operation scheme [1]. In order to realize top-up operation, this injector consists of a pre-injector and a synchrotron. The pre-injector is a 200MeV linac and injects the electron beam into the synchrotron. In the synchrotron, the electron beam is accelerated from 200MeV up to 1.8GeV and its emittance and energy spread are reduced. In order to realize this low emittance beam, modified FODO lattice is applied. The details are presented in this section.

INTRODUCTION

The Super SOR light source facility is a 3rd generation vacuum ultra violet (vuv) and soft X-ray light source to be constructed at Kashiwa campus of the University of Tokyo. This facility aims to generate a high brilliant light stably. In order to keep generating this high quality light, top-up injection scheme is nesseccery for keeping electron beam current of the main ring stably. The injector parts of the Super SOR are especially important to inject an electron beam into the main ring without beam loss during thsi top-up operation. Fig.1 shows the plan view of this injector part. It consists of two main parts. One is the pre-injector which generates the electron beam and acelerates its beam up to 200 MeV and the other is the synchrotron whcih also accelerates the beam from 200MeV up to 1.8GeV Reeduced beam emittance and energy spread enables us to inject the electron beam to the main ring smoothly. Required emittance and momentum spread are about 50 nm·rad and 0.1%, respectively.

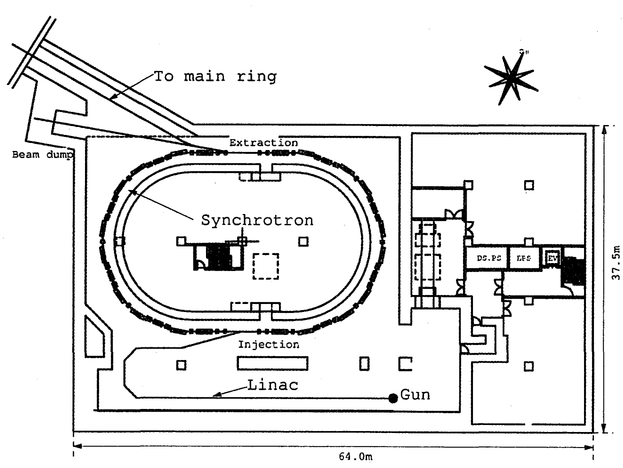

Figure 1: Plan view of the injector. All components are set under ground and shielded by concreate blocks.

This paper is organized as follows. We will describe pre-injector in the next section. In section 3, the synchrotron is presented. Final section is devoted to the discussons and conclusions.

PRE-INJECTOR

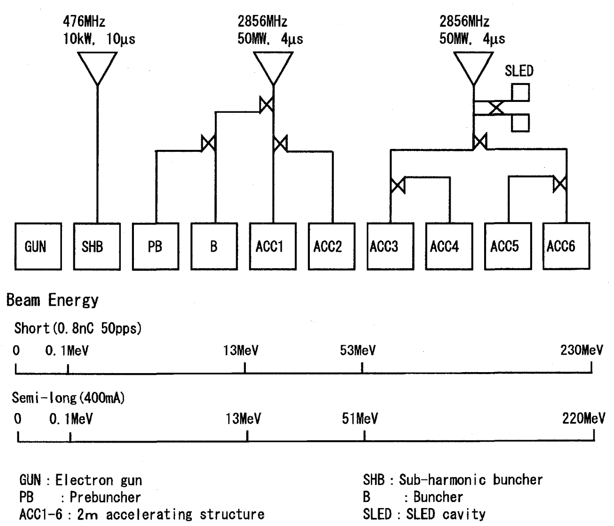

Figure 2: Layout of the pre-injector. The beam is accelerated in two different operation mode.

Fig.2 shows a layout of the pre-injector. It consists of a thermal gun, a sub harmonic buncher, a pre-buncher, a buncher and six accelerating structure units. Each accelerating structure is based on a SLAC type cavity and its length is 2m. The bunching section and accelerating sections are driven by two 50MW klystrons and SLED cavity. There are two operating modes. Short and semi-long pulse modes are provided for injection to the storage ring in single and multi bunch operation modes of the ring, respectively. Both modes will be also utilized and optimized for top-up injection. We describe both modes as follows.

* e-mail address: hrsakai@issp.u-tokyo.ac.jp

Energy	200 MeV	
RF frequency	2.856GHz	
Repetition rate	50Hz	
Beam pulse mode	Short	Semi-long
Pulse duration	1ns(10ps)	100 ns (max)
Peak current	0.8A	400mA
Normalized emittance	30 π mm·mrad	
Energy spread	0.5% (FWHM)	

Table 1: Parameters of the pre-injector.

In a short pulse mode, the electron beam is ejected as a single bunch from a thermal gun with 1ns bunch length. This beam is first compressed logitudinally (bunching) by a sub-harmonic buncher, a pre-buncher and a buncher and its bunch length is reduced less than 10ps. Emittance is maintained by adopting solenoid magnets. We calculate the emittance of the beam by PARMERA and it results in 30 π mm·mrad on the exit of buncher [2]. This beam is accelerated by accelerating sections up to 200MeV. In a semi-long mode, multi bunch electron beam with 100ns (max) pulse duration is accelerated. Beam energy becomes more than 200MeV at the end of the accelerating section. However in this mode, beam loading effect is dominant and total energy spread reachs to more than 4%. This does not meet with the aceptance of the synchrotron as described below. To reduce the total energy spread, we search the timing of phase reverse of SLED cavity corresponds to the beam injection timing. Fig.3 shows the diffenence of energy gain with and without beam loading. Thanks to the beam loading effect, 100ns flat top is achieved. Fig.4 shows the result of this search with beam loading. Each transverse axis shows the induced beam current and total beam length, vertical axis shows the energy spread. Energy spread is reduced less than 1% on each condition. Beam current is tunable by utilizing by collimater which locates in front of a cathod of gun. Parameters of pre-injector are summarized on Table.1.

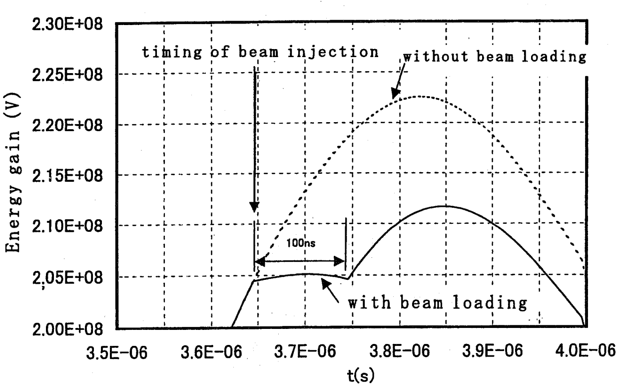

Figure 3: The energy gain on two condition (with beam loading and without beam loading)

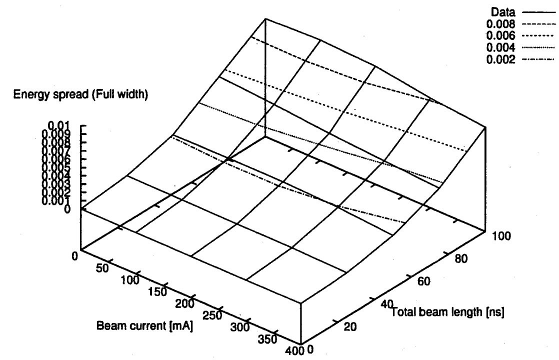

Figure 4: Results of injection timing search. Results of total energy spread are included beam loading effect.

SYNCHROTRON

In the synchrotron, the electron beam from the pre-injector is accelerated up to 1.8GeV and beam emittance is also reduced to meet with the injection condition of the main ring. In order to realize low emittance and small energy spread, larger circumference is better. Considering given areas of Kashiwa campus, we desided that circumference of the synchrotron is about 93m that is one-third of the main ring. Fig.5 shows the lattice design and Table.2 shows the parameters of synchrotron. Lattice is based on FODO. There are 6 families of quadrupoles (QF,QD,QFX on cell, QX,QY,QFM on straight section) and 2 families of sextupoles (SD, SF). In detail, one-cell consists of "QF-SF-QD-SD-B-QFX-B-SD-QD-SF-QF" (Modified FODO) as shown in Fig.5. Bending magnets are set on lower dispersion points, then we are able to reduce emittance lower. Its emittance is smaller than that of usual FODO lattice of same circumference. However, dispersion of QF is much bigger than others, then stronger magnetic field is required for QF. At present 19T/m is required, which is enough to realize this magnetic field. RF frequency is same as the main ring. The repetition rate of the synchrotron is 1Hz.

Dynamic aperture of this lattice is calculated by using SAD simulation code [3]. First we survey oprating point on tune diagram and select horizontal tune $\nu_x = 7.35$ and vertical tune $\nu_y = 3.30$. After that, we recalculate the dynamic aperture on this oprating point. Fig.6 shows the results of dynamic aperture survey. Transverse acceperance is larger than physical acceptance. Furthermore, energy accepetance is larger than $\pm 1\%$, which is enough for the electron beam from the pre-injector. Finally, $\varepsilon_x = 52.1$ nm·rad is realized.

SUMMARY AND DISCUSSION

We have described the calculated performance of the injector. The beam emittance is reduced to 52.1 nm·rad by the synchrotron. Both pre-injector and synchrotron are designed to operate on a single and a multi bunch modes. It

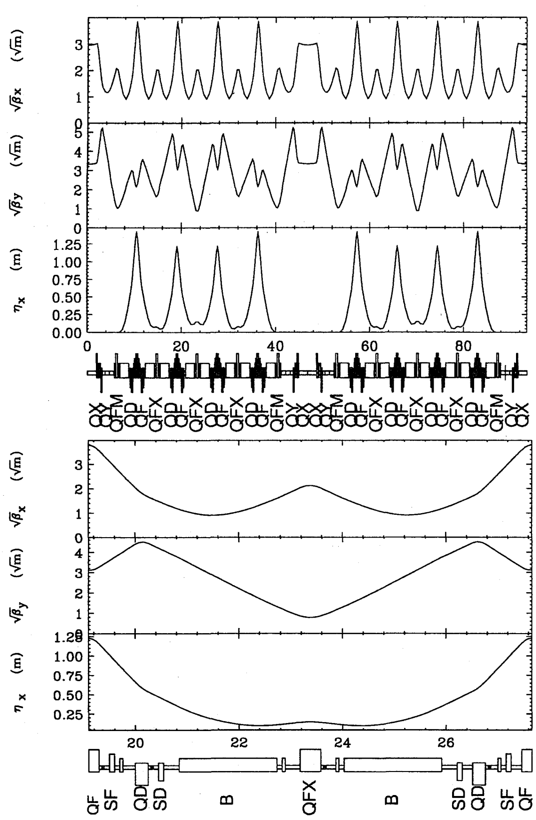

Figure 5: Lattice of the synchrotron. Top (Bottom) figure shows the lattice of all components (one cell). Square root of horizontal β function, square root of vetical β function and horizontal dispersion function are drawn at the top, middle and bottom on each figure.

Parameters	Extract	Inject
Energy	1.8GeV	0.2GeV
Circumference	93.5m	
Lattice	Modified FODO	
Harmonic number	156	
Horizontal emittance	52.1 nm·rad	-
Energy spread	7.06×10^{-4}	-
Bunch length	13.7mm	-
Betatron tune (x/y)	7.35/3.30	
Momentum compaction	0.0108	0.0108
Damping time (x)	5.73 ms	4.18 s
Damping time (y)	5.80 ms	4.23 s
Damping time (z)	2.92 ms	2.13 s
Bending field	1.25T	0.139T
Bending radius	4.8m	
Energy loss per turn	193.47 keV	29.49 eV
RF Voltage	500 kV	
RF frequency	500.1 MHz	
Bucket height	0.0070112	0.0307123

Table 2: Table shows the main parameters of the synchrotron.

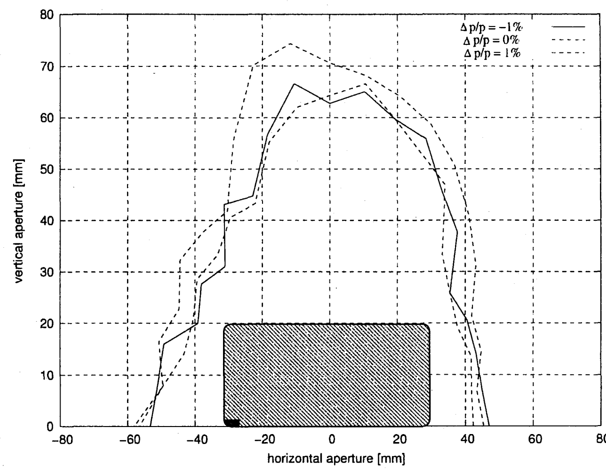

Figure 6: Results of dynamic aperture survey at 200MeV. Horizontal axis is the dynamic aperture of hosizontal direction and vertical axis shows the dynamic aperture of vertical direction. Three lines shows the dynamic aperture on each of three momentum deviation (Δp/p = -1%,0%1%), respectively. Shadow area shows the physical aperture of synchrotron.

is enough to inject the multi bunch beam to the main ring with the top-up injection scheme.

Capture efficiency of the synchrotron is not enough on a multi-bunch mode because of the followings. One is the defferent RF frequency between the pre-injector and the synchrotron. 2.856GHz is not devided by 500.1MHz, then 2.0ns spacing multi-bunch beam is not generated by the injector complex. And the other reason depends on large dispersion functions at QF. At present, energy acceptance is determined by the physical aperture at QF due to the large dispersion when the beam is injected. This calculation including these conditons shows the capture effeciency is around 45% [4]. In order to increase this capture effeciency and reduce the beam loss, some modifications are planning. One is an enlargement of the bucket height in the synchrotron to modelate the RF voltage, and the other is the reduction of the dispersion funcition at QF by changing the lattice slightly.

REFERENCES

[1] A.Kakizaki, "A New Synchrotron Radiation Facility Project of the University of Tokyo.", The 8th International Conference of Synchrotron Radiation Instruments 2003 ,San Francisco, (2003).

[2] PARMERA is a sumilation code of gun design.

[3] SAD is a computer program for accelerator design. See "http://acc-physics.kek.jp/SAD/sad.html".

[4] In a single bunch mode, the capture efficiency is 100%.