DESIGN OF HIGH CURRENT INJECTOR FOR SPring-8

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Abstract

The linac of SPring-8, Large Synchrotron Radiation Facility of Japan, has the option which is positron operation modes. The electron gun of this linac is designed on base of the optimization for a high current beam to get positrons as many as possible[1]. But otherwise this linac should be used as an accurate electron beam generator for commissioning on the whole facility. This report shows differences of the beam specification between a high current beam and a low current beam. The bunching section of this linac has just been constructed this summer at Tokai-Lab. of JAERI to be confirmed with the specification.

Introduction

The linac for SPring-8 injects 1.1GeV electron beam or alternatively 0.9GeV positron beam to the booster synchrotron. It consists of 26 accelerator sections of S-band, and the bunching section has two single cell pre-bunchers and a 13 cell buncher of standing wave type. The electron beam has a long pulse mode and a short pulse mode, and the short pulse mode contains low current mode and high current mode. In the part from the electron gun to the retractable target, the high current mode corresponds to positron beam mode. The beam optics is quite different between those modes, because the number of particles per bunch of short pulse high current mode is a hundred times as many as its of long pulse electron mode. The gun is designed to obtain extra high current up to 15A, 1ns. The same electron gun is used for every modes, and a small diameter iris is set just behind the gun when it's operated in electron modes. Axial magnetic field of eight helmholtz coils is superimposed with the region of two pre-bunchers and the buncher to prevent from radial expansion of the beam. These eight coils are exactly aligned by measuring the center of axial field line. Each of coils has a power source individually to be enable to set arbitrary magnetic field configuration.

Layout of the Bunching Section

The electron gun uses the cathode assembly of EIMAC Y796[1], the voltage is up to 200kV. To measure the performance of the gun, two kinds of core monitor[2] and a profile monitor are set behind the gun. Then the drift space from the gun to first pre-buncher (drift1) is rather long. The drift length between first pre-buncher and second pre-buncher (drift2) and the drift length between second pre-buncher and the buncher (drift3) are designed to make the bunch length into 40 degrees under optimum operation. After the buncher, the bunch length becomes 5 degrees. Spacial layout of this bunching section is as follows :

TABLE 1
Layout of Bunching Section

Gun	{ 200kV }	
Drift1	{ Gun – Prebuncher1 }	747 mm
Prebuncher1	{ SWT, single cell }	
Drift2	{ Prebuncher1 – Prebuncher2 }	220 mm
Prebuncher2	{ SWT, single cell }	
Drift3	{ Prebuncher2 – Buncher }	142 mm
Buncher	{ SWT, 13 cells }	

Low current mode

When electron mode is required, the center region of the beam which has good emittance is cut out for latter sections by putting a small iris (2.6mmϕ) located immediately behind the electron gun. Several types of iris are prepared, and the short pulse beam of 1ns 300mA is expected. The long pulse of this low current mode is 1μs 100mA. The maximum charge number is 100pC par bunch. The correlation of the radial motion of electrons in the bunch and the external axial magnetic field is satisfied with Brillouin flow condition. The equation of motion under the Brillouin flow condition is :

$$m_e\omega^2+e\frac{\partial V}{\partial r}-eB(r\omega)=0 \quad (1)$$

$$\omega=\frac{\omega_c}{2} \quad (2)$$

ω_c is cyclotron frequency :

$$\omega_c=\frac{eB_z}{m_e} \quad (3)$$

Charge intensity of the bunch under Brillouin condition is derived with (1), (2), (3) and Poisson eq. :

$$\rho=\frac{\varepsilon_0 eB_z^2}{2m_e} = 0.7786\,B_z^2 \quad (4)$$

If it is assumed that the bunch form is cylinder, the charge density would be 8.0×10^{-5}(C/m^3), and the axial field for Brillouin flow : B_z is 101G. Futhermore, kinetic energy eq. is :

$$\dot{z} + (r\dot{\theta})^2 = \frac{2eV}{m_e} \quad (5)$$

When

$$\dot{\theta} = \omega = \frac{\omega_c}{2} \qquad (6)$$

from eq(5),

$$\dot{z} = \left(\frac{2eV_0}{m_e}\right)^{1/2} \qquad (7)$$

'a' stands for beam radius, the current of Brillouin flow is :

$$I = -\pi a^2 \rho \dot{z} = \pi \eta^{3/2} \frac{\varepsilon_0}{\sqrt{2}} B_z^2 a^2 V_0^{1/2} \qquad (8)$$

When V_0 is 200kV (β=0.7), B_z for 300mA is required 107.5G.

High current mode

In order to get a good yield of positron, it is necessary to increase the beam current. The expected emission current of the electron gun is 15A 1ns at a short pulse mode, and 4.6nC per bunch is rather severe. The scheme of positron production is almost same as APS and ESRF, consists of a tungsten retractable target, a pulsed solenoidal and DC solenoidal field are superimposed on the target and the accelerator section for positron collection[3].

From eq(8), B_z for this high current beam is 304G. The peak current of the bunch becomes 42A just before the buncher, and B_z is needed 509G. The low β and high density bunch, such as this, would have a strong effect of longitudinal diffusion caused by space charge.

Simulation

The difference between the high current mode and the low current mode was compared by a simulation. The used simulation code is TRACE-PC, 3D code including a space charge effect.

The initial beam parameter was gave from a calculation of EGUN. The emittance is 26π mm•mrad, the beam size is 8.5mm and maximum dx is 42mrad. In this simulation, twiss parameters are assumed from the beam ellipse in a phase space. The beam ellipse of low current mode, $\alpha_x = \alpha_y = 2.0$ and $\beta_x = \beta_y = 0.5$ is shown in Fig.1. The beam ellipse of high current mode is assumed as $\alpha_x = \alpha_y = 7.0$, $\beta_x = \beta_y = 1.5$ which is shown in Fig.2.

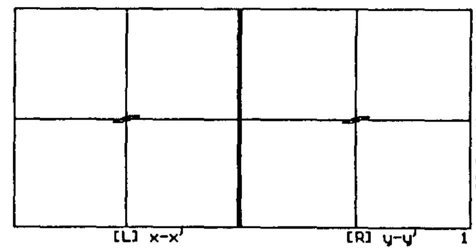

Fig. 1 beam ellipse of low current mode in phase space.

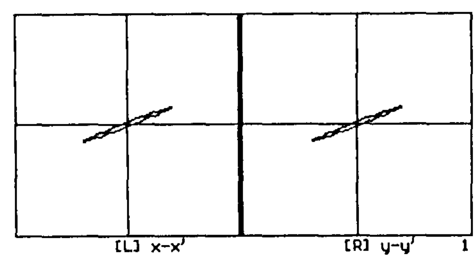

Fig. 2 beam ellipse of high current mode in phase space.

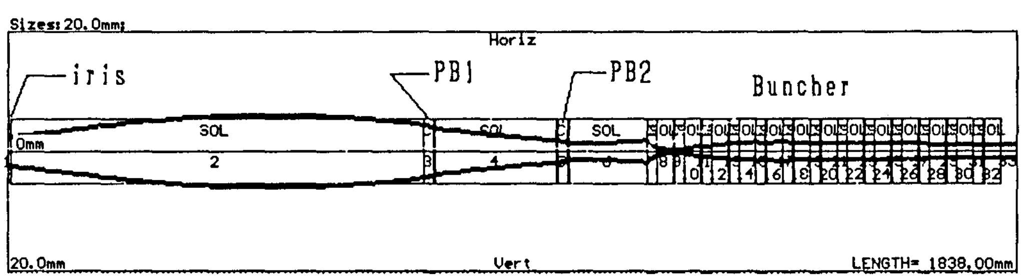

Fig. 3 beam envelope of low current mode.

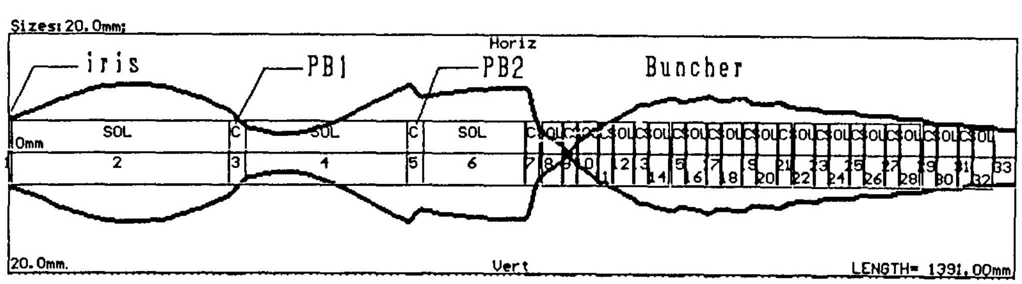

Fig. 4 beam envelope of high current mode.

From the result of this simulation, it is known that the beam of low current mode is bunched into 40° and the energy spread is ±30kV in front of the buncher. The beam envelope in the low current mode is shown in Fig.3. In this mode, it is possible to get the optimum transport condition by adjustment phase of pre-bunchers and bunching voltages.

If the beam of low current mode was operated under the axial magnetic field of the same parameter as the high current mode, it would be over bunched and the energy spread would be ±80kV.

When the high current mode operation is undertaken, Those monitors which are put for the measurement of the specification of the electron gun must be removed, and the drift length from the gun to the pre-buncher1 is re-arranged as short as possible. The support of machines is already prepared as a separate type, and the length of drift1 becomes 350mm. The beam envelope of the high current mode operation. If drift1 can not be shorten, it is impossible to carry the beam 15A, and the current decreases because of longitudinal diffusion.

Conclusion

Adjustment of the solenoid field is very important for the good beam transport in this injector section. The control of the bunching effect is easier than optimization of solenoid field because there are many parameter of the coils and field gradient to fit, and then simulation becomes important. It is difficult to set accurately the beam size, the waist point and twiss parameters, because no actual information of the beam envelope inside of the pre-bunchers can be obtained.

The optimization of the high current mode and of the low current mode is not consistent, therefore the optimum layout of machines is different and moreover the design of the electron gun is.

References

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[2] K.Yanagida, et al. "Development of Beam Diagnostics for SPring-8 Linac" ibid. 1992 Linear Acc. Conf. Proc.

[3] A.Mizuno, et al. "Simulation of Positron Focusing System for SPring-8 Linac" Proc. of HEACC'92