BEAM DYNAMIC BEHAVIOR OF THE INJECTIOR SYNCHROTRON IN THE 8 GEV SYNCHROTRON RADIATION FACILITY(SPring-8)

K.Nakayama,M.Kabasawa,T.Harami,H.Yokomizo,
T.Shimada,H.Ohtsuka and Y.Suzuki
Accelerator System Development Group
JAERI-RIKEN Synchrotron Radiation Facility
2-28-8 Honkomagome
Bunkyoku, Tokyo 113 Japan

Abstract

The 8 GeV synchrotron radiation facility named SPring-8 will be constructed at Nishi-harima in Hyogo prefecture. The injection system of this facility consists of the 1 GeV positron/electron linac and the booster synchrotron. We have investigated the beam dynamic behavior during the ramp. At injection energy the effect of eddy current and the beam instabilities are enhanced. We discuss the dynamic aperture with induced sextupole components due to the eddy current and also estimate the threshold current of beam instabilities.

Introduction

The synchrotron is used to accelerate the 1-GeV beam from the linac to the nominal 8-GeV operating energy of the storage ring. The repetition rate of the synchrotron is 1 Hz. The natural emittance is about 200nm.rad at 8 GeV. Figure 1 shows a layout of the synchrotron. The synchrotron has two dispersion-free straight sections on opposite sides of the ring. The synchrotron has 40 FODO cells including 32 normal cells. The rf cavities and pulse magnets for injection and extraction are installed in dispersion-free straight sections. Table 1 shows the major parameters of the synchrotron.

Table 1 Parameters of Synchrotron

Injection energy	1.0 GeV
Maximum energy	8.0 GeV
Circumference	396 m
Repetition rate	1 Hz
Natural emittance (8 GeV)	192 nm.rad
Momentum spread(8 GeV)	0.122 %
Radiation loss(8 GeV)	11.55 MeV/turn
Number of cells /periodicity	40 / 2
Nominal tune(ν_x/ν_y)	11.73/8.78
Natural chromaticity(ξ_x/ξ_y)	-15.3/-12.7
Momentum compaction factor	9.53×10^{-3}
rf frequency	508.58 MHz
Harmonic number	672
Accelerating voltage(8 GeV)	17.1 MV
Quantum lifetime	over 10 seconds

The beam spends relatively short time in the synchrotron (less than 1 second) in comparison with the stored time of many hours in the storage ring. The required current for the synchrotron is 10 mA that is much smaller than that for the storage ring. It follows that the requirements of the performance for the synchrotron are not so stringent than that for the storage ring. On the other hand, the beam is injected into the synchrotron at relatively low energy of 1 GeV where the beam instability might be enhanced. The injected beam is accelerated up to 8 GeV in less than 1 second.

In this paper, we examine the collective beam instability at the injection energy and investigate the dynamic behavior of the longitudinal and transverse emittance during the ramp. We also discuss the beam dynamic aperture.

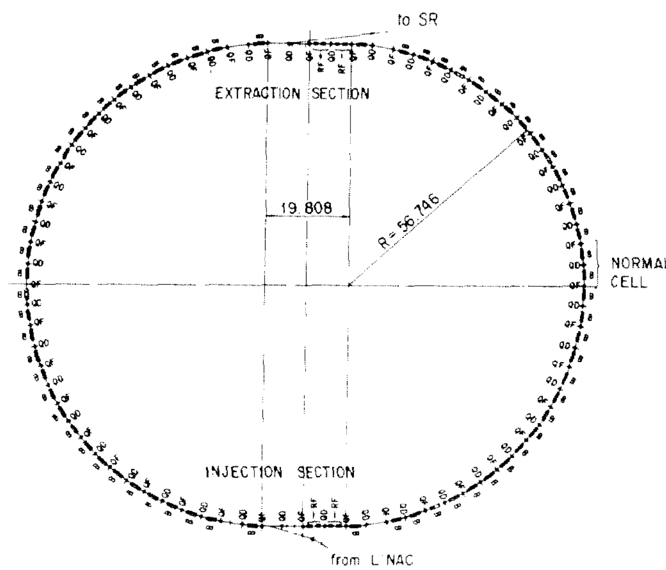

Figure 1. Layout of the Synchrotron

Beam behavior at injection energy

At injection energy the radiation damping effect is not so strong and the growth rate of the beam instabilities is larger. We examined the beam instabilities considering parameters of the injected beam. The injected beam from the linac is expected to have an rms emittance of about 1.0 mm.mrad in both transverse planes and an rms momentum spread of about 1.0 %. There are more disruptive elements such as kickers and septum in the synchrotron. It is assumed that the vacuum chamber impedance of the booster is higher than that of the storage ring. Therefore, we have used the value of 10 Ω for the synchrotron calculation, compared with an assumed value of 2 Ω for the storage ring.

(single bunch threshold)

At first we calculated the single bunch threshold by computer code ZAP[1]. Because of the large momentum spread, the threshold of the longitudinal microwave instability is quite high. The threshold current is more than 40 mA at injection energy of 1 GeV. In the most severe case, when the synchrotron operates in a single bunch mode, the design current is assumed only 1 mA. Thus, we can not expect any turbulent bunch lengthening at injection energy.

(head-tail instability)

The growth rate of the head-tail instability scales inversely with energy. At the injection energy the growth rate is as fast as 10 ms for the single bunch operation. Because the repetition of the synchrotron is 1 Hz, it may be necessary to correct the chromaticity in the synchrotron by sextupole magnets.

(coupled bunch instability)

We also calculated the growth rate of the coupled bunch instability. At injection energy, the growth rates predicted by ZAP are of the order of milliseconds for undamped rf cavities. It may be necessary for us to develop higher mode damper of the rf cavities.

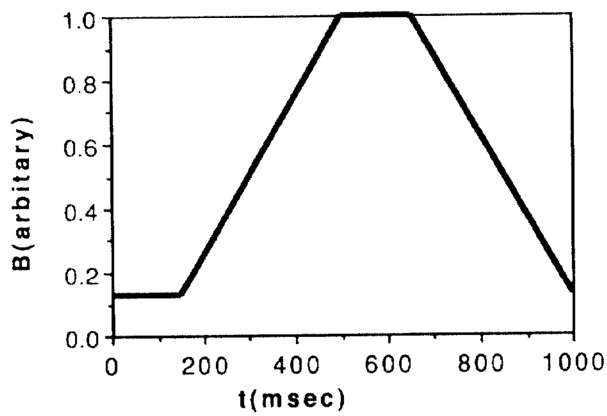

Figure 2. Ramping pattern of dipole magnets.

Beam dynamic behavior during acceleration

We have investigated the dynamic behavior of the longitudinal and transverse emittance during the acceleration. The ramping cycle of the bending magnets are shown in figure 2. The transverse emittance during the ramp is shown in figure 3. The dotted line shows the initial emittance of 1.0 mm.mrad that corresponds to the electron beam and solid line corresponds to the positron beam with initial emittance of 5.0 mm.mrad. At 8 GeV both electron and positron beam reach the emittance of 200 nm.rad that is a stationary value determined by the balance between the radiation damping and the quantum fluctuation.

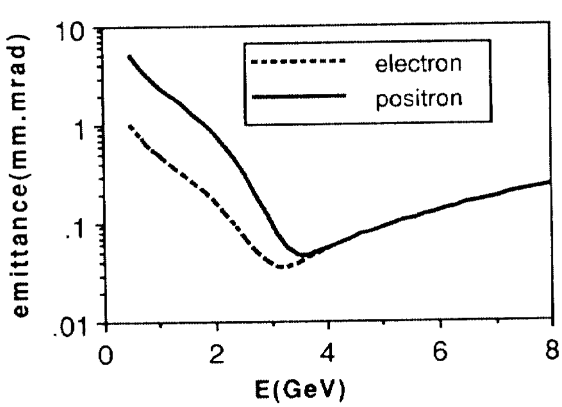

Figure 3 . Emittance change during acceleration.

The rf separatrix at injection energy is shown in figure 4. We will set the rf voltage at 2.0 MV in order to capture the beam from the linac with the energy spread of 1.0 % and with the bunch length of 1 ns (180 degree of 508.58 MHz). During acceleration the rf voltage will be increased linearly and will be set at 17.1 MV for maximum energy of 8 GeV.

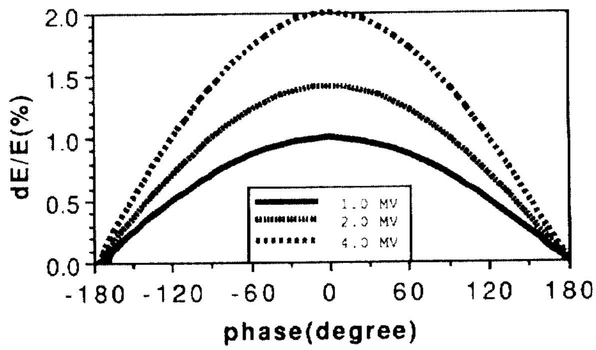

Figure 4. RF separatrix at injection energy.

In figure 5, we show the longitudinal bunch area and also show the rf bucket area in units of eV-s. At low energies,the bunch area decreases as energy increases by damping effect and reaches minimum around 4 GeV. At high energies, the bunch area increases by the influence of the quantum fluctuation. The ratio of bucket area to that of the bunch is about 3.5 at injection energy ; at full energy it is about 30.

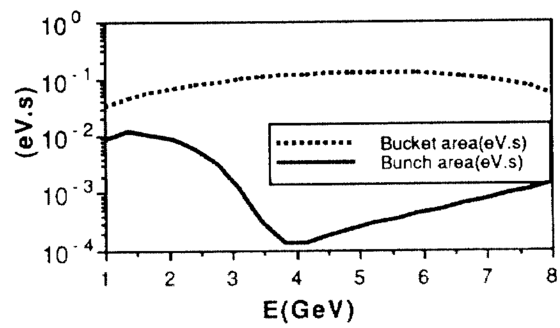

Figure 5. Bunch area during acceleration

The relative rms momentum spread is shown in figure 6. The relative momentum spread damps rapidly as the energy increases and has the minimum value around 3.5 GeV. At high energies, the momentum spread increases due to quantum fluctuation effect.

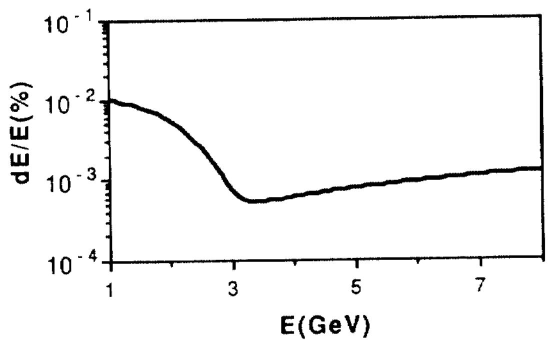

Figure 6. Energy width change during acceleration.

Beam dynamic aperture

The natural uncorrected chromaticities of the synchrotron are ξ_x=-15.3 and ξ_y=-12.7 . As discussed in previous section, the growth rate of the head-tail instability in 1-Hz synchrotron is fast enough that chromatic correction by sextupole magnets must be done during acceleration.

The correction is achieved by means of two families of sextupole magnets, denoted SF and SD ; there are one SF magnet and one SD magnet per normal cell. The strength of the sextupole magnets are 3.8 m^{-3} and 6.0 m^{-3} for SF and SD, respectively. The strength of SF is about half as that of SD so that it is possible to reduce the number of SF magnets if the dynamic aperture is still large enough. We investigated the dynamic aperture in the case of two different sextupole configurations. In figure 7, the dynamic aperture by the tracking code RACETRACK[2] are shown. Open circle represents for the case where the number of the SF magnets is as half as that of the SD magnets and closed circle shows the designed lattice where the number of the SF is the same as that of the SD. The rectangular at the center represents the size of the vacuum chamber. In order to keep larger dynamic aperture, we decided to use the same number of SF and SD magnets.

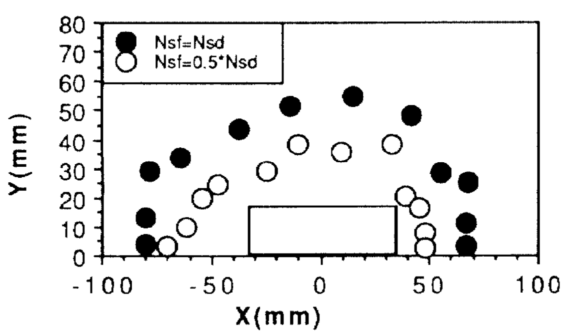

Figure 7. Dynamic apertures for different sextupole configurations.

In the synchrotron, additional sextupole component will be induced by the eddy currents in the vacuum chamber of the dipole magnets because of the rising magnetic field.

The sextupole strength is calculated as follows.[3]

$$m = (B\rho)^{-1}\, d^2B/dX^2 = \mu_0\, \sigma\, D\, (dB/dt)\, (B\rho h)^{-1}$$

where σ is conductivity of the vacuum chamber with thickness of D , B is the magnetic field of the dipole magnet whose gap length and bending radius are h and ρ . Using σ=1.3 10^6 /Ωm, D=3 mm, ρ=31.4 m and h=45 mm, the sextupole strength at injection energy is the maximum value of m= 0.1 m^{-3} and changes the linear chromaticity to ξ_x= -6.0 and ξ_y= -18.0. During acceleration process the sextupole strength due to the eddy currents decrease linearly as the energy increases and at full energy the value of the linear chromaticity reaches the designed value. It follows that the strength of the sextupole magnets that are used for the correction of the linear chromaticity should be changed during the ramp. We investigated the dynamic aperture at injection energy. The results are shown in figure 7. The closed circles represent for the case with no eddy current and the open circles are that with the eddy current effect. The dynamic aperture is deteriorated by the eddy current effect but still larger than the vacuum chamber.

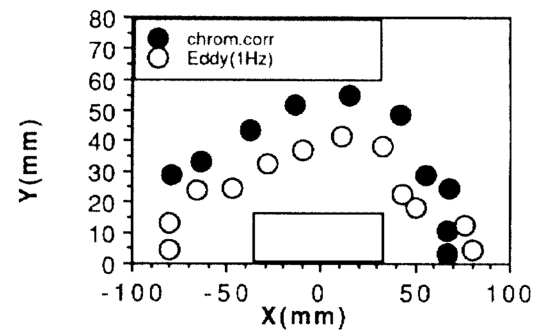

Figure 8. Dynamic aperture with eddy current effect at injection energy.

Conclusion

We have investigated the dynamic behavior of the longitudinal and transverse beam emittance during the ramping cycle of the synchrotron. At injection energy, we have estimated the effect of the sextupole component due to the eddy currents using the beam tracking and found that the dynamic aperture is larger than the physical aperture. We have also studied beam instabilities at injection energy.

The R&Ds for the injection system are planned to establish the design components.[4]

References

[1] M.S.Zismann ,S.Chattopadhyay, and J.J.Bisognanao "ZAP user's manual" .;LBL-21270 ,December 1986

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[4] H.Ohtsuka,et al., Proceeding of 2nd European Particle Accelerator Conference ,June 1990