ICANS-XV
15th Meeting of the International Collaboration on Advanced Neutron Sources
November 6-9, 2000
Tsukuba, Japan

6.7 Lattice design of 3GeV synchrotron for JAERI-KEK joint project

F. Noda* and JAERI-KEK Joint Team

Japan Atomic Energy Research Institute, Tokai 319-1195, Japan
*E-mail: noda@linac.tokai.jaeri.go.jp

Abstract

This paper summarizes the Lattice of 3GeV proton synchrotron for JAERI-KEK joint project. This 3GeV ring provides 3GeV proton beam for neutron science, muon science, exotic nuclear science facility and 50GeV ring. The output beam power of this ring is 1MW with 25Hz operation. This beam power is a few times higher than that of the existing accelerators. To achieve this goal, it is important to cure an uncontrolled beam loss. A power of uncontrolled beam loss must be smaller than 1W/m for hands-on maintenance. This uncontrolled beam loss is caused by beam injection, space-charge force, extraction and some known or unknown instability. The precise painting system, adequate aperture of ring and extraction line, and secure collimation systems are essential issues of this 3GeV ring.

1.Introduction

JAERI-KEK joint project team has designed the 3GeV. The circumference of this 3GeV ring is 313.5m and it accelerates beam from 400MeV to 3GeV. The cycle of operation is 25Hz and the maximum output beam power is 1MW. This 3GeV ring provides 3GeV proton beam for neutron science, muon science, exotic nuclear science facility and 50GeV ring. For this 3GeV ring, two type rings have been designed and compared. One ring is composed of FODO-arc and FODO-straight, and the other one is composed of FODO-arc and doublet-straight. A doublet straight has a long free space and makes injection and extraction easily, but a phase advance in straight section is small. A two-stage collimation system has some difficulties. On the other, FODO-straight lattice has the advantages of relatively low quadrupole gradient, smooth lattice function variation and large phase advance. However a free space is short, so an injection and an extraction system have some difficulties. If these disadvantage points are cleared, the FODO-straight lattice is good choice for especially a rapid cycle 3GeV ring. From these reasons, the latest 3GeV ring is composed of FODO-arc and FODO-straight. Figure1 shows the schematic layout, and Table 1 summarizes the main parameters of the latest 3GeV ring. This ring has a three-fold symmetrical structure, and each superperiod is composed of arc section and dispersion-free straight section. The arc section has functions of adjustment of the transition gamma and scattering of the longitudinal halo-beam. The three straight sections are using for injection/collimation, extraction systems and RF-acceleration, respectively. The details of lattice are presented in following section (Section2). The injection system, collimation and extraction systems are presented in Section 3,4 and 5, respectively. RF system is presented another paper in this meeting.

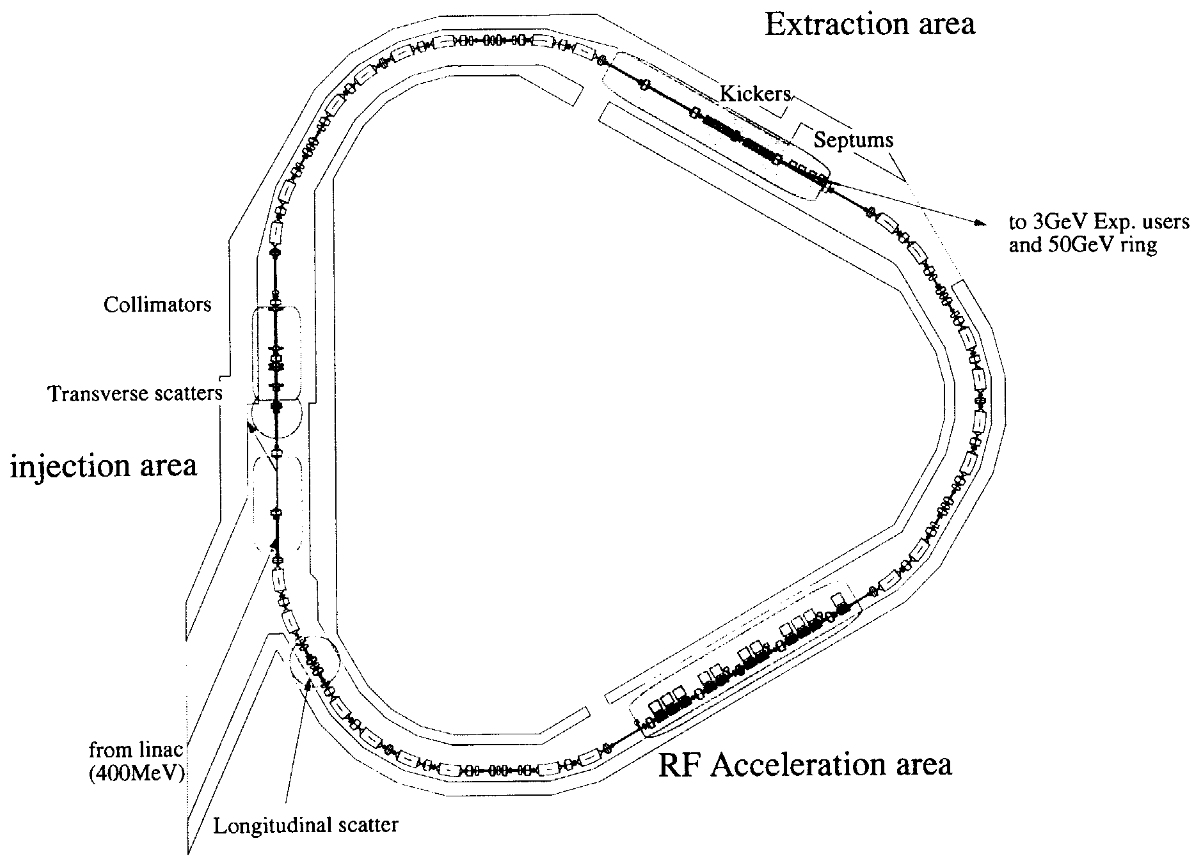

Fig. 1 Schematic layout of 3GeV synchrotron

Table 1 Main parameters of 3GeV synchrotron

Quantity	Value
Circumference	313.5 m
Average radius	49.9m
Injection energy	400 MeV
Extraction energy	3 GeV
Repetition rate	25 Hz
Beam power	1.0 MW
Number of protons	8.322×10^{13}
Physical Aperture	>324 π.mm.mrad
Collimation Aperture	216 π.mm.mrad
Momentum Acceptance	±1 %
Tune(Horizontal/Vertical)	7.35/5.8
Transition Gamma	9.05
Natural Chromaticity(Horizontal/Vertical)	-8.95/-8.54
Super-periods	3

2. 3GeV Synchrotron Lattice

2.1 Lattice functions

Figure 2 and Figure 3 show the schematic layout and lattice function of one superperiod. The lattice designs have been carried out using MAD [1] code. Arc section is composed of two modules, which is composed of three DOFO cells. Middle DOFO cell of an arc module is missing-dipole cell. The number of dipole magnets is four per one arc module, and bending angle of each dipole magnet is 15 degrees. The transition gamma is designed to large value using this missing-dipole cell, because the transition gamma must be so far one of 3GeV. The number of quadrupole magnets is six per one arc module and these magnets are composed of four families. One of main functions of these magnets is to make a dispersion-free at straight section. The number of sextupole magnet is three per one arc module. The central quadrupole magnet (QFN) of an arc module is separated to two pieces. The sextupole magnet named SFN and the longitudinal scatters are sandwiched between these pieces. This point is largest dispersion point, so this point is suited to correction of chromaticity and to scattering a longitudinal halo-beam. The other sextupole magnets (SDN) are set near the QDN in missing-dipole.

On the other hand, the long straight sections are composed of three DOFO cells. These sections are dispersion-free for transverse halo-beam collimation. The number of quadrupole magnets is six per one straight section. These quadrupole magnets are composed of three families. The quadrupole magnet named QFS1 is separated to two pieces for H- injection and the main charge-exchange is sandwiched between these pieces. The detail of injection system is presented in Section 3.

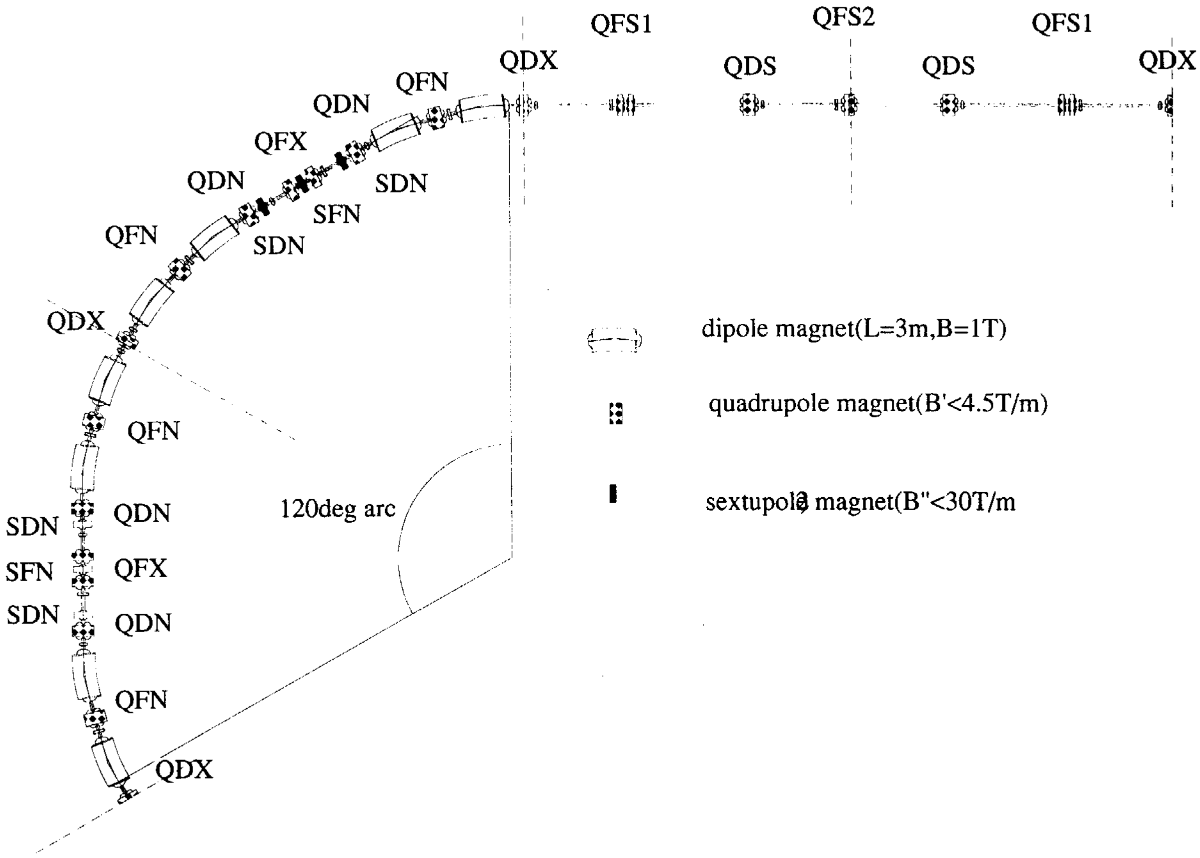

Fig. 2 Lattice layout of one superperiod (unit: m)

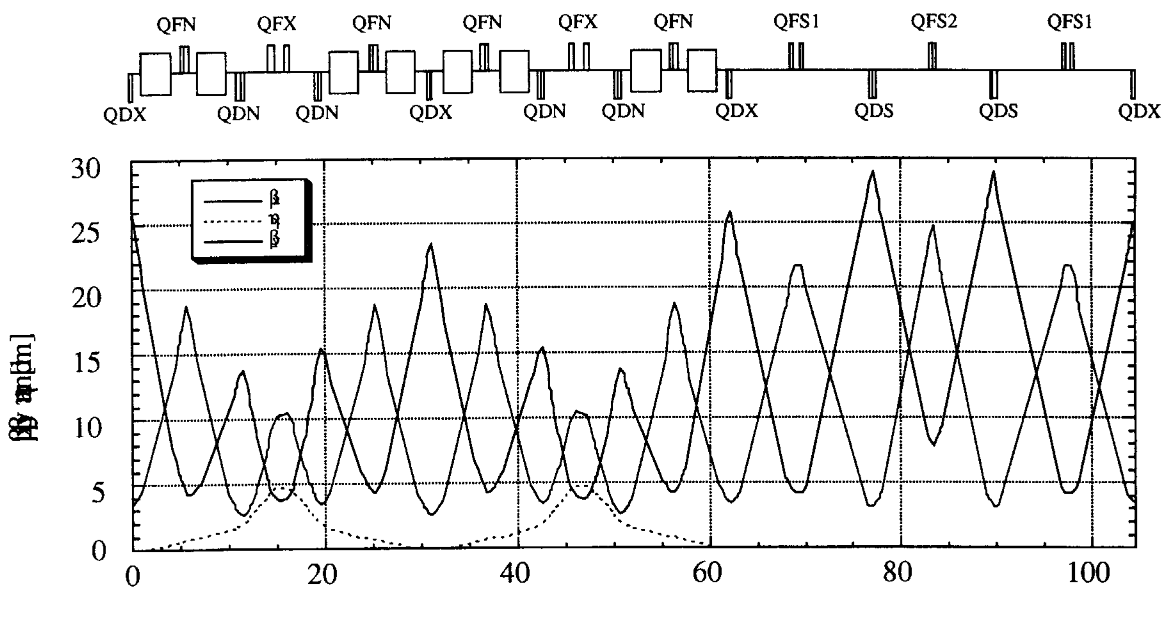

Fig. 3 Lattice functions of one superperiod

2.2 Operating tune

The 3GeV ring lattice has been designed symmetrically from the point of view of structure resonance. Operating tune of horizontal and vertical betatron oscillation is 7.35 and 5.8. However on this operation point the off-momentum beam that is especially $\Delta p/p=+1\%$ has large beta-x. The another problem is that this operating point of transverse tune is near the integer resonance line. The other operating point under study is 6.7 and 5.7. On this operating point, off-momentum beam is stable, but this point is near Qx+Qy=12 line. The more detail studies of operating points and tunability are currently under study. Operating points are adjusted using seven-families of quadrupole magnet. The separated power supply system has many advantages for selection of operating point. However tracking of dipole-quadrupole magnets is an essential issue for rapid-cycling synchrotron. The realization of this power supply system is a moot point.

2.3 Beam Emittance and Aperture

An adequate aperture is very importance to decrease an uncontrollable beam loss. Table2 shows the emittance and aperture. A beam emittance is blown by foil scattering and a space-charge effect. The collimators collimate halo beam at 216π.mm.mrad. On the other hand, aperture of magnets and vacuum duct is larger than 324π.mm.mrad. The physical aperture is larger than 648π.mm.mrad under full correction of chromaticity. The studies of beam collimation have been carried out using STRACT. The result of collimation study is presented in Section 4.

Table2 Beam emittances and apertures

Quantity	Value
Emittance of injection beam	4π.mm.mrad
Emittance of painting	144π.mm.mrad
Aperture of collimator	216π.mm.mrad
Physical Aperture of ring	324π.mm.mrad
Dynamic Aperture of ring (correction)	>648π.mm.mrad
Momentum Acceptance	(±1% for 324π.mm.mrad)
Ref.	
Vacuum duct(with shield)	15mm
Duct-pole clearance	1.5mm
COD	3mm

3.Injection

3.1 Injection layout

The injection beam is painted to 144 π.mm.mrad by using the multi-turn injection with charge-exchange method. The emittance of injection beam is 4 π.mm.mrad (99%). Figure 4 shows the schematic layout of injection system. In this figure, thick and broken lines indicate a bump orbit at a start of injection and a bump orbit at an end of injection, respectively. Horizontal bump orbit is produced by four bump-magnets in the ring. On the other hand, vertical bump orbit is produced by a bump magnet, which located at the π-radian upstream of the injection line. The charge exchange foil is located between the sprit quadrupole magnet (QFS1). The α_x is designed to zero and it makes possibility to separate the excited H^0 beam easily. Figure 5 shows lifetimes of excited H^0 beam. The magnetic strength of the sprit quadrupole is 0.09T at injection point (Δx=100mm). This magnetic field enables to split an excited H^0 beam at n=6 and lower state. The magnetic change of this quadrupole magnet during an injection period is lower than 0.03%. The maximum field of downstream bump magnet is 0.2T. This bump field enables to split an excited H^0 beam at n=5. However this field changes from 0.2T to 0.1T during injection period. In this case, H^0 beam in the state of n=6 becomes uncontrollable beam loss. However this power of loss beam is lower than 0.1 watt.

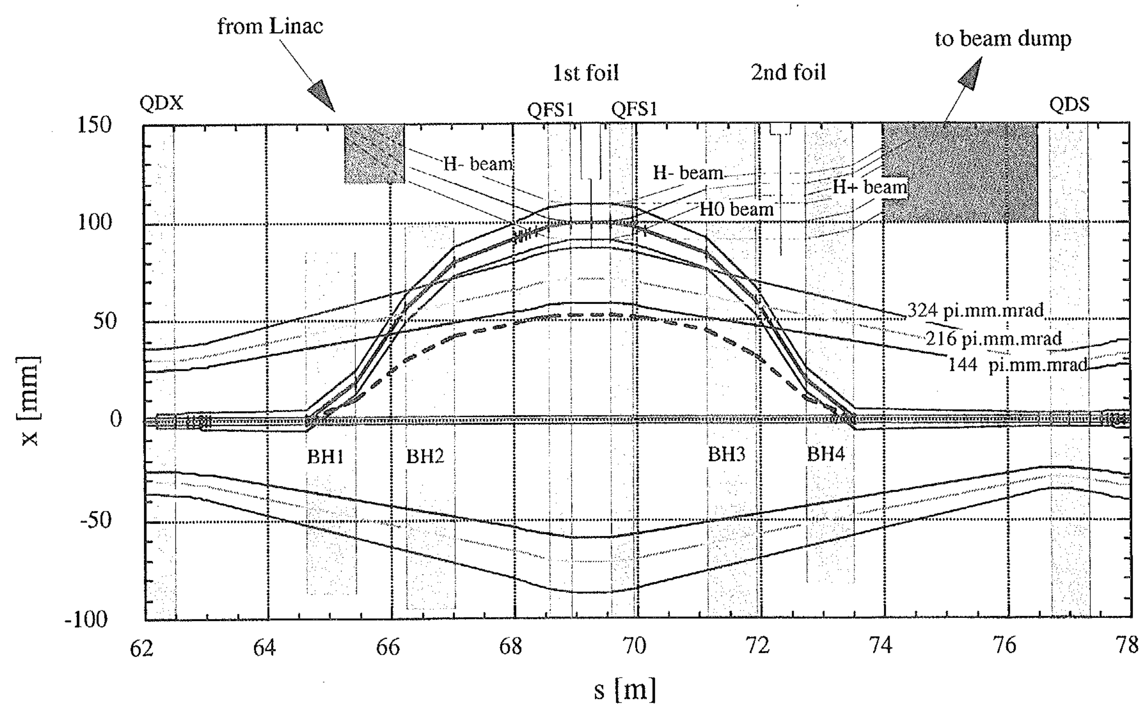

Fig.4 Schematic layout of injection section

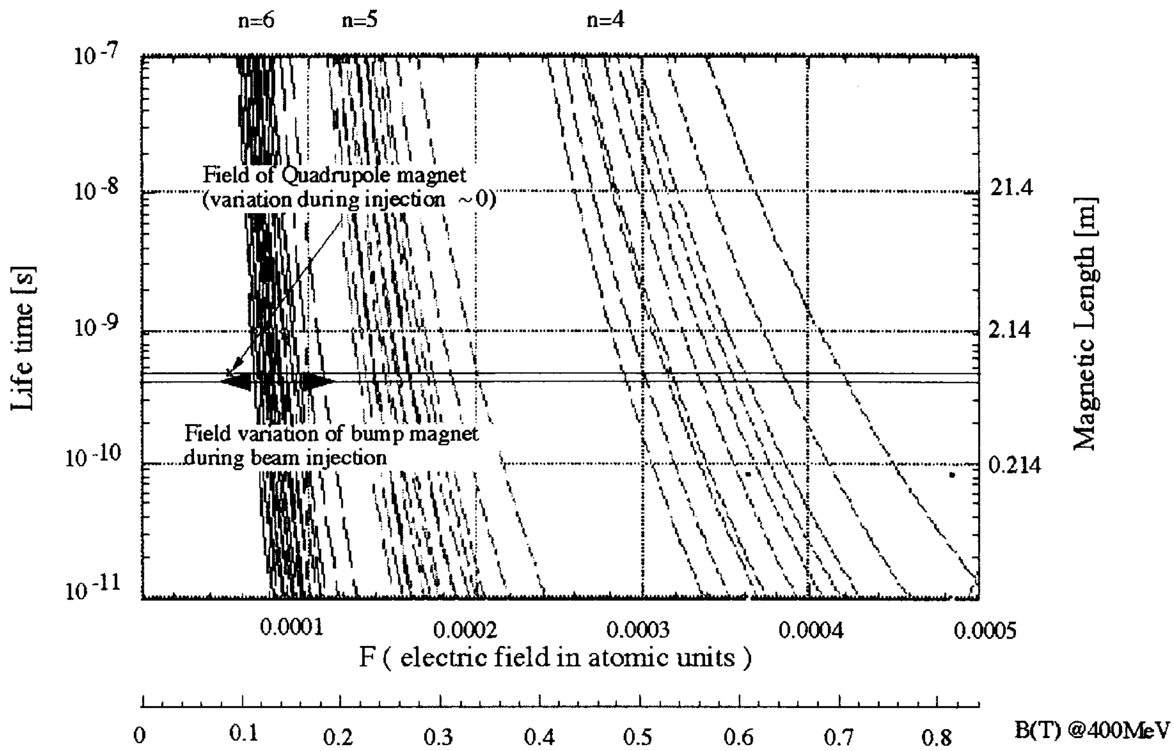

Fig.5 Life time of excited H^0 beam and operation point of injection magnets

3.2 Painting scheme

Figure 6 shows a schematic view of transverse painting. The painting functions are give by

$$x = 100 - 50\sqrt{\left(\frac{t}{T}\right)}[mm]$$

$$y' = 5\sqrt{1 - \frac{t}{T}}[mrad]$$

In these equations, T and t are the period of injection and injection time. The envelope of painted beam is round shape. This painting scheme has several advantages that necessary aperture is relatively small and power supply is relatively simple. However the latest study [2] shows that this painting scheme has a disadvantage from a point of view of beam blowup with space-charge force. A more detailed study with space charge force is currently under study by SIMPSONS [3].

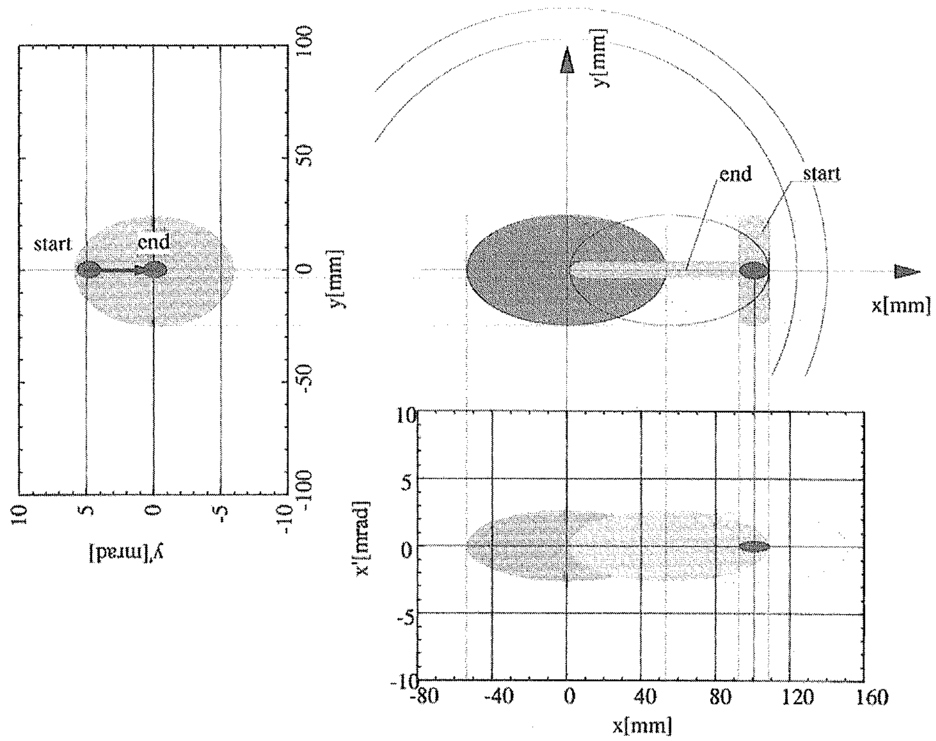

Fig.6 painting scheme

4.Collimation system

The halo of injection beam is collimated by the collimation system on the transport line. In the ring, the collimator system is composed of horizontal, vertical and longitudinal scatters and collimators. The horizontal scatter and the vertical scatter are set near the maximum beta-x and beta-y points of the dispersion-free straight section. The collimators are set in the same straight section. The phase advance of collimators' section is large value (~π-radian) enough to collimate the halo-beam effectively. Furthermore the dispersion is zero in this area, so the transverse halo-beam is collimated more effectively. The collimators are composed of two type collimators. One is movable type and the other is fixed type. The movable collimators are set at ~π/3-radian intervals in vacuum and these are adjusted to collimation emittance (216π.mm.mrad). The fixed collimators are set around the vacuum chamber. On the other hand, longitudinal scatter is set at upstream arc section of injection area. Longitudinal halo-beam is scattering with low angle at this longitudinal scatter and is collimated by collimators at injection area. The acceptance of transverse collimators and allowable Δp/p are 216π.mm.mrad and ±1%, respectively. The studies of beam collimation have been carried out using STRACT[4]. Figure7 shows the beam loss point and loss power. Table3 shows the collimation efficiency. In this case, the collimation efficiency is 98.5 percent of total loss beam.

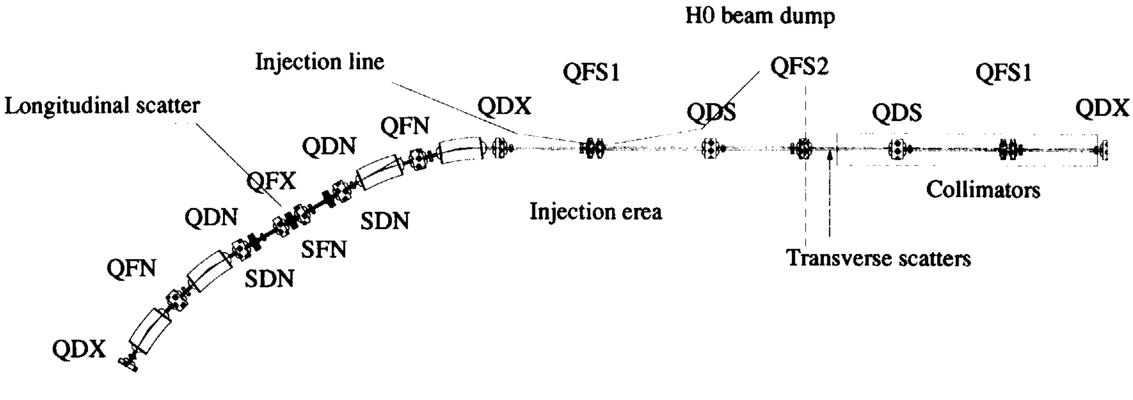

Fig.7 Collimator system layout of injection superperiod (unit:m)

Table3 Beam loss points and loss power (calculated with STRUCT)

Quantity	Value	
Number of Lost	18627	≡4kW
Number of Lost at collimators area	18347(98.5%)	3.94kW
Number of Lost at other point	280(1.5%)	0.06kW

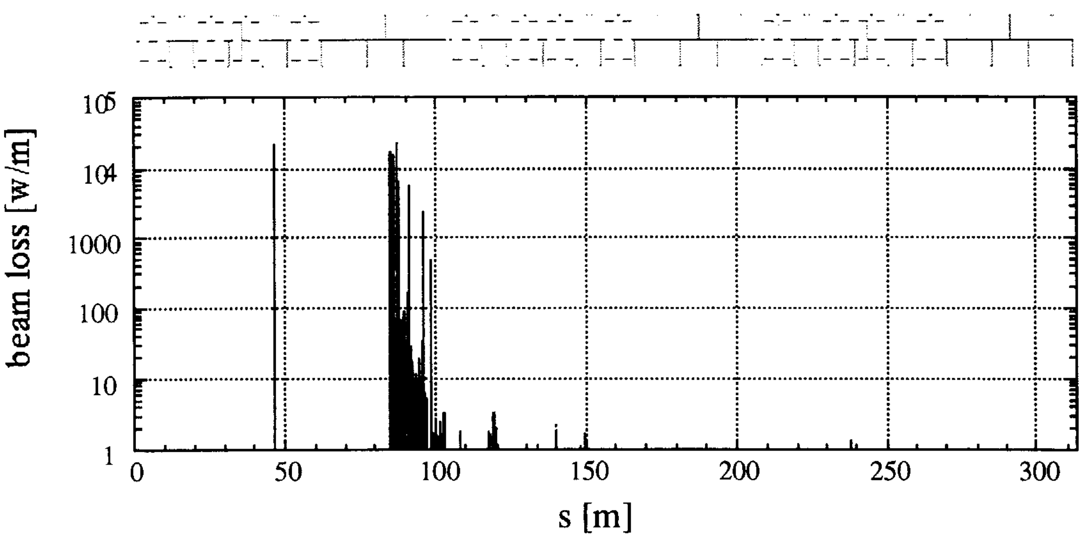

Fig.8 Loss points of halo beam (total loss power=4kW)

5.Extraction

The normalized emittance of beam becomes gradually small with the progress of acceleration and it becomes 54 π.mm.mrad at 3GeV. On the other hand, the physical aperture of extraction line has been designed at 216 π.mm.mrad. This value is equal to the emittance of ring collimator. Of course, the apertures of kicker-magnets are the same value of ring physical aperture (324π.mm.mrad). The extraction system is composed of eleven kicker-magnets and four DC-septum magnets. The eleven kicker magnets are set at three sections. The bunch gap is about 260nsec, so the raising time of kicker magnet must be shorter than 220ns(1-99%). These kicker magnets are installed in vacuum. If one of these kicker-magnets is failed, the beam loss will be increased, but the core beam (54 π.mm.mrad) is extracted perfectly. The rate of loss beam depends on the tail (from 54 to 216 π.mm.mrad) and detail study is currently under study.

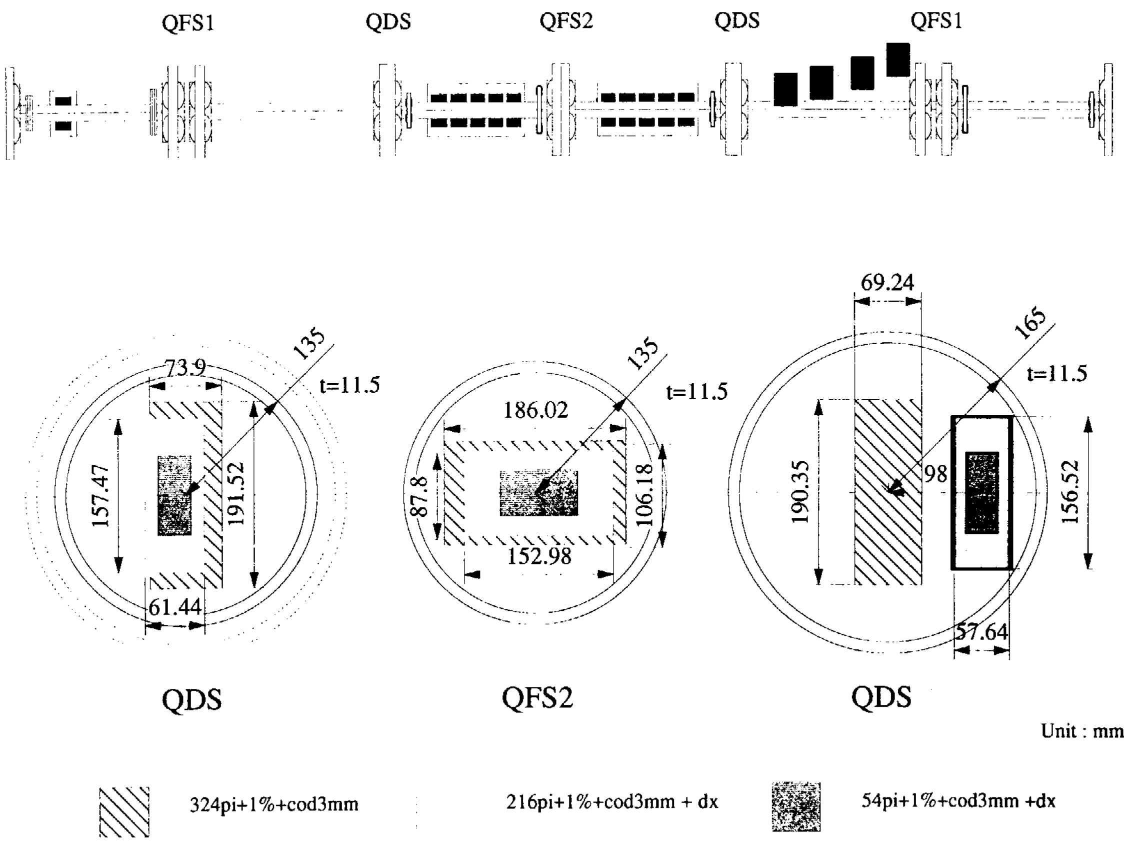

Fig.9 Beam positions at Quadrupole magnets around the extraction line

6.Summary

To achieve the 1MW output power in 3GeV rapid-cycling synchrotron for JAERI-KEK joint project, it is important to cure an uncontrollable beam loss. Therefore a precise painting system, an adequate acceptance of ring and extraction line and a secure collimation system are essential issues of this 3GeV ring.

The latest lattice structure of 3GeV ring is normal FODO lattice because of following reasons: (1) relatively low gradient of quadrupole magnet for B-Q tracking, (2) smooth lattice function variation and (3) large phase advance for two-stage collimation system.

The schemes of injection and extraction have been designed for this 3GeV ring. Furthermore the collimation systems of transverse and longitudinal have been designed, and the efficiency of collimation has been calculated. The schemes of injection, extraction and collimation have been confirmed reliabilities. A more detailed study is currently under study.

Acknowledgment

I wish to thank the members of the JAERI-KEK joint project team.

References

[1] I. Baishev *et al*, "The MAD Program User's Reference Manual", CERN/SL/90-13, 1993.
[2] J. Beebe-Wang *et al*, "SPACE CHARGE AND MAGNET ERROR SIMULATIONS FOR THE SNS ACCUMULATOR RING", p.1286. Proc. of EPAC 2000, 2000.
[3] S. Machida, "The Simpsons User's Manual", Dallas, 1992.
[4] I. Baishev *et al*, "STRUCT Program User's Reference Manual", SSCL-MAN-0034, 1994.