THE STATUS OF OPTICS DESIGN AND BEAM DYNAMICS STUDY IN J-PARC RCS

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Abstract

The 3GeV RCS at J-PARC is designed to provide the 3GeV proton beam and a goal of output beam power is 1MW. The beam commissioning starts on May 2007. At present more qualitative studies concerning beam dynamics are in progress: core beam handlings, halo beam handlings, instabilities and so on. In this paper the RCS optics design and the present status of beam dynamics studies are summarized.

OPTICS DESIGN OF J-PARC RCS

Overview of RCS

The 3GeV Rapid-Cycling Synchrotron (RCS) has several important roles: one is to make a high intensity and short pulse beam for the neutron and muon targets, and another is to make an injection beam for the 50GeV synchrotron, which is one of the reasons why we chose RCS. The main parameters are shown in Table 1. The injection energy is 181MeV at the first stage. It is upgrade to 400MeV at the next stage. The H^- beam is injected by the charge exchange method and accelerated to 3GeV. The output beam power is 1MW with a repetition rate of 25 Hz at goal, but it is 0.3-0.6MW at the first stage because of the lower injection energy.

Basic optics

The 3GeV RCS ring has a threefold symmetric lattice. Each super-period consists of two 3-DOFO arc modules and a 3-DOFO straight insertion. The arc module has a missing bend cell for the chromaticity correction magnets and longitudinal primary collimator. This missing bend makes a high transition gamma, which makes a manipulation of longitudinal beam profile easy. The dispersion has the largest value at the missing bend cell. It will make a collimation of momentum halo effective. The straight insertion is dispersion free area. It will make a transverse collimation effective. Furthermore, the effect of synchro-beta coupling becomes small by installing the RF cavity in this dispersion free area. The accessible tune range for RCS is $6< \nu_x, \nu_y <7$. We have carried out above basic calculations, using the SAD code [2]. The tune and beta modulations caused by various factors on RCS are shown in table 2. The most dominant factor of the tune modulation is the space charge effect. The space charge tune shift reaches -0.25 in the case of 600kW output power with the 181MeV injection, and it is -0.15 for the 1MW beam with the 400MeV injection. The tune deviations by the other factors are small enough, except for the chromatic tune shift. The chromatic tune shift corrected almost zero by the three-families of sextupole magnets. As for the beta modulation, the injection bump makes a large modulation at the start of the painting.

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Table 1: Basic parameters of RCS

Parameter	Values
Injection energy	181 / 400 MeV
Extraction energy	3GeV
Repetition rate	25Hz
Output beam power	0.3-0.6 / 1MW
Circumference	348.333m
Nominal tune	(6.68,6.27) $6< \nu_x, \nu_y <7$
Transition gamma	9.14
Chromaticity	-8.5/-8.8
Ring acceptance	486π.mm.mrad <
Painting emittance	216(30~324) π.mm.mrad
Collimator aperture	324(160~486movable) π.mm.mrad
Acceptable $\Delta p/p$	±1%
Extraction aperture	324π.mm.mrad

Table 2: Tune and beta modulation

Tune modulation	
Source	$\Delta\nu$
Space charge tune shift	-0.25 / -0.15
Chromatic tune shift	±0.088(before correction)
Quadrupole error	<±0.01
BQ tracking error	±0.01(0.03 at start)
Sextupole + cod	<±0.015(before correction)
Beta modulation	
Source	$\Delta\beta$
Injection bump	12% (max.)
Off momentum beam	6.6% for $\Delta p/p$=±1%
Quadrupole error	0.35%
BQ tracking error	1%
Sextupole + COD	1.5%(before correction)

Beam loss control system

In the design of RCS, it is very important to decrease and localize the beam loss for hands-on maintenance. The amount of the beam loss in RCS is summarized in table 3. The injection beam loss is caused by the following factors; (1) Lorenz stripping, (2) foil scattering, (3) decay of exited H^0, (4) fluctuation of injection beam, and so on. The parameters of the injection components such as magnetic field strengths have to be decided considering the above [3]. The dominant beam loss is from the excited H^0, which is expected to be 400W. However most of them

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will be exchanged to H^+ at the second foil and led to the injection dump. Consequently, the total amount of uncontrolled beam loss at the injection area is expected to be about 20W. The beam halo of the circulating beam is localized at the collimator area; the expected amount of the beam loss coming from the beam halo is less than 4kW for the 1MW output beam power. On the other hand, the amount of uncontrolled beam loss is about 80W in total for the whole ring. We chose the two stages collimation system, which is composed of three primary collimators and five secondary collimators. The apertures of the collimators can be adjustable independently; it is possible to adjust the load of the secondary collimators [4]. This adjustment will be done using point loss monitors, which are being designed now.

Table 3: beam loss budget

Area and source of loss	Values
Shield (injection area)	200W
Lorenz stripping	<1W, un-control
Foil scattering	<12W, un-control
Excited H^0 beam(n≥6)	<8W, un-control
Injection beam dump	1.0kW
Excited H^0 beam(n<6)	0.4kW*1, control
Ring collimators	4.0kW
Beam Halo	~4kW, control
Shield (normal area)	5W
Scattered beam halo	~80W/348m, un-control
Shield (extraction area)	500W with local shield
Extraction loss	~0
Extraction beam dump	4.0kW

*1 Foil thickness 300μg/cm^2 (99.7% charge exchange)

Correction system

The RCS has several kinds of correction systems for COD correction, chromaticity correction and third-resonance correction as listed in Table 4. Furthermore, trim quadrupole system will be installed in the future if required. The estimation of the other various resonances and the consideration of its correction scheme are in progress [5, 6]. For the effective correction, an adequate performance of monitors becomes important [7]. For example, in order to correct COD of ~10mm at maximum to 500μm, a position resolution of ~0.2mm is required for BPM's.

Table 4: Correction System of RCS

Correction system	Before correction	After correction
COD	~10mm (max.)*2	0.5mm (max.)
Chromaticity	-8.5	~0
Trim quadrupole		-0.2< Δν < 0.2

*2 COD source
Displacement error 2.5e-4 (both Δx and Δy)
Rotation error 4e-4,
BL, GL error 5e-4

BEAM DYNAMICS STUDIES

Beam physics issues on RCS

The beam physics issues in RCS are following: (1) nonlinear effect, (2) space charge effect, (3) other instabilities. The RCS magnets have very large apertures. The evaluation of nonlinear effect is very important and the studies of nonlinear effects of each magnet are in progress using both calculated and measured fields. Furthermore, the magnets are close to each other, and thus the interference of the magnetic fields will be a significant issue at RCS. The magnetic field measurements of the actual magnets are in progress, and the interference of magnetic fields between magnets will be measured for the most severe arrangement. The treatment of the leakage field from septum magnets is also important. This local error breaks the three-fold symmetry of RCS and it can drive non-structure resonances. The design of the septum magnets is in progress to reduce the leak field as low as possible. The studies of the other instabilities, wake-field effect, e-p instability, beam-duct coupling and so on, are also in progress [8]. A fatal problem hasn't been found in our study so far. Of course, the study of the space charge effect is very important. Some results are presented in the following.

Comparison of 181MeV and 400MeV injection

The injection energy is 181MeV at the first stage, which makes a beam control difficult. We have carried out simulations on the possible output beam power at the lower injection energy by using the SIMPSONS code [8]. For the 1MW beam with the 400MeV injection, which is the original design, the acceptable beam loss rate is 3%, and it corresponds to 4kW loss. The beam power for the lower injection energy has to be reduced to 300kW to keep the beam loss rate at the same value as the 400MeV injection case. In this case, the expected tune shift is -0.15, which is the same value as the 400MeV injection case. The acceptable amount of the beam loss in the collimator area is 4kW. In terms of this criterion, the output power possible in the lower injection energy is 600kW at maximum. In this case, the beam loss rate corresponds to about 10%.

Beam loss estimation including COD

In the case of high intensity accelerators such as RCS, it becomes important to consider the behavior of the beam halo as well as the beam core. Therefore, large number of macro-particles is necessary for the beam simulations. We need 2e6 macro-particles and more (ideally, more than 5e6) for accurate simulations. Figure 1 shows the beam survival rate assuming several CODs as a function of acceleration time. The beam loss is saturated within about 4-5 ms. The COD after correction is expected to be less than 0.5mm, corresponding to yellow line in the figure, and the corresponding beam loss rate is about 4% in the case of 600kW output with the181MeV injection. There still remain various errors to be included in the simulation, such as multipole components, leakage fields and various wake-fields.

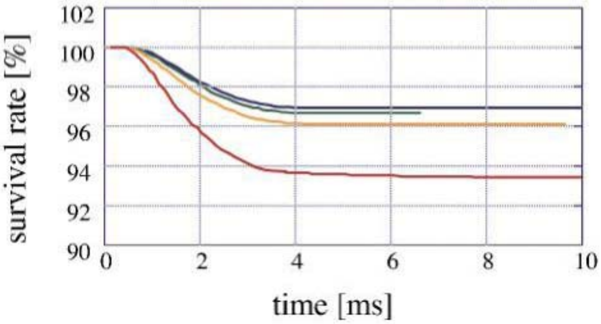

Figure 1: beam survival rate assuming several CODs
Blue: COD (rms)=0.0mm, Green: 0.2mm
Yellow: 0.5mm, Red: 1mm

Beam profile control

The painting injection is important not only to reduce the space charge force but also to control the transverse beam profile on the neutron target. However, it is not easy to control the beam profile at the extraction at RCS, because of the acceleration process. Therefore, the flexible paint injection system is prepared for RCS. In the RCS, both correlate and anti-correlate paintings are available [9]. Now we are investigating relations between the painting function and beam profile. The horizontal profile of the circulating beam is shown in Figure 2, as an example. The painting emittance of 216π.mm.mrad (correlate painting) and the beam power of 0.6MW are assumed in this simulation. The number of turns, 250, 2000 and 7000 corresponds to 183MeV, 353MeV and 1.64GeV, respectively. As shown in the figure, the peak of the beam density gets higher gradually as the turn number increases. In order to defuse the thermal shock wave on the neutron target, the beam profile should be flat. Now we are discussing the possible scheme together with the neutron target group [10].

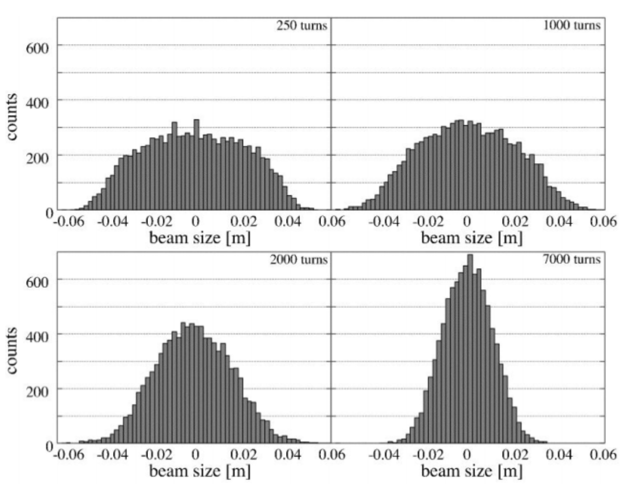

Figure 2: The horizontal profile of the circulating beam
Above left: beam distribution at 250turns, Right: 1000turns
Below left: 2000 turns, Right: 7000turns

SUMMARY AND FUTURE PLAN

We have carried out various estimations for optics design. We are in the stage to do more realistic evaluations based on various actual measured data at present. The measured field data of the dipole and quadrupole magnets will be available in the near future. The measurements of impedance for several components (kicker magnet, RF cavity, collimator and so on) are also in progress. Furthermore, the interference of the magnetic fields should be measured. We will perform single-particle tracking and multi-particle tracking simulations including the above, to estimate the beam loss more precisely and to optimize the operating pattern. In this connection, we try to improve the SIMPSONS code to get a faster tracking performance with the assist of the JAERI calculation center. Furthermore, we have started to build a virtual accelerator system. The virtual accelerator stores the integrated simulation codes (SAD, SIMPSONS, etc) and shares the database with the actual accelerator, and behaves like an actual accelerator. We expect that it is useful for the verification of systems and the beam study before the beam commissioning starts. After the operation of the actual accelerator starts, that will be utilized as a core of the operation system.

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