INJECTION AND EXTRACTION ORBIT OF THE J-PARC MAIN RING

M. Tomizawa, Y. Kamiya, H. Kobayashi, I. Sakai, Y. Shirakabe, KEK, Ibaraki, Japan,
S. Machida, ASTeC, Oxon, U.K.

Abstract

The J-PARC main ring (MR) accelerates a high intensity proton beam and deliver to the neutrino experimental hall by the fast extraction and to the hadron experimental facility by the slow extraction. The 3 GeV beam from the rapid cycle synchrotron (RCS) is injected by the bunch to bucket transfer into the MR. The MR has two beam dump lines, the first one is used to dump the beam at an injection energy and the second one can be used for beam abort. We summarize designs of injection and extraction orbits and discuss about beam apertures and the beam loss.

INTRODUCTION

The J-PARC accelerator complex comprises a 400 MeV linac, a 3 GeV rapid cycle synchrotron (RCS) and a 50 GeV main ring (MR). In the first beam commissioning, the linac energy is 181 MeV, and the maximum MR energy is limited at 40 GeV for the fast-extraction and 30 GeV for the slow extraction, respectively [1].

The MR with three fold symmetry has three 116.1 m long straight sections and three 406.4 m long arc sections. The MR has an imaginary γ_t lattice in order to avoid the beam loss during transition crossing [2]. The long straight section has zero dispersion. The MR has two beam dump lines, the first one is used to dump the beam at injection energy and the second one can be used to abort accelerated beam (see Figure 1).

The beam loss at the injection and extraction is one of the crucial part for high intensity proton accelerators. We have carefully designed the injection and extraction from low beam loss point of view. Parameters of the kickers, septa for the injection and the extraction are listed in Table1.

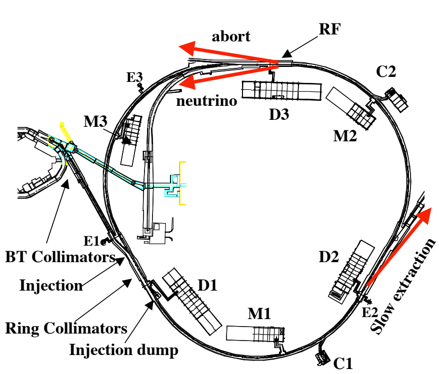

Figure 1: Layout of the MR.

Table 1: Parameters of kickers and septa.

		unit	length (m)	angle (mrad)	Field (T or kV)	V/H gap (mm)	thickness (mm)
Injection	SM1	1	1.8	192	1.36	98/181.5	67
	SM21	1	0.35	16.5	0.6	78/350	
	SM22	1	0.7	33	0.6	120/150	7
	SM23	1	0.35	16.5	0.6	78/250	
3GeV dmp	KM1,2	2	0.8	3.7	0.06	100/100	
	KM3	1	0.8	6.3	0.1	100/100	
	SM1	1	0.726	30.8	0.54	101/155	20
	SM2	1	1.9	225.4	1.51	93/205	35
fast/abort	KM1-5	5	2.43	1.18	0.0825	100/100	
	SM1	2	0.875	2.364	0.459	71/80	9
	SM2	2	0.875	2.364	0.459	71/80	9
	SM30	1	1.225	9.69	1.38	98/122	30
	SM31	1	1.66	16.01	1.66	93/117	42.5
	SM32E	1	1.9	18.23	1.66	61/150	62
	SM32A	1	1.9	18.23	1.66	81/150	62
	SM33E	1	1.9	18.23	1.66	61/150	62
	SM33A	1	1.9	18.23	1.66	81/150	62
slow	ESS	2	1.5	0.2	170	80/25	0.08 or 0.03
	SM10	1	1.5	1.0	0.114	55/80	1.5
	SM11	1	1.5	2.0	0.228	55/80	3.25
	SM21-24	4	0.8375	2.58	0.524	48/80	7
	SM30,31	2	1.14	9.61	1.432	70/120	31
	SM32,33	2	2.28	22.17	1.652	61/140	62

INJECTION

The collimator aperture in the RCS is set to 324π mm·mrad for both 180 MeV and 400 MeV injection from the linac. The extraction aperture of the RCS is same as that of the RCS collimators. A beam collimator is alos placed between the RCS-MR transfer line. The upstream line of the collimator has acceptance of 216π mm·mrad. The beam with halo from the RCS is cut at 54π mm·mrad by this collimator. The aperture of the downstream beam line from the collimators is 120π mm·mrad. The beam matched for Twiss parameters and dispersion is injected into the MR.

The injection device to the MR consists of the 2 magnetic septa (SM1, SM2), three kickers and three bump magnets (BMP1-3). The defocusing quadrupole magnet (QDT) is located between the septa and the kickers. The slow bump orbit to opposite side from the injection to keep an enough turn separation between the injection and circulating beam envelope at the SM2 clearing the QDT aperture. The bump orbit can be turned off after the beam injection. Figure 2 shows the beam envelope for injection area. The injected and circulated beam envelopes for the 81π mm·mrad + COD 1mm are drawn. The SM2 is, a new "opposite field" type which comprises three magnets [3]. The middle magnet (SM22) generates an opposite polarity magnetic field for the

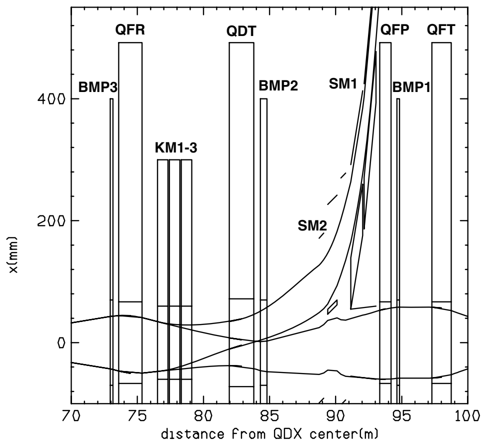

Figure 2: Injection beam orbit.

injection and circulating side. Bending magnets (SM21, SM23) at the both ends cancel the kick in the SM22 for the circulating beam. The turn separations at the downstream edge of the SM22 with 7 mm thick septum coil are 27 and 23 mm with and without the bump orbit, respectively. The septum coil is located outside of the 81π mm·mrad envelope without the bump orbit.

3 GEV DUMP

One path beam from the transfer line or circulating beam at 3 GeV can be dumped from the downstream of the injection straight section (see Figure 1). The 3 GeV beam dump with a beam duct surrounded by the iron shield has been buried in the tunnel wall and can accept 3 kW average beam (6.7% of full beam). The beam is extracted to the beam dump by three kickers and two magnetic septa. Figure 3 shows beam envelopes for kicked and circulating beams both with 81π mm·mrad+1 mm COD. The beam kicked by the last magnetic septa is transported into the beam dump about 18 m apart from the last magnetic septum exit without any focusing element. The beam size at the end of the beam duct of

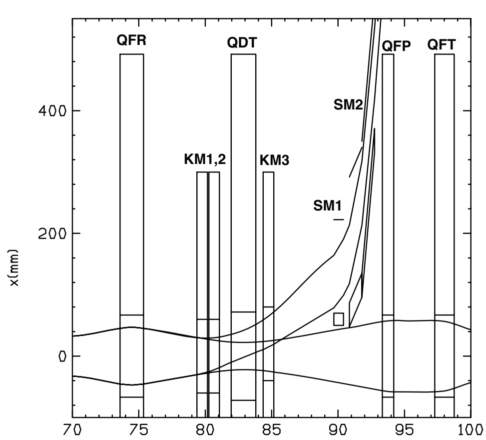

Figure 3: 3 GeV dump orbit.

ϕ600 mm inner diameter is ϕ370 mm. We can permit about 6 mrad error for total kick angle of 273 mrad for the extracted beam.

FAST EXTRACTION

The third long straight section is assigned for the fast beam extraction. A beam line for the neutrino oscillation experiment goes inside from the ring, on the other hand, a beam abort line goes outside. The fast extraction system comprises 5 kicker magnets and 14 magnetic septa which give a bipolar kick to both sides [4]. The beam with any energy in the range from the injection to the top can be aborted when an interlock system is fired. Since the beam size at the low energy is large, the beam edge hits on the vacuum chamber in the quadrupole magnets. But a residual activity by this beam loss can be small, since the beam abort does not frequently occurs. A mechanical damage at the vacuum chamber or the quadrupole poles due to the beam hit is also neglected, since an energy deposit per volume is small for the large beam size at the low energy.

Parameters of the kickers and the magnetic septa are listed in Table 1. Figure 4 shows envelops for extracted beam together with the circulating beam which has 81π mm·mrad + 1mm COD. The extracted beam energy is 40 GeV case, and the emittance is 7.6π mm·mrad, which is 1.5 times larger than that of adiabatically dumped one of 54π mm·mrad at the injection energy. An aborted beam envelope has a mirror symmetry on the beam center axis.

The acceptance for the 40 GeV extraction orbit is 19.5π mm·mrad, which is determined the QFR and SM1 apertures (see Figure 4). The permitted beam loss at the fast extraction area is 1.1 kW (0.15% of 750 kW), which determined the concrete wall thickness. A halo generated by the space charge force during acceleration may cause the beam loss at the extraction device. In order to estimate such a beam loss, a long term beam simulation including the space charge effect is underway [5]. On the other hand, we are proposing a different extraction scheme which uses large aperture kickers instead of the present thin septa. This scheme has a larger acceptance of 38π

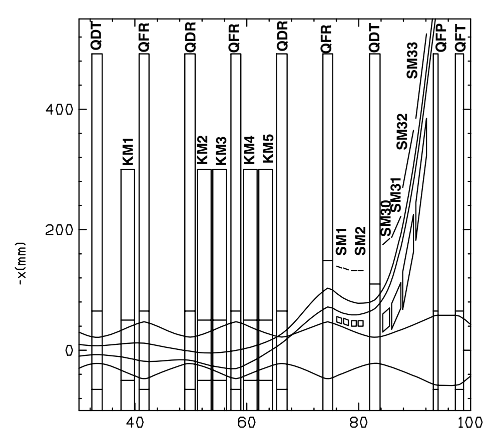

Figure 4: Fast/Abort extraction orbit.

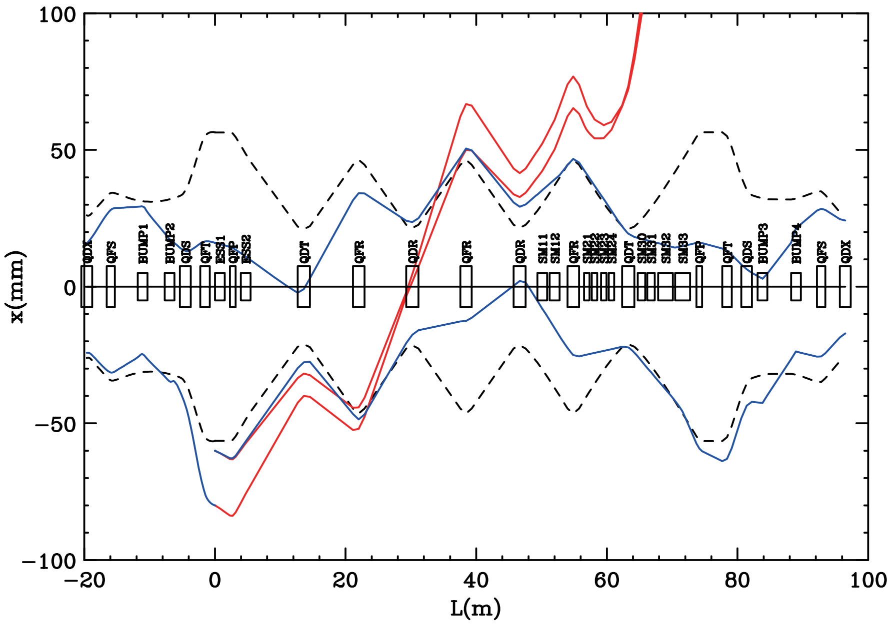

Figure 5: Slow extraction beam envelope.

mm·mrad, but needs development of a new large aperture kicker and would limit the extraction energy around 30 GeV. Repetition period at 30 GeV operation must be increased by about 2 times to keep the extracted beam power needed for the neutrino experiment. This increases the beam loss at the transfer line collimators.

An abort dump is located at about 70 m downstream from the ring exit. The beam duct in the dump has an inner diameter of ϕ738 mm. Even if any focusing element is not used in the 70 m beam line, 3 GeV beam with 54 π mm·mrad can be accepted in this duct. A quadrupole doublet can reduce the beam size at the duct end. This would give a larger margin for the kick angle error of the beam from the ring.

SLOW EXTRACTION

The main ring provides a beam to Hadron Experimental Facility by a slow extraction. From the radiation point of view, extremely low beam loss extraction is required. A third integer extraction has been adopted. A layout of the slow extraction is shown in Figure 5. The kick device for the slow extraction comprises two electrostatic septa (ESS1-2), two thin magnetic septa (SM10, SM11), four medium thick magnetic septa (SM21-24) and four thick magnetic septa (SM30-33). Four bump magnets are placed to make a bump orbit around these electrostatic and magnetic septa. These all septa and bump magnets are placed in the second long straight section with a zero dispersion. The 8 sextupole magnets with two family to excite the third integer resonance are located in the missing bending regions in the arc sections. The horizontal tune is approached to the resonance of the 3Qx=67 from a lower one by changing the field of the lattice quadrupole magnets (QFNs) in the arc sections. The ESS1 is placed the section between two focusing quadrupole magnets (QFT and QFP), which has a large β-function and a zero α-function. Moreover, the horizontal chromaticity is operated at a small value. This case, the separatrix does not depend on the momentum. In this condition, the bump orbit is changed to reduce the angular spread of the beam coming to the ESS1 during extraction. These slow extraction schemes can reduce the beam hit rate on the ESS1 wires less than 1% in case of 100 μm thick wires. Roughly 90 % of the beam hits on the ESS wires goes out by the multiple scattering. Some of the scattered beam is mainly lost at the slow extraction collimator (placed downstream of the ESS2) and the magnetic septa. The remaining scattered beam can extract from the ring. As a result, the extraction efficiency is estimated to exceed 99.7% from the simulation.

REFERENCES

[1] M. Tomizawa, "Machine Status of J-PARC", Nuclear Physics B(Proc. Suppl.) 154 (2006)123-128

[2] Accelerator Group JAERI/KEK Joint Project Team, "Accelerator Technical Design Report for J-PARC", KEK Report 2002-13, March 2003.

[3] I. Sakai "Operation of the Opposite Field Septum Magnet for the J-PARC Main Ring Injection", these proceedings.

[4] Y. Shirakabe, Y. Arakaki, T. Kawakubo, Y. Mori, S. Murasugi, E. Nakamura, I. Sakai, and M. Tomizawa, Proc. Of the EPAC2006, p. 1333-1335.

[5] A.Y. Molodozhentsev, M. Tomizawa, "Study of Particle Losses Mechanism for J-PARC Main Ring", these proceedings.