BEAM FAST EXTRACTION TUNING OF THE J-PARC MAIN RING*

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Abstract

Presented in this paper is beam commissioning of fast extraction system of the J-PARC (Japan Proton Accelerator Research Complex) MR (Main Ring). Before the start of beam tuning, simulation study with measured magnetic field of fast extraction septa had been done. Depended on this study, MR fast extraction of 30 GeV beam to neutrino beam line had been achieved on April 23rd 2009. After orbit correction with high accuracy in both horizontal and vertical, 70 kW continual operation to neutrino line have been achieved so far.

INTRODUCTION

In the MR, the third straight section is assigned for the fast extraction. A beam line for the neutrino oscillation experiment goes inside from the ring; meanwhile, a beam abort line goes outside which can deliver the beam aborted at an arbitrary energy to a dump just by using a quadrupole doublet for the focus. Just before commissioning, the measured magnetic field distribution of each fast extraction septum magnets showed non-linear profile along the horizontal direction. In order to investigate the influence, a beam simulation had been performed. This simulation and beam tuning for MR fast extraction will be mentioned in this paper.

SIMULATION STUDY OF THE MR FAST EXTRACTION

The MR fast extraction system comprises 5 kickers, 4 low-field septum magnets and 4 high-field septum magnets as shown in Figure 1 [1].

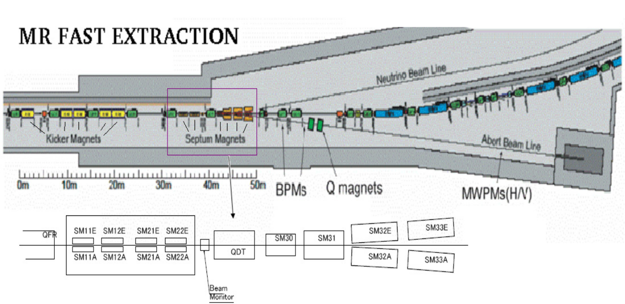

Figure 1: The layout of MR fast extraction.

Four low-field septum magnets are named as SM11, SM12, SM21, and SM22, while high-field septum magnets are named as SM30, SM31, SM32, and SM33. All the 5 kickers and 8 septum magnets give a bipolar kick for 30 GeV beam to neutrino beam line or abort dump [2]. The acceptance of this extraction line is 20.1 π mm·mrad, which is limited by the septa apertures.

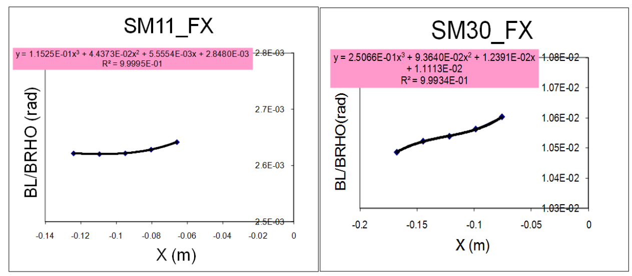

Figure 2: Measured magnetic field of each septa magnet. (Left: low-field septum magnet SM11; Right: high-field septum magnet SM30).

Before beam tuning of fast extraction, non-linear profiles along the horizontal direction were found in measured magnetic field of each septa magnet which can be seen in Figure 2. Those non-linear profiles showed quadrupole field component and higher order components.

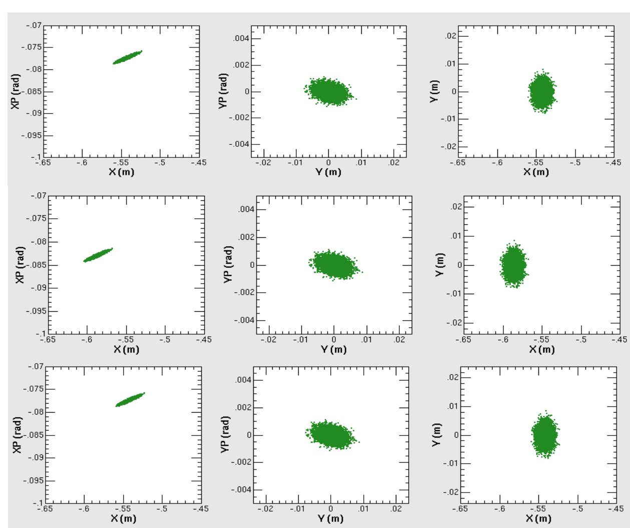

Figure 3: Particle distributions at end of the MR fast extraction. Upper three: with linear field of septa; Middle three: with measured field of septa at the measured current; Lower three: with measured field of septa at the fitting current for beam tuning.

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In order to find the influence, beam simulations had been performed considering quadrupole field component, sextupole field component and octupole field component of these measured field distribution. The simulation results are shown in Figure 3 and Table 1. Figure 3 gives the particle distributions at the end of fast extraction, where is also the beginning of neutrino beam line. Here three cases are shown for linear field in design, measured field at measured current, measured field at fitting current for beam tuning. Fitting current is the adjust setting of septa according to fast extraction orbit. The initial input beam is about 10 π mm-mrad which is considered as full emittance of MR fast extraction in design.

Table 1: Twiss Parameters at the End of the MR Fast Extraction Considering Linear or Non-linear Field of Setpa

	βx (m)	αx	Dx (m)	Emittance x πmm-mrad
Linear	38.104	-2.816	0.218	10.030
Non-linear	37.462	-2.805	0.212	10.031
	βy (m)	**αy**		**Emittance y** π mm-mrad
Linear	7.170	0.286		9.994
Non-linear	7.680	0.324		9.995

Table 1 shows the Twiss parameters at the end of the MR fast extraction considering linear or non-linear field of setpa. Beta functions show less than 7% different with others much less. For MR beam commissioning in first stage, the current case of extraction beam with full emittance 4 π mm-mrad, the influence will reduce to less than 2.8% for beta function, and less than 1.4% in beam size. So it is not a serious problem for beam tuning in initial stage but should be considered carefully for the future high intensity beam.

Fast extraction with horizontal envelope of 10 π mm-mrad is shown in Figure 4. Here apertures of the fast extraction magnets are also plotted.

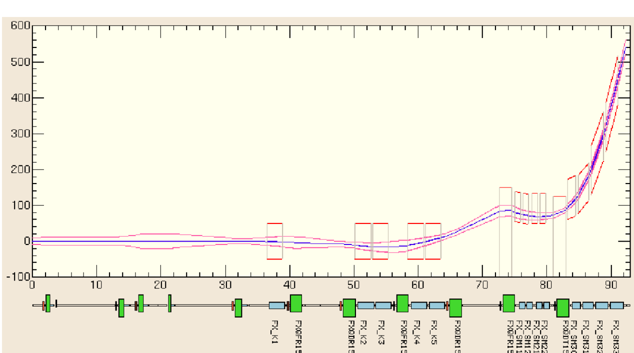

Figure 4: Beam fast extraction plot with envelope of 10 π mm-mrad and apertures of MR fast extraction magnets.

TUNING OF MR FAST EXTRACTION

Tuning of Beam to Neutrino Beam Line

According to the simulation study, fitting currents of fast extraction septum magnets were used for initial tuning. After simply tuning of beam to abort dump, the first beam transport to neutrino target was achieved on April 23rd 2009.

Because the neutrino oscillation experiment requires much accurate orbit in both horizontal and vertical, 0.5 mm and 0.5 mrad in maximum at the entrance of neutrino beam line for high power operation, orbit corrections were done furthermore. And model-based orbit response matrices from fast extraction magnet to according BPMs are used for horizontal orbit correction. Within 2-3 iterations, required fast extraction orbit can be got as shown in Figure 5.

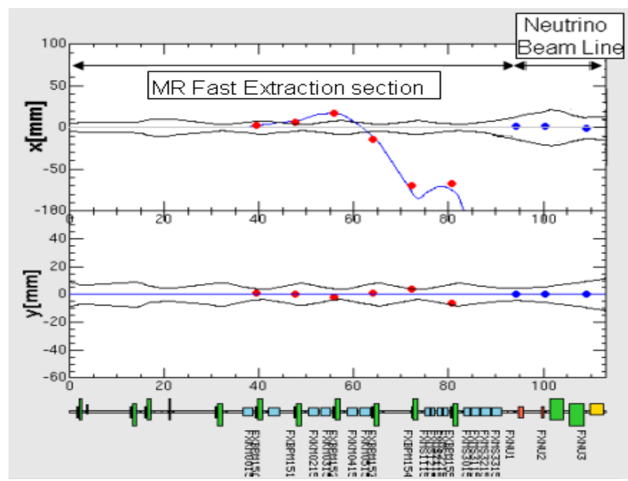

Figure 5: Tuning plot of MR fast extraction to neutrino beam line (Blue line: calculated orbit; Red point: MR BPM data; Blue point: Neutrino line BPM data).

For vertical orbit tuning, a vertical local bump in the MR fast extraction section was built. Firstly, required (dy, dy') at the entrance of SM30 was calculated with BPM data from the neutrino beam line. With this (dy, dy'), a vertical bump was built by four vertical steering magnets in MR as shown in Figure 7. Finally vertical orbit met the requirement of high power operation.

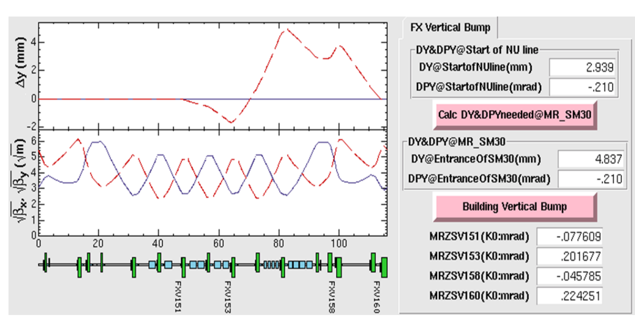

Figure 6: MR Vertical bump for fast extraction tuning.

Tuning of Beam to Abort Beam Line

In the initial, beam with 30 GeV energy and 3 GeV energy was planned to be tuned to abort dump. Almost same as 30 GeV beam tuning to neutrino beam line, tuning of 30 GeV beam to abort dump was also done using model-based orbit response matrices from fast extraction magnet to two abort BPM, shown in Figure 7.

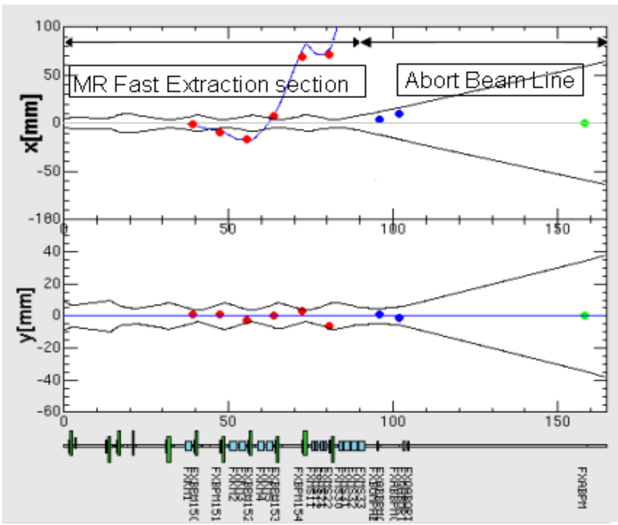

Figure 7: tuning plot of MR fast extraction to abort dump with BPM data (Blue line: calculated orbit; Red point: MR BPM data; Blue point: Neutrino line BPM data; Green point: beam position data at profile monitor just before abort dump).

For the case of 3 GeV beam fast extraction to abort dump, one important difference with 30 GeV beam extraction is beam emittance. For current situation, full emittance of 3 GeV beam is about 15 π mm-mrad, which is much larger than 4 π mm-mrad of 30 GeV beam. Thus suitable settings of kicker and septum magnets were used to fit this emittance, which can be seen in Figure 11. Only the last kicker was used for 3 GeV beam extraction. And beam positions at narrow area were also calculated carefully. Finally it was found than 3 GeV beam can pass through the fast extraction system without problems.

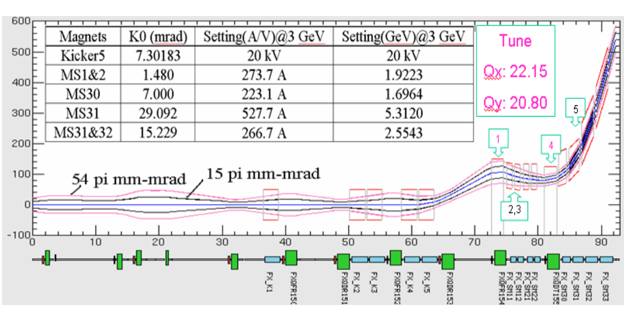

Figure 8: MR 3 GeV beam envelope to abort line.

Based on calculation shown in Figure 8, fast extraction of 3 GeV mode was tuned. And a quadrupole doublet in abort line was also tuned for smaller beam sizes at profile monitor which can be seen in Figure 9. With 600 A setting for the doublet, about beam sizes of 208 mm in horizontal and 128 mm in vertical were got at the profile monitor just located upstream of the abort dump, which were almost same as calculation.

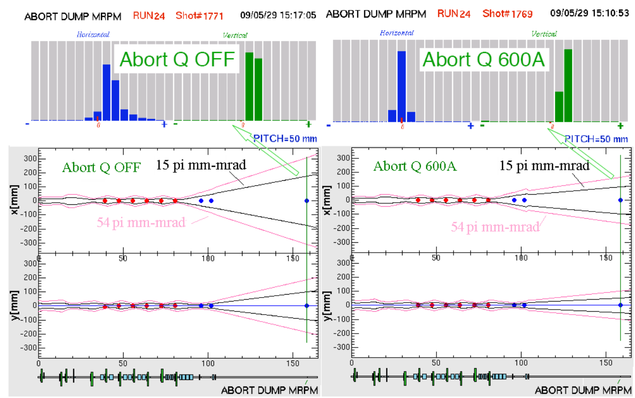

Figure 9: Tuning of beam size at profile monitor just before abort dump (Left: 0 A setting of Abort doublet; Right: 600 A setting of Abort doublet).

SUMMARY

Starting from May 2008, the MR commissioning is in good progress. The fast extraction commissioning in were done smoothly.

Although the measured magnetic field distribution of each fast extraction septum magnets showed non-linear profile along the horizontal direction, simulation results showed the influence can be ignored for 4 π mm-mrad beam of 30 GeV extraction.

Depended on this study, beam tuning of MR fast extraction was started. And 30 GeV beam to neutrino beam line has been achieved on April 23rd 2009. Due to real situations in commissioning, orbit corrections were done in both horizontal and vertical for fast extraction. Orbit offset of less than 0.5 mm and 0.5 mrad at the beginning of neutrino beam line were attained in both horizontal and vertical. So far, 70 kW continual operation to neutrino line have been achieved.

REFERENCES

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[2] M. Tomizawa, New Optics Design of Injection/Fast extraction/Abort lines of J-PARC Main Ring, Proc. of PAC07; http://www.JACoW.org.