EFFECT OF THE 2011 GREAT EAST JAPAN EARTHQUAKE IN THE INJECTION AND EXTRACTION OF THE J-PARC 3-GeV RCS

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Abstract

The ongoing schedule of the entire Japan Proton Accelerator Research Complex (J-PARC) was seriously interrupted due to the big damage of the whole accelerator facility caused by the 2011 great east Japan earthquake. In addition to the ring, the injection, extraction and the beam transport lines magnets of the 3-GeV Rapid Cycling Synchrotron (RCS) also experienced a noticeable position errors in all directions. However, a realistic realignment schedule of the RCS magnets was planned in 2013. The present work estimated the misalignment effect on the injected and extracted beams and possible solution for resuming the user operation as soon as possible. Fortunately, simulation results did not show any serious issue with either injected or extracted beam and thus the user operation was expected to resume as scheduled. The estimations were found to be consistent with post extraction beam study results and the user operation was thus resumed as scheduled.

INTRODUCTION

The 3-GeV Rapid Cycling Synchrotron (RCS) of Japan Proton Accelerator Research Complex (J-PARC) delivers a high power beam simultaneously to the spallation neutron source target in the Material and Life Science Facility (MLF) and to the main ring (MR) [1]. A 181 MeV H^- beam from the LINAC is injected into the the RCS through stripping to a proton beam by a stripper foil placed in the RCS injection point. The beam is then accelerated to 3 GeV and delivered to the downstream facility with a repetition rate of 25 Hz. As a result, the injection and extraction systems play important roles for the beam injection and extraction, respectively. The most updated design scheme of the RCS injection and extraction systems can be found in our earlier articles [2, 3].

The operation of the RCS was going well matching with overall J-PARC schedule. The RCS was delivering a stable and high power beam of 200 kW to the MLF as well as an equivalent beam power of 300 kW to the MR. Unfortunately, the on-going operation was seriously interrupted by the 2011 great east Japan earthquake due to the big damage of the whole accelerator facility including the infrastructure. Similar to whole facility, the ring including injection, extraction and the beam transport lines magnets of the RCS also experienced a noticeable alignment errors. Figure 1 shows such a misalignment of the RCS injection straight section magnets. Except from the horizontal direction, misalignment errors were found to be localized. The maximum error in the horizontal direction was about -3 mm.

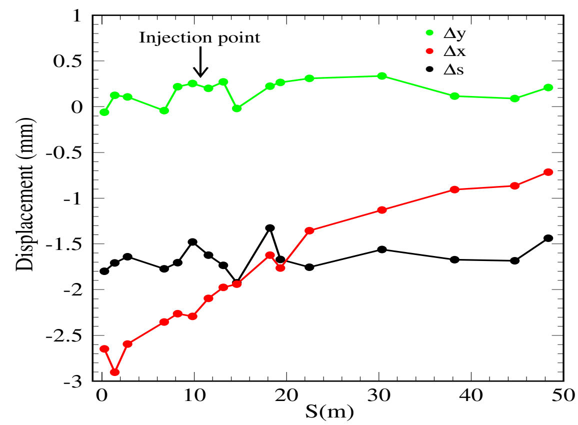

Figure 1: Misalignment of the RCS injection straight section magnets occurred by the earthquake.

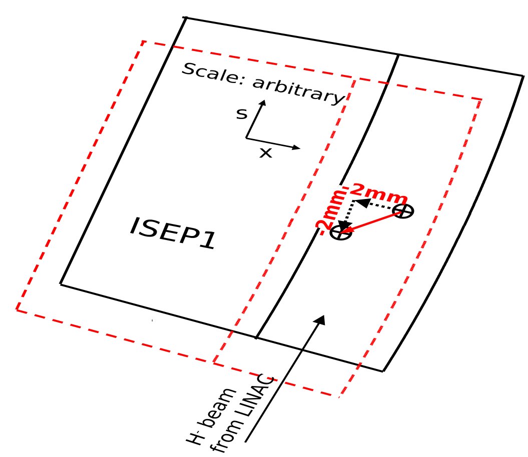

Figure 2: Close view of a typical misalignment of the 1st injection septum magnet. The misalignment in any direction was about -2mm, but it is magnified in the figure by drawing the actual volume of the magnet with arbitrary scales.

The septum magnets in the injection and the waste beam line also had similar misalignment as shown in Fig. 2. The misalignment in any direction was about -2mm, but it is magnified in the figure by drawing the actual volume of the magnet with arbitrary scales. The extraction region was also suffered by the same amount of misalignment. The angle of the injection and extraction beam transport lines were changed by about 0.1 mrad and 0.2 mrad from their design values of 306.9 mrad and 310.7 mrad, respectively.

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However, due to the tight schedule for the post earthquake recovery, a realistic realignment of the RCS ring and beam transport line magnets were thought to be done later, in case there arises no significant issues for resuming RCS user operation with some moderate beam power required by the downstream facilities. The beam dynamics simulation for the circulating beam showed some realistic possible solutions [4]. In a similar way, present work also estimated the misalignment effect on the injected and extracted beams and possible solutions for resuming the user operation. Although injection and extraction regions were designed with sufficient aperture margin, there are many different types of the operation patterns as well as beam studies. As a result, a detail investigation was necessary for a possible restoration of the original beam parameters within the present capability of all magnets. The power supplies of almost all injection magnets have enough margin at the present 181 MeV injection as they were installed to fit even for the design injection energy of 400 MeV. The aperture was thus the biggest concern in the injection in contrast to both aperture and power supply margin in the extraction region.

SIMULATION AND BEAM STUDY RESULTS

The simulation was done by using the SAD simulation tool [5]. In the lattice file, all the magnets including beam monitors are placed in the new positions and first central trajectory of the beam was calculated. Naturally, the trajectory was found to be different as compared to the nominal one, but it was possible to adjust by varying kick angles of the septum magnets only a little.

Injection

Due to varieties injection patterns, the injection part is rather complicated. The incoming H^- and the waste beam share very off center of the ring quadrupole magnets named QFL and QDL, respectively [3]. A change of the field uniformity as well as the aperture margin for the painting injection are main concerns. One more key issue here is that the injected beam should be matched to the closed orbit of the circulating beam. That means the phase space coordinates of the injected beam should be matched to that with circulating beam at the injection point [3]. Otherwise there occurs a large betatron oscillation of the circulating beam resulting a beam loss. A closed orbit distortion of 2 mm and -0.05 mrad in the horizontal direction (negligible in the vertical direction) was estimated due to the misalignment of ring including injection chicane magnets.

Taking in account all effects in the present simulation, first the nominal central trajectory of the beam was reproduced by changing bending angle of all septum magnets. Fortunately, the simulation did neither show any big change of the septum parameters nor the shift of the central trajectory as compared to those in the operation. Figure 3 shows an expected shift of the central trajectory of the injected and the waste beam along the beam axis starting from the end of L-3BT (Linac-to-3-GeV Beam Transport) line to the injection waste beam dump. The shift was within ± 2 mm and thus the aperture reduction was not a big concern. Table 1 gives a comparison of the expected change of septum currents to those with beam study results and was found to be consistent for injection septa ISEP1&2. Due to installation of a new collimator system in the downstream of the injection point, new shielding and repositioning were done for the 1st septum in the dump line (DSEP1) [6]. It was thus not so straight forward to made a similar comparison for the H0 dump line septa (DSEP1 and DSEP2).

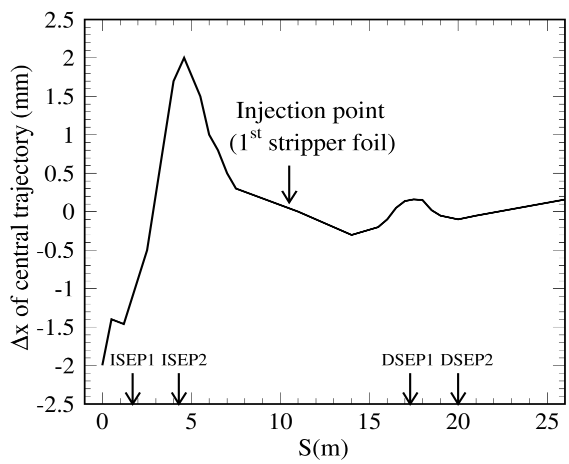

Figure 3: Expected shift of the central trajectory of the injected and the waste beam due to the longitudinal position error of magnets. The shift was within ± 2 mm and was thus considered to be negligible.

Table 1: Expected change of the septum currents in order to restore the nominal beam trajectory was found to be consistent with beam study results.

Name	I (Opr.) (A)	ΔI (Sim.) (A)	ΔI (Beam study) (A)
ISEP1	1560	26	19
ISEP2	3437	-100	-93
DSEP1	3075	-50	—
DSEP2	1754	10	—

It is worth pointing out that the injected beam profile was also estimated to be no change. Figure 4 shows injected beam profiles at the injection point before and after the earthquake measured by a multi-wire profile monitor and were found to be very identical. The amount of waste beam in the H0 dump line was also measured to be as expected so as to confirm that there has no unexpected halo in the post earthquake injected beam. The injection tuning as a whole was thus went very smoothly.

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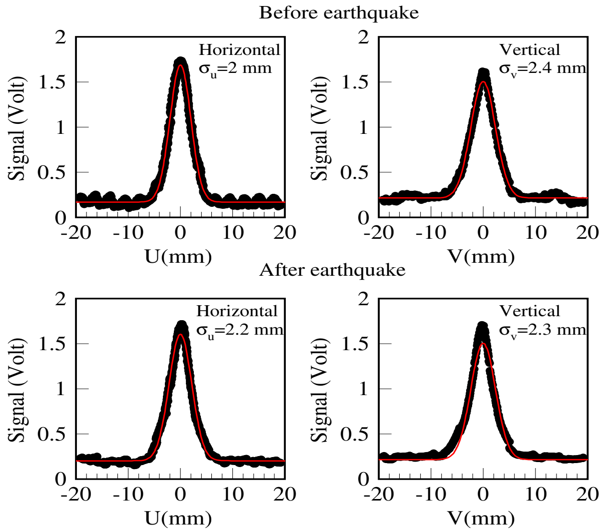

Figure 4: Measured injected beam profiles before (top) and after (bottom) the earthquake were found to be identical.

Extraction

A set of 8 pulse kicker magnets and 3 DC septum magnets (ESEP1$\sim$3) are used in order to extract two bunches of the 3-GeV beam from the RCS [2]. The misalignment in the extraction region was 1$\sim$3 mm but the direction was opposite as compared the injection region. Namely, longitudinal position error was a maximum of 2.7 mm, where it was $\sim$1 mm in the transverse direction. The horizontal position and angle at the RCS and 3-NBT (3-GeV-to-Neutron-target Beam Transport) intersection point (locates just after ESEP3) was found to be changed by about 1 mm and -0.2 mrad, respectively. In the beam tuning process, first two beam position monitors (BPM) in the 3-NBT line are used and fine adjustment is done by ESEP2&3. Similar to the injection, all magnets and monitors are repositioned and then the nominal extracted beam orbit was restored by varying ESEP2&3. All other magnets were set for nominal parameters. Here also the central trajectory of the extracted beam was easily restored by varying bending angles of ESEP2&3 only a little. As shown in Table 2, the change of ESEP2 and ESEP3 currents were found to be only -15 A and 30 A, respectively. The estimated changes were almost negligible as they are operated with more than 10 kA and thus nominal central beam trajectory in the beam study was restored without any change of the septum parameters. The extracted beam profiles before and after the earthquake measured near to the neutron target for a beam power of 200 kW is shown in Fig. 5. They were also found to be identical and thus there was no any significant issue with the post earthquake extracted beam for such a beam power or even more.

SUMMARY

The misalignment effects on the RCS injected and extracted beams and possible solutions for resuming RCS operation were estimated in the present work. It was found that there needed no significant changes for any of the injection and extraction magnet parameters in order to restore the nominal beam characteristics. In addition to the beam simulation done for the circulating beam, the present simulation results were also very important in order to make a realistic realignment plan of the RCS magnets to perform not soon in the tight recovery schedule right after the earthquake, but to shift later in the summer shutdown period of 2013. The post earthquake beam study results were found to be consistent with expectation. The overall tuning of the RCS injected and extracted beam were thus went smoothly so as to resume the operation as scheduled.

Table 2: Estimated changes of septum currents in order to restore the nominal beam trajectory were found be almost negligible as compared to their operational parameters of more than 10 kA and thus there was no change with beam.

Name	I (Opr.) (A)	ΔI (Sim.) (A)	ΔI (Beam study) (A)
ESEP1	9556	0	0
ESEP2	9938	-15	0
ESEP3	10500	30	0

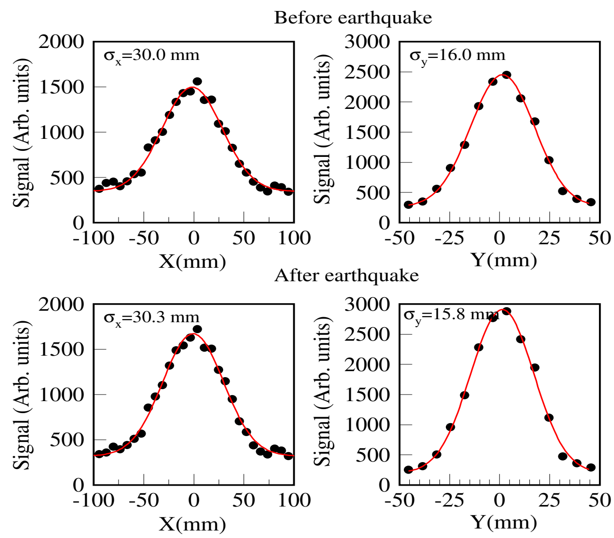

Figure 5: Extracted beam profiles measured after the earthquake (bottom) were found to very identical to those with before the earthquake (top).

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