BEAM COMMISSIONING RESULTS OF THE RCS INJECTION AND EXTRACTION AT J-PARC

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Abstract

The beam commissioning of J-PARC (Japan proton accelerator research complex) 3 GeV RCS (rapid cycling synchrotron) has been started from the end of year 2007 and is in progress. As usual, injection is in the very first stage and strongly related to the other part of RCS commissioning including the extraction, where an extracted beam finally reflects the overall commissioning result. Starting with so-called center injection in the beginning, design operation, so-called painting injection study has already been started from the last run. This paper reports the summary of RCS injection and extraction beam commissioning results achieved so far.

INTRODUCTION

Aiming to the design goal of 1 MW output power, the beam commissioning of J-PARC RCS is in progress. As designed, RCS is already acting as an injector to the main ring (MR) as well as delivering beam to the the spallation neutron target. The output power of 1 MW from RCS is expected to achieve with the injection and extraction energy of 0.4 and 3.0 GeV, respectively, and with a 8.3×10^{13} protons per pulse at a repetition rate of 25 Hz [1]. However, at the present stage, incoming beam energy from Linac is 0.181 GeV and and expected goal is to achieve a output beam power of 0.6 MW. As also stated earlier, injection commissioning becomes an important factor for the commissioning of the rest of the ring. At the injection, a precise beam position and angle of the incoming beam is required to know. The beam position and angle at the injection can thus be adjusted as required by the Ring. On the other hand, an well extraction of the beam reflects the overall success of the entire commissioning. Extraction unit is needed to be very precise in timing and should have well acceptance in order to extract all the beam to the particular destination as required.

Fig. 1 shows the general layout of RCS injection and the successive H0 dump line. A detail explanation of the injection design and the beam optics can be found in Ref. [1, 2]. In the normal operation mode of RCS, incoming H^- beam from the Linac is converted to H^+ by the 1st foil located in between SB2 and SB3, partially stripped H^0 and unstripped H^- beams are converted to H^+ by the 2nd and 3rd foil, respectively and driven to the H0 dump. In this mode, unless any damage of the 1st foil or any fault, the main component of the beam which goes to H0 dump is the partially stripped H^0 one (after converting to H^+ by the 2nd foil), where the unstripped H^- component is negligibly small [2]. The name of the dump is thus the H0 dump.

COMMISSIONING STRATEGY

The beam commissioning of RCS was started with the injection and the H0 dump line and was called as H0 dump mode operation. The incoming Linac beam energy and the peak current were 0.181 GeV and 5 mA, respectively. At this stage, only the 3rd foil was installed in order to convert incoming H^- beam to H^+ so as to drive that to the H0 dump. At the first stage, the injection and the H0 dump line orbit was established with a set of six multi-wire profile monitors (MWPM) placed in the injection H0 dump line as seen in Fig. 1. An elaborate explanation of these MWPM, concerning the construction, properties as well as method of profile measurement can be found in Ref. [3, 4]. In addition, there are also several beam position monitors (BPM) named as I-BPM (located in between ISEP1 and ISEP2), big-BPM1 and big-BPM2 (located near the QFL and QDL, respectively). The beam orbit at the L3BT line was adjusted as close to the design and thus the all the RCS injection parameters were set as designed. In order to make the situation a bit simpler, the shift bump magnets (SB1∼4), which are the horizontal bump magnets in order to form a close bump orbit were not excited at the first stage and thus H^- beam was then suppose to go straight after the exit of QFL until the 3rd foil. With an iteration of few times, a roughly beam orbit at the injection to the H0 dump line was established. The transmission of beam was confirmed from the signal of a current transformer (CT) placed at the entrance of the H0 dump. The MWPM each by each were then used as scan mode (10 mm move with 0.1 mm step, total 100 pulses with 1Hz) for an accurate measurement of the beam position and beam profile as well. The shift bump magnets were then excited and beam positions at each monitors starting from the MWPM3 were measured again. The beam orbit only in the shift bump region was changed as almost expected. At present, beam profiles measured by these MWPM and single wire scanners in the L3BT line are used together in order to obtain the beam twiss parameters at the RCS 1st foil [4]. Direct measurement of the twiss parameters at the 1st foil is very important for the RCS injection, especially, for the painting injection study.

As for the extraction, the extracted beam was driven to

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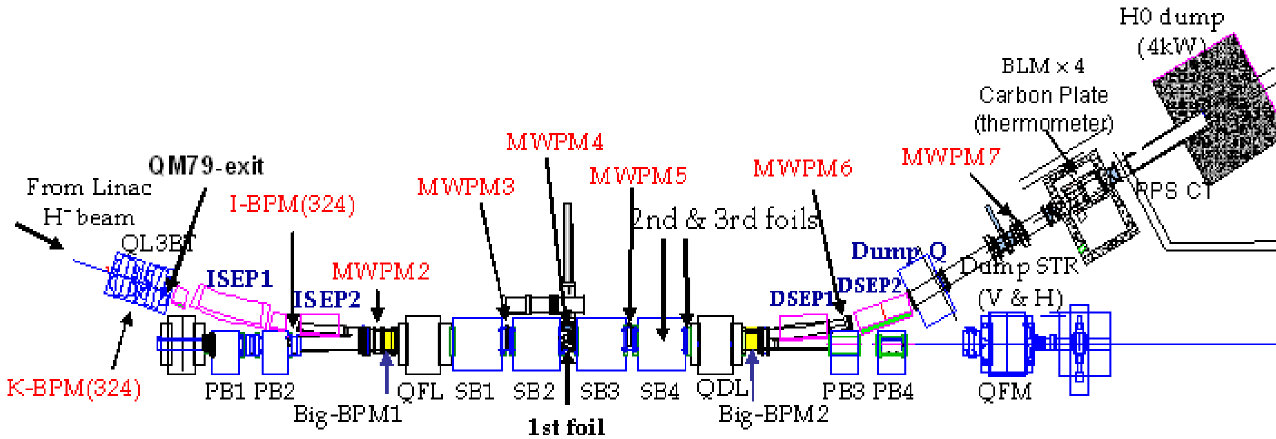

Figure 1: Layout of the RCS injection and H0 dump line. SB and PB stand for horizontal shift bump and paint bump magnet, SEP for septum magnet and BPM for beam position monitor. Two vertical paint bump magnets are located at the downstream part of the L3BT line (not seen here) and is used for RCS painting injection in the vertical plane.

the so-called 3NBT dump used for the RCS commissioning and is located at about 40 m distance from the last extraction device (3rd extraction septum) of RCS. At first the beam was extracted with RCS of 1/3 mode, where two DC kickers and the extraction septum magnets were used. The next RCS operating mode was DC circulating mode and for the extraction of 181 MeV circulating beam, two of eight pulse kickers and all three septum magnets were used. Finally, for the RCS of 3 GeV mode, all the eight pulse kickers and all three septum magnets were used as designed. The commissioning results of the RCS kicker system can be found in Ref. [5]. The extraction orbit as well as the extracted beam profile is measured by several BPM and fixed type MWPM, respectively.

COMMISSIONING RESULTS

Injection and Extraction in General

Table 1 represents a comparison of the calculated and measured injection to the H0 dump line orbit as seen from the RCS circulating orbit. Except for I-BPM, calculated and measured orbit are found to be agreed well. The magnet parameters are also found to be agreed within ±2% except for ISEP2. Detail analysis are underway and would be reported soon somewhere else, where some more experimental data are also needed. As for the simulation, SAD (Strategic Accelerator Design) was used [6]. The extraction unit is found be consistent with the design parameters although detail study with more experimental data are needed. Unlike injection, there is lack of monitor in the extraction area and makes the comparison difficult. Recently we have done a good progress to observed clearly the circulating beam orbit turn-by-turn through the whole cycle and would be very helpful for the comparison. The extraction beam orbit stability was found to within ± 0.4 mm (σ) measured recently at the downstream of 3NBT line [7].

Painting Injection Study

Aiming for high power beam from RCS, recently we have started the painting injection study. In order to defuse the space-charge force, beam density can be controlled by utilizing the painting injection (500 μsec, about 235 turns) in the transverse direction and an RF operation mode in the longitudinal direction. The general painting injection procedures can be found in Ref. [1, 2]. At this stage, we have tried to check the response of all paint bump magnets in both horizontal and vertical plane, for example, the balance adjustment of all four horizontal paint bump magnets (PB1 4) in order to close the bump orbit exactly and so on. Two vertical paint bump magnets are also needed to set with a correct combination so as to sweep the injection beam vertically and only in the y' direction. Response of all paint bump magnets were found to be almost as expected, although a bit more study is needed. We have developed several tools for the precise understanding so as the correction of the phase space coordinates of the painting injection or in other words, to know and optimize correctly the painting area. One is with BPM single pass (turn-by-turn) mode, where a BPM pair in a drift space was chosen. In RCS, there are such two pairs of BPMs located in the extraction (pair 1) and RF straight section (pair 2), respectively. Two BPMs in each pair are located at a distance of about 5.5 m. After substracting the ring COD (closed orbit distortion) at each BPM, the measured phase space coordinate from each pair can be take back to the injection point using a transfer matrix so as to get the phase space coordinate at the foil. The other method is using a tune BPM spectrum placed at the end of extraction straight section. By measuring betatron response matrix and by detecting the real and imaginary part of the betatron sideband peak gives the phase space coordinates at the injection point [8]. In addition, we also measured the circulating beam profiles (H and V) by two ionization profile monitors (IPM) placed in the first arc

Table 1: Comparison of calculated and measured injection-H0 dump line orbit (horizontal) as seen from the RCS circulating orbit as a reference. Units in mm

Data	I-BPM	MWPM2	BPM1	MWPM3	MWPM4	MWPM5	BPM2	MWPM6	MWPM7
Calc.	418	226	215	133	88	132	218	491	3435
Meas.	412	228	214	133	88	132	219	491	3435

section of RCS [9]. Unlike the designed painting pattern, we excited the horizontal paint bump magnet on the top the shift bump magnet with a constant pattern of 400μsec flat top and 500μsec falling time for different painting area in the horizontal plane. Instead of multi-turn injection, only a single pulse having a width of 0.56μsec injected to RCS in order to correctly extract the betatron phase space information turn by turn. As BPM gives only the beam center of the whole bunch, the multi-turn injection is thus gives a collective information an almost impossible to extract the correct information needed for this purpose. The RCS was in DC circulating mode. Fig. 2 shows the horizontal phase space coordinates at the injection point obtained from the BPM single pass information as explained above (blue and green data points are with BPM pair 1 and 2, respectively). The black large ellipse represents the circulating beam phase space at the injection point having an emittance of 150π.mm.mrad, where the red ellipses are drawn by using the preliminary measured injection beam emittance of 3.5π.mm.mrad for a paint area of 150π.mm.mrad (1), 100π.mm.mrad (2) and 50π.mm.mrad (3). The central emittance were then expected to be 124π.mm.mrad (1), 75π.mm.mrad (2) and 27π.mm.mrad (3), respectively. It can be seen that the present result shows the painting area was a bit smaller (10% in all three cases) than expected and can be optimized by changing (simply 10% stronger) paint bump excitation pattern. The present result also confirmed by directly measuring the beam position and angle of the injection beam using the MWPM. It it important to mention that almost similar result was also obtained with the other method as explained above [8]. The normalized phase space distributions were also obtained from those two pairs of BPM single pass data. Results from both pairs were found to be very close to each other, where the central emittance were obtained to be 100π.mm.mrad, 64π.mm.mrad and 25π.mm.mrad, respectively, for the case of (1), (2) and (3) in Fig. 2. The obtained phase space coordinates plotted in Fig. 2 also have the same emittances as above and thus again demonstrate the consistency of the BPM single pass data. Similar consistent result for painting in the vertical plane was also obtained from the BPM single pass data, although a detailed study could not be carried out so far.

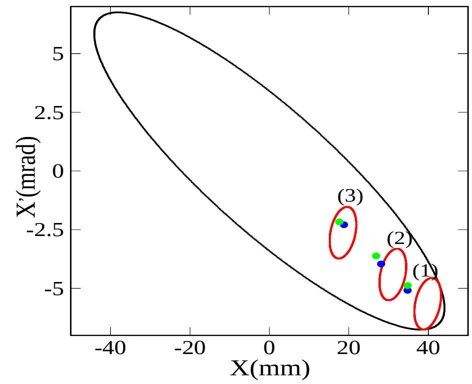

Figure 2: Phase space coordinate (blue and green dots) at the injection point for different painting area are extracted accurately from the BPM single pass data. See text for detail.

SUMMARY

Starting from the end of last year, RCS commissioning is in good progress. The injection and extraction commissioning in the beginning were done very smoothly and is in full cooperation with the RCS overall commissioning without any trouble. Almost all parameters of the injection and extraction using for commissioning are found to be almost consistent with those used in the design stage. The beam orbit stability for both extraction and injection were found to be very good so far. Aiming for high output beam power, RCS already started painting injection study. In order to understand the painting process very precisely as well as for the direct feedback towards the painting injection study, BPM single pass data from two pairs located in two different places in RCS are found to be very efficient and accurate.

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