PERFORMANCE OF THE BUMP SYSTEM FOR THE PAINTING INJECTION AT J-PARC

T.Takayanagi[#], T.Ueno, T.Togashi, H.Harada, P.K.Saha, H.Hotchi, M.Kinsho, J.Kamiya, M.Watanabe, M.Yoshimoto
JAEA/J-PARC, 2-4 Shirakata-Shirane, Tokai, Ibaraki, 319-1195, JAPAN
Y.Irie, K.Satou, KEK/J-PARC, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, JAPAN

Abstract

The painting injection of the 3-GeV RCS [1] in J-PARC (Japan Proton Accelerator Research Complex) [2] has been tested since May in 2008 [3] [4]. The shift bump-magnets, which give a constant bump field in a horizontal plane during injection, comprise four magnets connected in series [5] [6]. However, the total integrated magnetic field over the four magnets is not zero because of the magnetic field interferences with the neighbouring quadrupole magnets. So the gap of each magnet was adjusted by inserting thin insulator sheet into the splitting plane of the side yoke so that the field integration becomes almost zero [7]. The thickness was determined experimentally. The closed orbit distortion (COD) due to the field imbalances, which is the circulating beam of the RCS, has been confirmed to be less than 1 mm.

Four horizontal paint bump-magnets and two vertical paint magnets [8] are also necessary to give time-dependent fields for the painting injection. They are connected to their own power supplies, separately. The excitation current of each horizontal paint bump-magnet is calibrated by using the circulating beam. So that the created painting injection trajectory satisfies the position and the inclination at the injection point, and there are no orbit distortions outside the injection area. As for a vertical plane, two vertical paint magnets are located pi-radian upstream of the injection point to control the vertical angle of the injection beam.

INTRODUCTION

The preliminary test of the painting injection in the transverse plane has been performed with the injection bump system of the 3-GeV RCS in J-PARC. The horizontal painting injection is executed with four shift bump-magnets and four horizontal paint bump-magnets, and the vertical painting injection is executed with two vertical paint magnets.

The shift bump-magnets produce a fixed main bump orbit to merge the injection beam from the LINAC [2] into the circulating beam of the RCS. The horizontal paint bump-magnets deflect the circulating beam for the horizontal direction by utilizing the decay waveform with the square root functions during the injection time (500 μs). The vertical paint magnets control the injection angle of the injection beam for the vertical at the first charge-exchanging foil position. The injection beam with a small emittance from the LINAC (4 π.mm.mrad) is uniformly distributed to the circulating beam. So the large beam of the high intensity that the design of the painting injection areas to the MLF (Material and Life science Facility) beam and the MR (50-GeV Main Ring) beam are 216 π.mm.mrad and 144 π.mm.mrad, respectively is produced.

The COD due to the imbalance of the magnetic field of the shift bump-magnets was measured. Moreover, the response of the beam with four horizontal paint bump-magnets was measured, and the balance adjustment of the excitation current was performed in each power supply. And for the procedure of the painting injection, each phase space coordinates for the horizontal direction and the vertical direction at the injection point was measured by using the horizontal paint bump-magnets and the vertical paint magnets.

Thus, it has been confirmed that the bump system have the ability to control the injection and the circulating beam with good accuracy.

BEHAVIOR OF A CIRCULATING BEAM WITH THE SHIFT BUMP-MAGNET

Beam Trajectory

To form the accurate a fixed closed bump orbit without exciting timing error of each magnet, the four shift bump-magnets are connected in series. However, the total integrated magnetic field of the four magnets was not zero because of the magnetic field interferences between the quadrupole magnet (QFL or QDL) that adjacent to the upstream and the downstream of four shift bump-magnets, respectively. In order to decrease the imbalance of the total integrated magnetic field of the four shift bump-magnets, 0.3 mm insulator thin sheet was inserted at the median plane of the return yoke of the second and the third shift bump-magnet. As the measurement result using the mapping search coils, the decrease of the total integrated field to be –71.6 Gauss-cm from 2358.0 Gauss-cm was confirmed [7]. According to the analysis result of the SAD, the decrease of the integrated field is equivalent to the COD decrease from 6 mm to less than 1 mm [9].

The beam commissioning at the 181 MeV circulating mode was performed. The COD of the circulating beam was measured using the beam positioning monitor (BPM) [10]. The BPM measures the phase space coordinates of the central trajectory of the circulating beam. Fig. 1 shows the measurement result of the deflection for the horizontal direction (dx). It has become less than 0.5 mm and the agreement to the analysis result has been obtained.

[#]tomohiro.takayanagi@j-parc.jp

Beam Displacement

The displacement of the injection beam orbit (Dx) to a set current of the power supply of the shift bump-magnet was measured using the Multi-Wire Profiles Monitor (MWPM) [11]. The MWPM#4 is installed at the mid-point of the four shift-bump magnets, where the bump orbit is largest is measured.

The measurement result is shown in Fig. 2. The beam displacement was smaller than that by using the magnetic measurement result. The in-situ measurement of the magnetic field using the mapping coil was performed [7]. Therefore, the influence of the magnetic field interference with the adjacent quadrupole magnets is included in the analysis result. Another possibility to explain the decreasing in that the magnetic field controlling effect by the eddy current is caused in the flange of the duct installed in each shift bump-magnet. This verification must be executed by both of the magnetic field measurement in the locale and 3D dynamic magnetic field analysis.

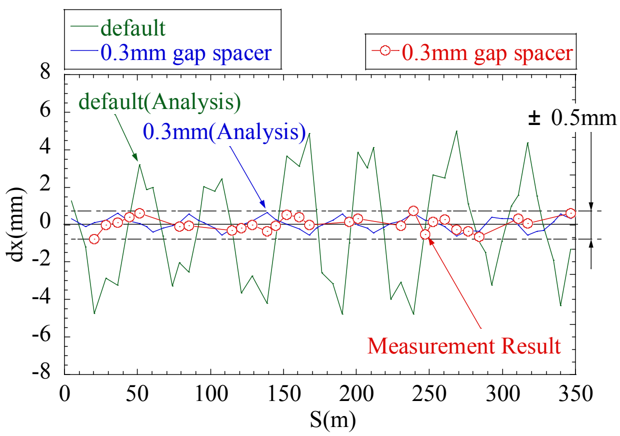


Figure 1: Measurement and analysis result of the circulating beam COD caused by the magnetic field distortion of the shift bump-magnet.

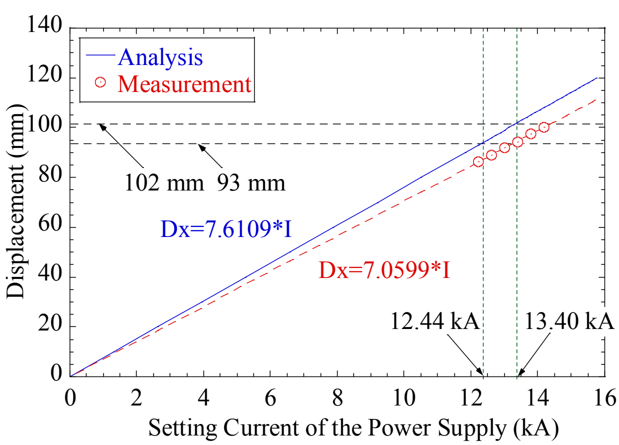
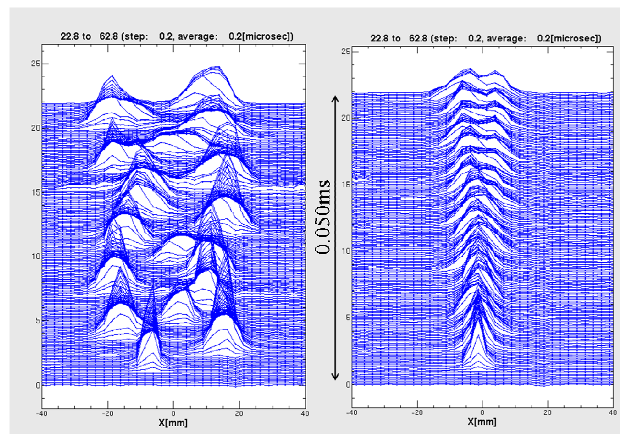


Figure 2: Measurement result of the beam displacement.

Center Injection

The beam profile of the circulating beam was measured using the Residual Gas Ionization Profile Monitor (IPM) [12]. In the case of the power supply setting for the beam displacement of 93 mm and 102 mm (see Fig. 2), each beam profile was measured, as shown in Fig. 3. In the case of the 93 mm setting, there was a large betatron oscillation due to the offset injection. When the setting of the power supply was 93 mm, the mismatch between the injection beam orbit and the circulating beam orbit was about 17 mm from measurement of the MWPM#4. Then, it was set up in 102 mm, which displaces the beam more 9 mm that is about half of the distance away. As a result, the injection beam and the circulating beam became the same trajectory, and the decrease of the betatron oscillation was confirmed.



(a) 93mm (b) 102mm

Figure 3: Beam profile measured by the IPM. Left (a) is 93 mm setting (12.22 kA) and right (b) is 102 mm setting (13.40 kA).

PAINT BUMP-MAGNET TEST

Balance Adjustment of the Exciting Current

Two horizontal paint-bump magnets are located on each of upstream and downstream of the shift-bump magnets in the straight section of the injection area in the RCS. These total eight bump-magnets produce the closed bump orbit for the horizontal painting injection. Four paint bump-magnets are connected to their own power supplies, separately. The excitation current of each magnet was adjusted using the COD measurement results.

The COD due to the imbalance of the exciting current for the paint bump-magnets was measured using the flattop current of a trapezoidal pattern [13]. Fig. 4 shows the measurement results of the COD that are before and after the adjustment. The COD became less than 1 mm.

Confirmation of Phase Space Coordinates

The phase space coordinate of the transverse direction was measured using the two MWPMs. MWPM#3 is installed between the first and the second shift bump-magnet, and MWPM#5 is installed between the third and the fourth shift bump-magnet. The painting injection trajectory was generated by using a flat top current of the trapezoid waveform with the paint-bump magnet [13].

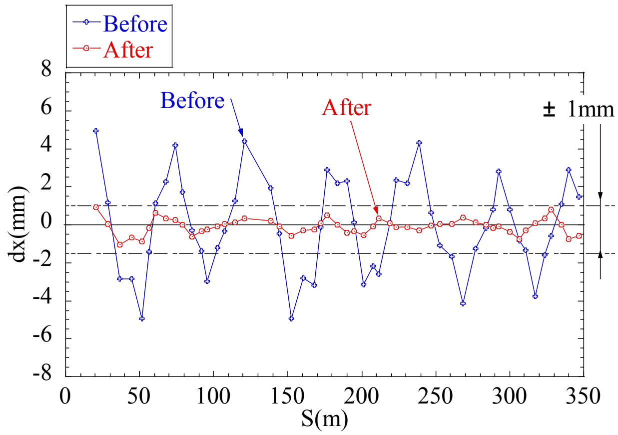


Figure 4: Measurement result of the circulating beam COD caused by the paint bump-magnets.

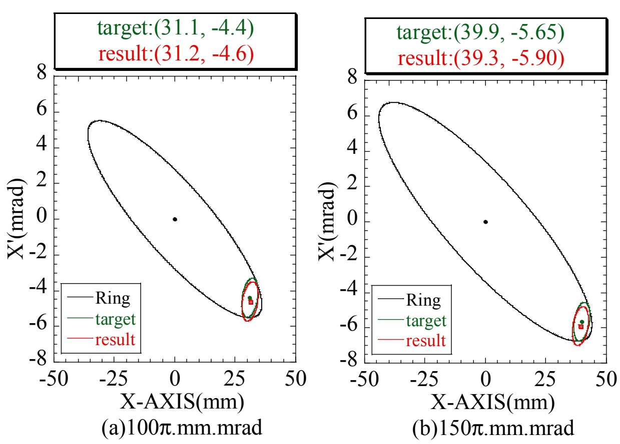


Figure 5: Measurement results of the phase space coordinates for the horizontal direction with beam emittance of 100 π.mm.mrad (a) and 150 π.mm.mrad (b).

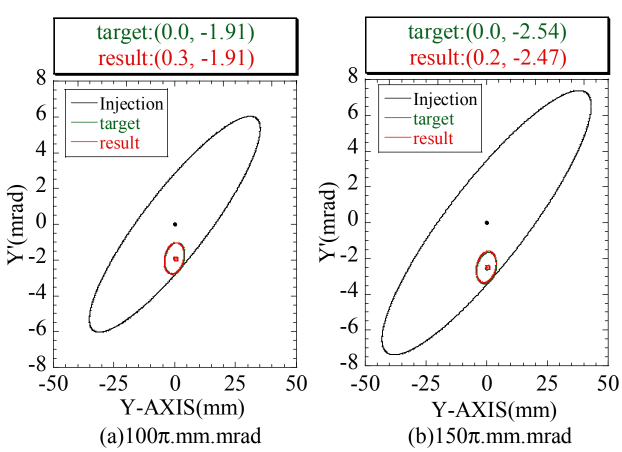


Figure 6: Measurement results of the phase space coordinates for the vertical direction with beam emittance of 100 π.mm.mrad (a) and 150 π.mm.mrad (b).

Measurement results of the horizontal and the vertical phase space coordinates are shown in Fig. 5 and 6, respectively. They contain both 100 π.mm.mrad and 150 π.mm.mrad beam emittance. As a result, the balance adjustment of each power supply was executed, and the preparation for the painting injection has been achieved.

SUMMARY

It has been confirmed that the magnetic gap of the horizontal shift bump-magnets were adjusted using the measurement result of the magnetic field and the COD due to the magnetic field distortion of the shift bump-magnets became less than 0.5 mm. Moreover, the balance adjustment of the excitation current in each power supply of the horizontal paint bump-magnets was executed with trapezoid waveform pattern. The COD due to the imbalance of the exciting current became less than 1 mm. The phase space coordinates of the horizontal and the vertical direction were measured, respectively. As the result, a good performance of the injection bump system of the RCS was confirmed. So the procedure for the painting injection has been completed.

All power supplies of the bump system are composed of the IGBT assemblies with a multiple-connection. For the painting injection, the decay waveform pattern during the injection time (500 μs) is produced by the power supplies of the horizontal paint bump-magnets and the vertical paint magnets. Each power supply has the ability to produce the flexible current pattern of the square root functions with a high frequency switching [13]. And, it aims at the high intensity beam generation of 0.6 MW with 181 MeV beam injection.

REFERENCES

[1] M. Kinsho, PAC09, TU6PFP065
[2] Y. Yamazaki, PAC09, MO2BCI03
[3] H. Hotchi, et al., Physical Review Special Topics Accelerators and Beams
[4] P.K.Saha, et al., Physical Review Special Topics Accelerators and Beams
[5] T. Takayanagi, et al., IEEE Transactions on Applied Supercond., vol.16, no.2, pp.1358-1361, June. 2006.
[6] T. Takayanagi, et al., IEEE Transactions on Applied Supercond., vol.16, no.2, pp.1366-1369, June. 2006.
[7] T. Takayanagi, et al., IEEE Transactions on Applied Supercond., vol.18, no.2, pp.306-309, June. 2008.
[8] T. Takayanagi, et al., IEEE Transactions on Applied Supercond., vol.18, no.2, pp.310-313, June. 2008.
[9] H.Harada and P.K.Saha have helped calculation.
[10] N.Hayashi, et al., Proceedings of EPAC08, Genoa, Italy, p.1128-1130
[11] S.Hiroki, et al., Proceedings of EPAC08, Genoa, Italy, p.1131-1133
[12] K. Sotou, et al., Proceedings of EPAC06, Edinburgh, Scotland, p.1163-1165
[13] T.Takayanagi, et al., PAC09, TU6RFP083