THE NEW HIGH FIELD INJECTION SEPTUM MAGNET SYSTEM FOR MAIN RING OF J-PARC

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Abstract

We have been improving the Main Ring (MR) for the beam power of 750 kW which is first goal of MR in J-PARC. The repetition period of the Fast eXtraction (FX) must be shorten to 1.3 sec from the current period of 2.48 sec for the increasing the beam power. We have been upgrading injection and FX magnets. We have exchanged an injection septum magnet which were located at the injection line from RCS to MR and its power supply in summer 2016. In this paper, we describe the final results of the measurement of the gap-field, leakage field. We also describe the result the beam study for evaluation of the effect by the leakage field of the new injection septum magnet.

NEW INJECTION SEPTUM MAGNET SYSTEM

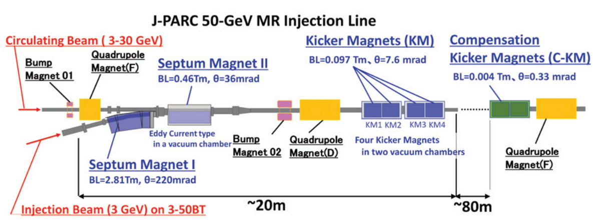

Figure 1: The schematic of the Injection Magnets group in MR in J-PARC.

The beam power in FX operation of J-PARC MR have achieved 470 kW in Mar. 2017. For upgrading to 750 kW, which is our first goal of the beam power, we need to increase beam intensity and extraction repetition. The present repetition period is 2.48 sec and our first goal is 1.3 sec. We have been upgrading the Injection and FX magnet systems for the high power beam. The schematic chart of the present Injection magnets in the MR are shown in Fig. 1. These magnets inject the 3 GeV-proton beam from the RCS[1] into the MR in 120 msec. There is an injection septum magnet, which the field of the previous one was 1.44 Tesla and integrated field (BL) was 2.81 T·m and the bending angle was 220 mrad for beam operation. We are calling it High-Field Septum Magnet(HF Inj-Septum). The replacement of the HF Inj-Septum is one of the project of the upgrading to high power beam. We have finished the replacement of the HF Inj-Septum into the MR in summer 2016. The detail of the motivation and its specification were described in [1]. The final figure of the HF Inj-Septum after installation of the new injection and circulating duct is shown in Fig. 2 [2].

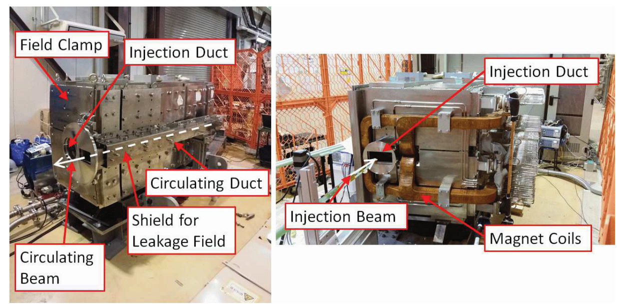

Figure 2: The photogtaphs of the new HF Inj-Septum which were assembled in early of Jlu 2016.

FINAL EVALUATION OF THE NEW HF INJ-SEPTUM

Measurement of Gap Field

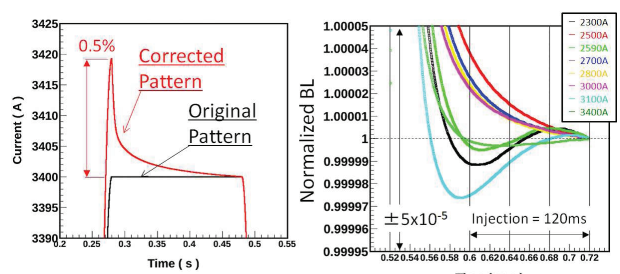

Figure 3: The original and corrected pattern(Left) and results of BL with the corrected patterns(Right).

The final measurement of the gap field and leakage field along the circulating line was conducted in end of July 2016. We used the search coils for measurement of gap field, and used hole sensor for measurement of leakage field. The BL were calculated by using waveforms of magnetic field which were measured along the tracks. One of the important is flatness of the BL at flat-top of the current pattern. The orignal current pattern waveform had perfect flatness at the flat-top, but the flatness of its BL was not perfect due to the induced field which is generated by eddy current on the surface of the injection duct. We made the corrected current patterns for cancelling of the effect of the eddy current. The Figure 3 shows the original and corrected current pattern waveform(left), and the BL with corrected patterns of

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[1] Rapid Cycling Synchrotron

[2] We produced a new inejcton duct and circulating duct in Mar. 2016 [1]

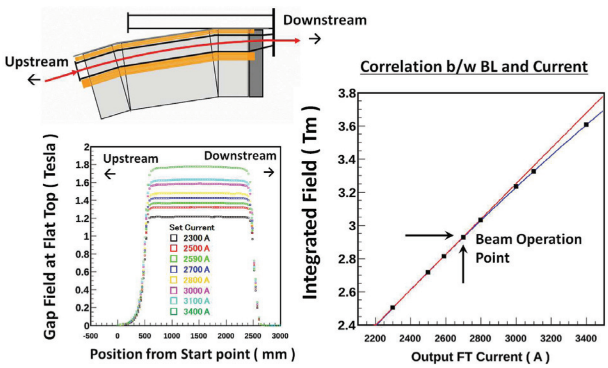

Figure 4: The Gap field(Left) and the correlation between the BL and the setting current(Right).

which the current were varied from 2,300 A to 3,400 A. The vertical axis is normalized with the BL value at the end of flat-top. All of flatness achieved below $\pm5\times10^{-5}$. The gap-field distribution along the track of center of beam with the corrected patterns and the correlation between the measured the BL and the setting current are shown in Fig. 4. In the left figure, the maximum magnetic field with 2,300 A and 3,400 A were 1.32 Tesla, 1.78 Tesla, respectively [3]. In the right figure, the red line means a straight line and a blue line means fitting line. We could see that the correlation has good linearity below the 2,800 A, by contrast we could see that the saturation of BL above 2,800 A. The design BL with the previous magnet was 2.81 T·m. The current for the beam operation was estimated 2,590 A which corresponds with 2.81 T·m. The bending angle was estimated 221 mrad.

Measurement of Leakage Field

We have constructed the triple magnetic shields for reducing the leakage field along the circulating beam line. The most inner shield is the circulating duct itself of which the material is pure-iron [1], and another two shields are also pure-iron which are covering the circulating duct(Fig. 5(Upper). We have measured the leakage field on three tracks of which the length were about 4.5 m along the circulating duct. The mapping and the BL with 2,700 A and 3,400 A are shown in Fig. 5, where the position of 0 mm was at the edge of downstream of the magnet. The magnetic field in the figures means the average value in 120 msec time window for beam injection, and the positive direction of the field was defined as down to up. In case of 2,700 A, the maximum leakage along the circulating duct on the center of track was about -0.5 Gauss. We could see the multi-pole field component by the dependence on the distance from the septum plate. We detected about 7 Gauss leakage on the center track in the upstream region from the edge of the circulating duct. The source of the large field is magnet coil at injection port which has no shield such as field clamp. These BL were calculated in the extent from -124 cm to +250 cm along each track. According to the results(Fig. 5(right), the BL in beam injection time window with 2,590 A and 3400 A

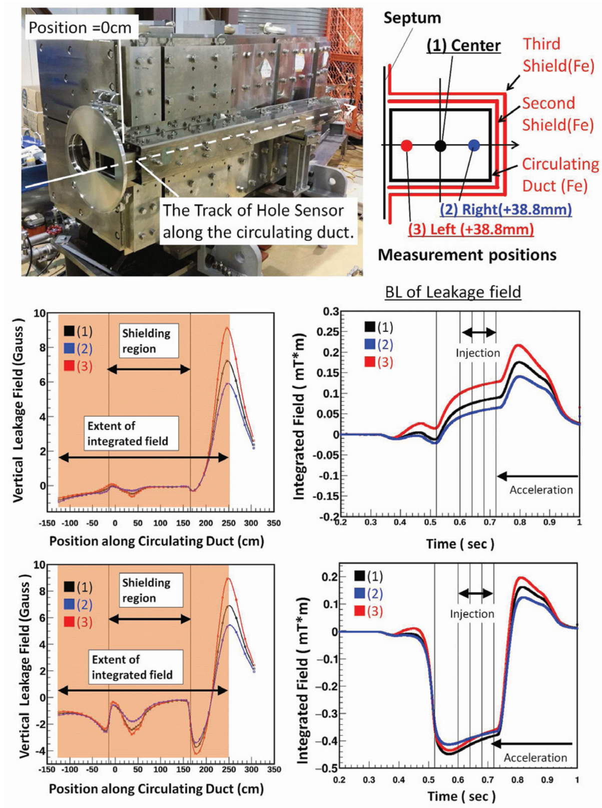

Figure 5: The vertical leakage field and its BL with 2590 A(Upper) and 3400 A(Lower), where the leakage field was calculated as average in beam injection time. We did not intergate the region above +250 cm, because a QM is located at this position in real beam line.

were 0.1 mT·m and 0.4 mT·m, respectively. On the other hand, the BL in beam acceleration time window were about 0.2 mT·m. These BL with the new magnet are smaller than that with the previous magnet From above, we could confirm that the leakage field was enough lower than that of the previous.

Consumption Power with 1 Hz Operation

We summarize the results of measurement of consumption power of the power supply and joule heat of the magnet coil under 1 Hz operation. The consumption power with 2,590 A and 3,400 A were 140 kW and 240 kW, respectively. The joule heat were 63 kW and 200 kW. We estimated the consumption power with 2,590 A under 2.48 sec repetition, which is present MR beam operation condition, as 56 kW, and it was about half of that with previous power supply. The consumption power with previous power supply under same condition was about 100 kW.

THE BEAM OPERATION WITH THE NEW HF INJ-SEPTUM

After the final measurement of the magnetic field, we replaced the original HF Inj-Septum and its power supply

[3] The maximum field of the previous one was 1.47 Tesla

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with new. Figure 6 and 7 show the new magnet and the power supply which were installed in MR.

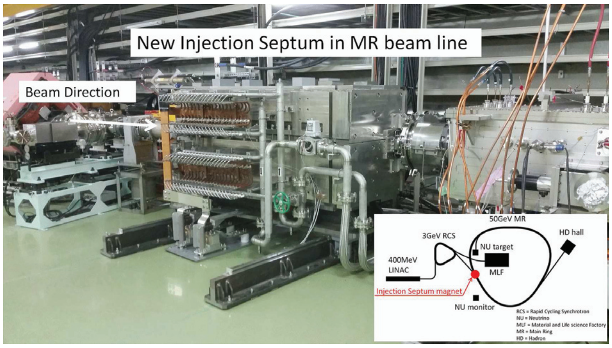

Figure 6: The new HF Inj-Septum which were installed in the beam line in MR in summer 2016.

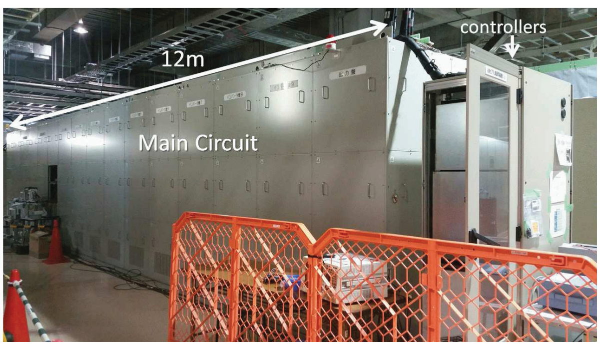

Figure 7: The new power supply of the HF Inj-Septum which were installed in power supply building in MR area.

The beam operation with the new HF Inj-Septum was started in Oct. 2016. The latest operation current which were optimized by injection beam tuning, in Apr. 2017, is 2,598 A. The one of the most important is the potential of the leakage field to impact the circulating beam. We have evaluated the impact by monitoring the position of the circulating beam during beam study of MR in Nov. 2016. The beam position was measured with a Beam Position Monitor(BPM) which are located near the HF Inj-Septum. In the beam study, we changed the time width of flat-top of the pattern current for HF Inj-Septum from 0.2 sec to 0.4 sec. The time variation of the beam position measured by the BPM is shown in Fig. 8. The HF Inj-Septum exicited until 550 msec in the left figure. We could see that the beam position was -0.2 mm during no leakage time region. On the other hand the beam position was 0 mm during flat-top of the HF Inj-Septum, furthermore the beam position changed about 0.4 mm during fall time. The kick angle(BL) corresponds with the 0.4 mm shift was estimated approximately 2.5 mT·m with SAD, so the kick angle consistent with the results of the measurement of leakage field. The kick angle is not serious problem for the present beam condition, but we plan to install the additional shield for reducing the leakage as much as possible. However, we must be careful the leakage field of a QM which is located at the upstream of HF Inj-Septum. Because about 200 Gauss leakage field from the QM also exists in same area. The rejection of the leakage field of the QM can not be permitted, because the beam condition are optimized including the leakage. So, we are making the design of the additional shield for rejecting only the leakage field from the magnet coil of HF Inj-Septum. We plan to produce the additional shield by summer 2017.

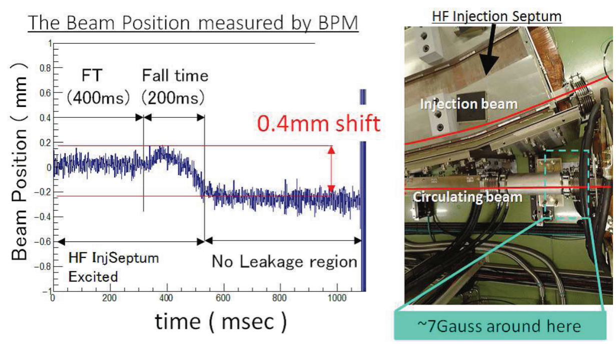

Figure 8: The shift of the beam position which was measured with BPM due to the leakage field of the injection septum.

SUMMARY

We have conducted final measurement of the magnetic field. The maximum magnetic field, BL with the new High-Field Injection Septum were larger than previous one. On the other hand, the current for beam operation was lower than previous one. Its leakage were lower than previous. The installation of the new High-Field Injection Septum was completed in summer 2016. At the beam study for evaluation of the effect of the leakage field, we could confirmed the small kick angle to the beam, but it is not serious problem. However since we understand the source of the leakage, we plan to install additional shield for reducing the leakage in summer 2017. Finally, the new High-Field Septum magnet system have been operating in very stable.

REFERENCES

[1] T. Shibata *et al.*, in *Proc. IPAC'16*, pp. 1338-1339.