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

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Abstract

We are improving the Main Ring (MR) for beam power of 750 kW which is the first goal of J-PARC. The repetition period of the Fast eXtraction(FX) must be short to 1.3 sec from the current period of 2.48 sec for the improvement of the beam power. It is necessary to exchange a high field injection septum magnet which will be installed at the injection line from RCS to MR and its power supply, because the current injection septum system can not be operated with 1.3 sec repetition. Since confirmed the large leakage field around current circulating beam line of the injection magnet, we must improve the shielding structure which make low leakage field. We started the development of the new injection septum magnet and its power supply in 2013. It can operate with 1 Hz repetition and the low leakage field which its order is 10^{-4} of the gap field. The new Injection septum magnet and the new power supply were constructed in 2014. We had many improvement of the magnet and power supply. We will install the new injection septum magnet system in this summer. In this presentation, we will report the detail of the results of its performances.

NEW INJECTION SEPTUM MAGNET SYSTEM

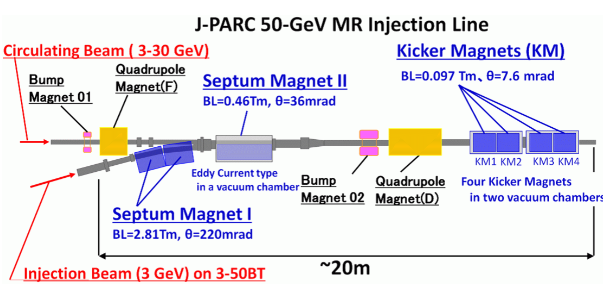

Figure 1: The schematic of the Injection Magnets group in MR.

The beam power for FX mode of J-PARC MR achieved 395 kW in Feb. 2016. For 750 kW in which 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 goal is 1.3 sec[1]. We are 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[2] into the MR in 120 msec. The first injection septum magnet of which the field is 1.44 Tesla(BL=2.81 T·m) bends the proton beam 220 mrad. We are calling it as High-Field Septum Magnet(HF Inj-Septum).

There are several reasons of necessity of a new HF Inj-Septum. The main reason is the present power supply(P.S.) can not operate with 1 Hz. The present P.S. outputs a pattern current of which the rise time is 0.25 sec, flat-top time is 0.2 sec, and the fall time is approximately 1 sec. The source of such a long fall time is that the output inverter unit has 1-IGBT and it does not control negative voltage. The joule heat at the coil will increase by 1 Hz operation, and the size of its hollow must be larger than present size, ϕ4.8 mm. The second reason is the beam duct needs more large aperture for the high power beam. The aperture of the present injection duct is 150 mm(H)×80 mm(V), but it is not enough size for high power beam emittance such as 80π. The third reason that he leakage field around downstream region of the beam duct is still high for high power beam, and we need to reduce more. The present HF Inj-Septum has two magnetic poles of which the length is 900 mm each other, and the leakage field exists at the opening space of them [1]. The current for normal operation is 2800 A, but since the maximum current is 2900 A the present P.S. can not operate for 3.3 GeV injection which is one of the future plan. The important requirements for the new are 1 Hz operation, large aperture, low leakage field, and high current for 3.3 GeV injection. We developed a new one which satisfies all of above requirements in 2014. Fig.2 shows the new magnet and components of the P.S. The input AC400 V is rectified to DC480 V by IGBT converter units and charges are stored in the capacitor units. The output inverter units have 4-IGBT units and it can output negative voltage to control its fall time. The rise, flat-top and fall time with the new P.S. are all 0.2 sec. The digital feedback system is used for high stability of its output current. To reduce its consumption power, the magnetic energy in the inductance of the magnet returns to the capacitors. The new P.S. bases on new power supply for the main magnets of J-PARC MR. We also designed a new magnet for resolving above problems. The new HF Inj-Septum is "sector" type septum [2]. We installed an end field clamp for covering the edge of coils at the exit of the injection duct for reducing the leakage field. The field clamp consists with laminated Si-steel sheets which are covered with SUS plates. The new aperture of the injection duct is 180 mm(H)×80 mm(V). We se-

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[1] We are calling it as 1 Hz operation.

[2] Rapid Cycling Synchrotron

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lected new hollow-conductors of which the hollow size are ϕ6.0 mm. We will install the new HF Inj-Septum into the MR in summer 2016.

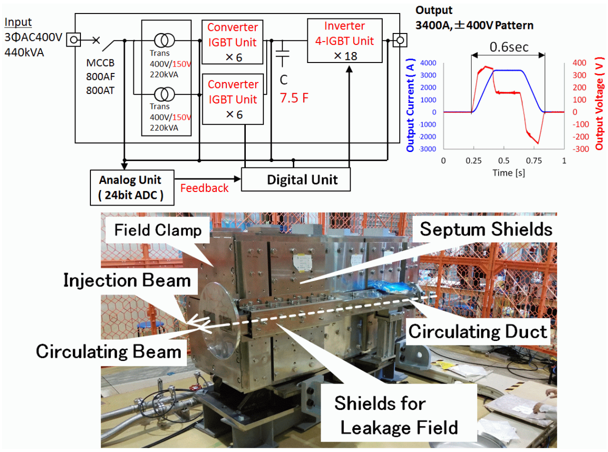

Figure 2: The diagram of the new power supply(Upper). The photograph of the new magnet(Lower).

EVALUATION OF THE NEW HF INJ-SEPTUM

The gap field must be stable and its BL must be flat at flat-top. The required reproducibility of the gap field and flatness of the BL are less than 10^{-4}. The leakage field must be less than 1 Gauss which is 10^{-4} of the gap field. To evaluate the new HF Inj-Septum, we measured the gap field and leakage field. We produced some search coils to measure the gap field. The search coil consists of 1,000 turn coils which winds on a ϕ4 cm diameter non-magnetic bobbin. The output voltage of the search coil is proportional to time difference of magnetic field. We also produced X-Y-Z scanner with three electric sliders for mapping of gap field. We used a gauss-meter(model 8030 of F.W.BELL) which uses hole sensors to measure the leakage field. The waveforms of field were recorded with a 16 bit ADC board (model SL1000 of YOKOGAWA-DENKI). Its sampling rate was 5 kSamples/sec, and the recorded time window was 1 sec.

Measurement of Gap Field and Flatness of BL

We measured the BL with 2800 A and 3400 A[3] output. The results of the mapping of gap field and its BL are shown in Fig.3, where the 0 mm position was defined as face of upward flange of the injection duct. We confirmed that the measured BL with 2800 A was large than 2.81 T·m, it was enough large for normal MR operation. The flatness, which we defined as the difference of BL between 120 msec which is timing difference of first and last beam bunches injection, were $2.5{\times}10^{-4}$ and $4.2{\times}10^{-4}$ with 2800 A and 3400 A, respectively. Both of them were large than 10^{-4} and they did not satisfy our requirements. The main source of problem was effect of magnetic field by eddy current which

[3] The current at flat-top.

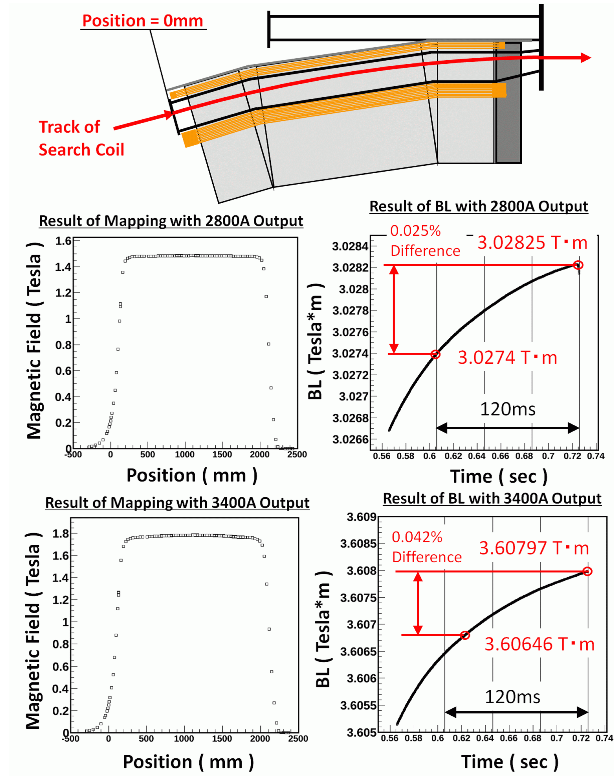

Figure 3: The results of the gap field(Left) and BL(Right).

were induced at the surface of the injection duct. We made the corrected current patterns for reduction of the effect of eddy current. Fig.4 shows the corrected current pattern for 3400 A and the results of BL with corrected patterns for 2700 A, 2800 A, 3100 A and 3400 A. The vertical axis was normalized with maximum value of BL in flat-top. All of results of the flatness were 10^{-5}.

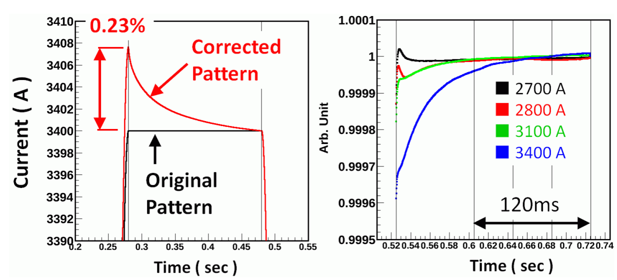

Figure 4: The normal and corrected pattern(Left) and results of BL with the corrected patterns(Right).

Measurement of Leakage Field

We installed some additional inner SUY shields of which their thickness were 5 mm to reduce leakage field in the circulating region. We measured the leakage field at the center of the duct along beam direction. Fig.5 shows the mapping and its BL of leakage field with 2800 A and 3400 A, where the 0 cm position was the edge of magnetic pole. The average means averaged value in 120 msec at flat-top and the peak means peak value in beam acceleration time during

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fall time. The -1.5 Gauss existed at 1.2 m far from the exit of the circulating duct with 3400 A. The leakage field increased at the outside of circulating duct, because of no shield around there. We confirmed that the leakage field with 2800 A was less than 1 Gauss in the circulating duct and it was enough lower than our requirement. The BL with 2800 A was ~1 Gauss·m and it is also less than that of present magnet. The BL with 3400 A in beam injection time was ~4 Gauss·m, it was same as present.

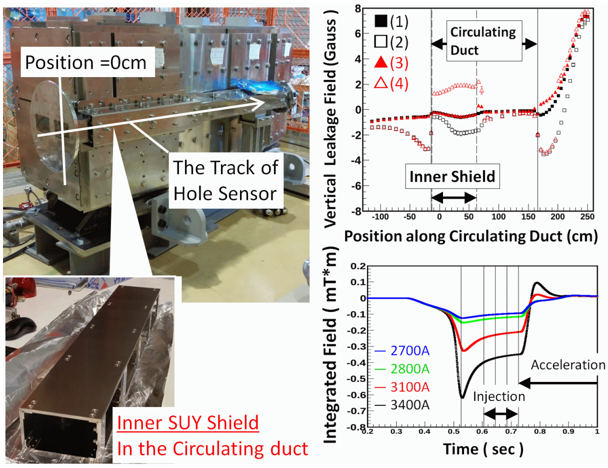

Figure 5: The leakage field with 2800 A and 3400 A(Right upper), where(1)Average in injection time with 2800 A (2)Average with 3400 A (3)Peak in Acceleration time with 2800 A (4)Peak with 3400 , The BL with 2700 A,2800 A,3100 A,3400 A(Right Lower).

The serious vacuum leak at the welding position which were connected the flange and injection duct was happened in Aug. 2015. The main source of the problem could be presumed the structural defect of the edge of the injection duct. We had to redesign a new injection duct to solve its defect. We also decided to redesign a new circulating duct of which the material was SUY. Because the inner SUY shield was very effective, and we wanted to unify the inner shield and circulating duct. The production of the new injection and circulating ducts were completed in Mar. 2016. We have plan to measure the leakage field and BL again with the new ducts.

Reproducibility of Current and Gap Field

We will describe the reproducibility of the gap field and current. We used output signal of a DCCT, which is used for feedback system, in the output unit of P.S. to measure the current. The output signal of DCCT were converted to current difference by 20-bit AD and DA converters and feedback controller. The current difference means the difference between setting and measurement current. We kept the operation several hours with 0.5 Hz repetition for monitoring its time variation. Only gap field had obvious variation because of thermal expansion of search coil, and we used events only after stabilization for evaluation of reproducibility. The definition of reproducibility is ratio of the r.m.s. and average. The setting output current were 2700 A,2800 A,3100 A,3400 A. The result of 3400 A output is shown in Fig.6. The reproducibility of the gap field and current were $\sim 4\times10^{-5}$ and $1 \sim 3\times10^{-6}$, respectively. We can see the reproducibility of the gap field was one order larger than that of current, because the accuracy of the measurement by the search coil is approximately 1×10^{-5}. The reproducibility of the gap field and current were less than 10^{-4} which we expected. The results of reproducibility and flatness are summarized in Table.1.

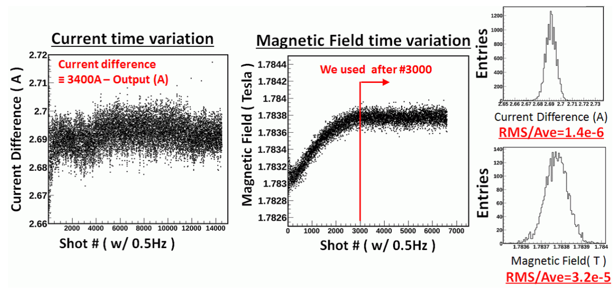

Figure 6: The reproducibility of current and gap field.

Table 1: The Results of Reproducibility of (1)Gap Field, (2)Output Current and (3)Flatness of BL

Set Current	(1)	(2)	(3)
2700 A	3.8×10^{-5}	2.2×10^{-6}	1×10^{-5}
2800 A	3.7×10^{-5}	2.5×10^{-6}	1×10^{-5}
3100 A	3.4×10^{-5}	2.3×10^{-6}	1×10^{-5}
3400 A	3.8×10^{-5}	1.2×10^{-6}	$3\sim6\times10^{-5}$

The 1 Hz Operation and its Consumption Power

We operated with 1 Hz, which the output current were 2800 A and 3400 A, and measured the consumption power and joule heat at the magnet coil. The consumption power for 2800 A and 3400 A were 163 kW and 240 kW, respectively. The joule heat were 133 kW and 200 kW, respectively. The consumption power with 2800 A and 2.48 sec repetition can be estimated as 66 kW, and it is lower than present one which we estimated as 100 kW.

SUMMARY

We described about the new HF Inj-Septum and its performance. We confirmed that the reproducibility of field and current and the flatness of BL and leakage field satisfied our requirements, We could operated with 1 Hz and its consumption power was lower than present one. We will install in this summer.

REFERENCES

[1] K. Fan et al., in Proc. IPAC'10, pp. 295-297.

[2] K. Fan et al., in Proc. IPAC'14, pp. 2097-2099.

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