ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPTS030

THE NEW HIGH FIELD SEPTUM MAGNETS FOR UPGRADING OF FAST EXTRACTION IN MAIN RING OF J-PARC

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Abstract

The J-PARC Main Ring (MR) is currently working on improved beam power to 750 kW by shorting the beam operation cycle from 2.48 s to 1.3 s. We will complete the upgrade of the four high-field septum magnets (HF FX-Septa) which are used in the fast extraction in 2021. The present power supplies (PS) will be reused at that time. The new three HF FX-Septa were produced in 2015. In autumn of 2018, we conducted the first operation test of the one of the HF FX-Septa with the present PS. To begin with, we tested high repetition rate operation of which the minimum cycle was 1.16 s, and we had no trouble. Then, we measured the magnetic gap fields along the extraction lines and the leakage field along the circulating line. Regarding the magnetic gap field, it had good linearity with the output current, and the field integral satisfied the expected value. However, we found the discrepancy of 0.4% between the neutrino extraction and abort extraction. The leakage field and its field integral were small at the center of circulating line. However, the end fringe field was large. Furthermore, we found the asymmetric field along the transverse direction. In order to solve these issues, more precise approach is needed.

INTRODUCTION

Figure 1: The photographs of the new HF FX-Septa.

At J-PARC Main Ring (MR), we are working on improved proton beam power with energy of 30 GeV for the T2K experiment from present 500 kW to 750 kW. In order to realize the higher power, the cycle of beam operation must be shortened from present 2.48 s to 1.3 s [1]. Furthermore, it must be shortened to 1.16 s for 1.3 MW high power beam. The injection and Fast-eXtraction (FX) systems of MR is being upgraded for 1.3 MW [2–4]. The present FX system is used for extracting the beam to the neutrino facility (NU) or beam abort dump (ABT). It consists of five kicker magnets, two low-field septum magnets, and four High-Field Septum magnets (HF FX-Septa) of which their magnetic gap field are ~1 T [5]. We have a plan to replace the present HF FX-Septa with new magnets by the following reasons. First, the total length of the HF FX-Septa must be decreased due to 500 mm increase of the magnet length of a defocusing quadrupole at upstream of the HF FX-Septa [6]. Second, the extraction beam ducts of stainless steel must be changed to ceramics duct to suppress the eddy current which is induced on the surface of conductive duct by pulsed magnetic field. In such case, the thickness of the ceramics beam duct must be thick enough to keep its strength, thus the air gap must be expanded to keep physical aperture as same as present one. Third, we must increase the physical aperture and change the circulating beam duct of stainless steel to titanium duct to reduce the level of the radioactivation due to beam loss of high intensity beam halo. For these reasons, we decided to replace the HF FX-Septa with new magnets. The four HF FX-Septa are called SM30, SM31, SM32, SM33 from upstream [5], and the SM30, SM31 and SM32 will be replaced in 2021. The SM33 will not be replaced because the new SM33 is able to be constructed by utilization of the present SM33 and SM32 which will be removed in 2021. The length of magnetic core of the SM31 and SM32 were decreased significantly. However, since we need to keep their total field integral (BL) same as the present 6.55 T·m, the BL of each new septum except SM32 must to be larger than present one. Thus, their output current also must be higher than present one [1]. The present power supplies (PS) will be reused even for new the HF FX-Septa because their maximum rated current satisfies required high current. Installation of the new HF FX-Septa in MR will be completed in 2021. The three new HF FX-Septa were produced in 2015 (Fig. 1), and the specification and parameters for beam operation of the present and new HF FX-Septa are summarized in Tab. 1.

We focus on the new SM30 in this paper. The present and new SM30 are bipolar septum with one magnetic core which generate two magnetic field of opposite direction for the NU and ABT extraction, and a circulating line is located between

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[1] The output current of the new SM32 must be also higher than present one, however its BL is shorter than present one due to the length of magnetic core is 37 % shorter.

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Table 1: The specification and parameters for beam operation of the present and new HF FX-Septa. The physical aperture means inner size of the beam duct at the edge of magnetic core. CIR. means Circulating line.

		SM30		SM31		SM32	
		present	**new**	**present**	**new**	**present**	**new**
Physical aperture (H(mm)×V(mm))	NU	113×86	98×88	106×81	98×88	136×48	136×70
	ABT					136×68	
	CIR. upstream	60.5×106	62×106	70×106	100×106	110×110	110×110
	CIR. downstream	80.5×106	82×106	140×106	200×106	Φ144 mm	110×110
Magnetic field (T)		0.89	0.98	0.99	1.20	0.92	0.98
Field integral (T·m)		1.18	1.292	1.75	1.808	1.81	1.198
Output current (A)		2930	3600	2486	3300	2454	2950
Magnetic core length (m)		1.225	1.225	1.660	1.417	1.900	1.200

the two extraction lines (Fig.1). This paper describes the performance of the new SM30 based on the results of the operation test in 2018.

OPERATION TEST OF THE NEW SM30

In autumn of 2018, we conducted an operation test of the new SM30 to evaluate the high repetition rate operation and to measure the magnetic gap field (gap field) and leakage field. The PS for the present SM30 was used.

High Repetition Rate Operation

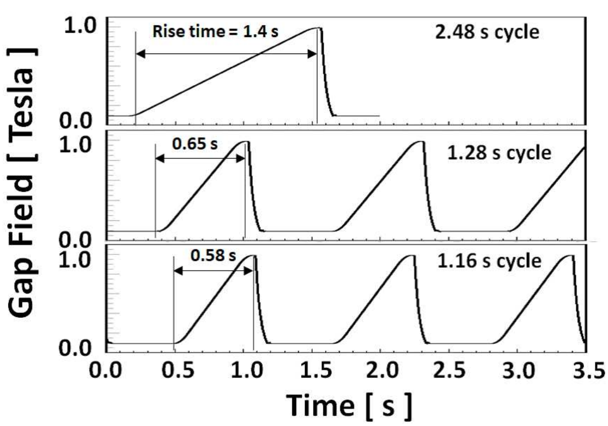

Figure 2: The waveforms of gap field at 2.48 s, 1.28 s and 1.16 s cycle.

The operation cycles which we tested were 2.48 s, 1.32 s, 1.28 s and 1.16 s. The current pattern had to be changed to fit each high repetition rate operation, then the rise time was 1.4 s, 0.7 s,0.65 s, and 0.58 s which is same as that of the main magnets in MR. The flat top current was varied from 500 A to 3,850 A. The waveforms of gap field which were observed in each cycle are shown in Fig. 2. We also measured the increase of temperature of cooling water in the magnet coils by using a radiation thermometry during the operations. Consequently, the temperature increased ~20 °C, which was acceptable level. It was concluded that there was no problem in the high repetition rate operations.

Measurement of Gap Field

We measured the gap field of the NU and ABT lines by using a hall sensor; it can be moved 1.8 m range along the beam direction on a rail which was mounted in the beam duct to measure the longitudinal distribution. The output current was measured by using a DCCT which is mounted in the PS.

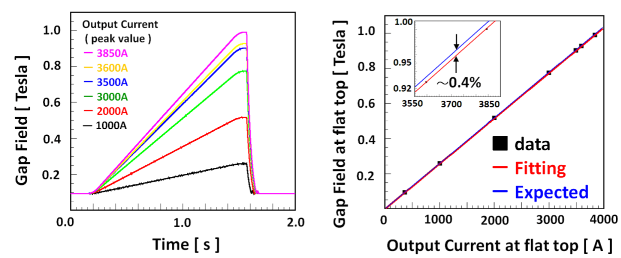

Figure 3: The linearity of the gap field in the NU line to the output current at flat top.

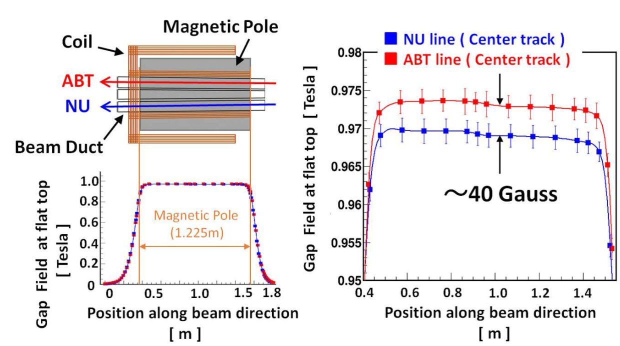

Figure 4: The gap field along the beam direction in the NU and ABT extraction. The error bar of each points is r.m.s. which is approximately 0.15 %.

At first, we confirmed a good linearity of the gap field to the output current on a fixed position in the NU line (Fig.3). On the other hand, the gap field was ~0.4% lower than expected value which was estimated by the air gap of 116.2 mm and the output current The longitudinal distributions of the gap field with the output current of 3,754 A along the beam direction in the NU and ABT line are shown in Fig. 4. We

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found a discrepancy of ~40 Gauss (0.4%) on the gap field between the NU line and that in the ABT line. The maximum gap field in the NU and ABT line was respectively 9,696 Gauss and 9,736 Gauss. At least, the air gap of both sides was almost same, which was 116.2±0.1mm of the NU side and 116.3±0.2 mm of the ABT side. Some candidates of the causes of the discrepancy are defect of the magnet coil and the leakage of the magnetic flux from the core. However, since it was also difficult to understand the gap field of the present SM30 without simulation, we started to study the magnetic field and magnetic flux by simulation to solve these problems in Apr. 2019.

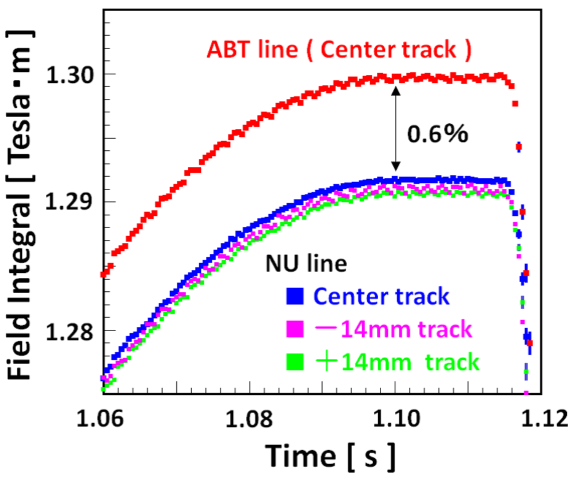

Figure 5: The time dependent BL of the gap field along the NU and ABT line.

Finally, the time dependent BL along the center tracks of the NU and ABT line were shown in Fig. 5. The BL along the NU line at flat top was 1.292 T·m with the output current of 3,754 A, which satisfied the expected BL (see Tab. 1). However, the discrepancy on the BL between the NU line and the ABT line was ~0.6%. On the other hand, since the BL along the center and ±14 mm tracks agreed within 0.1%, the discrepancy is not caused by the transverse nonuniformity.

Measurement of Leakage Field

We measured the longitudinal distribution of the leakage field and the time dependent BL along the circulating line by using the same hall sensor (Fig. 6). The level of the leakage field in the magnetic core region was negligible. On the other hand, the end fringe contribution of which the maximum value was 50 Gauss on the +9 mm track was still large. Thus, we need to reduce the end fringe field by using additional magnetic shields. The maximum BL along the center track and +9 mm track was respectively 3 Gauss·m and 8 Gauss·m, of which the bending angle corresponds to respectively 0.003 mrad and 0.01 mrad. We found the asymmetric structure along the transverse direction because the leakage field on the +9 mm track was twice higher than that on the -9 mm track. We must investigate the source and solve the problems.

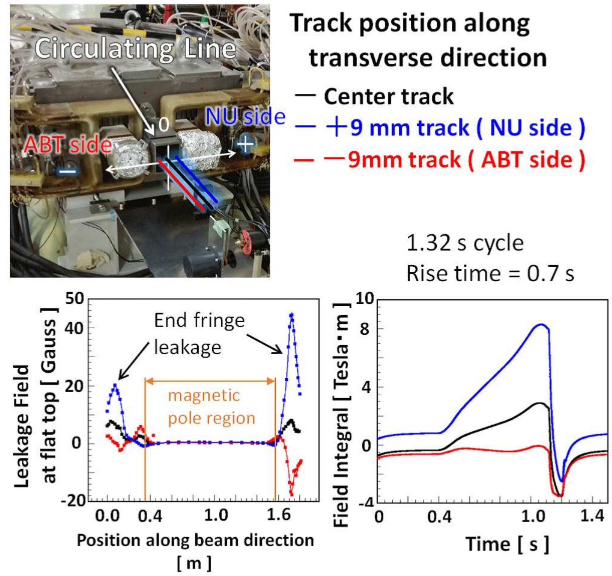

Figure 6: The definition of the tracks for leakage field measurement (Top). The longitudinal distribution along the circulating line (Left). The time dependent BL (Right).

SUMMARY

We are working on increasing the beam power for FX to 750 kW in J-PARC MR. We have a plan to replace the HF FX-Septa in 2021. The operation test of the one of the new HF FX-Septa, SM30, was conducted in 2018. The high repetition rate operation did not have any problem. The level of the gap field satisfied our expectation, however we found an asymmetric structure between the NU and ABT line. The level of the leakage field in the magnetic core region was negligible. However, the end fringe field was still large. Thus, we need to reduce the end fringe field, and to solve the asymmetric structure of gap field and leakage field.

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