THE DEVELOPMENT OF A NEW LOW FIELD SEPTUM MAGNET SYSTEM FOR FAST EXTRACTION IN MAIN RING OF J-PARC

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Abstract

The J-PARC Main Ring (MR) is being upgraded to improve its beam power to the design goal of 750 kW. One important way is to reduce the repetition period from 2.48 sec to 1.3 sec so that the beam power can be nearly doubled. We need to improve the septum magnets for Fast eXtraction(FX). We are improving the magnets and their power supplies. The present magnets which is conventional type have problem in durability of septum coil by its vibration, and large leakage field. The new magnets are induced eddy current type. The induced eddy current type does not have septum coil, but has a thin plate. We expect that there is no problem in durability, we can construct the thin septum plate, the leakage field can be reduced. The output of the present power supply are pattern current of which flat top is 10 msec width, the new one is short pulse which of one is 10 μsec. The short pulse consists of 1st and 3rd higher harmonic. We can expect that the flatness and reproducibility of flat top current can be improved. The calorific power can be also reduced. This paper will report the field measurement results with the eddy septum magnet systems.

NEW LOW FIELD SEPTUM MAGNET FOR FAST EXTRACTION

For 750 kW in which our first goal of beam power of the MR, we need to increase beam intensity and extraction repetition [1]. The present repetition period is 2.48 sec and our goal is 1.3 sec[2]. We are upgrading the FX magnets for the high power beam. The schematic of the present FX magnets in the MR are shown in Fig.1. The FX magnets are using for sending the proton beam to the neutrino or beam abort line. The FX magnets consist of 5 Kicker magnets(FX-Kickers), 2 Low-Field Septum magnets(LF FX-Septa), 4 High-Field Septum magnets(HF FX-Septa), and 1 Abort DC Quadrupole magnet. In the case of FX-Kickers, we are developing and improving the power supply for 1 Hz operation. We had installed one power supply which we improved for 1 Hz operation, and we are using for normal operation of the MR. There is necessary to upgrade all of Septa and its power supplies(P.S). In the case of the HF FX-Septa, the three Septa also must be exchanged because of changing the size of the upstream Quadrupole magnet for high power beam [1]. We also changed the material of the beam ducts for neutrino and beam abort lines from SUS to ceramics for reducing the joule heat by high eddy current. These magnets were produced in 2015. We are discussing the improvement of P.S. for shortening the fall time for 1 Hz operation. The HF FX-Septa will be installed in the MR after 2018.

In the case of the two LF FX-Septa, we must also exchanged them. There are several reasons for exchanging to new. The present LF FX-Septa are conventional type and we are using hollow conductors as magnet coils, but we afraid of the damage of the insulators on the coils by their vibrations. We need large aperture for reducing the radioactivation by beam loss of beam halo which can be large size due to high intensity beam in future. The leakage field in the present circulating line is 10^{-3} of the gap field, but we need to reduce to 10^{-4}. Fig.2 shows the new LF FX-Septum. The new LF FX-Septum is induced eddy current type which can cancel the leakage field by only induced field by eddy current on the septum plates. This type does not have septum coils, but has only thin septum plates for cancelling the leakage field, and we can solve the problem of durability of insulation of the coils. We designed the 6 mm thick oxygen-free copper plates and 0.5 mm thick SUY plate for septum plate which we can expect to reduce the leakage field less than 10^{-4}. The LF FX-Septum has two magnetic poles which are located in the symmetry around circulating line. The two gap fields are opposite direction, and the center of circulating line can be cancelled by the opposite leakage field perfectly. We use also oxygen-free copper plate for the return coils instead of the hollow conductors. We expanded the aperture of gap from 80 mm(H)×71 mm(V) of the present size to 140 mm(H)×80 mm(V). The short pulse current is needed for the induced eddy current type, but the present P.S. can not make short pulse because it makes only pattern current of which the total width is approximately 1.5 sec. Then, we also need to develop the new pulse P.S. for the new LF FX-Septa. The new P.S. consists with two chargers which output pattern voltage, a dropper circuit which adjusts the charging voltage, a capacitor bank, a switch bank which uses thyristors, a surge absorber and two control units. The pulse current shape is composite wave of half-sin(fundamental) wave and 3rd harmonic sin-wave. Its time width is about 1 msec(10μsec at flat-top). The maximum output voltage and current are 6.6 kV×22 kA. The flatness at the flat-top which we required is less than 10^{-4}. The flatness can be adjusted by tuning of timing difference between fundamental and 3rd harmonic waves. The digital feedback system will be used for the high stability of output current. First new LF FX-Septum were constructed in 2014, and we are evaluating and adjusting. Two vacuum

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[1] Present max power is 395 kW in April 2016
[2] We are calling it as 1 Hz operation.

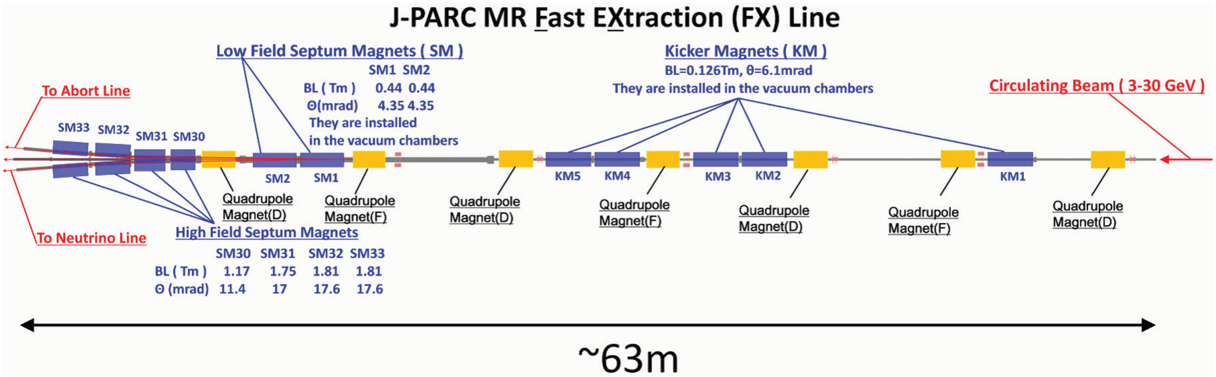

Figure 1: The schematic of the FX Magnets group in the MR.

chambers for housing of the magnets were also produced in 2014. Second LF FX-Septum were produced in Mar. 2016. We have plan to install the second magnet into the vacuum chamber.

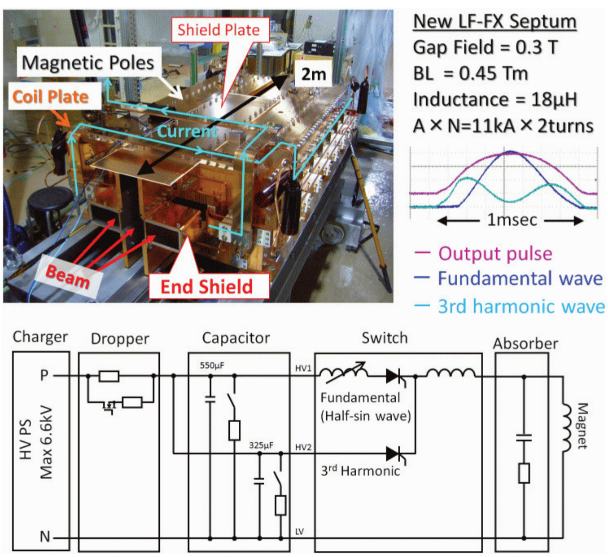

Figure 2: The photograph of magnet of the new LF FX-Septum(Upper). The diagram of the P.S. for the new LF FX-Septum(Lower).

THE EVALUATION OF THE NEW LF FX-SEPTUM SYSTEM

We measured the magnetic field and current for evaluation of the new LF FX-Septum. The new LF FX-Septum was not installed in the vacuum chamber, but be constructed in a clean booth. We used two search coils for measurement of gap and leakage field. The current was measured by CT installed to the return cables of the magnet. The output waveforms of the search coils and CT were recorded with oscilloscopes or ADC boards.

Measurement of the Leakage Field

We used the 8 bit oscilloscope (model WaveRunner 6040 of LeCroy) to record the waveforms. We measured the leakage field in the circulating line along beam direction, and the measured positions were center of circulating line and ±30 mm shifted from center to transverse direction. The charging and output voltage were 3 kV. Fig.3 shows the results of position dependence. We confirmed that 10 Gauss leakage field still existed around the outside of the end shields on the tracks of ±30 mm. Serious problem was that almost all positions had large leakage field than 0.3 Gauss. The required leakage field is less than 0.3 Gauss which is 10^{-4} of the gap field. We need to improve the shielding to reduce them.

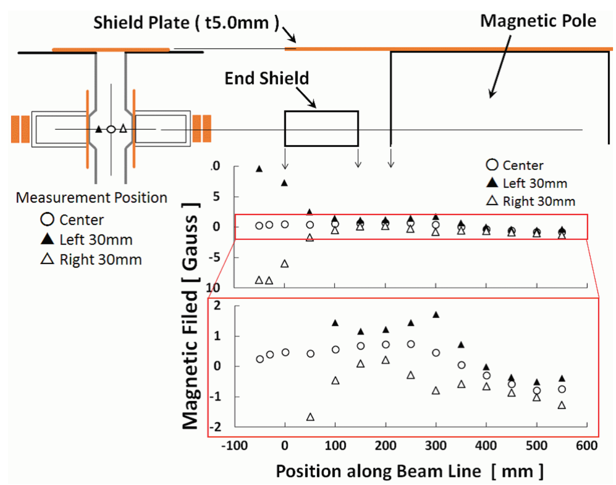

Figure 3: The measured leakage fields in the circulating line along beam direction.

Measurement of the Gap Field

We measured the gap field at the center of each gap along beam direction. We used the 12 bit oscilloscope (model HRO66Zi of LeCroy) to record the waveforms. The charging and output voltage was 3 kV. Fig.4 shows the results of measurement. The fluctuation of the field at the positions larger than 350 mm was ±20 Gauss which was 0.7% of its average, 2950 Gauss. We presume the sources of such large fluctuation are noise of the search coils and oscilloscope. We need to investigate the source and reduce the fluctuation.

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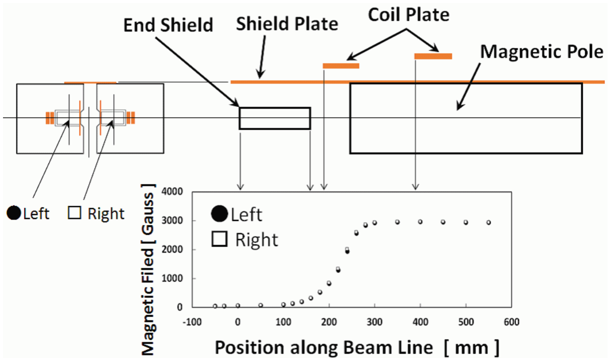

Figure 4: The measurement of the gap field along the center of beam line.

Reproducibility and Stability of Gap Field and Output Current

We measured the gap field and current for evaluation of the reproducibility of pulse by pulse and stability of long time variation. The output waveforms of the search coils were recorded with 16 bit ADC board of YOKOGAWA-DENKI. The reproducibility was defined as ratio of r.m.s. and average. We operated two hours with 0.3 Hz and 3kV charging. The results of reproducibility and stability are shown in Fig.5. The reproducibility of gap field and current were 1.3×10^{-4}, 2.6×10^{-4}, respectively. These results did not satisfy our requirement. The reason is low precision of the search coils and CT. In specially, the fluctuation of DC noise level at flat-top was approximately 0.3 Gauss which is 10^{-4} of gap field. We need to reduce the fluctuation of that or increase the S/N of signal. There is plan to product new search coil which output signal can be 10 times larger than present one. About stability, the both gap field and current decreased 3.4×10^{-4}、 5.3×10^{-4} in 1 hour. We guess that the variation came from temperature variation of P.S. It is necessary to investigate the source and reduce the variation for improvement of their stability.

Flatness of Gap Field at Flat-top

We measured flatness of gap field waveform at the flat-top. We used the 12 bit ADC board of YOKOGAWA-DENKI for recording the waveforms. The definition of flatness was Δ/B_{peak}, where B_{peak} means the peak value in flat-top region, and Δ means difference between B_{peak} and field at arbitrary time around flat-top. Fig.6 shows the results of measurement of flatness. In left figure, the waveform line means average of all of events and the error bars mean r.m.s. The flatness of 10 μsec time window was 1×10^{-4}, it satisfied our requirement. We expect that the flatness can be improved to 10^{-5} by adjusting the timing of the fundamental and 3rd harmonic waves.

Adjustment of Power Supply

We are adjusting the P.S., and we confirmed the reproducibility of the charging voltage to the capacitor was less than 5×10^{-5}. This result satisfied the required value of 10^{-4}, but we will improve more by adjusting the dropper circuit. We found a problem in follow-up of charging voltage. The rise speed of charging voltage was slower than that of setting pattern. We presume that the charging voltage at flat-top will be a little lower than setting value in 1 Hz operation and 6 kV charging. We will investigate and solve of the problem. We also installing the feedback system for improvement of long term stability of output current.

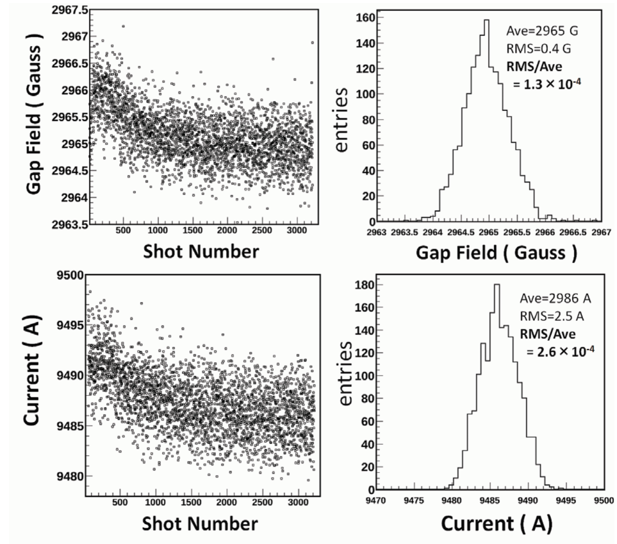

Figure 5: The time variation and reproducibility of gap field and output current.

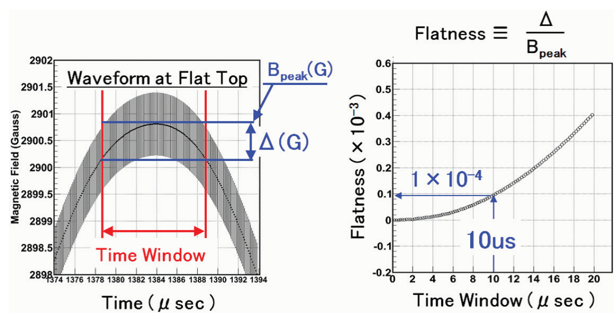

Figure 6: The flatness of the flat-top of gap field waveform.

SUMMARY

We are upgrading the FX magnets group for high power beam of the MR. We evaluated the new LF FX-Septum which is induced eddy current type. The reproducibility of charging voltage was less than 50 ppm. The flatness of 10 μsec at flat-top was 10^{-4}. We need to improve the precision of measurement of field and current, and shielding for reducing the leakage field. We will install the new LF FX-Septa in 2017.

REFERENCES

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