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 value of 750 kW in Fast eXtraction (FX). 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 have been improving the injection and FX magnets and their power supply for the high-power beam. One of them, the Low-Field Septa, which are conventional type, have a problem in durability of septum coil by its vibration, and large leakage field is also problem. We have been developing new one and plan on replacing the present with the new in 2019. The new magnets are induced eddy current type. The induced eddy current type does not have septum coil, but has a thin plate. We can expect that there is no problem in durability and the leakage field can be reduced. The first new induced eddy current type Low-Field Septa and its power supply were constructed in 2014. In this paper, we describe the status of the development of the power supply and its performance.

NEW LOW FIELD SEPTUM MAGNET FOR FAST EXTRACTION

For our first goal of beam power of the MR in J-PARC, 750 kW for Fast eXtraction (FX), we need to increase its intensity and extraction repetition[1]. The present repetition period is 2.48 sec and our first goal is 1.3 sec. We have been upgrading almost all injection and FX magnet system for 750 kW [1]. The installation of a new high-field injection septum magnet system was finished in summer 2016 [2]. We plan on exchanging the present Low-Field Septa (LF-Septa) and its Power Supply (P.S.) for new one due to several reasons. The first thing is that the present LF FX-Septa are conventional type and we are using hollow conductors as magnet coils, but we afraid the damage of the insulators on the coils by their vibrations. The second is that we need large aperture for reducing the radioactivation by collision with beam halo which could be high intensity in future. Another thing is that the leakage field in the present circulating line is 10^{-3} of the gap field, but we need to reduce it below 10^{-4}. The new LF FX-Septa are induced eddy current type[2] which can cancel the leakage field by only induced field by eddy current on the surface of the septum plates in principle (Fig. 1). This feature of the eddy-septum is that it has no septum coil, but has thin septum plate for cancelling the leakage field, so, we can solve the problem of durability of insulation of the septum coils. We designed the septum plate which consists 6 mm thick oxygen-free copper plate, which is appropriate material because of low resistance and low gas emission, and 0.5 mm thick pure-iron plate. We are expecting to reduce the leakage field below 10^{-4} of the gap field. The LF FX-Septum has two magnetic poles which are located symmetric 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 designed return coil by using oxygen-free copper plate instead of hollow conductors. We expanded the aperture of gap space from 80 mm(H)×71 mm(V) of the present size to 140 mm(H)×80 mm(V). Anyway, the short pulse current must be supplied to the eddy-septum, but the present P.S. cannot make short pulse current because it makes only pattern current which is fixed the format, so, we also need to produce a new P.S. The new P.S. (Fig. 1) consists of the Chargers which output pattern voltage, a Dropper circuit which makes the output voltage stable preciously, a Capacitor bank, a Switch bank which uses thyristors, a surge absorber and two control units. The several Chargers can be operated by parallel connection for fast response. The Capacitor bank has two parallel capacitors of which the capacities are 550 uF and 325 uF, respectively. We can fire each line with different timing in Switch bank. Then the output pulse current shape of the P.S. is composite wave of fundamental (half-sin) wave and 3rd harmonic sin-wave. Its time width is about 1 msec (10μsec at flat-top), the maximum output is 6.6 kV×22 kA. The output is controlled by digital feedback system for high stability and reproducibility. First new LF FX-Septa and P.S. were constructed in 2014, and we have been evaluating and adjusting the P.S.

THE STATUS OF THE POWER SUPPLY

We describe the recent results and status of the P.S. as follows.

The Long-term Stability of Output Current

The requirement of long-term stability of output current is below 10^{-4} with digital feedback system. Before installation of the feedback system, we had seen 430 ppm drift in a few hours operation in Apr. 2016. A feedback system by using PXI and FPGA for keeping the long-term stability of output current were installed in Dec. 2016. PXI[3] is platform for development of measurement/control system which National Instruments developed. The aim of using PXI is recording the output current waveform [4] by using the high

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[1] The beam power achieved 470 kW for FX operation in Mar. 2017

[2] We call the magnet as eddy-septum.

[3] PXI stands for PCI eXtensions for Instrument

[4] The output current is detected with a Current Transfer (CT) which is located in the Switching bank.

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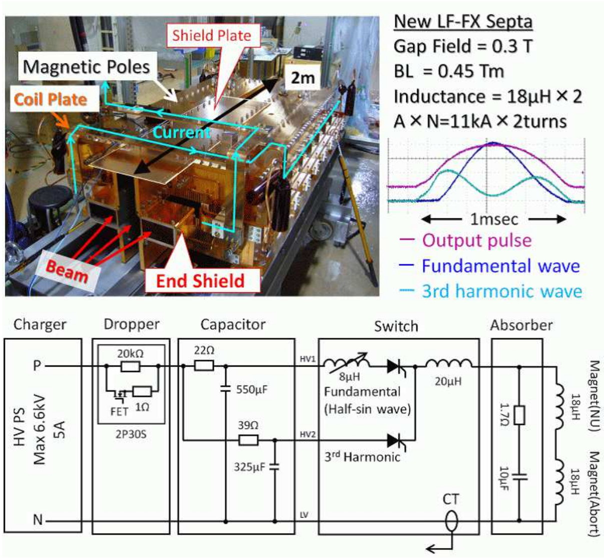

Figure 1: The photograph of the new LF-Septa (upper). The diagram of the new P.S. (lower).

resolution (20 bit) and high-speed (5 MS/sec sampling rate) ADC module [5]. The feedback procedure is shown in Fig. 2. The first step is calculation of the current residual between measured and expected. The expected current are estimated by setting voltage. The current residual is transformed to the residual of output voltage and be accumulated. Then a command value of corrected output voltage is calculated and be sent corrected reference voltage to the Charger. Figure 4 (left) shows the output current had 500 ppm drift during 2 hours without the feedback system, Fig. 4 (right) shows the no-drift in the output current with the feedback system.

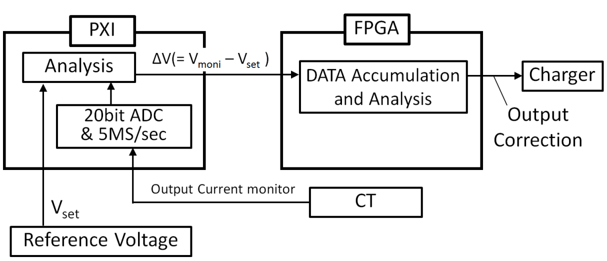

Figure 2: The scheme of the procedure of the feedback system with PXI+FPGA.

The Synchronized Noise with MR Beam

Before Dec. 2016, we have used a trigger signal, which did not synchronize with any triggers for MR beam operation, to operate the P.S. of the LF-Septum. In Dec. 2016, we have started using a trigger signal which synchronizes with MR beam operation. The P.S. needs two triggers for starting charging and discharging. One trigger signal was used for starting the charging and second trigger was synchronized with beam extraction. On starting the operation under the trigger condition during FX operation, we have found the periodic noise in the reference voltage signal (Fig. 3). As the results, the reproducibility of the output current pulse by pulse became to be worse by the noise. The fluctuation of the output current was 50 ppm (Pk-Pk) during Beam OFF which is shown in Fig. 4 (left). By contrast, we observed large fluctuation with 200 ppm (Pk-Pk) during Beam ON, which is shown in Fig. 4 (right).

[5] PXI-5922 is being used as ADC.

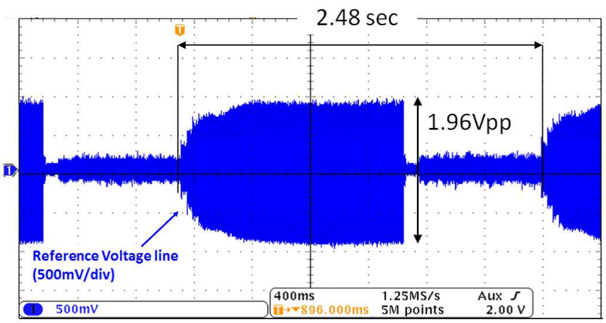

Figure 3: The periodic noise in the reference voltage signal.

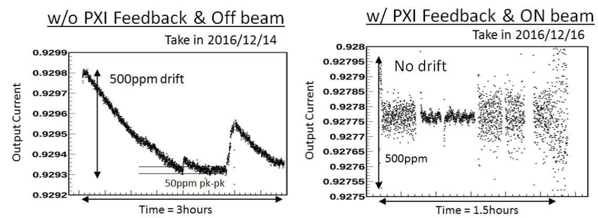

Figure 4: The time variation of the output current in Dec. 2016.

We had seen the same kinds of the periodic noise in reference voltage signal (V.ref) in May 2016. These noises were almost disappeared during turn off the MR beam. We could detect the noise in FX and SX operation, but those noise level were not same. Fig. 5 shows the V.ref signal and periodic noise on the V.ref signal. We are studying the feature and propagation route of the noise in order to reduce the fluctuation the output current. We need to improve the protection from the noise in future.

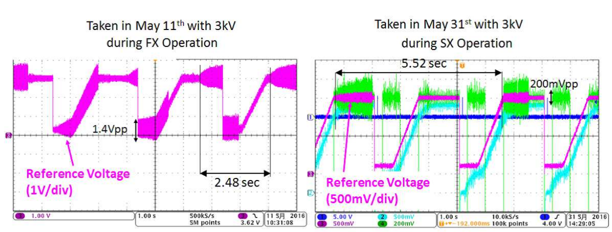

Figure 5: The periodic noise in the reference voltage signal which were taken in May 2016.

Proposal of a Sub-Charger

Our requirement of reproducibility of output current pulse by pulse is below 10^{-4}, and the requirement was satisfied with the Dropper circuit. The Dropper circuit receives the output high voltage, which is about 10% higher than setting voltage, from the Charger and drops to setting voltage with high accuracy by using FETs. There are 60 FETs (2P×30S) in the Dropper circuit. The Dropper circuit could achieve the reproducibility of output current 5×10^{-5} [1]. On the other hand, there were several problems regarding the Dropper circuit. One thing is that the control of the drain current in the FETs is very important, then we need to adjust the gate voltage of all of FETs, and need to take long time to finish. Second thing is that it is very difficult to detect the balance of current, so we could hardly detect the breakdown when the balance of current is broken. Once the Dropper broke down, we must replace and adjust all the FETs. In fact, we had several experiences of the breakdown of the FETs. We considered the risk of using the Dropper circuit in beam operation, then we discussed about the possibility of a new logic instead of the Dropper circuit. As the result, we have proposed to remove the Dropper circuit and construct a new scheme which consists of the Main-Charger and a Sub-Charger. The basic new scheme is shown in Fig. 6. The Main-Charger is present Charger, but it charges to the capacitors in the Capacitor bank directory. The Sub-Charger, which consists a dropper circuit which has only a few FETs, the switching circuit which makes input voltage to pattern form, and a HV transformer, also charges to the capacitors in parallel connection with the Main-Charger. The reproducibility will be guaranteed by the Sub-Charger. We need to modify the present Chargers and the controllers for construction the new logic with a Sub-Charger. We plan to complete to construct the new scheme in this fiscal year.

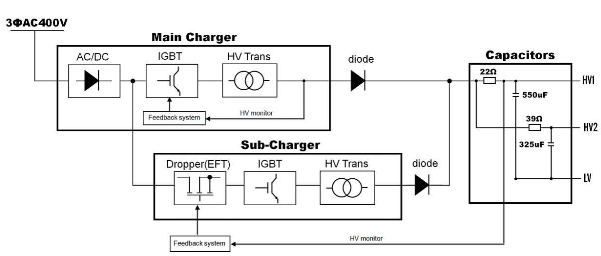

Figure 6: The illustration of idea of new scheme with a Sub-Charger.

Improvement of Measurement of Magnetic Field

The original search-coil to measure the magnetic field does not have enough S/N, because the fluctuation of the DC-like offset by electric noise corresponded about 0.3 Gauss. So, we produced a new search-coil of which the output voltage is ten-fold of original one. The fluctuation of the offset was about 0.06 Gauss by the new search-coil. The S/N corresponds 2×10^{-5} to 0.3 Tesla (Fig. 7).

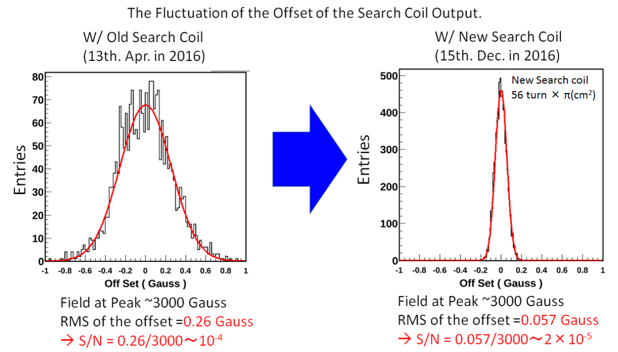

Figure 7: The fluctuation of the offset of measurement of the filed with old and new search-coil.

FUTURE PLAN

The important theme is improvement for the suppress the noise which syncrhonizes with MR beam, and production of the Sub-Charger by end of this fiscal year. In 2018, we plan to measure the output current and magnetic field with the Sub-Charger system for evaluation of the stability and reproducibility and flatness. Finally, we plan to install the new LF-Septa and their P.S. in summer 2019.

SUMMARY

The first goal of 30-GeV proton beam power of MR in J-PARC is 750 kW. We are conducting upgrade the injection and FX magnets system In this paper, we described the status of the new LF-Septa and its P.S., The new LF-Septa are induced eddy current type. The requirement for the reproducibility of the output current pulse by pulse was satisfied, and the long-term stability was also satisfied by installation of the feedback with PXI+FPGA. By contrast, we have found some problems regarding the P.S. One thing is that the Dropper circuit had been breakdown several times, and we had to take long time to recover. We proposed to produce a new Sub-Charger instead of Dropper circuit as the counter-measure to the problems. Second thing is that we have observed large fluctuation of output current by large periodic noise which synchronizes with MR beam, but the problem is under investigation. The new LF-Septa and its P.S. will be installed in 2019 summer.

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