POWER SUPPLIES FOR MAIN MAGNET OF J-PARC MAIN RING

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Abstract

A large magnetic field ripple of the order of 10^{-2} were observed at the first beam commissioning of J-PARC main ring in 2008, To eliminate the ripple, we had improved the magnet power supplies by reconstructing a band pass filter of 600 Hz and adopting an additional DCCT. We made differential circuit and symmetrical wiring for all magnets. On the other hand, acceleration period was reduced from 2.5 s to 1.4 s for increasing the beam power with feedforward control. We summarize the improvements of the magnet power supplies in this paper.

INTRODUCTION

Japan Proton Accelerator Complex (J-PARC) has been built with cooperation between High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Agency (JAEA). J-PARC Main Ring (MR) has been providing 30-GeV proton beam for Neutrino experimental facility of T2K (Tokai to Kamioka) experiment and Hadron experimental facility of several nuclear and particle physics programs. The beam power of 390 kW are provided for the T2K experiment [1] with some improvements of magnet power supplies.

When the first beam was injected to the MR in May 2008, the beam had oscillated by the magnetic field ripples owing to the current ripples of the power supplies. It was hard to accelerate the beam at that time. Then we have improved the power supplies, and re-wired between the power supply and magnets to supress the current ripples.

MAGNET POWER SUPPLY

The power supplies for the main magnets of the MR is shown in Table 1. 96 bending magnets are driven by 6 power supplies. The Number of the quadrupole magnets is 216 and they are separated into 11 families by their pole length and bore diameter. Each of families is driven by one power supply. All of the 72 sextupole magnets are the same pole length and bore diameter. They are separated into 3 families by 24 magnets. Each of the sextupole families is driven by one power supply.

The power supplies are located in three buildings named D1, D2 and D3. They receive AC 22kV at the yard which adjoins the buildings for power supply. The AC 22kV is stepped down to the respective voltages by the stepdown transformers at the each yards and the power supplies are received them.

Figure 1 shows a schematic view of the power supply. The incoming AC voltage is converted directly to the pattern current by the AC-DC converters. This method could remove a large capacitor for energy storage and a DC-DC converters. However the absence of the bank capacitor causes the voltage fluctuation on the incoming lines. The stored energy in the magnets is directly moved to the AC lines in proportion to the output pattern current. Then the voltage fluctuation limits the MR cycle time.

The MR cycle times are 2.48 s for T2K experiment and 5.52 s for Hadron experimental Facility. Each time of beam injection (0.14 s) and acceleration (1.4 s) is the same between the T2K experiment and the Hadron experiments. The beam extraction time is different. On the T2K experiment, the accelerated beam is extracted at the end of the acceleration time. Then the extraction time is 0 s. On the other hand, the accelerated beam is extracted during 2.93 s for the hadron experiments.

IMPROVEMENT OF THE POWER SUPPLY SYSTEM

After the first beam commissioning in 2008, we had improved the magnet power supply system to ensure the next step of the beam commissioning, which was beam acceleration. And then we have proceeded the improvements of the power supplies to increase the beam power and stability [2] step by step.

Table 1: Power Supplies of Main Magnets of the MR

Power supply	The number of power supply	Rated output current (A)	Rated output voltage (V)	Peak power (MW)
Bending magnet	6	1600	4200	6.7
Quadrupole magnet in the arc section	4	700	2100 ~ 4200	1.5 ~ 3.0
Quadrupole magnet in the straight section	7	600 ~ 900	400 ~ 800	0.3 ~ 0.7
Sextupole magnet	3	170 ~ 280	300 ~ 400	0.1

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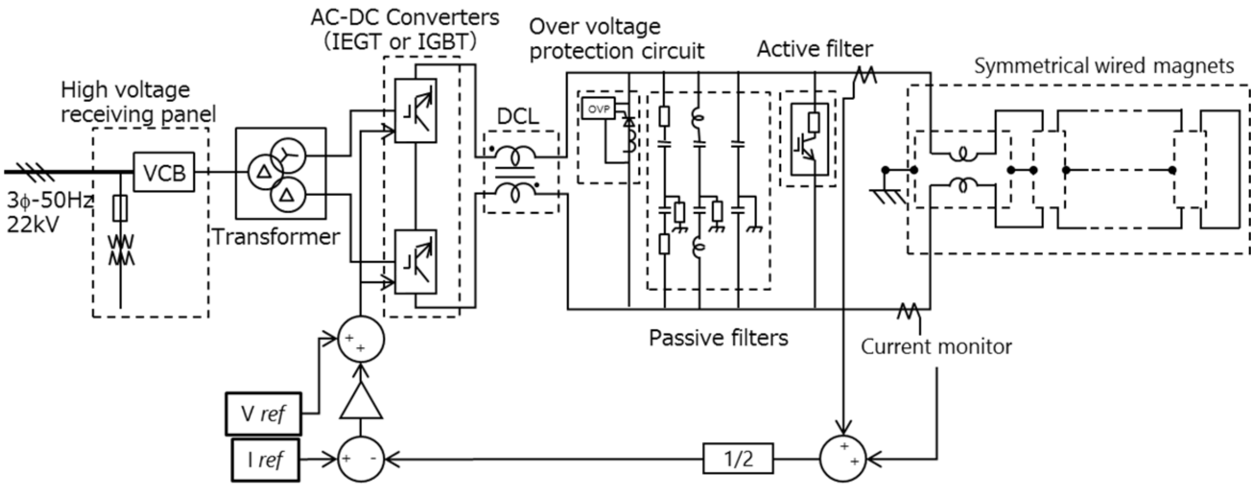

Figure 1: Schematic view of the present power supply. We have changed the passive filters, active filters and wiring. And we have added a current monitor to ignore the common mode current ripple, and a feedforward circuit with voltage reference (V_{ref}) to decrease a tracking error.

Re-Wiring

The same kind of the electro-magnets need the same current to generate the same magnetic field in the circular accelerator. Then the magnets and the power supply were wired in series. The bending magnets and their 6 power supplies were connected in series in the MR especially. Because of these wiring, the power supplies were unstable and magnetic field ripples were large.

We have re-wired between the magnets and the power supplies; a) one power supply drives a series of the magnets, b) positive output of the power supply which is connected to a series of the S-poles of the magnets and negative output of the power supply which is connected to a series of the N-poles are united at the end of the series of the magnets as shown in Figure 2.

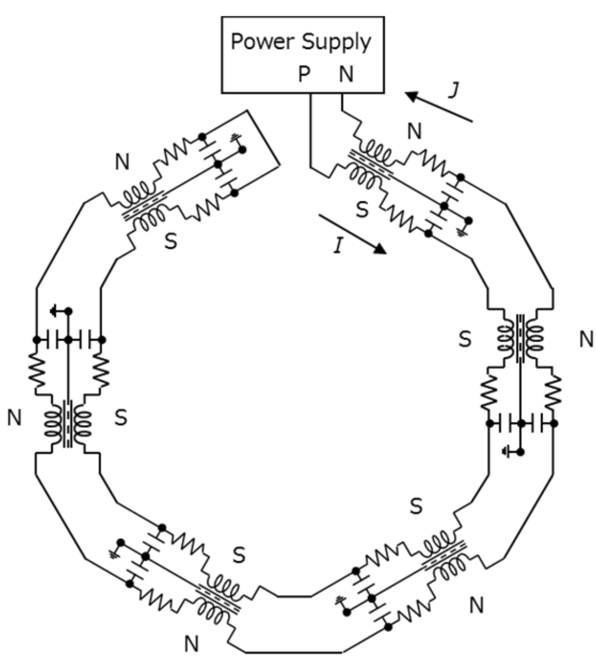

Figure 2: Symmetrical wiring.

Owing to this wiring, magnetic field ripples of common mode are suppressed and current ripples with normal mode and common mode are decoupled. Then the current deviation in time domain is improved remarkably in QFR power supply as shown in Figure 3(a). The current ripples are also suppressed as shown in Figure 3(b).

Additional Current Monitor

We used a DC current transducer (DCCT) for the current feedback control. In this case, the current ripples of normal mode and common mode could not be distinguished each other. Then the feedback gain was limited by the large current ripples.

One DCCT has been added to the opposite output terminal of the power supply and an average current of the two DCCTs are used for the current control. Because the average current is normal mode only, the current ripples become small and the feedback gain is enhanced.

Reconstruction of Passive Filters

Passive filters of the power supply is consist of a low pass filter, common mode filter and band pass filter for rectifier frequency of 600 Hz. At first the Q-value of the band pass filter was 4; capacitance was 500 μF and inductance was 0.14 mH. This Q-value was too small to exclude ripple enhancement due to the anti-resonance of the filter.

After Q-value have been increased up to 38; capacitance is 28 μF and inductance is 2.4 mH, the current ripple of 600 Hz becomes less than 1×10^{-5} which is 1/8 time smaller in the extraction region. The capacitance of the common mode filter is increased from 0.5 μF to 11 μF to suppress the common mode current.

Resistance Reduction of the Active Filter

The active filter was expected to suppress the anti-resonant between the inductance of the DC-coil (DCL) and the capacitance of the low pass filter. The active filter is consist of resistances and switching device. However

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the switching frequency was enough to work, the resistance was so large that the active filter could not play its role on the injection current and the first half of the acceleration region. Then the resistance have been decreased.

Feedforward Control with Reference Voltage

The reference voltage pattern have been inserted into the current control circuit for the feedforward control. Owing to the feedforward control, the tracking error is decreased. Then the acceleration time becomes 1.4 s.

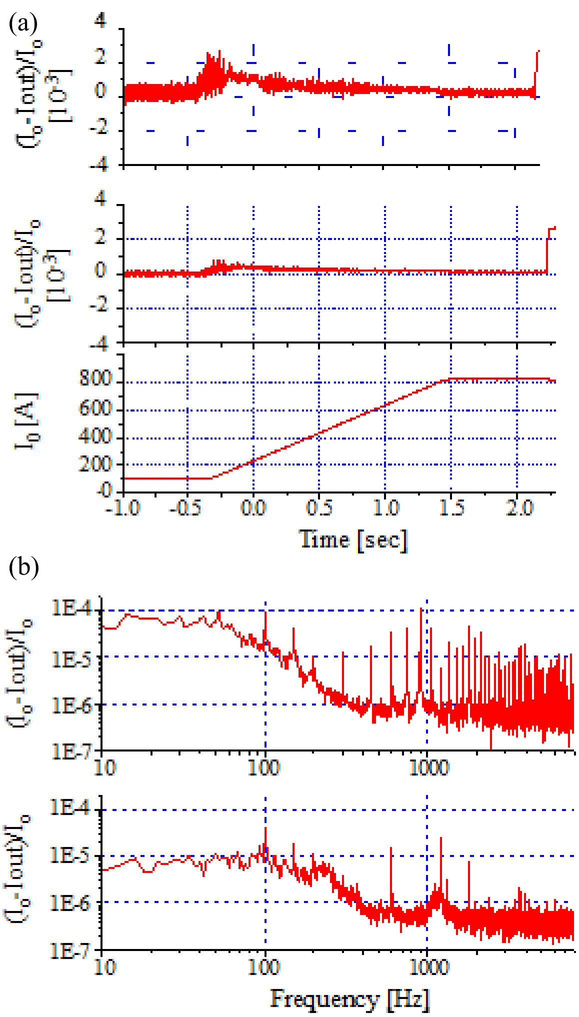

Figure 3: (a) Current deviation of the QFR power supply, which is a kind of quadrupole magnet in the straight section. Upper graph shows before re-wiring, middle graph shows after re-wiring and lower graph shows a reference current pattern. (b) Current ripples in frequency domain at the extraction time region.

CONCLUSION

Several improvements of the power supply have been done (see Fig. 4). The current ripples and tracking errors are supressed comparing with those of the first conditions as shown in Table 2. Most of the value in "before" column are the sum of normal mode and common mode due to the single DCCT measurement. On the other hand, * means the average of two DCCTs. The values in "after" column are the average of the DCCTs. The MR cycle time is also shorten and the beam power is increased.

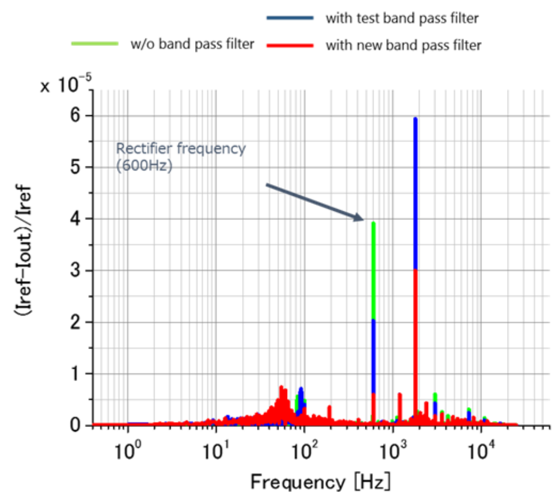

Figure 4: Current ripples with and without band pass filter. Green line shows a current ripple without band pass filter and blue line shows that with test band pass filter and red line shows that with new band pass filter.

Table 2: Current Deviation of the Power Supplies

Power supply	before	after	
	3 GeV DC	Injection	Extraction
BM1	3×10^{-3} (*)	1.4×10^{-3}	0.3×10^{-3}
BM2	13×10^{-3}	0.7×10^{-3}	0.1×10^{-3}
BM3	19×10^{-3}	1.2×10^{-3}	0.2×10^{-3}
BM4	14×10^{-3}	1.1×10^{-3}	0.2×10^{-3}
BM5	11×10^{-3}	1.1×10^{-3}	0.2×10^{-3}
BM6	12×10^{-3}	1.3×10^{-3}	0.3×10^{-3}
QDR	2×10^{-3}	0.4×10^{-3}	0.1×10^{-3}
QDS	5×10^{-3}	0.5×10^{-3}	0.1×10^{-3}
QDT	3×10^{-3}	0.4×10^{-3}	0.1×10^{-3}
QDN	6×10^{-3}	0.6×10^{-3}	0.2×10^{-3}
QDX	7×10^{-3}	1×10^{-3}	0.3×10^{-3}
QFR	2×10^{-3}	0.4×10^{-3}	0.1×10^{-3}
QFS	10×10^{-3}	0.5×10^{-3}	0.1×10^{-3}
QFT	4×10^{-3}	1×10^{-3}	0.2×10^{-3}
QFP	4×10^{-3}	1×10^{-3}	0.1×10^{-3}
QFN	9×10^{-3}	0.5×10^{-3}	0.1×10^{-3}
QFX	2×10^{-3} (*)	0.6×10^{-3}	0.1×10^{-3}
SDA	5×10^{-3}	2×10^{-3}	1×10^{-3}
SDB	5×10^{-3}	2×10^{-3}	0.5×10^{-3}
SFA	3×10^{-3}	2×10^{-3}	0.5×10^{-3}

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[2] T. Koseki *et al.*, "Challenges and Solutions for J-PARC Commissioning and early Operation", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper TUYRA02, pp. 1304-1308.