MAGNET POWER SUPPLY WITH SMALL RIPPLE USING SUB-CONVERTER AND SYMMETRICAL STRUCTURE

S. Nakamura#, S. Yamada, KEK, Ibaraki, Japan

Abstract

High precision tracking and small current ripple are necessary for a magnet power supply of a high power accelerator. A prototype power supply of 100 kW class is developed with an aim of small current ripple less than 10 ppm, which employs a combination of main and sub-converter with symmetrical structure. The main converter unit supplies pattern current by voltage feed forward control, while the sub unit by current feedback control. The symmetrical structure of the power supply is adopted to decouple normal mode ripple from common mode ripple. Each converter unit is modularized and surrounded by a Faraday cage for suppressing radiation of electrical noise and for ease of maintenance. Its performance is studied using a set of 24 units of sextupole magnets installed in the J-PARC Main Ring (MR).

INTRODUCTION

The J-PARC MR provides proton beam to two experimental facilities, which are neutrino facility with fast beam extraction and hadron beam facility with slow extraction. High precision power supply for main magnets is necessary to increase beam power for the facilities. A prototype power supply of 100kW class is developed and applied the current to sextupole magnets installed in the MR.

SPECIFICATION

Main parameters of the prototype power supply are presented in Table 1. The power supply provides a pattern current with a minimum current of 15 A and a maximum current of 220 A. Figure 1 shows a reference pattern. It is an aim of this power supply that a current ripple normalized by a reference current is less than 10^{-5} in time domain and 2×10^{-6} in frequency domain. A Tracking error normalized by the reference is less than 10^{-4} between flat bottom to flat top.

Table 1: Parameters of the Power Supply

Parameter	Value
Average power	72 kW
Maximum voltage	±480 Vp
Maximum current	220 Ap
Minimum current	15 A
Assumed load	0.41 H, 1.68 Ω

#shu.nakamura@j-parc.jp

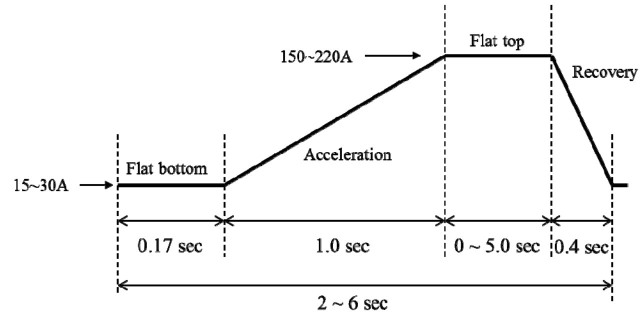

Figure 1: Reference pattern.

Main and Sub Converters

Figure 2 shows a schematic view of the prototype power supply. The power supply consists of two parts: One is a main power supply which provides is an H-bridge chopper using IGBT with carrier frequency of 18 kHz. The main power supply is controlled with a voltage feed forward using a reference voltage pattern. Thus it takes care of 90% of a load voltage.

The other is a sub-converter system which is a step-down chopper using MOS-FET with carrier frequency of 80 kHz. The sub-converter supress a current ripple and tracking error by current feedback control. Its carrier frequency is chosen as high as possible to reduce magnetic field ripples at the frequency component. The sub-converter unit applies unipolar output to protect the bank capacitors against an overcharge. Output from the main power supply is controlled to be less than reference current due to the unipolar output of the sub-converter.

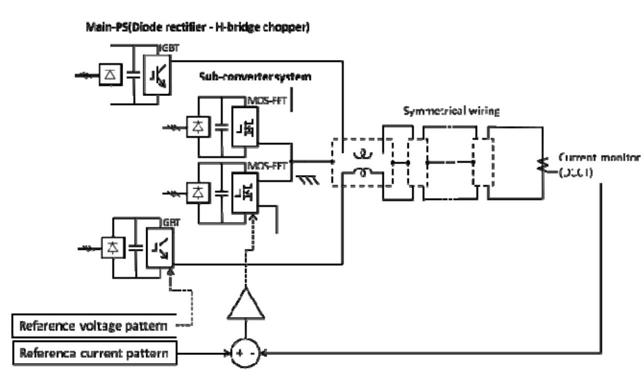

Figure 2: Schematic view of the prototype power supply.

Symmetrical Structure

Output current from the power supply has normal and common mode ripples. The common mode ripple flows between the main circuit and the ground via leakage capacitance. Output current is measured by a direct-

ISBN 978-3-95450-122-9

current current transformer (DCCT), which do not distinguish normal mode from common mode. Thus the feedback control couples the common mode with the normal mode ripple. In addition, unsymmetrical wiring of a main circuit merges the normal mode and common mode [1]. It is confirmed that symmetrically wired magnet system decouples those coupled modes, and common mode do not generate magnetic field [2]. However, the current ripple still has common mode due to the unsymmetrical circuit in magnet power supplies. In the prototype power supply, a power supply with positive output and that with negative output are connected in series and grounded at the midpoint as shown in Fig. 2, and symmetric noise filters are also applied to remove the common mode noise in addition to the normal mode.

Modularized and Faraday Cage Unit

Each chopper unit is modularized for ease of maintenance in order to reduce a down-time of accelerator operation by a device accident. When the device accident occurs in a modularized unit, the damaged unit is replaced with a spare unit and the accelerator operation can restart in a brief stop time. Cause of the failure of the damaged unit is studied by bench test independent of the operation.

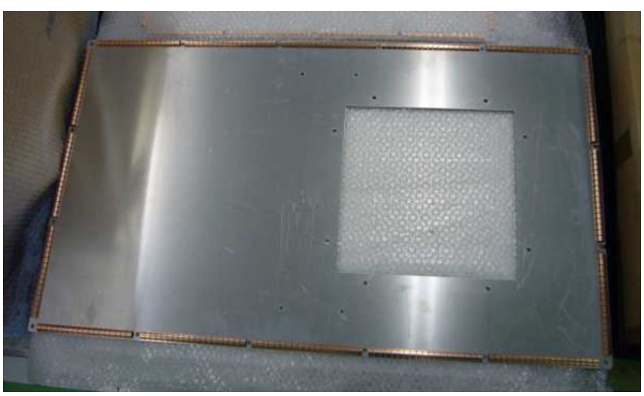

Figure 3: Picture of a contact finger of a panel.

Fast switching device makes an electromagnetic noise of high frequency which is a cause of an electromagnetic interference (EMI). When high power devices (e.g. magnet power supplies) have been driven, EMI has occurred in high precision low power devices (e.g. beam monitors) in the J-PARC MR. Thus the prototype power supply is designed to be a Faraday cage to prevent the EMI. Panels surrounding the power supply are contacted by a contact finger with a chassis of it as shown in Fig. 3.

MEASUREMENT

The performance of the prototype power supply is studied using a set of sextupole magnets installed in the J-PARC MR. The specified parameters of the sextupole magnet are presented in Table 2. The wiring of those magnets has been arranged symmetrically as shown in Fig. 2. Magnetic cores have been connected in series and grounded at the midpoint of the power supply. Figure 4 shows a current ripple and magnetic field ripple in frequency domain at the reference current of 200 A. Two colours indicate different measurements of frequency range. A DCCT is installed in a positive output of the power supply and measured the current ripple. The magnetic field is measured by a search-coil installed in minimum gap of magnetic poles.

Table 2: Parameters of Sextupole Magnets

Magnet name	Number of magnets	R, mΩ/magnet	L, mH/magnet
SDB	24	42.1	17.5

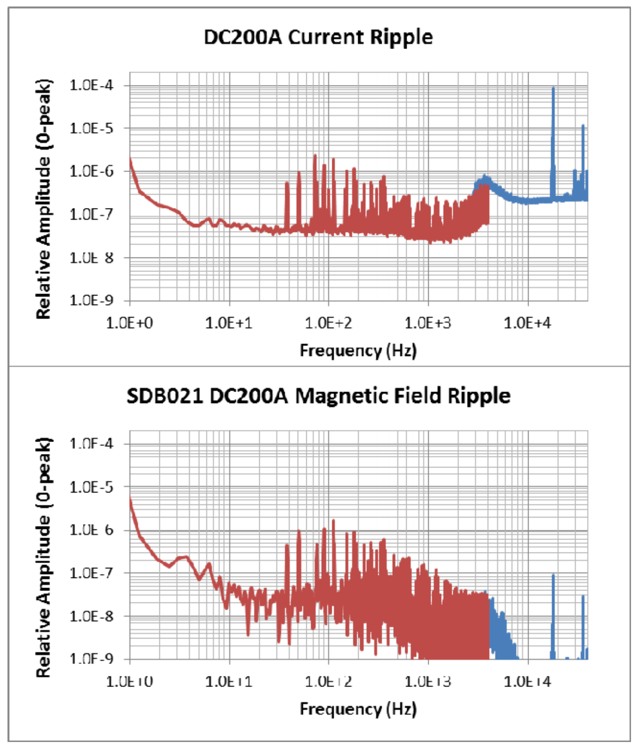

Figure 4: Current ripple and magnetic field ripple in frequency domain. Two colours indicate different measurements of frequency range.

Two frequency components of current ripple are larger than the order of 10^{-5}, which are carrier frequencies of IGBT (18 kHz) or MOS-FET (80 kHz) units. On the other hand, the same frequency components of magnetic field ripple are suppressed less than 10^{-6} by inductance of the sextupole magnets. Figure 5 shows a linear scale graph for taking notice of the frequency range less than 200 Hz. A frequency component of 73 Hz is a noise caused by the DCCT used for measurement, and that of 113 Hz is caused by the DCCT for feedback control. The latter is the largest current ripple and generates a magnetic field. When other frequency components of the current ripple are compared with that of the magnetic field, there are no differences. The DCCT installed in the positive output measures the current ripple of both normal and common modes. The power supply do not have common mode ripple because the common mode ripple does not generate magnetic fields in the magnets with symmetrical wiring.

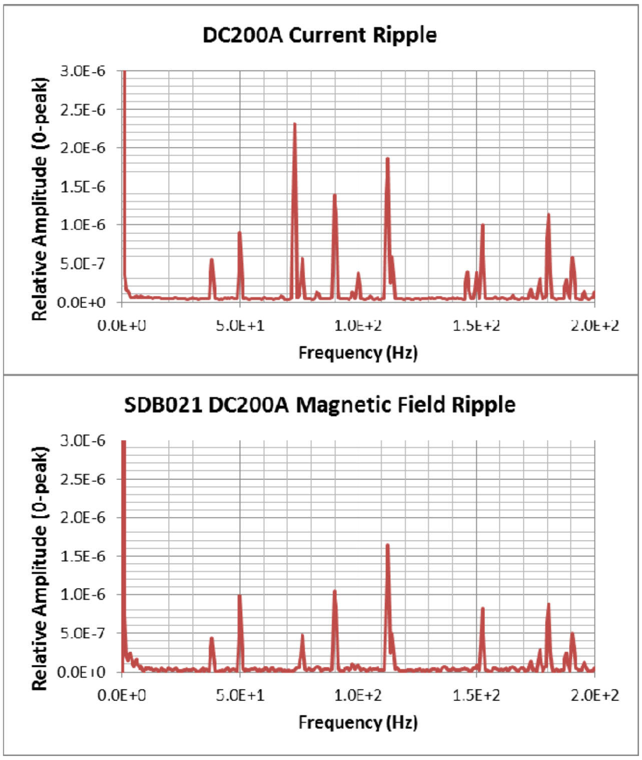

Figure 5: Current ripple and magnetic field ripple in frequency domain between 0 and 200 Hz. 73 Hz of current ripple is a noise caused by the DCCT for measurement. 113 Hz is caused by the DCCT for feedback control. (Linear scale)

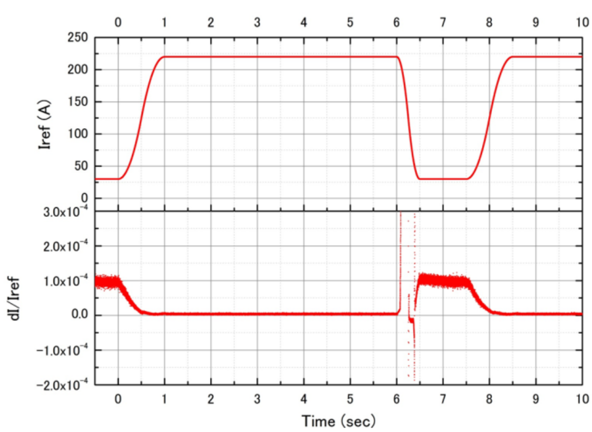

Figure 6: Output current and current deviation from the reference pattern. (Time domain)

Figure 6 shows an output current and current deviation from the reference pattern of time domain. There is a current ripple of 5×10^{-5} peak to peak and current offset of 10^{-4} at a flat bottom. The current ripple at flat top is an order of 10^{-5} peak to peak. Causes of the offset at the flat bottom seem to be; lack of an adjustment of the feedback control, or unbalance of the output current between the main power supply and sub-converter.

SUMMARY

A 100 kW class power supply is developed and studied using magnets installed in the J-PARC MR. The common mode current at the output of the power supply is suppressed by the symmetrical structure and wiring. The frequency components of current and magnetic field ripples are achieved to be less than 2×10^{-6} except carrier frequencies of converters. However the current ripple of time domain is 5×10^{-5} peak to peak due to the many frequency components. The tracking error should be improved with the parameter adjustment of the power supply.

REFERENCES

[1] K. Sato and H. Toki, "Synchrotron magnet power supply network with normal and common modes including noise filtering," Nucl. Instrum. Meth. A 565 (2006) 351-357.

[2] H. Kobayashi et al., "BEAM COMMISSIONING OF THE J-PARC MAIN RING," PAC'09, Vancouver, May 2009, WE1GRI02, p. 1823 (2009); http://www.JACoW.org

ISBN 978-3-95450-122-9