

DEVELOPMENT OF POWER SUPPLIES FOR FAST EXTRACTION SEPTUM MAGNETS OF J-PARC 50GEV SYNCHROTRON

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Abstract

Power supplies for the fast extraction septum magnets of Japan Proton Accelerator Research Complex (J-PARC) require not only a large current output (more than 6000A) but also low current ripple with a very small inductance of several mH. Additionally, these power supplies require low tracking error for any increasing current reference, in order to abort the accelerating beam when any machine trouble occurs within the accelerator. The developed power supplies adopted a chopper circuit as its power circuit because of its fast switching ability. Therefore, both large current and high accuracy can be achieved.

The evaluation test was carried out under two conditions. One is for the SM1&2 power supply, which has the largest current output and also has drives magnets with the smallest inductance. The other condition is for the SM32&33 power supply using actual septum magnets. Test results show that the current ripple is less than 1×10^{-4} p.p and the tracking error is less than $\pm 5 \times 10^{-4}$. Accordingly, the developed power supplies showed good results in the evaluation test.

INTRODUCTION

At J-PARC, a great amount of research using the highest intensity proton beam is planned. One of the important experiments is a neutrino experiment. For this experiment, a proton beam accelerated to the maximum energy of 50GeV is extracted to the Neutrino Facility by the fast extraction kicker magnets and the septum magnets. The fast extraction magnets have a unique function of aborting the accelerating beam when any machine trouble occurs within the accelerator[1]. Therefore, the septum magnets have to ramp up output current with an increment of beam energy. It is required not only low ripple when the beam is extracted, but also low tracking error for any increasing current reference.

The septum magnets need large current to build up the magnetic field because coils cannot be wound so many times. Then, the inductance of septum magnets is much smaller than any other main magnets. As a result, achievement of low ripple is quite difficult, compared with other conventional power supplies.

For J-PARC, four kinds of power supplies were developed and two evaluation tests were carried on. One of the tests is for the SM1&2 power supply, which has the largest current output and drives magnets with the smallest inductance. The other is for the SM32&33 power supply using actual septum magnets.

CONFIGURATION

Main circuit

Figure 1 shows the schematic diagram of the power supplies main circuit. Table 1 indicates the specifications of these power supplies. In order to comply with low ripple and low tracking error requirements, a chopper circuit was adopted as its power circuit because of its fast switching ability.

AC 6.6kV is converted to DC voltage by a step down transformer and a 12-pulse rectifier. By using the diode rectifiers, the main circuit can be minimized and simplified.

The output current is adjusted by multiplex chopper circuit. By connecting nine units of chopper for SM1&2 and six units for other power supplies in parallel, large current can be handled. In order to achieve low ripple, the phases of all nine or six units are shifted. The switching devices are CM600-24NF(1200V-600A) IGBTs, which are able to handle large current. By connecting four devices in parallel, the unit can conduct 1000A continuously. Figure 2 shows the outline of the SM1&2 power supply. Dimensions are 3600mm in width, 2200mm in depth, and 2800mm in height. The cubicle accommodates nine chopper units and a filter circuit.

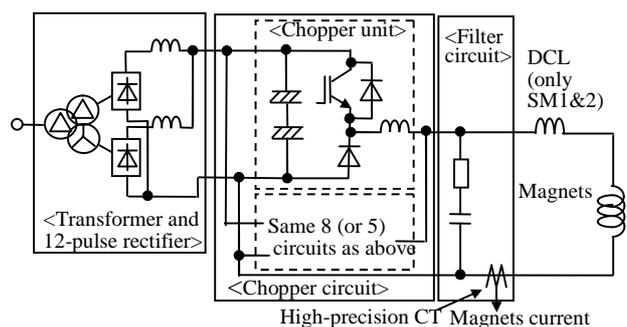


Figure 1: Schematic diagram of main circuit.

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Table 1. Specification of the Septum power supplies

Item	Specification			
	SM1&2	SM30	SM31	SM32&33
Output current (A) (maximum)	6480 (6800)	4480 (4700)	4095 (4300)	4480 (4700)
Output voltage	226	309	380	318
Output power (MW)	1.5	1.4	1.6	1.4
Configuration	12-pulse rectifier + Multiplex chopper			
Equivalent switching frequency (kHz)	22.5	15.0		
Magnet impedance	1.2mH - 31mΩ	2.9mH - 60mΩ	7.4mH - 75mΩ	13.2mH - 56mΩ
Current ripple rate	less than 1×10^{-4} P-P (at the top of current)			
Tracking error	less than $\pm 5 \times 10^{-4}$			
Stability	less than $\pm 5 \times 10^{-4}$			

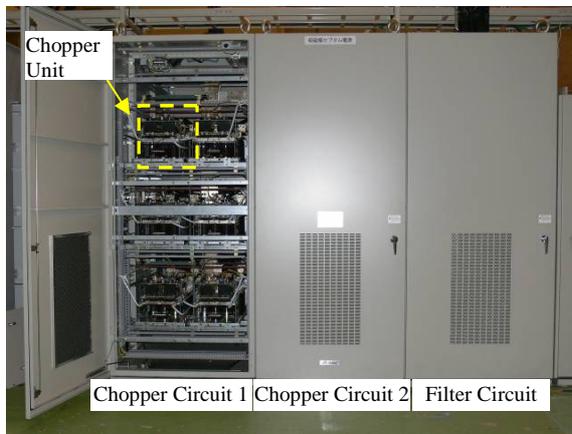


Figure 2: Main circuit panel of the SM1&2 power supply.

Controller

The controller consists of an analog and a digital circuit as shown in figure 3 in order to achieve both high accuracy and high stability.

The analog circuit calculates the deviation of the output current from the current reference and converts the amplified calculation result to digital signal. On the other hand, at the digital circuit, a feedback controller minimizes the above deviation. Also, the feed-forward controller calculates the necessary output voltage from the current reference directly and adds it to the output of the feedback control. These calculations are performed in a 32bit-DSP.

The current reference is generated with a general

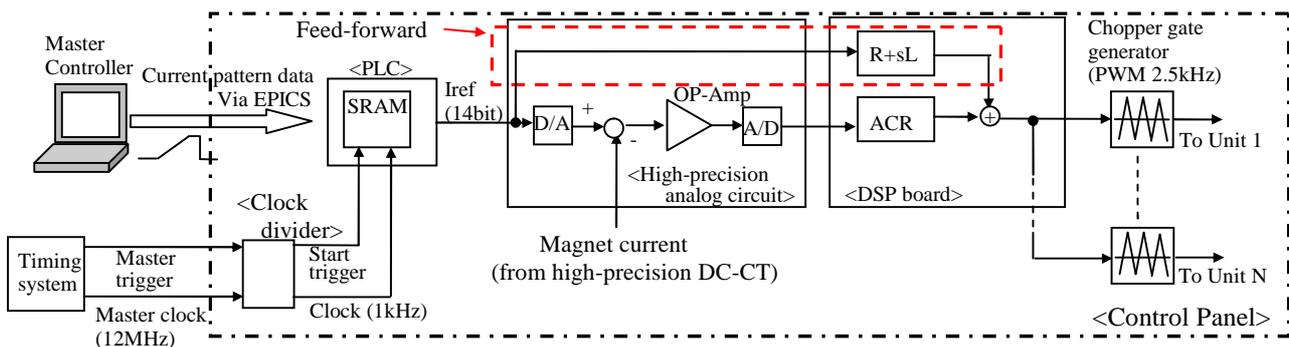


Figure 3: Control block diagram of the septum power supply

purpose Programmable Logic Controller (PLC). The current reference data is memorized into the PLC and is read out according to the 1kHz clock timing that is synchronized to the master 12MHz clock.

Filter Circuit

For a power supply feeding to a small inductance load like the septum power supply, it is necessary to include a low pass filter circuit in order to achieve small current ripple. Figure 4 shows the characteristic of the low pass filter with a capacitance of 150μF and a resistance of 0.89 ohm for SM1&2. The gains are -14.9dB at equivalent switching frequency of 22.5kHz and +1.23dB at resonance frequency, respectively.

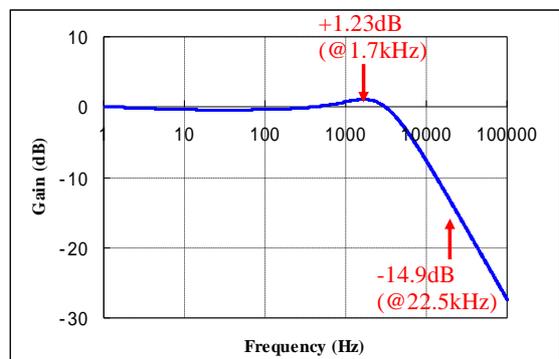


Figure 4: Characteristic of the low pass filter for SM1&2.

PERFORMANCE TEST

The performance test was carried out under the following two conditions.

(1) SM1&2

- The load impedance was 1.0mH-32mΩ, as same as the actual magnet.
- The output current was ramped up from 300A to 6480A during 1.9 sec.

(2) SM32&33

- The load was the actual magnet.
- The output current was ramped up from 300A to 4480A during 1.9 sec.

The performance test was carried out as shown in Figure5. The actual transformer and rectifier were used in order to achieve the same condition as in actual operation.

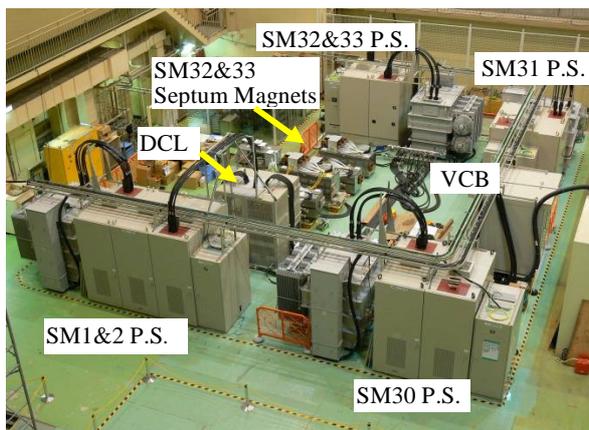


Figure 5: The whole view of evaluation test at KEK.

(1) SM1&2

Figure 6 indicates the results of the performance test for SM1&2. The waveform shows that the tracking error is less than $\pm 5 \times 10^{-4}$ from the base to the top. In ramping up output current, the tracking error oscillates at 1kHz because the current reference is read out at 1kHz. The current ripple was 0.6×10^{-4} P-P at the top. These results of tracking error and current ripple satisfy the specifications.

(2) SM32&33

The waveforms of the performance test are shown in Figure 7. The tracking error is less than $\pm 5 \times 10^{-4}$. The current ripple at 4480A was calculated from the load impedance at the DC voltage waveform spectrum and was normalized by the maximum current 4480A. The current ripple was less than 1×10^{-4} P-P at each frequency and satisfied especially, at the equivalent switching frequency of 15kHz. The filter circuit has shown enough damping characteristic.

SUMMARY

Power supplies for J-PARC have been developed and an evaluation test was carried out. By connecting large current handling choppers in parallel and shifting the phases of each unit, more than 6000A output current can be driven and low ripple can be accomplished.

The two kinds of evaluation tests were carried out at KEK. One is for SM1&2 power supply, which has the largest output current and drives magnets with the smallest inductance. A load impedance same as the actual magnet was used. The other evaluation test is for SM32&33 using actual septum magnets. Both evaluation test result, the current ripple is less than 1×10^{-4} P-P and the tracking error is less than $\pm 5 \times 10^{-4}$. In short, with these satisfactory results, the authors prospect to achieve the specifications with the actual system.

In the near future, four developed power supplies will be evaluated with actual septum magnets and the current ripple and tracking errors will be optimised. Additionally, these power supplies will be tested in long term and their stability will be evaluated.

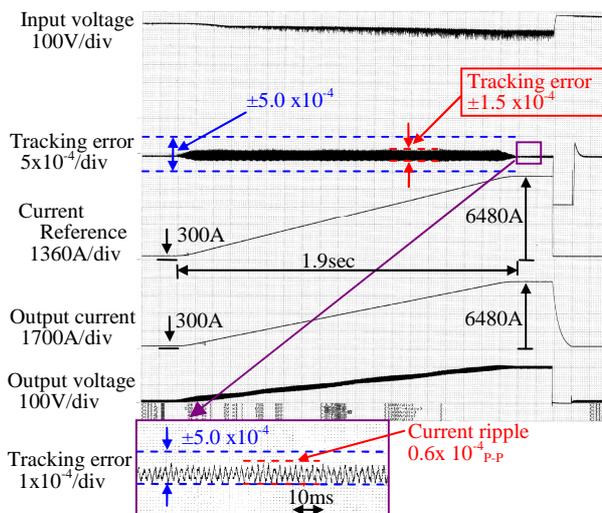


Figure 6: Waveforms of evaluation test for SM1&2.

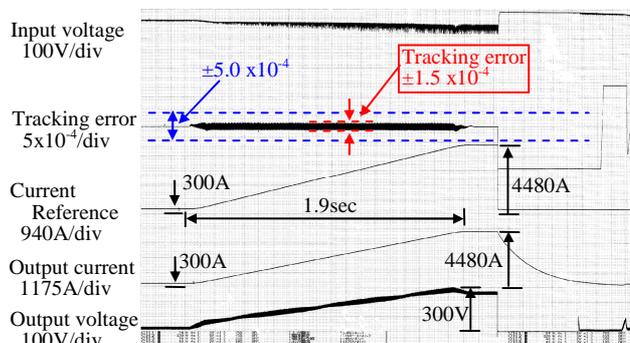


Figure 7: Waveforms of evaluation test for SM31&32.

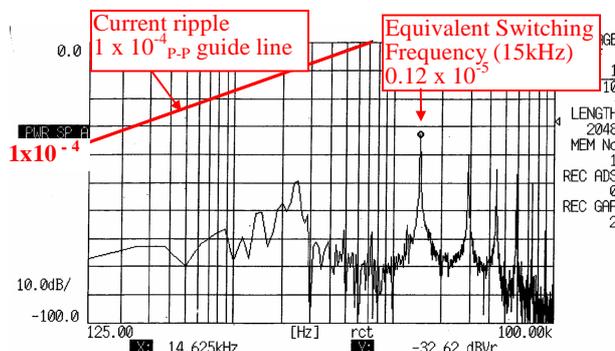


Figure 8: Output voltage waveform spectrum of SM32&33 (@4480A).

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