PROTOTYPE POWER SUPPLY FOR SuperKEKB FINAL FOCUS SUPERCONDUCTING CORRECTOR MAGNETS

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Abstract

A prototype power supply for the SuperKEKB final focus superconducting corrector magnets was developed. The aiming specifications of the power supply are a DC rated output of ± 60 A–± 5 V bipolar, current setting resolution < 1 ppm, current stability < 5 ppm/8 h, temperature coefficient < 1 ppm/degree, and current ripple < 5 ppm, where the assumed magnet inductance and cable resistance are 0.2–8.7 mH and 75 mΩ, respectively. High power tests were performed and expected results were obtained.

INTRODUCTION

KEKB [1], [2] was the leading electron-positron collider in the world and. Its recorded peak luminosity is 21.083×10^{33} cm^{-2} s^{-1}. KEKB concluded its operation in June 2010 to start the upgrade for SuperKEKB [3] aiming 40 times higher luminosity. The installation of new accelerator components is near completion. Since February 1st, 2016, trial operation of SuperKEKB has started.

For SuperKEKB, the final focusing system installed around the interaction point is the most important component in order to achieve the desired luminosity. The system consists of eight superconducting main magnets, four superconducting compensation solenoids, and 43 superconducting corrector coils [4]–[6]. The power supplies for the final focus superconducting magnets should be designed to exhibit high performance for its output DC current. For the main magnet, a full-scale prototype power supply was developed to achieve such a high-performance power supply [7].

In this report, a developed prototype power supply for the corrector magnet is reviewed. The aiming specifications are shown in Table 1.

Table 1: Aiming Specifications

Rated output	DC ± 60 A–± 5 V
Magnet inductance as a load	0.2–8.7 mH
Cable resistance as a load	< 75 mΩ
Current setting resolution	< 1 ppm
Current stability	5 ppm / 8 h
Temperature coefficient	1 ppm/degree
Current ripple (< 10 kHz)	< 5 ppm (rms)
Current noise (> 10 kHz)	< 5 ppm (zero-peak)
Ramping ratio	< 10 A/s

PROTOTYPE POWER SUPPLY

The developed power supply is a switched–mode constant–current power supply. It receives a three-phase AC input (210 V ± 10%) voltage. A three-phase full-wave diode bridge rectifier converts the AC input voltage to DC voltage. The switched-mode power module, which is controlled by a pulse-width modulation circuit, regulate the DC voltage. Passive filters for normal-mode and common-mode ripple/noise are employed to filter the output of the power module. The positive and the negative sides of the circuit are symmetrical to the ground line in order to separate the normal-mode ripple/noise from the common-mode one. A quench protection circuit, which is based on a basic technology as shown in [8], consists of protection diodes and surge absorbers.

Two DC current transducers (DCCTs) are positioned on the output terminal of the power supply. One is used for a current control loop, and another is used only for a current monitor. In order to measure a normal-mode current, both of the power cables — one is connected from positive side of the output terminal of the power supply to its load, another is connected from the load to the negative sides of output terminal — pass through the DCCT. The output signal of the DCCT is divided by 2, and is used as the normal-mode output current value of the power supply. The measured output current is used as the input for the analog current control loop, which keeps the output current constant and reduces the normal-mode current ripple.

Figure 1 shows the developed power supply undergoing the performance test at the factory.

Figure 1: The prototype power supply at the factory.

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PERFORMANCE TEST RESULTS

Current Stability

An output current was measured for 4 h by the DCCT, which is Hitec TOPACC and is placed on the power cable to the dummy load, using a Keithley model 2002 digital multimeter. The result is shown in Fig. 2. Although ambient temperature is fluctuated, the constant climate chamber, in which electric components for current control loop are located, works well. AC input voltage is also fluctuated, however the influence cannot be seen in the output current. In the result, the current stability after 30 min warming-up is 1.9 ppm (peak-to-peak)/4 h.

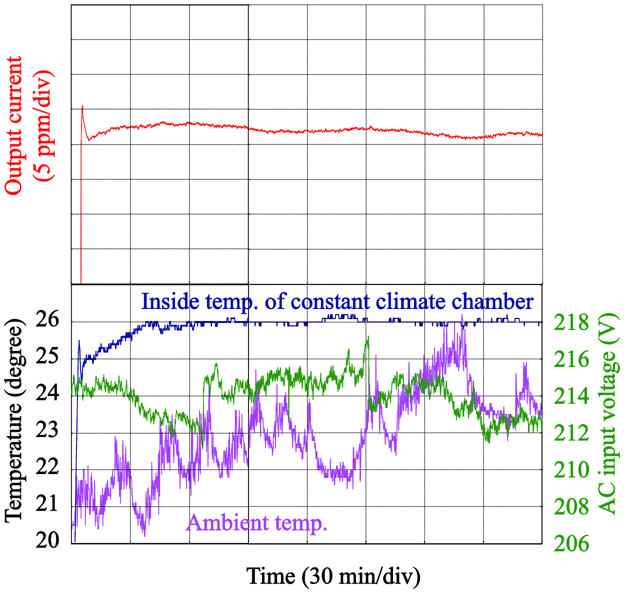

Figure 2: Test result of current stability. The output current is measured by DCCT for 4 h. Ambient temperature, inside temperature and AC input voltage are also plotted here.

Current Ripple and Noise

A voltage ripple on the output terminals was measured using Ono Sokki CF-7200A FFT analyser for lower frequency range (< 100 kHz) and Yokogawa DL9240 digital oscilloscope for higher frequency range, respectively. The magnitude of the impedance for the dummy load, which nominal values are 0.21 mH and 75 mΩ, is measured by HP 4284A precision LCR meter. The measured voltage ripple was divided by the measured magnitude of the load-impedance, so that the current ripple was obtained. The measurements were performed for both the normal-mode and common-mode. The results are shown in Fig. 3. The square root of the sum of the normal-mode components in the frequency range lower than 10 kHz is 4.04 ppm (rms). The components of power line frequency and its higher harmonics are enough suppressed, and cannot be seen in the results. The component of the switching frequency (70 kHz) and its second harmonic are around 0.4 ppm (rms). Although the common-mode current ripple is gradually increased with frequency due to the capacitance to the ground, it is lower than 0.2 ppm (rms) below 1 MHz.

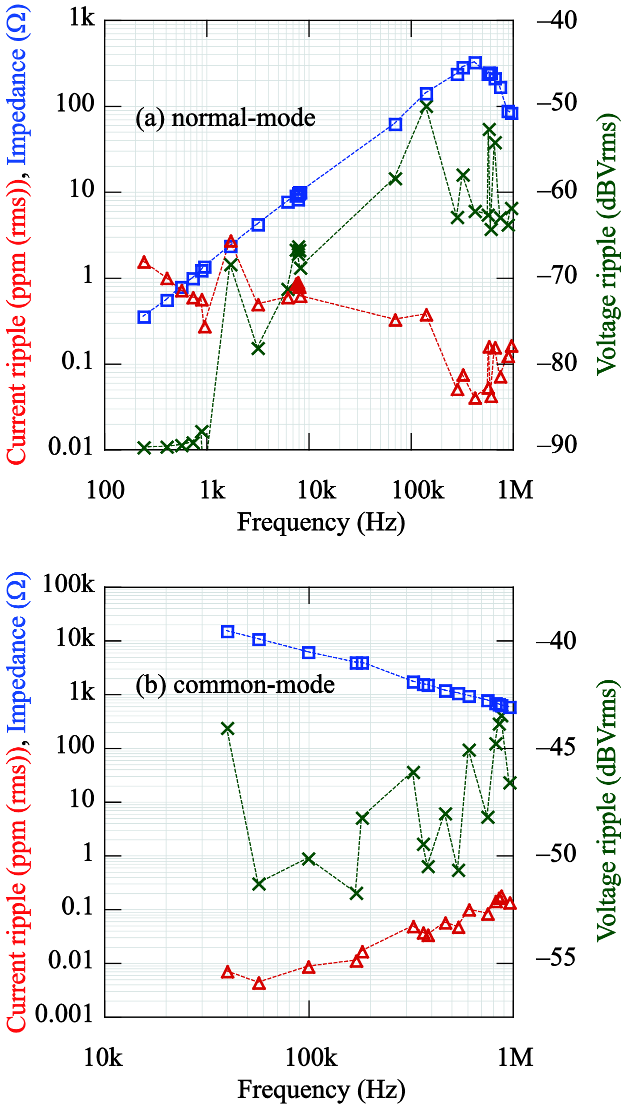

Figure 3: Test results of (a) normal-mode and (b) common-mode current ripples. By dividing the measured voltage ripple (cross) by the measured magnitude of load impedance for the dummy load (box), the current ripple (triangle) is obtained.

Quench Protection

A test for the quench protection circuit was performed to measure the output voltage, output current, and trigger from the quench detector. The results are shown in Fig. 4. The trigger immediately (< 10 μs) opened the output circuit, and the output voltage exceeds the turn-on voltage of the protection diodes. So that the diodes consumed the stored energy of the load. The induced voltage between the output terminals was 8.6 V, which is lower than the withstanding voltage of 200 V of the superconducting magnet. The output current gradually reduced and reached 0 A within 1.5 ms for a 0.21 mH load or 53 ms for a 8.6 mH load. These values agree with the estimated one of 1.46 ms or 60 ms (= load inductance of 0.21 mH or

8.6 mH × output current of 60 A / turn-on voltage of a protection diodes of 8.6 V).

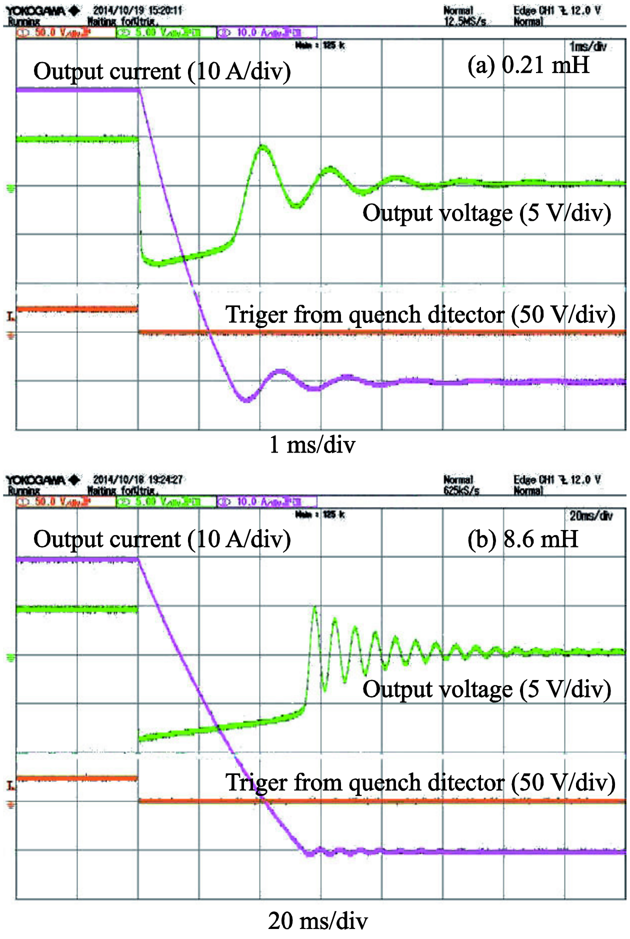

Figure 4: Quench protection circuit test results: two type of dummy loads, whose nominal values are respectively (a) 0.21 mH and (b) 8.6 mH, were used.

CONCLUSION

A prototype power supply for the SuperKEKB final focus superconducting corrector magnets was developed. The high power tests showed the expected results. Based on these results, mass production was carried out in financial year 2015.

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