DEVELOPMENT AND EXPERIMENTAL VALIDATION OF A MODULAR MAGNET POWER SUPPLY FOR THE KOREA-4GSR STORAGE RING

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Abstract

The Korea 4th Generation Synchrotron Radiation (Korea-4GSR) storage ring comprises 1,184 magnets, 792 of which require rated currents of 140 A or 280 A. To drive these magnets, a magnet power supply (MPS) supporting parallel operation was developed to minimize the number of MPS types, thereby improving maintenance efficiency and reducing manufacturing costs. To ensure beam stability and low-emittance operation, current accuracy below 100 ppm and stability below 10 ppm are required. This paper presents a storage ring modular MPS (SR Modular MPS) rated at 140 A, designed with master–slave parallel operation capability to expand the rated output current to 280 A through two-unit parallel configuration. Operating-condition-dependent calibration methods are applied to satisfy the performance requirements over the entire operating range. Experimental results demonstrate that the developed SR Modular MPS achieves an accuracy of 45.79 ppm and a stability of 2.28 ppm in single-unit operation, and 45.88 ppm and 5.1 ppm, respectively, in parallel operation.

INTRODUCTION

The Korea-4GSR storage ring comprises 28 cells, each containing Center-bend, Quad-bend, Reverse-bend, Quadrupole, Sextupole, and Corrector magnets, as shown in Fig. 1 [1]. Among the 1,184 magnets, 792 require rated currents of 140 A or 280 A with a current accuracy below 100 ppm and stability below 10 ppm to ensure beam stability and low-emittance operation. A modular 140 A-rated unit featuring master–slave parallel operation was developed to cover both current ratings with a single MPS type, enabling expansion to 280 A through two-unit parallel configuration. This approach reduces manufacturing costs and simplifies maintenance. This paper describes the power stage configuration, calibration methodology, and experimental validation of the developed SR Modular MPS.

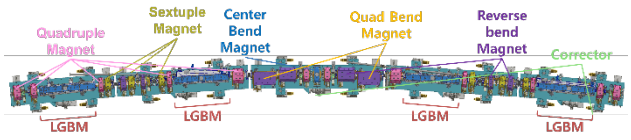

Figure 1: Layout of one cell in the Korea-4GSR storage ring.

POWER STAGE AND PARALLEL OPERATION

Figure 2 illustrates the power stage of the SR Modular MPS. At the input stage, the AC power is isolated by a switched-mode power supply (SMPS) and converted to DC to form the DC-link voltage. This DC-link voltage is supplied to a full-bridge inverter based on SiC MOSFETs operating at a switching frequency of 100 kHz. The high-frequency ripples generated by the inverter are attenuated via an LC–LC–RC output filter, delivering a stable, low-ripple DC output current to the magnet load.

In parallel operation, synchronization between the digital signal processor (DSP) Pulse Width Modulation (PWM) loop and Small Form-factor Pluggable (SFP) frame transmission is critical. The SFP frame aligns with the 33.3 kHz DSP interrupt loop (PWM: 100 kHz), while Programmable logic (PL) internal sync is managed via AXI. Header–Payload–CRC packets exchange master duty commands and slave feedback (current, status, and faults).

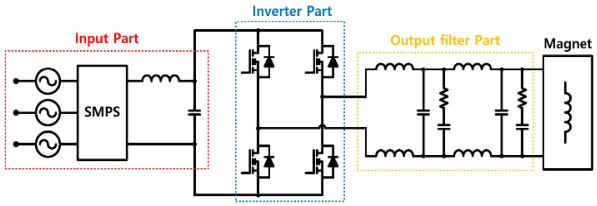

Figure 2: Power stage of the SR Modular MPS.

ACCURACY IMPROVEMENT VIA CALIBRATION

Offset Calibration

Offset calibration is implemented to reduce the fixed deviation between the command current and the measured output current. The rated current range (1–140 A) is swept at 1 A intervals, and the stabilized mean current is measured at each point to construct an offset calibration table. During operation, the DSP references this table and applies the corresponding correction to the command value in real time, thereby minimizing the offset error across the entire operating range.

Temperature Calibration

Temperature calibration compensates for current drift caused by ambient temperature changes and internal heat generation, thereby ensuring output precision during long-term operation. A thermocouple is mounted on the sensor board housing the analog-to-digital converter (ADC) to acquire real-time temperature data. The MPS is operated at the rated current of 140 A over an extended period, and the resulting temperature–current correlation is used to derive temperature-dependent correction coefficients. These coefficients are applied in the DSP firmware to compensate for thermal drift in real time.

As shown in Fig. 3, both calibration methods effectively reduce the current error over the entire operating range.

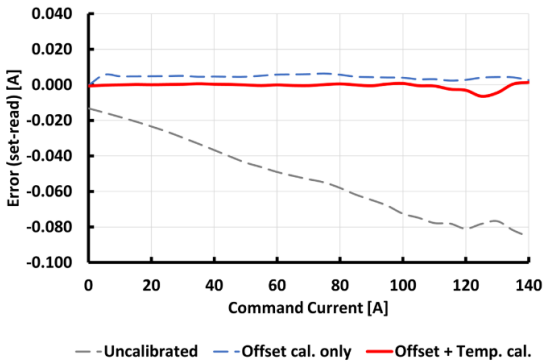

Figure 3: Offset and temperature calibration of SR Modular MPS.

EXPERIMENTAL RESULTS

The main parameters of the SR Modular MPS are summarized in Table 1. Two units of the SR Modular MPS prototype were fabricated, and offset and temperature calibrations were applied as described above. The performance was evaluated using a magnet load (2 mH, 0.28 Ω), as shown in Fig. 4. Accuracy was assessed by sweeping from 1 A to the rated current at 1 A intervals with a 7 s measurement duration per point, and stability was measured over a 4-hour continuous operation at the rated output current. As shown in Fig. 5, the single-unit operation (140 A) achieved an accuracy of 45.79 ppm and a stability of 2.28 ppm, while the parallel operation (280 A) achieved an accuracy of 45.88 ppm and a stability of 5.1 ppm. Both configurations satisfy the target specifications of 100 ppm accuracy and 10 ppm stability, confirming the feasibility of the proposed modular design for the Korea-4GSR storage ring.

Table 1: Main Parameters of SR Modular MPS

Parameters	Value
Output voltage	40 V
Output current	140 A (single), 280 A (parallel)
Switching frequency	100 kHz
Accuracy	< 100 ppm @ rated current
Stability	< 10 ppm @ rated current

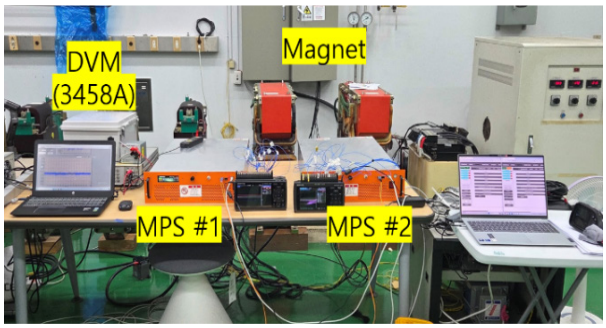

Figure 4: Experimental test setup.

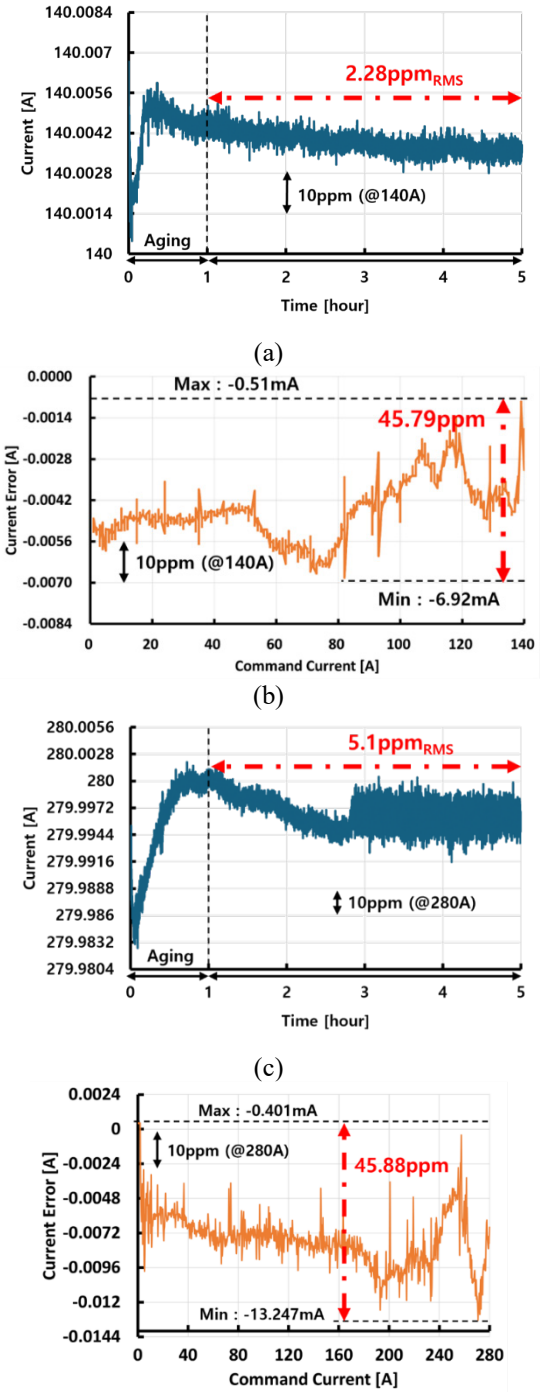

Figure 5: Measured performance of the prototype MPS. (a) Stability in single-unit operation, (b) accuracy in single-unit operation, (c) stability in parallel operation, (d) accuracy in parallel operation.

CONCLUSION

A storage ring modular magnet power supply rated at 140 A was developed for the Korea-4GSR storage ring. The modular design with master–slave parallel operation capability enables the rated output current to be expanded to 280 A through two-unit parallel configuration, thereby reducing the number of MPS types required and improving

maintenance efficiency. Offset and temperature calibration methods were implemented to satisfy the stringent current accuracy and stability requirements. Experimental results showed an accuracy of 45.79 ppm and a stability of 2.28 ppm in single-unit operation, while parallel operation yielded 45.88 ppm and 5.1 ppm, respectively.

REFERENCES

[1] J. Kim, G. Jang, J. Lee, and J. Seok, "The Korea-4GSR storage ring lattice design", in *Proc. IPAC'25*, Taipei, Taiwan, Jun. 2025, pp. 789-792.
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