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MAGNET POWER SUPPLY CALIBRATION WITH A PORTABLE CURRENT MEASURING UNIT AT THE J-PARC MAIN RING

Kazuki Miura*, Tetsushi Shimogawa, Takao Oogoe, Yoshinori Kurimoto, Daichi Naito, Yuichi Morita, High Energy Accelerator Research Organization, Tsukuba, Ibaraki, Japan Yuu Kuniyasu, Mitsubishi Electric System & Service Co., Ltd., Tsukuba, Ibaraki, Japan Kazufumi Ooya, SANKYU PLANT TECHNO Co., Ltd., Chuo-ku, Tokyo, Japan
Ryu Sagawa, Universal Engineering, Mito, Ibaraki, Japan

Abstract

In the J-PARC Main Ring (MR) 96 bending magnets are employed in total. Every 16 magnets, which are connected in series, are separately driven by six individual power supplies. Although the power supplies are identically designed, the output currents of the six power supplies are expected to be slightly different due to individual differences of the electronic circuits used for the current feedback system. To calibrate the output currents, we made a current measurement unit with a portable DC current transformer (DCCT) as an independent reference, and confirmed the expected performance. Moreover, we measured the output currents of the six power supplies for the bending magnets. The system will be used for the calibration of new magnet power supplies [1], whose installation will be scheduled in 2021.

INTRODUCTION

In the J-PARC MR, 96 bending magnets are employed in total. Every 16 magnets, which are connected in series, are separately driven by six individual power supplies. The group of magnets driven by a single power supply is called a "family". Since the six bending magnet families are symmetrically located in the ring, all output currents of the six power supplies are required to be same. It is natural that the six power supplies of the bending magnets are identically designed. Despite of the identical design, analog amplifiers and analog-to-digital converters [2], which are used for current feedback in the power supplies, have individual differences of their properties. These differences cause small variations among the six output currents. Therefore, the output currents of the power supplies need to be calibrated by an independent current sensor. The independent current sensor is also useful when a magnet power supply is replaced with new one to guarantee the same output current after the replacement. Actually, most of magnet power supplies in the J-PARC MR will be replaced with new ones in 2021.

For the calibration of the magnet power supplies, we make a current measurement unit using a portable DCCT as an independent current sensor. This report describes not only the details of the system but also the measurement of the six power supplies for the bending magnets using the system.

* kazuki.miura@kek.jp

CONFIGURATION OF THE MEASUREMENT SYSTEM

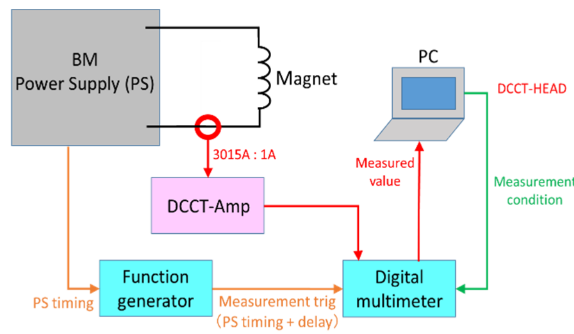

Figure 1: Configuration of the measurement system.

The configuration of the portable current measurement unit is shown in Fig.1. A bus bar to which the DCCT head is attached is inserted between the output terminal of the BM power supply and the cable. The secondary current of the DCCT head, which is proportional to the primary output current, is measured by a digital multimeter (KEITHLEY Model 2000) via the DCCT amplifier. The multimeter employs an integral type analog-to-digital converter. The integration time needs to be longer than 20 ms to achieve the maximum accuracy. This is the reason that a 250 ms flat-top is added to the current waveform for the measurement. By taking into accounts the ratio of the DCCT (HITEC C40-8-3015), which is 3015 A: 1 A, the measurement accuracy of the output current using the digital multimeter is down to the order of 1 mA. Furthermore, the measurement error (standard error) of the mean value is suppressed to less than 1 mA by taking the average of all measurements for continuous 1000 cycles of the pulse shown in Fig 2. This measurement accuracy is sufficient for a BM power supply with a peak output current of approximately 1600 A. The timing at which the digital multimeter acquires the data is controlled by using a function generator that gives an arbitrary delay to the operation trigger of the BM power supply, as shown in Fig. 1. The current output in the pattern can be acquired at an arbitrary time at every operation cycle, and the number of measurements can also be changed from a PC. The three points in Fig. 2 represent the measurement of the output current samples of each BM power supply under the same measurement conditions (beam energy: A = 3 GeV

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equivalent, B = 8 GeV equivalent, C = 30 GeV equivalent). These measurements are used to determine the individual differences among the output currents of the six BM power supplies.

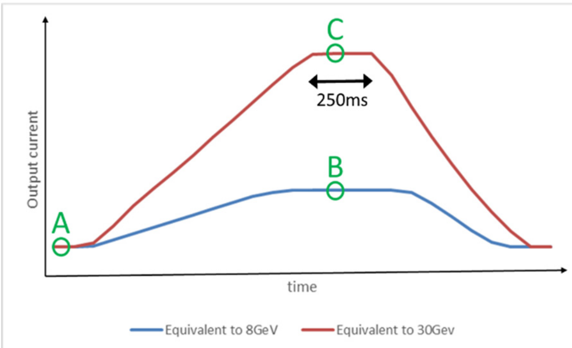
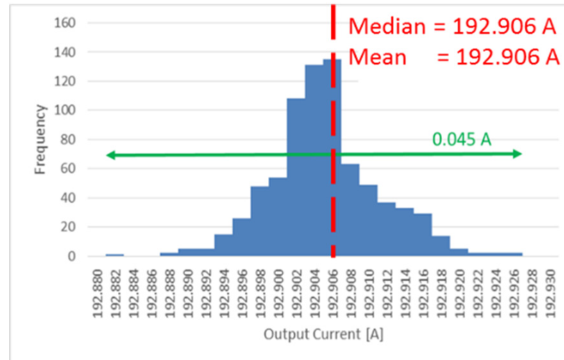


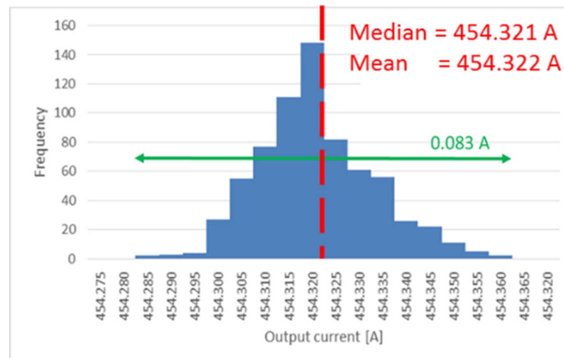
Figure 2: Schematic diagram of output current patterns.

PERFORMANCE EVALUATION OF MEASUREMENT SYSTEM

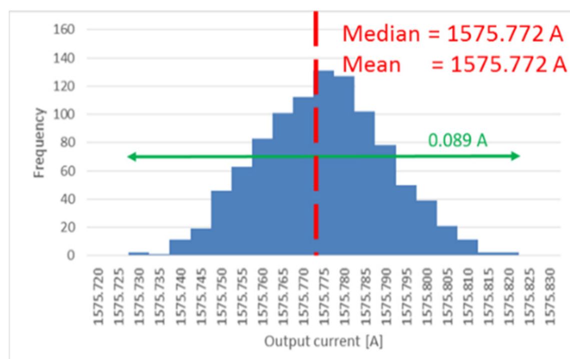
In Fig. 3, we show three distributions of the continuous 1000 measured values for the 3 points (A, B, and C shown in Fig. 2). The full widths of the distributions are within 100 mA while the maximum difference between the median and the mean value is 1 mA. This means that the validity of the measurement results using the system is confirmed. As mentioned before, it was also confirmed that we can evaluate the variation among the output currents of the power supplies using the mean values. We actually took ten sets of the continuous 1000 measurements for checking the reproducibility of the measurement. The mean values for each set are within 6 mA (No.3 – No 6) as shown in Table 1. The full width of the distributions was about 100 mA, and the measurement error was less than 1 mA. It was confirmed that there is no problem in the reproducibility of the measurement system.



(a) Point A (3 GeV).



(b) Point B (8 GeV).



(c) Point C (30GeV).

Figure 3: Histograms of measured values (1000 cycles).

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Table 1: Variation of Each Measurement

	(1) Measured average [A]	(2) Full width [A]	(3) Error ($\sigma/\sqrt{N}$) [A]
No.01	1575.794	0.098	0.0005
No.02	1575.794	0.086	0.0005
No.03	1575.796	0.097	0.0005
No.04	1575.791	0.094	0.0005
No.05	1575.792	0.096	0.0005
No.06	1575.790	0.089	0.0005
No.07	1575.792	0.085	0.0005
No.08	1575.793	0.089	0.0004
No.09	1575.793	0.086	0.0004
No.10	1575.793	0.105	0.0004

MEASUREMENT RESULT OF ALL BM POWER SUPPLIES

Using the system, we performed continuous 1000 cycles measurements for the six BM power supplies. The results are shown in Table 2. For the comparison, we use the fractional deviations of the mean values (BM1-6) from their reference (I_{ref}). As shown in Fig. 4, the three measured currents corresponding to 3, 8 and 30 GeV for the 6 BM power supplies are fitted with linear functions. The fitting results are shown in Table 3. Since the scale factors to the reference are approximately 1, for all the power supplies, all the dotted lines in Fig. 4 appear to be overlapped in the display range. Thus, it was confirmed that the present BM power supplies can regulate the output current with good linearity with respect to the reference. The calibration of them can be done by the offset adjustment, which is up to approximately 400 mA at maximum as shown in Table 3.

Table 2: Formatting of References

	3 GeV	8 GeV	30 GeV
I_{ref} [A]	193.198	454.586	1575.914
(BM1 - I_{ref}) / I_{ref} [%]	-0.159	-0.062	-0.011
(BM2 - I_{ref}) / I_{ref} [%]	-0.131	-0.059	-0.030
(BM3 - I_{ref}) / I_{ref} [%]	-0.229	-0.105	-0.043
(BM4 - I_{ref}) / I_{ref} [%]	-0.151	-0.084	-0.050
(BM5 - I_{ref}) / I_{ref} [%]	-0.129	-0.051	-0.010
(BM6 - I_{ref}) / I_{ref} [%]	0.001	-0.004	-0.006

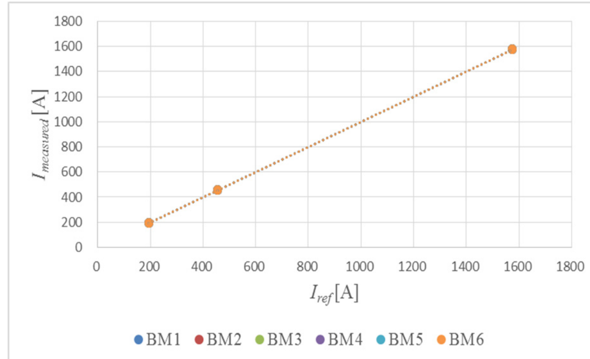

Figure 4: Linearity of reference current and measured current.

Table 3: Results of Linear Approximation

Power Supply	Linear approximation (y: I_{ref}, x: $I_{measured}$)
BM1	y = 1.0001x - 0.3244
BM2	y = 0.9998x - 0.2081
BM3	y = 0.9998x - 0.4058
BM4	y = 0.9996x - 0.2193
BM5	y = 1.0001x - 0.2629
BM6	y = 0.9999x + 0.0134

CONCLUSION

A portable current measurement unit that consists of a DCCT and digital multimeter was made for the calibration of the magnet power supplies in the J-PARC MR. The output currents of the power supplies can be continuously recorded at any given timing using the system. Since the accuracy and reproducibility of the system was confirmed in the performance evaluation test, the system were sequentially corporated into the six BM power supplies for the comparison of the six output currents. As a result, the linearity of the output currents with respect to the reference is confirmed although the offset deviations are found as an individual differences.

In future, we plan to evaluate the influence of this offset on the beam. In additions, we will carry out individual difference measurement and calibration of the new magnet power supply using the system.

REFERENCES

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