ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB370

DEVELOPMENT OF LONG COIL DYNAMIC MAGNETIC FIELD MEASUREMENT SYSTEM FOR DIPOLE MAGNETS OF HEPS BOOSTER*

Yiqin Liu[†,1], ShuaiLi[1], Jianxin Zhou Institute of High Energy Physics (IHEP),
Chinese Academy of Sciences (CAS), Beijing, China
Wen Kang, Changdong Deng[1], Xi Wu[1], Yuwen Wu[1], Li Li, IHEP, CAS, Beijing, China
[1]also at Spallation Neutron Source Science Center, Dongguan, China

Abstract

A magnetic field measurement system for dipole magent of High Energy Photon Source (HEPS) Booster is designed and developed. The system uses the long coil upflow method to measure the dynamic integral field of the magnet, and the long coil transverse-translation method to measure the integral field distribution error of the magnet.

In this paper, the design and implementation of the magnetic measuring system are introduced in detail, and the magnetic field measurement results of the prototype magnet are shown. The measurement results show that the repeatability of the dynamic integral field measurement system is about 2×10^{-4}, and the repeatability of the uniform distribution of the integral field is better than 1×10^{-4}, which meet the test requirements of the discrete integral field of bulk magnets ±1‰ and the uniformity of the integral field $\pm5\times10^{-4}$ @ 6 GeV and $\pm1\times10^{-3}$ @ 0.5 GeV.

INTRODUCTION

HEPS is the fourth generation of synchrotron radiation source, and its beam emittance is close to the diffraction limit, small aperture machine technology (magnet, vacuum, insert, etc.) is a difficulty in accelerator technology [1]. HEPS accelerator mainly consists of a linear accelerator with energy of 500 MeV, a storage ring with a circumference of 1360 m and energy of 6 GeV, and a booster with a circumference of 453 m and initial energy of 500 MeV [2].

Dipole Magnets of HEPS Booster are 1 Hz AC magnet with DC bias. The magnetic field varies from 0.05 T to 0.68 T, and the rise time is 400 ms, the flat top time is 200 ms, and the fall time is 200 ms. These magnets are H-shaped linear structure, with an air gap height of 34 mm, an effective length of 1450 mm, and an external size of about 1500 mm. Figure 1 shows the physical design model of dipole magnet for HEPS booster [3]. The model number of these dipole magnets is HEPS-BS-34B, which is used to refer to the dipole magnet of HEPS Booster.

The field is designed to reach 40×20 mm, and the field uniformity of high and low fields is required to be 1×10^{-3} and 5×10^{-4}, respectively. The integral field dispersion of magnet is required to be 0.1%. Some physical design parameters are shown in Table 1.

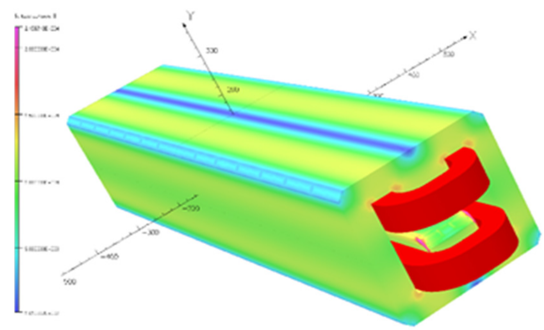

Figure 1: Physical Design Model of Dipole Magnets for HEPS Booster (HEPS-BS-34B).

Table 1: Design Parameters of the Dipole Magnet of HEPS Booster (HEPS BS-34B)

Type	BS-34B
Numer	128
Effective Length	1.45 m
Magnet Gap	34 mm
Core Length	1.425 m
Chord and Arc Difference	8.9 mm
Width of Pole Surface	105 mm
Turning Radius	29.54 m
Max. Working Magnetic Field (@ 6 GeV)	0.68 T
Min. Working Magnetic Field (@ 500 MeV)	0.05 T
Good Field Range	30 mm×20 mm
Integral Field Uniformity in Good Field Area	1×10^{-3}@ 0.5 GeV 5×10^{-4} @ 6 GeV
Discreteness of Integral Field for Bulk Magnets	0.1%

LONG COIL DYNAMICAL MAGNETIC MEASUREMENT SYSTEM

The conventional measurement scheme of the dipole magnet is generally a translational long coil system, such as CSR dipole magnet measurement of Lanzhou heavy ion accelerator [4-6] and enhancer dipole magnet measurement

* Work supported by High Energy Photon Source (HEPS), a major national science and technology infrastructure in China.
† liuyq@ihep.ac.cn

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB370

of Shanghai synchrotron radiation source [7, 8]. The dipole magnet of both devices are C-type magnets.

The scheme of measuring dipole magnets of HEPS booster adopts the way of integrating long coil, and the integral field is measured by up current method; at the same time, the transverse field distribution is measured by translating the long coil; in addition, hall probe measurement is needed to calibrate the long coil [9]. The frame of the measurement system for dipole magnets of HEPS Booster is shown in the figure below (Fig. 2).

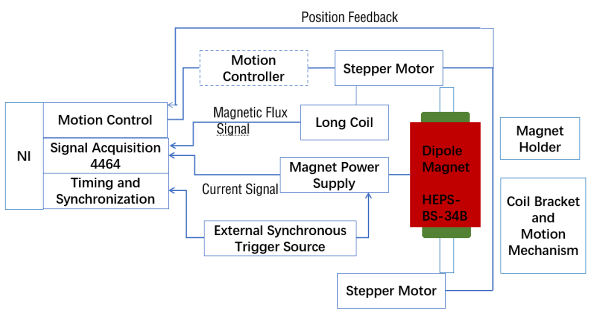

Figure 2: Frame diagram of the measurement system for dipole magnets of HEPS Booster.

Composition of the Long Coil Dynamical Measurement System

The magnetic measuring system consists of a over 2.0 m long measuring coil, a mechanical platform with a stroke within plus or minus 300 mm, a motion control system and a signal acquisition equipment.

The magnetic measuring system selects Yasawa stepper motor and Taidao iMac-FX controller, and the signal acquisition equipment adopts 24-bit NI-4464 signal acquisition card. The long coil winding frame width is 4 mm, the length is 1.8 m, and the number of turns is 342.The coil uniform motion range is greater than 40 mm, the positioning accuracy is ±3 µm, and the repeated positioning accuracy is ±1.5 µm. Figure 3 shows the realization of the long coil dynamic measurement system for dipole magnets of HEPS booster.

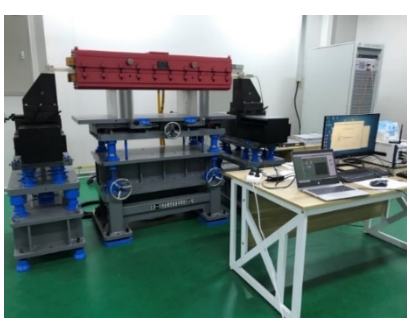

Figure 3: The long coil dynamic measurement system for dipole magnets of HEPS Booster.

Software for Magnetic of the Long Coil Dynamical Measurement System

The magnetic measurement program is specially written by LabVIEW, which is divided into the translation long coil uniformity measurement program and the long coil upflow method integral field measurement program.

The integral field, excitation curve and current magnetic field waveform were measured by the long coil upflow method, the field uniformity was measured by the long coil translation method under DC current, and the coil coefficient was calibrated by the integral field measured by the Hall point measurement system. The interface of the two magnetic measurement programs is shown in Figs. 4 and 5.

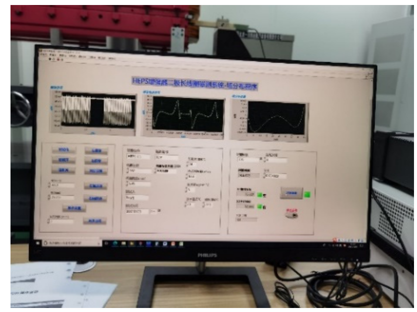

Figure 4: Interface of the translation long coil uniformity measurement program.

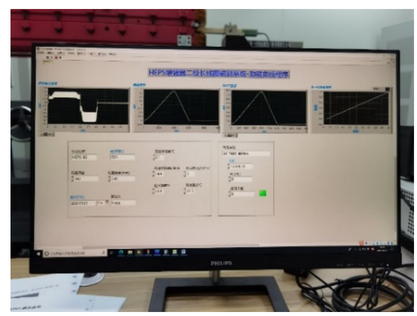

Figure 5: Interface of the long coil upflow method integral field measurement program.

RELIABILITY VERIFICATION AND PROTOTYPE TEST OF THE MAGNETIC MEASUREMENT SYSTEM

The long coil is placed on the center line of the magnet center plane, and the magnet is electrified with different current waveforms to test the corresponding magnetic field response. The repeatability of integral field measurement is tested by multiple measurements. Figure 6 shows the repeatability of six measurements of the integral field in the process of current rising from 30 A to 770 A.

Field uniformity measurement is to move the long coil laterally under DC, and measure the integral field deviation at different positions relative to the center. We measured the field distribution error at 56.5 A, 385 A and 770 A DC respectively, and measured several times at each current. Figures 7 and 8 show the field uniformity measurements at 56.5 A and 770 A, respectively.

Measurement Repeatability of the Long Coil Dynamical Measurement System

The repeatability accuracy of integral field measurement by upflow method is better than 3×10^{-4} at low field,

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB370

1×10^{-4} at midfield and 3×10^{-5} at high field. The repeatability of the field distribution error with the translation method is better than the 7×10^{-5} repeatability of the 5 times measurement.

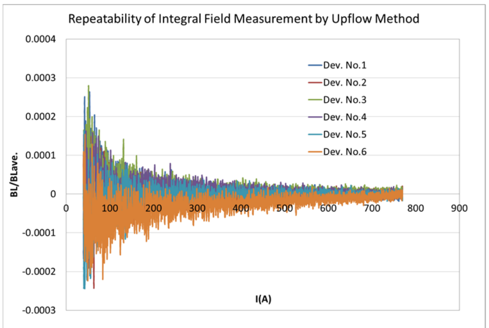

Figure 6: The repeatability of six measurements of the integral field.

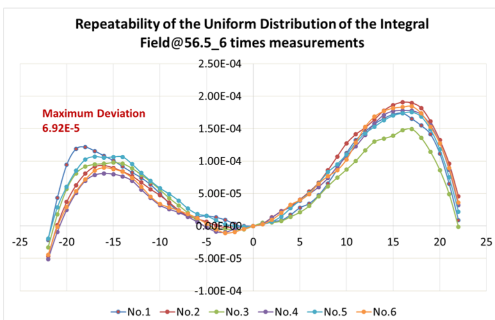

Figure 7: The field distribution error at 56.5 A.

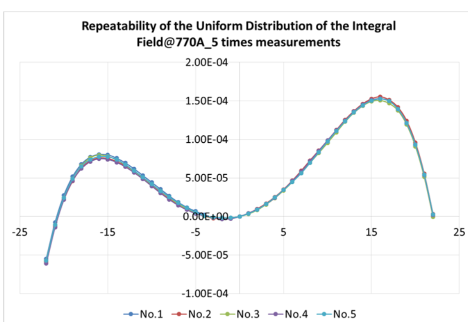

Figure 8: The field distribution error at 770 A.

Some Results of the Measurement of the Prototype

The integral field measurements are completed by the upwelling method under different current waveforms, such as 0-770 A, 30-770 A, 0-800 A, 0-850 A, 30-800 A, 30-850 A.

A Hall probe measurement system is used to measure point by point at 56.5 A and 420 A direct current, and the integral field obtained by Hall is compared with that of the long coil by rising current method of the corresponding current, and the calibration coefficient is obtained.

Figure 9 shows the normalized magnetic field current waveform in the prototype measurement by the long coil up-flow method. Figure 10 shows the integral field distribution error of the prototype under three currents by the long coil translation method.

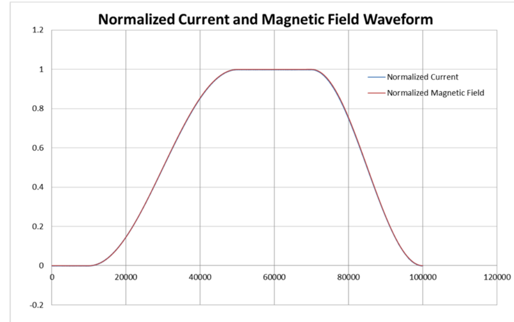

Figure 9: Normalized current and magnetic field waveform of the prototype.

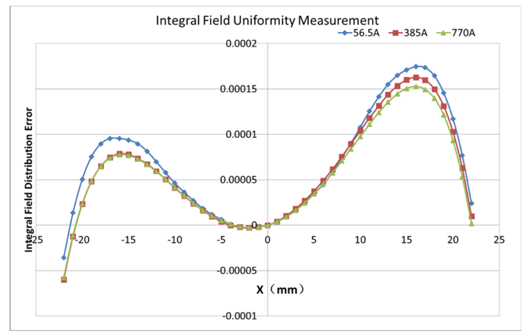

Figure 10: The integral field distribution error of the prototype.

In the measurement of field uniformity translation method, the long coil moves between X =± 32 mm, and we obtained the integral field error between X = ± 22 mm, with an interval of 1 mm.

The field distribution error measurement results of the prototype show that the error of the integrated field of each position relative to the central position x = 0 mm is about -3.6×10^{-5} to 1.75×10^{-4} within the measurement range X = ± 22 at 56.5 A. At 385 A and 770 A, it is $-6.0\times10^{-5} \sim 1.63\times10^{-5}$ and -5.77×10^{-5} to $\sim 1.53\times10^{-4}$.

CONCLUSION

This paper introduces the basic parameters and test requirements of the booster dipole magnet, develops a long coil dynamic magnetic field measurement system, and verifies the measurement reliability of this system through magnetic measurements of the dipole magnet prototype, including the measurement of the integral field distribution error by the up current method and the measurement of the integral field distribution error by the translation method. The repeatability of the measurement of the integral field and the distribution error of the integral field of the system can meet the requirements of the bulk magnetic measurement of dipole magnets of HEPS booster.

ACKNOWLEDGEMENTS

Thanks to Zhou Jianxin, Li Shuai, Kang Wen and other colleagues for their help and support in this work. Thanks to all my colleagues in the magnet group of IHEP.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB370

REFERENCES

[1] J. Chen, "HEPS Injection and Extraction System Design", IHEP, Beijing, China, Rep. IHEP-Main building A-214, Jun. 2020.

[2] J. Chen *et al.*, "Development of On Axis Injection Impactor System and Prototype of Fast Pulse Power Supply for HEPS", *High Power Laser and Particle Beams*, vol. 31, no. 4, p. 040017-1, Apr. 2019. doi:10.11884/HPLPB201931.190007

[3] Y. Chen, "Physical Design of Dipole Magnet Prototype for HEPS Booster", IHEP, Beijing, China, Rep. IHEP-Main building C-209, Aug. 2019.

[4] H. Xiong *et al.*, "Integral Magnetic Field Measurement of Dipole Magnets", *Nuclear Physics Review*, vol. 20, no. 1, p. 34, Mar. 2003

[5] Y. He *et al.*, "Magnetic Measurement System for Cooling Storage Ring of Heavy Ion Research Facility in Lanzhou", *Atomic Energy Science and Technology*, vol. 39, no. 3, p. 257, May. 2005. doi:10.7538/yzk.2005.39.03.0257

[6] Y. He *et al.*, "Measurements of the Dipoles for Cooller-Storage-Ring Main Injection Beam Line", *High Power Laser and Particle Beams*, vol. 15, no. 10, p. 1023, Oct. 2003.

[7] Y. He *et al.*, "Booster Model Dipole Field Measurement and Study of Pole Ends Chamfering", *Journal of China University of Science and Technology*, vol. 31, no. 2, p. 202, Apr. 2001.

[8] J. Zhang *et al.*, "Design and Fabrication of a Long Coil Magnetic Measurement System", *Nuclear Techniques*, vol. 26, no. 5, p. 333, May. 2003

[9] Y. Liu *et al.*, "Scheme Design of Measurement System for Dipole Magnet of HEPS Booster", presented at the 2020 Annual Meeting of Accelerator Devices of Institute of High Energy Physics, Dongguan & Beijing, China, Sep. 2020, unpublished.