15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPR45

TEST MAGNET FOR THE EIC RAPID CYCLING SYNCHROTRON*

H. Witte†, J. Avronsart, V. Teotia, S. Notaro, G. Mahler, P. Joshi, V. Ranjbar
Brookhaven National Laboratory, Upton, NY, USA

Abstract

Brookhaven National Laboratory (BNL) was recently chosen to host the Electron Ion Collider (EIC), which will collide high energy and highly polarized hadron and electron beams with a center of mass energy up to 140 GeV and a luminosity of up to 10^{34} cm^{-2} s^{-1}. Part of the accelerator complex is a Rapid Cycling Synchrotron (RCS), which is planned to accelerate electrons from 400 MeV to 18 GeV.

Due to the large energy range and the given circumference of the ring, the magnetic fields of the RCS magnets at injection are very low (~mT). A test dipole magnet was constructed to study differences in field quality from 5-50 mT. The paper discusses the design of the test magnet and first measurement results.

INTRODUCTION

The design of the Electron-Ion collider (EIC) at Brookhaven National Laboratory (BNL) is well underway. The new facility is based on the existing RHIC complex; new additions are an electron storage ring (ESR) and an injector, the rapid cycling synchrotron (RCS). EIC will be capable of colliding up to 275 GeV protons with 18 GeV electrons.

The planned injector, the RCS, is expected to accelerate electrons from 400 MeV to 18 GeV. Due to the large circumference of the RHIC ring the dipole field in the RCS dipoles is only about 0.25 T at 18 GeV. This implies that at injection the field is as low as 5 mT. The pole tip field of the quadrupoles and sextupoles is similar.

This is a very low field, considering variations of the magnetic permeability for low field intensities, hysteresis effects and stray magnetic fields. The magnets are expected to have a field quality of a few units (normalized to 10000 units of the main field component). Of particular concern are the field quality at such low field levels and the repeatability. A series of studies is underway to assess the implications of this, which include stray field measurements in the RHIC tunnel [1] and better material models to predict the behaviour at low fields [2]. For experimental verification a test magnet was constructed and measured, which is described in this paper.

THE MAGNET

The test magnet was designed for an existing rotating coil in BNL's Superconducting Magnet Division, which is used for measuring harmonics of a superconducting magnet energized at low currents at room temperature. The rotating coil has a radius of 50 mm and a length of 220 mm. The coil was chosen as it is suitable to measure with sufficient accuracy with a main field of 7 mT.

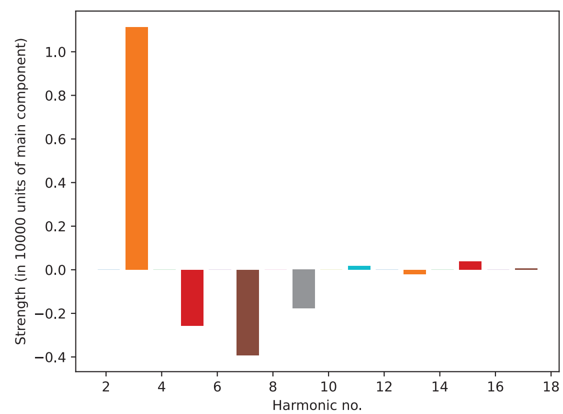

Figure 1: Harmonics.

A dipole design was chosen for simplicity. The gap size is 120 mm, with a yoke length of 500 mm. The yoke material is AK Steel DI-MAX M-15, which is a non-grain oriented Si-steel. Each lamination is 0.340 mm thick. The yoke was stacked and glued by an external vendor.

The expected harmonics are simulated using Opera 3D from Dassault. The results are shown in Fig. 1. The normal (B_n) and skew (A_n) harmonics are defined as:

$$B = \sum_{n=1}^{\infty} [B_n + iA_n] \left(\frac{z}{R_{ref}}\right)^{n-1} .$$

As seen in the figure, at a reference radius of 50 mm the calculated harmonics are very good if the rotating coil is fully immersed in the body of the magnet. This approach was favoured to rule out effects from saturated ends. Using a 30 A power supply the magnet can be energized to a field of about 50 mT. The yoke is far from saturation, as can be seen in Fig. 2.

ROTATING COIL MEASUREMENTS

The magnetic measurements on RCS test magnet are carried out using the rotating coil bench at BNL [3]. Two sets of measurements were done. The first set measured the body harmonics using a 110 mm long PCB based Radial coil [4] at reference radius of 50 mm. This coil is like that used for MQXFS Quadrupole measurements [5]. The second set of measurements was done using an ~920 mm long rotating mole at reference radius of 31 mm [6]. As an extension to the second set of measurements, repeatability tests of the

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the US Department of Energy.
† hwitte@bnl.gov

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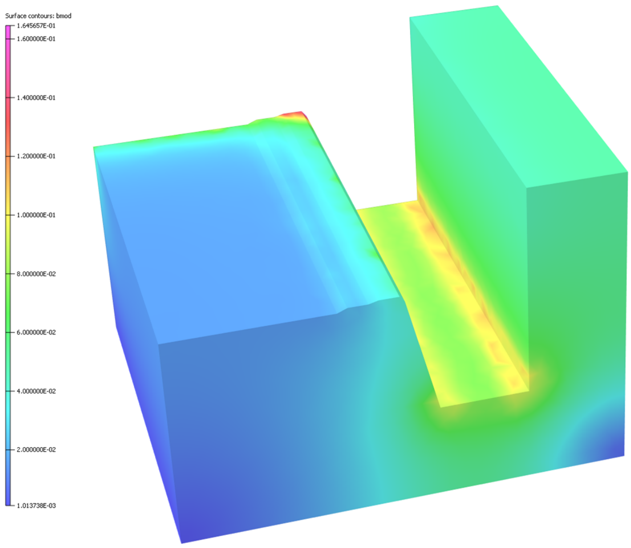
Figure 2: Yoke magnetization.

transfer function and harmonics were carried out for four cycles after the initial bipolar pre-cycling of the magnet. Here we report on the first set of measurements.

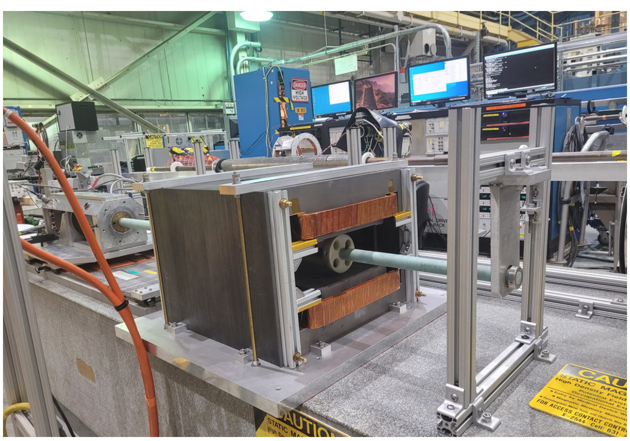
Figure 3: RCS test magnet on rotating coil bench.

Figure 3 shows the RCS test magnet on the rotating coil test bench. Initial rotating coil measurements showed higher than expected harmonics, which was attributed to the assembly method. This was deemed acceptable, as the main interest is in relative changes.

MEASUREMENT RESULTS

Deviation From Linearity

The deviation from linearity can be seen in Fig. 4. The deviation was measured using a calibrated hall probe and derived from the rotating coil measurements.

As shown in the figure, the agreement is very good. A maximum peak deviation of 100 μT was observed; the obtained results are repeatable.

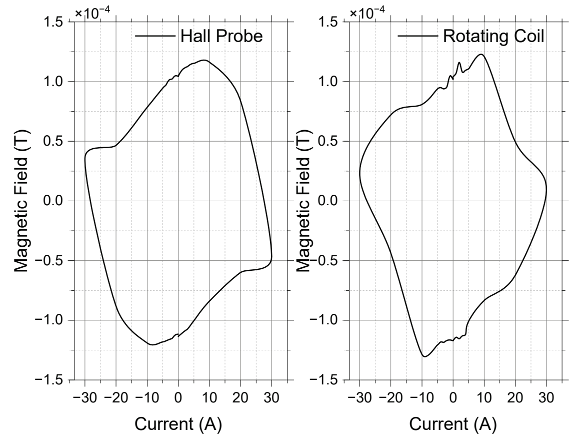

Figure 4: Deviation from Linearity. The left figure shows the hall probe result, the right figure the rotating coil result.

Measurement of Harmonics

Figure 5 shows the variation of the sextupole component for various currents and up to four cycles.

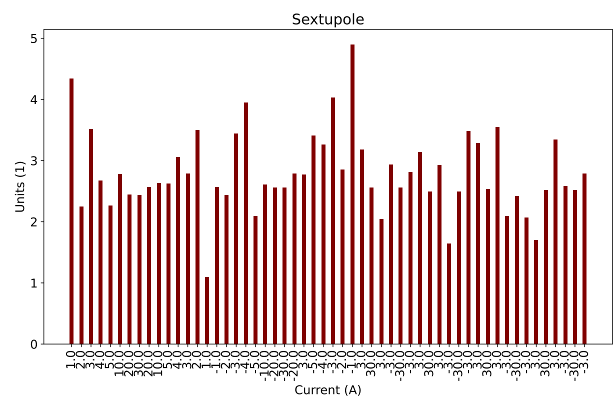

Figure 5: Variation of the sextupole component at select currents for four cycles.

As shown in the figure, the sextupole component changes with excitation current and also slightly for different cycles.

Figure 6 shows the variation of the octupole component for different cycles and excitation currents. Similar as for the sextupole component, a few units of variation depending on the cycle and current can be observed.

Harmonics after Demagnetization

Harmonics were also measured after an additional demagnetization cycle. The demagnetization cycle is shown in Fig. 7.

The measured sextupole and octupole component after the preceding demagnetization cycle are shown in Figs. 8 and 9.

As shown in the figures, the harmonics are more constant over a wider range, but the absolute change of the harmonic components is roughly similar.

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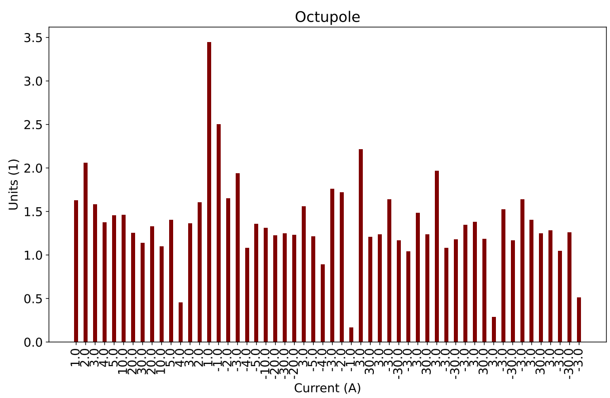

Figure 6: Variation of the octupole component at select currents for four cycles.

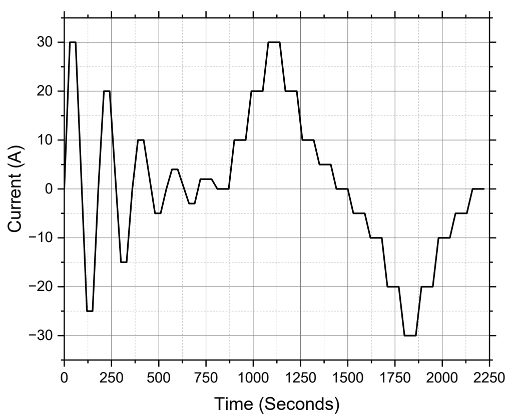

Figure 7: Demagnetization cycle.

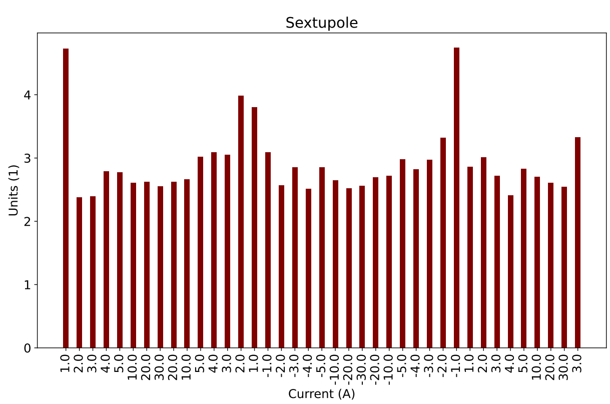

Figure 8: Sextupole component after demagnetization cycle.

CONCLUSION

A test dipole magnet was built to measure the harmonics at very low field levels. Due to the known variation in magnetic permeability at low field strengths a change in harmonics can be expected, which was verified in the tests. We observe a few units variation in the higher order harmonics

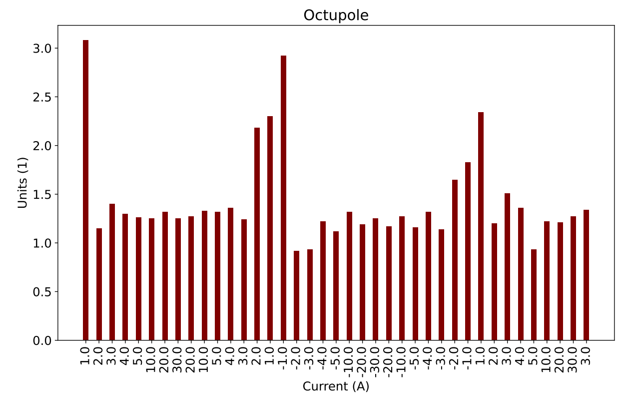

Figure 9: Octupole component after demagnetization.

(quadrupole up to dodecapole), which should be considered if magnets are used in this low field regime.

We plan to upgrade the magnet with coils with more turns, which would allow to measure harmonics between 5 and 250 mT, which is the range of the RCS dipole magnet.

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