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AUTOMATIC MEASUREMENT OF THE STRAY MAGNETIC FIELD IN THE RCS LOCATIONS OF RHIC BY USING THE SPOT ROBOT

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Abstract

The Electron Ion Collider (EIC) will collide high energy and highly polarized hadron and electron beams with luminosities up to 10^{34}/cm^2/s. In the Conceptual Design Report baseline scope, the electron beams, accelerated in the Rapid Cycling Synchrotron (RCS), are vulnerable to the outside magnetic field due to its low injection energy at 400 MeV. In addition, when the Hadron Storage Ring (HSR) and Electron Storage Ring (ESR) are in operation, the leaking field from the HSR might also affect the operation of RCS, because they are close to each other. Mapping the stray magnetic field throughout the Relativistic Heavy Ion Collider (RHIC) tunnel (will be used for EIC) is essential to assess its impact on potential low-energy electron beam injection. A robot dog (SPOT) is used to automate the measurement of this stray magnetic field during the RHIC (or future EIC) operation at any location continuously. This quadrupedal robotic technology can also be applied to other future applications, including radiation, temperature, pressure, and other properties measurement during EIC operation.

INTRODUCTION

In the conceptual design report (CDR) baseline scope of the electron ion collider [1, 2], the electron beams, accelerated in the Rapid Cycling Synchrotron (RCS) [3], are designed at the injection energy at 400 MeV. At this low energy, the dipole field in the ring is as low as 57 Gauss, the electron beams thus are very sensitive to the ambient magnetic field (1-2.5 Gauss could kick beam out of the pipe). In addition, the magnetic fields due to the Hadron Storage Ring (HSR) and the Electron Storage Ring (ESR) being at full energy could also affect the RCS operation. The magnetic field at the RCS locations of the Relativistic Heavy Ion Collider (RHIC) tunnel have been mapped entirely without operation [4]. Measuring the stray magnetic field during RHIC operation is important to study the effect of the HSR to RCS design, however, access is limited during the operation. Therefore, a robot is used to automatically measure the magnetic field without people access. The robot used is the "SPOT" from Boston Dynamics [5, 6]. Layout of the EIC at the conceptual design phase is shown in Fig. 1, where the dark blue is the RCS ring, the light blue is the ESR, and red is the HSR.

EXPERIMENTAL METHOD

The RCS location is shown at Fig. 2 by the representative design at interaction point (IP) 12, where the center is located about 40 cm from the tunnel wall and about 35 cm from the ground. For the rest section in the tunnel, the RCS locations are similar.

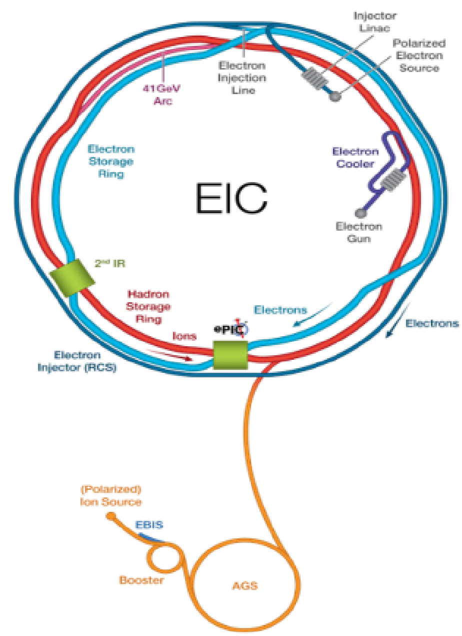

Figure 1: Layout of the EIC at the conceptual design phase. The dark blue is the RCS ring, the light blue is the ESR, and red is the HSR.

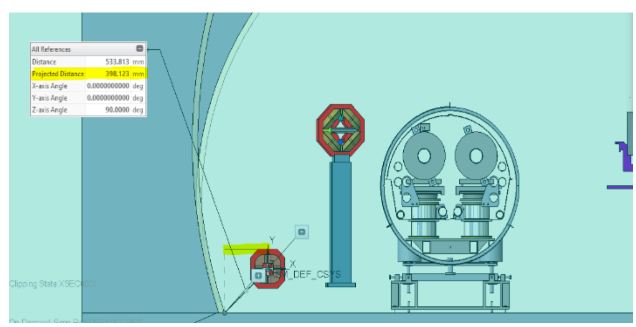

Figure 2: RHIC interaction point (IP) 12 layouts, where the lower left is the location of the RCS, the center is about 40 cm from the wall and 35 cm from the ground.

To automatically measure the magnetic field, the SPOT needs to map the route before RHIC operation. First, it reads the Fiducial as the initial position, shown in Fig. 3. Then, the SPOT moves back and forth (Fig. 4 and Fig. 5) using the remote controller based on the planned locations. The route is mapped and stored in the SPOT with the LiDAR technology [7]. After mapping the route, the superconducting magnets of RHIC are turned on after sweeping (no staff inside, but the SPOT is there).

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Figure 3: The SPOT in the RHIC tunnel to map the route, the barcode on the left is the Fiducial for the SPOT to recognize at the initial location. The magnetic sensor is placed on top of the SPOT.

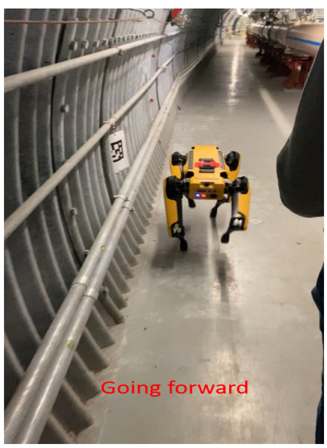

Figure 4: The SPOT goes forward in the RHIC tunnel.

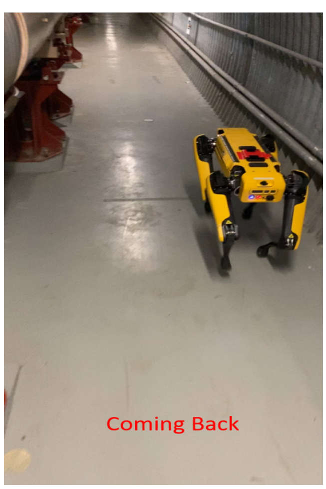

Figure 5: The SPOT comes back to the initial position (Fiducial) in the RHIC tunnel.

The SPOT will move following the mapped route automatically, and the magnetic field measurement is done during that time. The calibration of the magnetic sensor has been demonstrated in [5]. A camera is installed in the SPOT to let the user know where the SPOT is located during its movement, the SPOT is located at IR 10 to measure the magnetic field, as it is shown in Fig. 6, the position of the SPOT is monitored at the main control room, about one mile from the SPOT in the RHIC tunnel, connected through WiFi at BNL.

Figure 6: Sector 10 at the RHIC Tunnel outside radius.

RESULTS AND DISCUSSION

The superconducting dipole current is shown in Fig. 7, where the current is ramping from 500 A to about 5000 A in about 7 minutes, then the ~5000 A is kept for about 14 minutes for the SPOT to move back and forth three times. The magnetic field is measured during the 14 minutes.

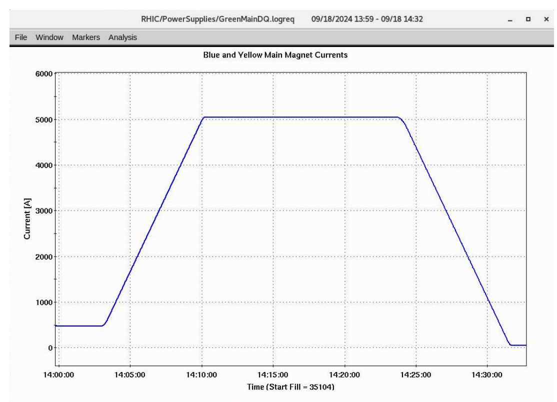

Figure 7: RHIC superconducting dipole current.

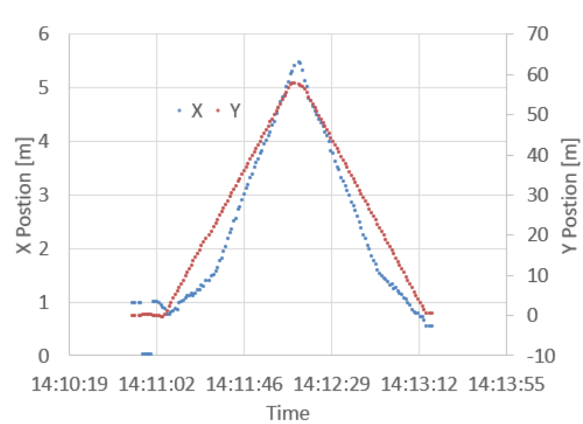

Figure 8: The X and Y position of the SPOT during RHIC magnets on, where Y position is the longitudinal direction, the SPOT walked about 60 m in one way, and X position is the horizontal cross tunnel direction.

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The transverse and longitudinal movement of the SPOT is shown in Fig. 8, where Y position is the longitudinal direction and X position is the horizontal cross tunnel direction. The measurement was performed at RHIC IR 10 arc location. Therefore, the X position also moves relatively to the initial Fiducial location.

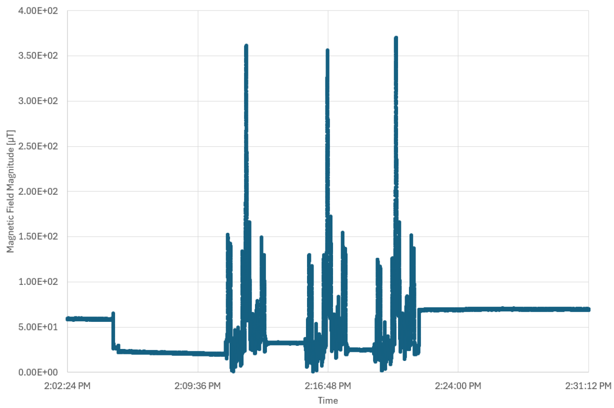

Figure 9: The measured magnetic field at the RCS locations of IR 10 during RHIC magnets on.

The measured magnetic field at the RCS locations at IR10 with time is shown in Fig. 9. At first, the SPOT is laying down, thus the magnetic sensor is closer to the ground, the measure magnetic field is slightly over 0.5 Gauss (50 µT), which is close to the earth magnetic field. Then the SPOT is turned on and started to be standing up, where the sensor is a little further from the ground, the measured field is around 0.25 Gauss. At around 2:11:00 PM, the SPOT starts to move along the mapped route, the measured field is changing with the time, with a maxi-mum of 1.5 Gauss. After walking for around 60 m, the SPOT turns around and walks back. The peak measured field at 3.5 Gauss is due to the sensor very close to the operating superconducting magnet during its head turning around. When the SPOT walks back, the maximum measured field is also about 1.5 Gauss. The measurement is repeated three times, as shown in Fig. 9 with measured peak field at 3.5 Gauss also repeated three times.

Table 1: Magnetic Field at RHIC Sector 10

Location	Magnets off	Magnets on
DU7Q5	0.48	0.62
D5	1.01	1.51
D5Q6	1.00	1.49
DU7	0.93	1.41
Q9	1.12	3.51

The comparison between the measured magnetic field at RHIC interaction region (IR) 10 with magnets off and on is shown in Table 1, where several locations at IR 10 is measured. DU7Q5 refers to the location between Dummy Magnet 7 and quadrupole 5, D5 is at the dipole magnet 5, and Q9 refers to the quadrupole 9. Overall, the fields with magnets on have higher values than that with magnets off, as shown in Fig. 10, due to the operational superconducting magnets at the blue ring, which is used to con-struct the HSR for EIC. The maximum measured magnetic field is about 1.5 Gauss, which might affect the RCS operation with 400 MeV injection. The new layout the EIC is shown in Fig. 10, where the ESR and HSR are still inside the RHIC tunnel, however, the RCS ring has been moved out from the tunnel due to its sensitivity to the ambient magnetic field and other effects. Another tunnel for the RCS will be built to accelerate the electron beams.

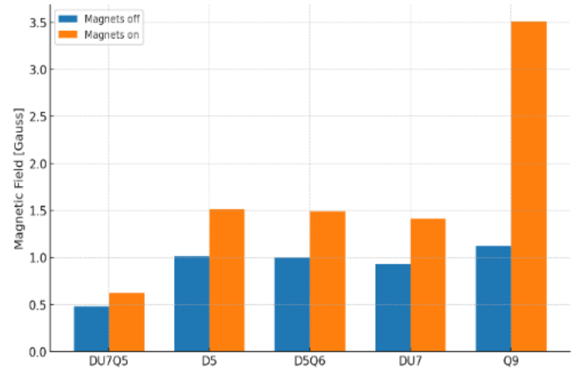

Figure 10: Comparison of the measured magnetic field with the HSR magnets on and off.

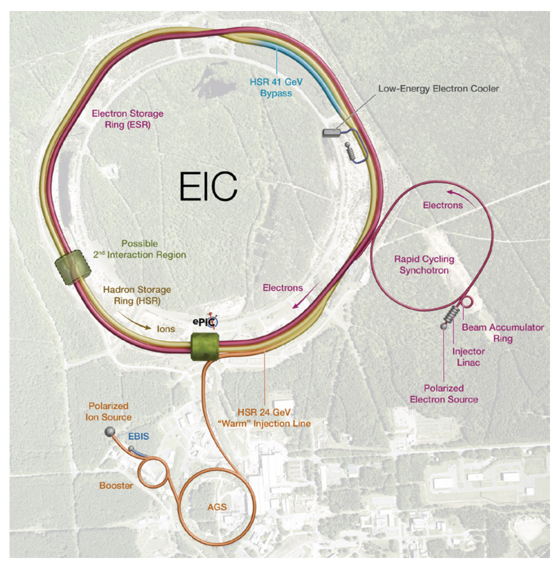

Figure 11: New layout of the EIC, where the RCS ring has been taken out of the RHIC ring.

CONCLUSION

The stray magnetic field at the RCS locations of the RHIC tunnel for the EIC conceptual design phase has been measured automatically using the robot SPOT at sector 10 with the superconducting magnets in the blue ring turning on. Measurements showed that the ambient magnetic field in the RHIC tunnel increases significantly when the superconducting magnets are powered, with peaks up to 1.5 Gauss at IR10 and localized maxima of 3.5 Gauss near the magnets. These values exceed Earth's field and could disrupt RCS operation at 400 MeV injection energy. Consequently, the EIC design has relocated the RCS ring outside the RHIC tunnel, as shown in Fig. 11.

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