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THE ELECTRON-ION COLLIDER HADRON STORAGE RING 10 O'CLOCK SWITCHYARD DESIGN

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Abstract

The Electron-Ion Collider (EIC) [1] Hadron Storage Ring (HSR) will be composed of the current Relativistic Heavy Ion Collider (RHIC) [2] yellow ring sextants with the exception of the 1 o'clock and the 11 o'clock arc. These two arcs use the existing blue ring inner (1 o'clock) and outer (11 o'clock) magnetic lattice for 275 GeV proton operation. The inner yellow 11 o'clock arc is used for 41 GeV energy operation. A switching magnet must be used to guide the hadron beam from the low and high energy arc respectively into the shared arc. This report provides the necessary lattice configuration, magnetic fields, and optics for the 10 o'clock utility straight section (USS) switchyard for both high and low energy while providing the necessary space allocations and beam specifications for accelerator systems such as an additional superconducting radiofrequency cavity and beam dump.

INTRODUCTION

The design of the EIC includes a newly designed electron storage ring (ESR) [3] capable of storing polarized electron beams with energy of 5, 10 or 18 GeV. A Rapid Cycling Synchrotron (RCS) will serve as the injector into the ESR. The RCS will ramp the electron beam from an energy of 400 MeV injection energy up to 18 GeV extraction. A 400 MeV linear accelerator will also be built as the pre-injector to the ESR. The HSR will have newly designed straight sections. The interaction point (IP) at the 6 o'clock location will have a 25 mrad full horizontal crossing angle. Injection will occur in the 4 o'clock USS [4], while the beam cooling systems will be in the 2 o'clock USS [5]. The 12 [6] and 10 o'clock USS will be the area for switching high and low configurations through the use of proposed normal conducting switching dipole magnets. We switch lines to create a shorter path length for the 41 GeV proton beam relative to the 100 and 275 GeV proton beams, so that orbit periods can be made the same at all energies to maintain synchronization with the electron bunches. We also radially shift the hadrons in the HSR arcs to increase or decrease the path length by applying a $\Delta B/B$ to the arc dipoles [7] to optimize the synchronization to the ESR. The 8 o'clock USS will be the location of another future experimental detector [8], which is not part of the current EIC scope.

10 O'CLOCK USS

The 10 o'clock USS will be composed of RHIC insertion quadrupoles with the dispersion matching section D9, Q9, D8, Q8, Q7, D6, Q6, and D5 where "D" designates a dipole magnet and "Q" a quadrupole. The number indicates the slot position decreasing towards the midpoint of the USS. Within the dispersion matching section in the D7 slot of sector 9, a helical dipole snake for spin preservation. The Q5 and Q4 doublet and the Q3, Q2, and Q1 triplet are located in their appropriate slots and are used for β function matching. The TQ6, TQ5, and TQ4 trim quadrupoles are used for additional β function correction. There are four γ transition quadrupoles in slots 6 and 8 for the outer beam line or 5 and 7 for the inner beam line. The RHIC DX magnets, the final beam crossing before collision, will be removed. A 5.2 m superconducting 591 MHz cavity (SRF) will be placed in the 10 o'clock USS. The cavity is half the HSR ring away from the copper warm cavities in the 4 o'clock USS due to the SRF cavities of the ESR and RCS also being in the 10 o'clock region.

The HSR 4.7 m dump will be an internal dump inside the tunnel but outside the vacuum which is designed to handle the a beam current of up to 1 A for protons and 0.57 A for Au^{+79} with a 290 to 1160 bunch train of circulating hadrons. The dump location is approximately 5 m upstream of the CQT cryostat which houses the TQ4 quadrupole. The dump is separated from the from the vacuum chamber by a Ti alloy window and carbon-carbon blocks. The entire assembly is surrounded by marble slabs. It has been suggested that a different Ti alloy window, an additional vertical kicker to distribute the beam more efficiently on the window, or an in vacuum beam dump. The latter negating the need to use a Ti alloy window [9].

The five module abort kickers are located 24 m upstream from the beam dump. An estimate of 5 kW heat load per beam dump is absorbed by the abort kicker CMD10 ferrites. An upgraded cooling system from the RHIC kicker cooling system will be necessary for the HSR.

The power supply shunting scheme is preserved for the insertion quadrupoles in the 10 o'clock USS. The 10 o'clock USS houses the return for the quadrupole circuit. The quadrupole main bus is located in the 4 o'clock USS. The two sides of the 10 o'clock USS are independently powered. The quadrupole gradients in the USS can only be varied over a limited range due to limitations of the nested power supply

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scheme shown in Figure 1. This places significant limits on our ability to match this section.

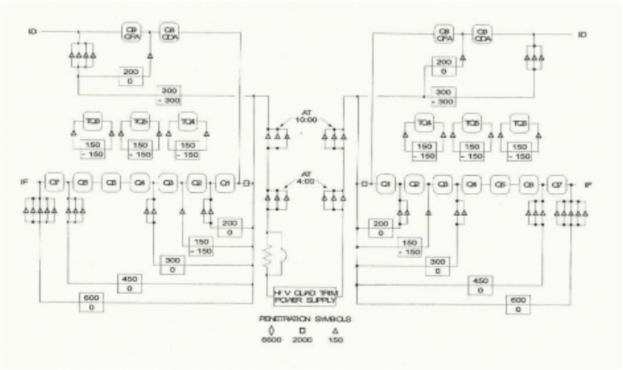

Figure 1: The shunt power supply scheme for RHIC insertion quadrupoles. The scheme will is also applied to the HSR.

Cold Dipole Configuration

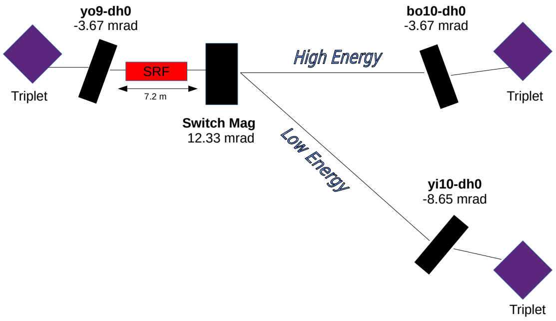

Figure 2: Cold dipole configuration. Purple squares: quadrupoles, black boxes: dipoles, red box: RF cavity. The hadron beam travels from right to left.

The cold dipole configuration for the 10 o'clock switchyard consists of the current RHIC configuration from the quadrupole of slot 10 (Q10) to the quadrupole of slot 1 (Q1) of the triplet magnets. Between the triplet magnets are the 3.69 m RHIC D0 dipoles, the SRF and immediately upstream of cavity is the warm 5 m switching dipole magnet. Figure 2 is a schematic of the cold dipole configuration.

The high energy beam, 41 GeV and greater, will enter a de-energized switching dipole and encounter zero field. The D0 magnets are curved with a 7.6 mm sagitta and an aperture of 100 mm. The upstream cold D0 dipole will need to be rotated about the z-axis by 180° to accommodate for the sagitta of the hadron beam. If the energy is below 41 GeV, the switching dipole will be energized to produce a 0.84 T magnetic field for Au^{+79}that will bend the beam at an angle of 12.33 mrad.

The optical design of the 10 USS preserves the RHIC triplet optics where at operating energies the β^* is 5 m in both planes due being to the shunt power supply range. In RHIC, the β^* is chosen as 5 m to move the nonlinear parameter α_1 closer to an ideal value of -1.5 [10]. The optics and dispersion curves are found in Figure 3. The magnet configuration for the high energy configuration is symmetric about the midpoint of the USS while the low energy configuration is anti-symmetric.

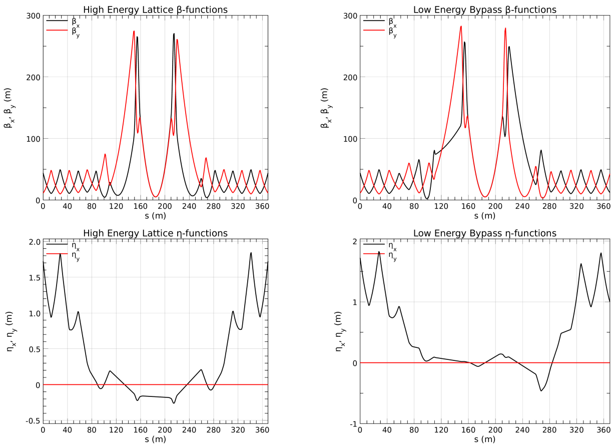

Figure 3: The β and η functions for two configuration using the RHIC cold D0 dipoles. The hadron beam propagates with decreasing s, right to left.

Warm Dipole Configuration

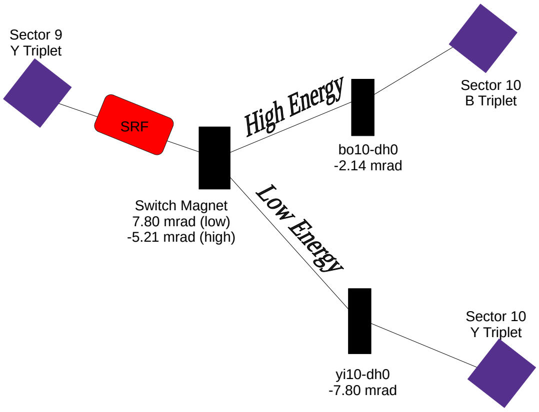

Figure 4: Warm dipole configuration. Purple squares: quadrupoles, black boxes: dipoles, red box: RF cavity. The hadron beam travels from right to left.

An alternative design of the 10 o'clock USS has been proposed using warm dipoles in place of the cold 3.69 m D0 magnets [11]. The warm D0 magnets have a length of 5 m. In addition to the replacement of the cold D0 magnets with warm magnets, the downstream D0 magnet will be removed. The SRF will remain immediately downstream of the switching magnet. Figure 4 shows the layout using the warm dipoles.

The removal of the downstream D0 forces the switching magnet to need a bend the beam at angles -5.21 mrad at high energy and 7.80 mrad at the lower energy. To compensate the upstream D0 magnets will need to bend at angle -2.14 mrad for the D0 of the high energy outer beam line and -7.80 mrad. Table 1 lists the magnet parameters of the cold and warm configurations.

Table 1: Switching and D0 magnets bending angles and strength for the cold and warm low energy (LE) and cold and warm high energy (HE) configurations. The low energy magnet parameter calculated with Au^{+79} species.

Magnet	Cold Angle (mrad)	Cold Field (T)	Warm Angle (mrad)	Warm Field (T)
Switch (LE)	12.33	0.84	7.80	0.53
Switch (HE)	0.0	0.0	−5.21	0.96
Outer D0 (LE)	−3.67	−0.35	–	–
Outer D0 (HE)	−3.67	0.94	−2.14	0.39
Inner D0 (LE)	−8.65	−0.82	−7.80	0.53

Similar to the cold D0 dipole configuration, the triplet optics are preserved. The missing dipole field has very little effect on the dispersion at the center of the USS since the dispersion suppression section of the original RHIC lattice, from D9 to D5, remains unchanged. Figure 5 shows the β functions and dispersion for the high energy lattice and the low energy bypass.

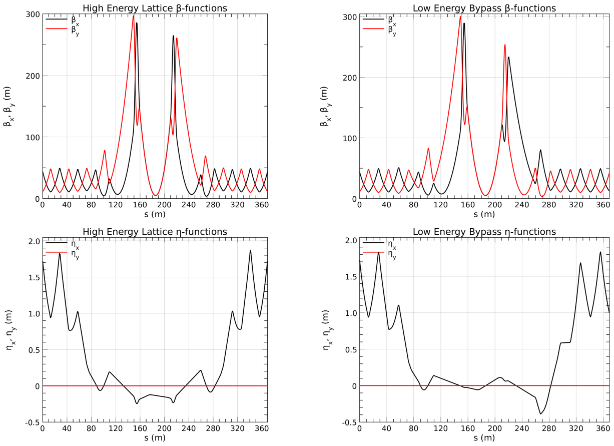

Figure 5: The β and η functions for two configuration using the warm 5 m D0 dipoles. The hadron beam propagates with decreasing s, right to left.

SUMMARY

The modifications necessary for the EIC HSR upgrade compared to the RHIC layout have been presented. The majority of RHIC will be preserved with the exception of the elements between the Q1 magnets of the lattice. An additional SRF cavity will be added to the 10 o'clock USS. Two different configurations were designed, one using 3.69 m cold dipoles and the other using the 5 m warm dipoles. A warm switching dipole is used in both configurations.

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