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CONCEPTUAL DESIGN OF THE ERHIC STORAGE RING MAGNETS*

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Abstract

Presently the electron-ion collider eRHIC is under design, which aims to provide a facility with a peak luminosity of 10^{34} cm^{-2}sec^{-1}. Part of the eRHIC accelerator is the addition of an electron storage ring to the existing tunnel.

This paper describes the magnets required for this storage ring. The necessary bending is provided by a triplet of dipole magnets, which generate excess bending to create additional radiation damping to allow a larger beam-beam tune shift. Each triplet consists of two long, low field magnets and a short, high-field magnet. This paper also describes the quadrupole and sextupole magnets necessary for this machine. All magnets require a large aperture to accommodate the beam-pipe.

INTRODUCTION

For eRHIC it is planned to add an 18 GeV electron storage ring to the 3834 m long RHIC tunnel. The lattice requires dipole, quadrupole and sextupole magnets, which are described in this paper. More information on the status of eRHIC can be found in [1].

In total 756 dipole magnets, 464 quadrupole magnets and 308 sextupole magnets are required for this storage ring. The next section discusses the design of the dipole triplet.

DIPOLE MAGNETS

The eRHIC storage ring employs a triplet of dipole magnets, called superbends, to provide the necessary bending. The triplets generate excess bending to create additional radiation damping to allow a larger beam-beam tune shift. Two of these magnets, labelled D1 and D3, are long low-field magnets. The D2 magnet, which is a short, high-field magnet, is located in between D1 and D3. The drift sections between the magnets are 0.15 m long each; the length was chosen to ensure that crosstalk between the magnets is not a concern; this was verified by simulations. The general arrangement is shown in Fig. 1.

The D1/D3 and D2 magnet designs are shown in Fig. 2. As shown in the figure, for both designs a c-core geometry is chosen to allow easy access and synchrotron radiation to escape naturally.

The D1/D3 transverse magnet size is smaller due to the lower magnetic field (0.25T vs 0.7T); less iron is necessary to return the magnetic flux and no special precautions are necessary to avoid saturation in the pole. Both magnets assume a gap size of 52 mm to accomodate the beam pipe. The pole width for each of the magnets is driven by three factors: the field quality requirement (1×10^{-4} in a horizontal region

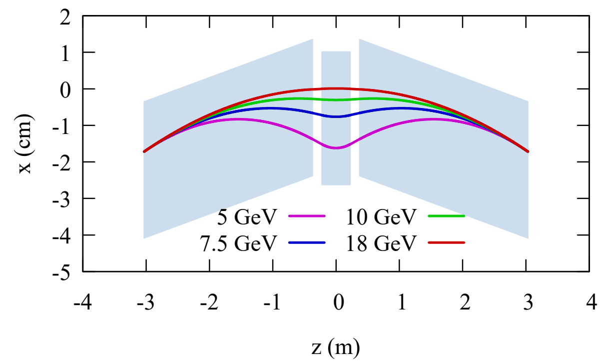

Figure 1: The dipole triplet superbends.

Table 1: Arc Dipole Magnet Specification

Parameter	D1/D3	D2	Unit
Magnetic length	2.6594	0.4449	m
Dipole field, min	0.1533	-0.7	T
Dipole field, max	0.248	0.248	T
Good field radius	0.016	0.016	m
Required field quality	1×10^{-4}	1×10^{-4}	
Weight iron	322	1010	kg/m
Gap height	52	52	mm
Power Loss	1162.5	5940	W/m
Cross-section conductor	40x50	47x65	mm^2
Current	5200	14053	A
Voltage	1.02544	0.6735	V
Magnetic energy	252	2390	J/m
Inductance	50	10.8	μH

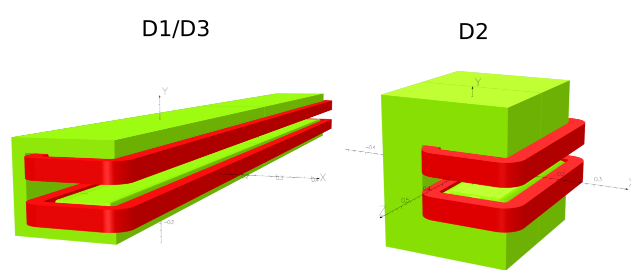

Figure 2: Magnet Geometries.

of ±16 mm), end effects (especially for D2) and saturation effects in the corners for the D2 magnet.

To avoid saturation effects the Rogowski profile or roll-off [2] is employed for the yoke ends and the pole shape of the D2 magnet.

To improve the field quality of the D2 magnet a notch is introduced to the pole end as shown in Fig. 3. The depth of the notch in combination with the transverse position allows to control the sextupole and quadrupole component of the

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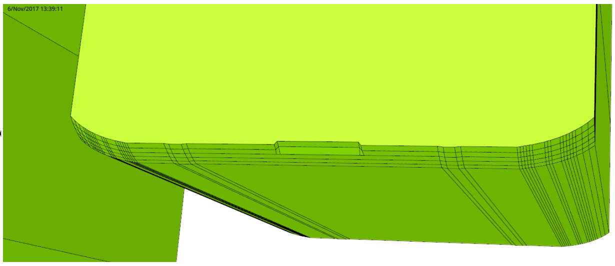

Figure 3: End chamfer of the D2 magnet.

ends, respectively [3]. The notch shown in the figure is 1 mm deep and shifted by 2 mm from the centre towards the backyoke of the magnet. Due to the Rogowski end-profile the saturation in the magnet ends does not exceed 1.5 – 1.6 T as shown in Fig. 4.

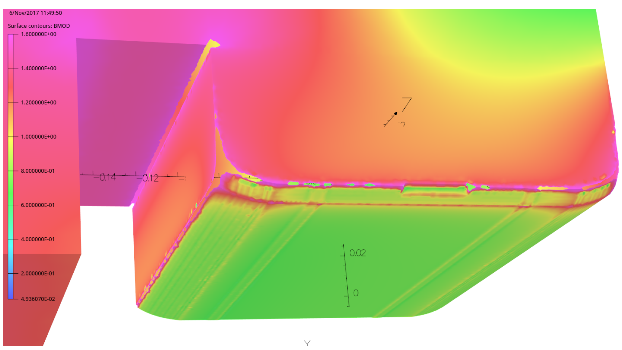

Figure 4: D2 magnet, magnetization.

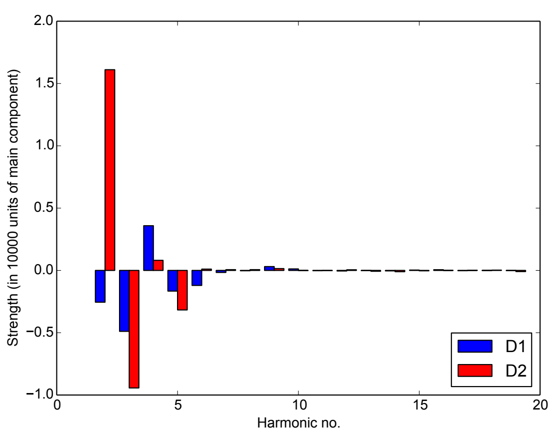

Figure 5: Higher order harmonics (real) of the D1 and D2 magnet (normalized to 10000 components of the main component).

The expected field quality was determined in a 3D non-linear finite element simulation using Opera[1]. The higher order harmonics for a reference radius of 17 mm are shown in Fig. 5. The figure shows the real harmonics; all skew components are zero.

[1] Cobham Technical Services, Network House, Langford Locks, Kidlington, OX5 1LH, Kidlington OX5 1GA, United Kingdom

As shown in the figure, the higher order multipole components are small; outside the radius of 17 mm the field quality deteriorates slowly. The field quality is within the specification up to ±20 mm of the aperture; for ±25 mm the field quality drops to 2×10^{-4}.

QUADRUPOLE MAGNETS

The focusing and defocusing quadrupole magnets for the eRHIC storage ring are very similar in their requirements; the required specification is shown in Table **??**. Due to the similarity of the gradient we propose a single quadrupole geometry which is suitable for both scenarios. Required is a quadrupole design which delivers about 18.4 T/m over a length of 0.6 m. A relatively large inscribed radius of 37 mm is necessary to clear the beam-pipe.

Table 2: Arc Quadrupole Magnet Specification

Parameter	Qf	Qd	Unit
Count	253	241	
Magnetic length	0.6	0.6	m
Gradient	18.1	-18.4	T/m
Radius good field	0.015	0.015	m
Required field quality	1×10^{-4}	1×10^{-4}	
Physical width	0.42	0.42	m
Physical height	0.42	0.42	m
Weight iron	784	784	kg/m

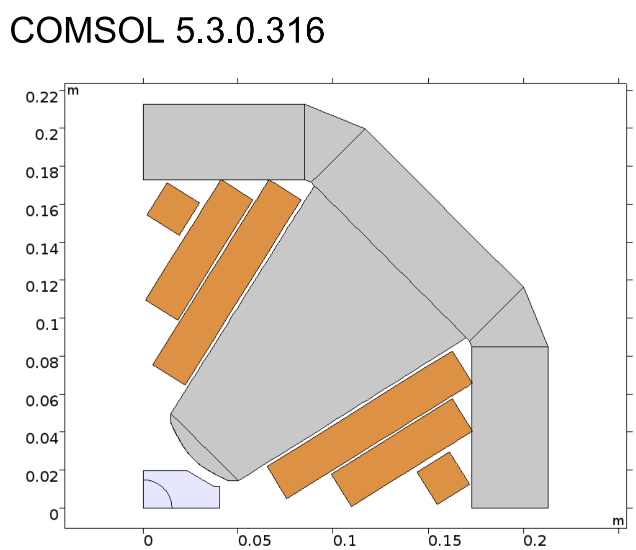

Figure 6: eRHIC Storage Ring Quad.

Figure 6 shows a cross-section of the quadrupole magnet design. The pole is moderately tapered which helps to decrease the magnetization; the pole itself is generally hyperbolical with chamfers at the corners in order to achieve the required field quality. The excitation coil is given as much space as possible which limits the power dissipation. The figure also shows the geometry of a possible beam-pipe, which clears the pole comfortably.

Figure 7 shows the yoke magnetization evaluated in a 3D finite element simulation. The yoke is designed to have a

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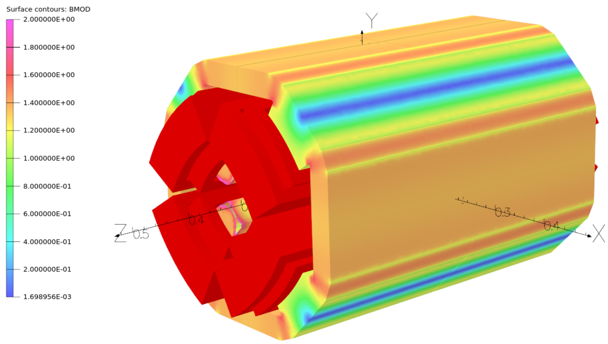

Figure 7: eRHIC Storage Ring Quad.

magnetization around 1.4 T at peak excitation. The maximum pole tip field is about 0.8 T. The higher order harmonics for an inscribed radius of 15 mm are shown in Fig. 8; the highest order multipole is the dodecapole with 0.15 units. The current density at peak excitation is 2.4 A/mm^2; the peak power dissipation is 3kW.

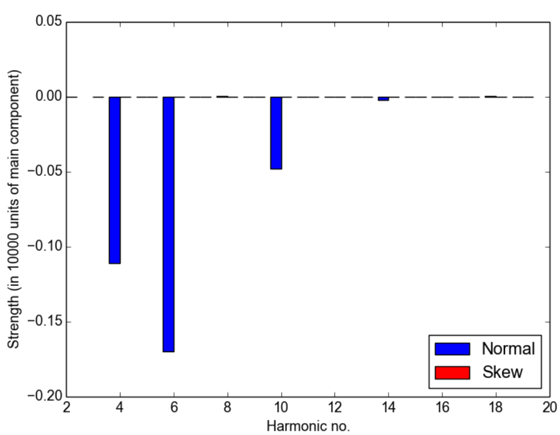

Figure 8: eRHIC Storage Ring Quad, higher order harmonics (normalized to 10000 components of the main component).

SEXTUPOLE MAGNETS

The sextupole magnets required for the storage ring have a magnetic length of 0.5 m. The required good field radius is 15 mm; to clear the beampipe the minimum inscribed pole radius is 40 mm. Figure 9 shows the geometry of the eRHIC arc magnet sextupole magnet, which can satisfy the field strength requirement of 480 T/m^2. The main parameters are summarized in Table 3; Figure 10 shows the calculated higher order harmonics.

CONCLUSION

This paper summarizes the design for the eRHIC storage ring magnets. All magnets show a good field quality in 3D simulations; the power dissipation is acceptable. Optimizations on the pole ends should improve the field quality further, which is planned for future studies.

Table 3: Arc Sextupole Magnets

Parameter	Qf	Qd	Unit
Magnetic length	0.5	0.5	m
Physical length	0	0	m
Physical width	0.36	0.36	m
Physical height	0.36	0.36	m
Weight iron	504	504	kg/m
Pole inscribed radius	40	40	mm

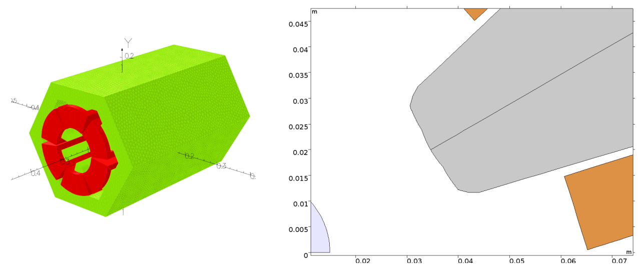

Figure 9: eRHIC storage ring sextupole geometry (left) and pole tip (right).

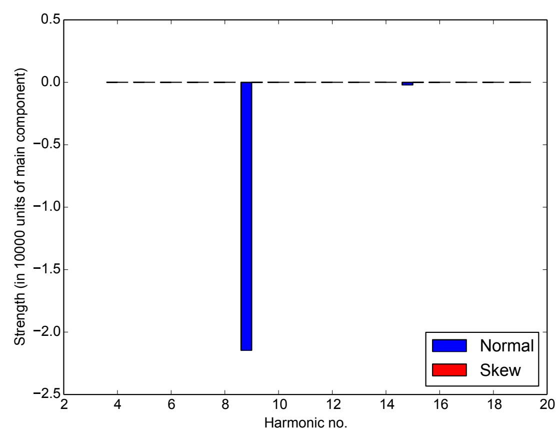

Figure 10: eRHIC Storage Ring Sextupole, higher order harmonics (normalized to 10000 components of the main component).

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