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IMPACT OF BEAM SCREEN EDDY CURRENTS ON TRANSITION CROSSING IN THE EIC HSR*

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Abstract

The Electron Ion Collider (EIC) hadron storage ring (HSR) requires a beam screen made of a 75 µm copper layer on top of a 1 mm thick 316LN stainless steel sheet. The eddy currents produced by the dynamic fields at the beam screens of the gamma transition jump quadrupoles will increase the field response delay. The field response curve depends on the thickness and Residual Resistivity Ratio (RRR) value of the copper layer. Manufacturing variances of thickness and RRR in the beam screens of the gamma transition quadrupole will result in different field response delays. This paper summarizes the expected impact of the beam screens on transition crossing and plans to verify their effects in Relatavistic Heavy Ion Collider (RHIC). From the varying delays, the β-wave and η-wave may exceed typical RHIC values. The effectiveness of the jump will be estimated using simulations of the existing RHIC lattice.

INTRODUCTION

The EIC project will require the building of an Electron Storage Ring (ESR) [1], the Rapid Cycling Synchrotron (RCS), a 3 GeV booster, and a 200 MeV linear accelerator (LINAC). These accelerators will be newly built in the existing Relativistic Heavy Ion Collider (RHIC) tunnel and will take a polarized electron beam from 200 MeV to 18 GeV. The hadron accelerator chain will include the 200 MeV proton LINAC, which contains the Optically Pumped Polarization Source (OPPIS) [2] that provides polarized beam. The Electron Beam Ion Source (EBIS) [3], will provide polarized $^{+}$3He and and un-polarized heavier ions. The Alternating Gradient Synchrotron (AGS) booster [4] and the AGS [5] are the injectors for the Hadron Storage Ring (HSR). The existing RHIC [6] will be use to build the HSR with significant modifications to the interaction region.

The EIC will address the fundamental questions of the subatomic world, such as [7]:

- What generates the mass of the nucleon?
- What gives the spin to the nucleon?
- What are the properties of dense gluonic systems?

by colliding the electron and hadronic beams at a maximum center of mass energy that will allow the probing of the gluon-dominated regime.

TRANSITION CROSSING

A particle in which the slippage, $\eta_s < 0$, is below transition while a particle with $\eta_s > 0$ is above transition transition.

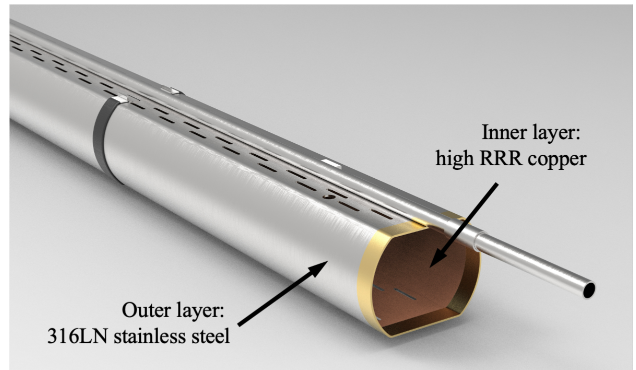

Figure 1: HSR beam screen before the amorphous carbon layer has been applied.

At transition, the slippage is zero and the beam suffers from a host of instabilities [8–10]. To mitigate the effect of transition crossing, the HSR will pulse 24 G family and 16 Q family quadrupoles to distort the optics of the lattice. The distortion will increase the dispersion in the arcs and lower the lattice γ_T value [11, 12]. This method is known as the First Order Matched (FOM) Scheme [13] and is currently implemented in RHIC.

THE HSR BEAM SCREEN

Motivation

The HSR will use the superconducting (SC) magnets from RHIC, including the gamma transition jump quadrupoles. The present cold bore of these SC magnets is a 316LN stainless steel tube which features too large impedance and too high secondary electron yield (SEY) for the high current beams that will circulate in the HSR. Every SC magnet will be updated with a beam screen made of a 75 µm copper layer on top of a 1 mm thick 316LN stainless steel sheet. The copper layer has high Residual Resistivity Ratio (RRR) for reduced impedance to the beams. The screen will be coated with few hundred nm thick amorphous carbon film with low SEY to suppress electron cloud formation [14]. The HSR beam screen in shown in Fig. 1.

Effect on Transition Quadrupoles

The eddy currents produced by the dynamic fields at the beam screens of the gamma transition jump quadrupoles will increase the field response delay. The field response curve depends on the thickness and Residual Resistivity Ratio (RRR) value of the copper layer. A round tube with electrically thin metallic walls embedded in a time-varying quadrupolar magnetic field $K_0(t) = K_0 \sin(\omega t)$ will shield

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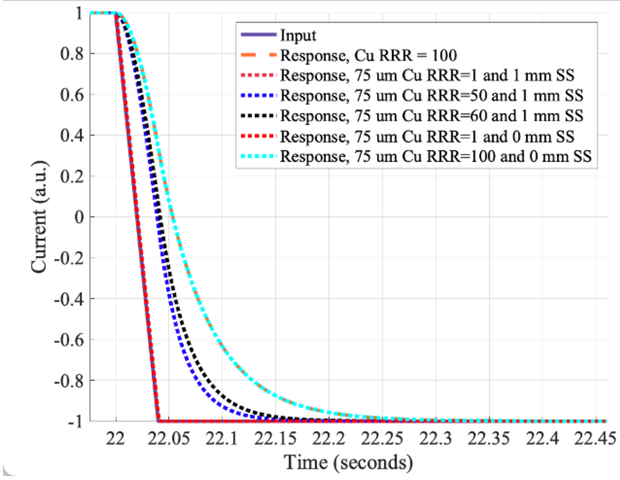

Figure 2: Dependence of field response on RRR and thickness of copper for a given external input field signal.

the field, with the resulting field inside the tube being:

$$K(t) = \int_0^\infty dt_1 K_0(t - t_1) \exp(-t_1/2\tau)/2\tau$$
$$= \frac{K_0}{\sqrt{1 + (\frac{\omega\tau}{2})^2}} \sin\left(\omega t - \arctan\left(\frac{\omega\tau}{2}\right)\right) \quad (1)$$

where $\tau = \mu_0\sigma_c bd/2$ is the time constant, μ_0 is the permeability in free space, σ_c is the electrical conductivity of the tube wall, b is the radius of the tube, and d is the thickness of the tube wall.

The beam screens delay the field response, as shown in Fig. 2 in function of the RRR and thickness of the copper layer (in the plot, RRR encompasses both as the time response is proportional to the product of both variables). Manufacturing variances of thickness and RRR in the beam screens for the gamma transition quadrupoles will result in different field response delays. While the timing of each power supply feeding each group of 4 gamma transition jump quadrupoles can be timed properly to ensure that the jump occurs within transition crossing, the jump will be effectively slower than the 40 ms established for RHIC [15].

RHIC APEX 24-13

Accelerator Physics EXperimental (APEX) beam studies in RHIC intend to evaluate the impact of the beam screens on the HSR's transition crossing. The results are important to assess if the baseline beam screen design enables successful transition crossing or if special screens with slots to damp the eddy currents need to be designed for the the gamma transition jump quadrupoles.

Method

The effect of the beam screens is mimicked by adjusting the timing of the different power supplies that feed each group of gamma transition jump quadrupoles. Figure 3 shows an example of how this method can reproduce the delayed field response introduced by the beam screens.

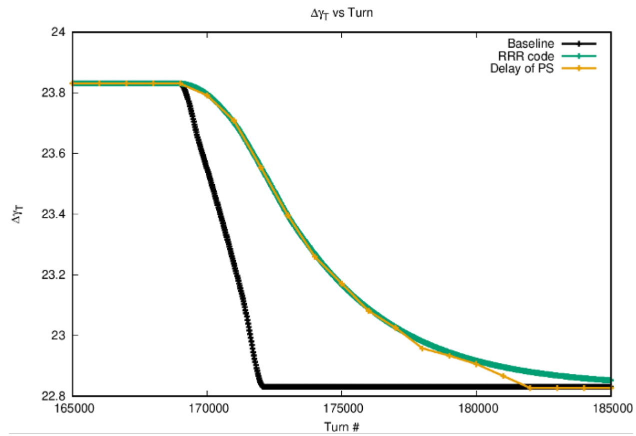

Figure 3: The field response of the gamma transition jump quadrupoles with and without beam screens is depicted by the green and black lines, respectively. The delayed transition crossing mimicked by proper selection of the timing at which different power supplies that feed each group of gamma transition jump quadrupoles is shown in orange.

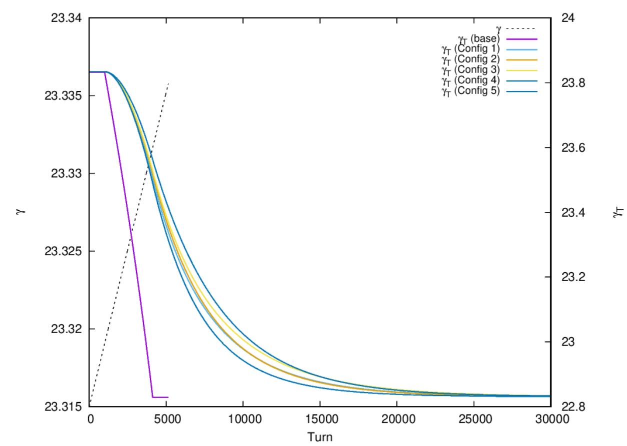

Figure 4: The change in γ_T with respect to the turn number from maximum absolute excitation to minimum. The dashed line is the Lorentz γ.

Simulation Results

The model is based on the RHIC Au20-31GeVlow optics. Using the Bmad toolkit [16], an energy ramp is generated in which the transition quadrupoles are ramp from the maximum absolute excitation to the minimum absolute excitation. The value of transition, along with the tunes are recorded and compared to the typical RHIC values. Figure 4 shows the change in γ_T with respect to the turn number. Transition occurs when the dash black curve intersects the solid curves, and it clear that transition is delayed due to the inclusion of the effect from the beam screens.

From the model, the field after transition is a concern. The relatively slow flip of the jump quadrupole field delays the return to the "safe" designed tune space of the lattice which is set as an anchor point or "stone" after the jump. Failure to predict carefully the time of the jump, or the tunes during

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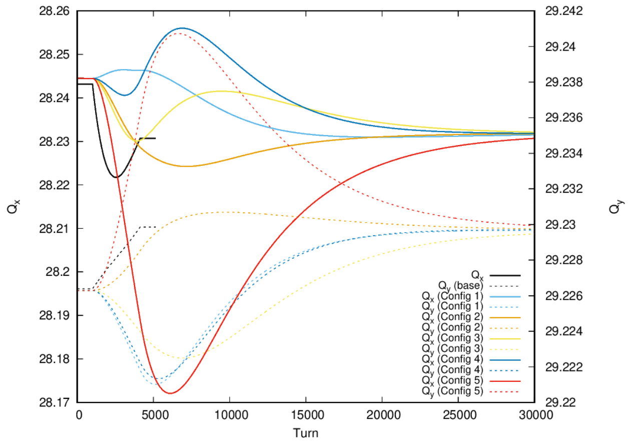

Figure 5: The tune change during transition for five different uniform random distribution of γ_T quadrupole beam screen thickness. The screen thickness is allowed to vary from jump quadrupole to jump quadrupole ±45%. The black solid and dashed lines show the expected results without the beam screens.

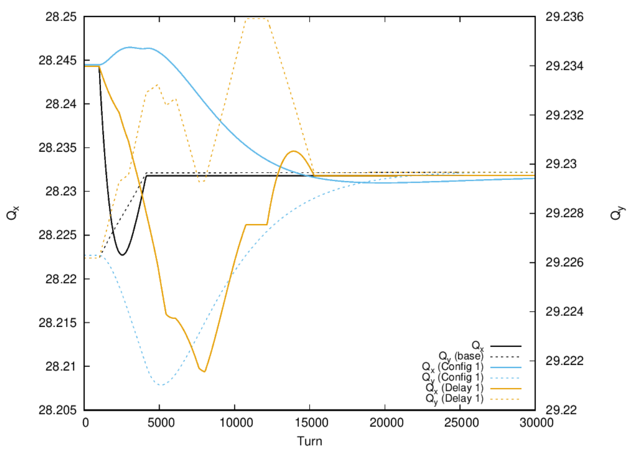

Figure 6: A comparison of tunes between the response expected from the beam screens and the cascading power transition jump quadrupole power supplies.

the jump will result in larger emittances and beam loss. Figure 5 shows the results of five configuarations of the jump quadrupoles where the thickness from jump quadrupole to jump quadrupole is allow to vary, over a uniform random distribution, ±45%. The tunes of the lattice in configuration 4 and 5 cross the 4^{th} and 5^{th} order resonances during the jump.

In RHIC, the 48 transition jump quadrupoles are grouped into twelve power supplies per ring. Each power supplies control four quadrupoles and the powers are further divided into two families. The one family, the G-family located in the arcs, control the transition of the lattice. The other, the Q-family located in the low dispersion are of the insertion region, compensates for the tune change generated in the arcs [13, 17]. This scheme is expected to be preserved in the EIC HSR [12]. The delay to the power supplies is applied to the G-family and Q-family of a sextant and empirically distributed to the other sextants. Figure 6 shows the result on the tune from delaying the jump of the transition quadrupole power supplies on the tunes. It is clear the 4^{th} and 5^{th} order resonance are not crossed.

SUMMARY

Fast transition crossing is critical to avoid beam losses and beam quality deterioration. The HSR screens will delay transition crossing. The proposed APEX study will evaluate the feasibility of transition crossing with the baseline screen design. A realizable experiment has been designed to acquire meaningful information for the EIC design.

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