ISBN: 978-3-95450-247-9
ISSN: 2673-5490
doi: 10.18429/JACoW-IPAC2024-MOPS22

RESISTIVE WALL HEATING AND THERMAL ANALYSIS OF THE EIC HSR BEAM SCREEN*

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Abstract

The Electron-Ion Collider (EIC) design is based on the existing RHIC complex. To mitigate electron clouds and beam instabilities in the Hadron Storage Ring (HSR) of the EIC, actively cooled beam screens are being designed for installation inside the stainless-steel vacuum chambers to operate around 10 K. One of the main concerns is the beam-induced heating caused by the resistive wall, particularly due to the large radial offset of the proton beam in the arcs, ranging up to ± 20 mm depending on energy. In this paper, we discuss the RW heating and thermal analysis of the EIC HSR beam screen. Our approach involves the insertion of a copper-coated stainless steel beam screen with cooling channels and longitudinal slots. We conducted a detailed thermal analysis, assessing piecewise RW losses around the beam screen's profile due to an offset beam, employing the 3D commercial code CST. The loss due to electron cloud are calculated separately. These losses, along with boundary conditions, were then integrated into another code, ANSYS, to determine the thermal distribution.

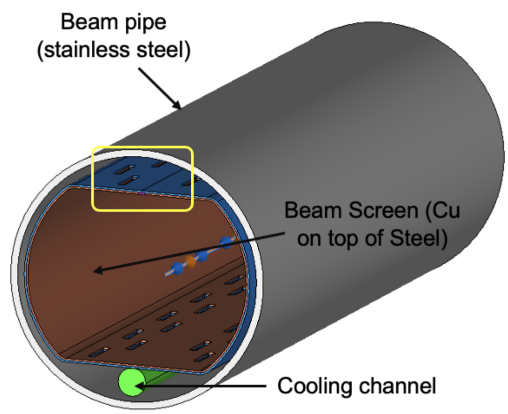
INTRODUCTION

The EIC [1–4] is designed to be built at Brookhaven National Lab in a closed collaboration with Jefferson Lab. EIC takes the advantages of existing Relativistic Heavy Ion collider (RHIC) complex to collide a polarized beam of hadrons with electrons. The EIC Hadron Storage Ring (HSR) will accumulate an average current of 0.69 A from 290 bunches with a 60 mm rms bunch length for the worst-case scenario in terms of resistive wall (RW) heating. In addition, the hadron beam undergoes a large horizontal offset, up to ± 20 mm [5], to synchronize bunch collisions with the electron beam. This large radial offset significantly increases the RW heating [6, 7]. In this paper, we primarily focus on the RW heating and thermal analysis of the EIC HSR beam screen. The papers on beam-induced heating and thermal analysis for other EIC vacuum components can be found in [8–11]. Our thermal analysis procedure entails computing heat loads from beam-induced RW loss and electron cloud effect. Subsequently, we integrate these results into ANSYS simulation to find temperature distribution.

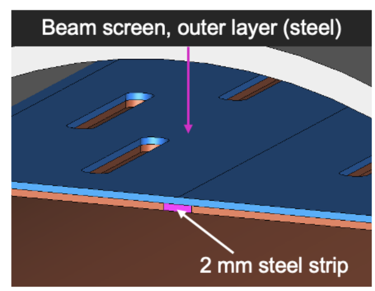
HSR BEAM SCREEN GEOMETRY

A complete geometry of the HSR beam screen integrating all it components such as longitudinal slots, cooling channel, and the outer jacket (beam pipe) is as shown in Fig. 1 (a). The beam screen has a race-track shape profile having the horizontal dimension of 64 mm and the vertical dimension of 50 mm. We plan to insert this screen into the RHIC beam pipe having the diameter of ~ 69 mm. The welding process of the beam screen exposes a thin longitudinal stainless steel strip (~ 2 mm wide) within the copper screen. Fig. 1 (b) depicts a magnified image of the complete geometry showing the 2 mm steel strip, which is placed opposite to the cooling channel. The actual beam screen has a copper plating on top of stainless steel, however for the simulation, we used thick copper to save computational resources.

The HSR beam screen's simplified geometry having a longitudinal steel strip (without slots) is depicted in Fig. 2.



(a)



(b)

Figure 1: (a) A CAD model of the HSR beam screen having inner copper layer (orange) and outer steel layer (blue) along with stainless steel beam pipe (grey), and helium cooling channel (green). (b) Magnified image of the top geometry (yellow rectangular section) showing the 2 mm wide steel strip opposite to the cooling channel.

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.
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Table 1: HSR proton beam parameters for the largest RW heating (also the highest center-of-mass energy)

Parameters	Value	Unit
RMS bunch length (σ_{rms})	60	mm
Average beam current	0.69	A
Charge per bunch (Q_b)	30.5	nC
Number of bunches (M)	290	NA
Beam Energy	275	GeV

Initially, we aimed to place this strip along the top flat surface (see Fig. 2 (a), right). However, the vendor initially rejected this idea, assuming fabrication complexities. They proposed placing the strip on the curved wall, positioned 11 mm below the flat top (see Fig. 2 (a), left).

Since the HSR beam undergoes large radial offset [5], the RW loss on the steel strip is notably high due to its proximity to the offset beam indicated by the dark blue curve in Fig. 2 (b). Consequently, we proposed relocating the strip closer to the corner between the flat top and curved surfaces. The vendor agreed to adjust the strip's position, moving it up to a point 6 mm below the top surface. After this adjustment, they now feel confident in fabricating the beam screen with the steel strip positioned on the flat top surface, as shown in Fig. 2 (a), right.

We compared the RW loss on the stainless steel strip across the three locations, see Fig. 2 (b), with the beam parameters listed in Table 1. These parameters produces the highest RW heating. Comparison showed the lower RW heating for the horizontal beam offset greater than 12 mm, when the strip is positioned at the flat wall (green curve in Fig. 2 (b)). However, for beam offsets less than 11 mm, losses are higher on the strip. Given that the EIC typically involves hadron beam offsets exceeding 10 mm, placing the strip at the center seems advantageous.

After finalizing the strip location on the beam screen, we performed simulations for the complete geometry, Fig. 1. Heating on the beam screen geometry is mainly due RW loss, and the electron cloud effect which we discuss separately in the following sections.

RW HEATING

We evaluated the RW loss for the HSR beam screen (copper) using the beam parameters listed in Table 1 for the beam having horizontal and vertical beam offsets of 23 mm (20 mm offset and additional 3 mm due to the mechanical tolerance of the bellows), and 2 mm (due to beam oscillation at the injection) respectively for the worst-case scenario. Because of the offset beam the RW losses are highly asymmetric. Therefore, we calculated the piece-wise loss, Fig. 3 to perform more reliable thermal analysis. For the piece-wise evaluation, we sliced the beam screen into 18-pieces, each of which subtends 20° at the center. The piece-wise loss showed that the piece near the beam receives the highest

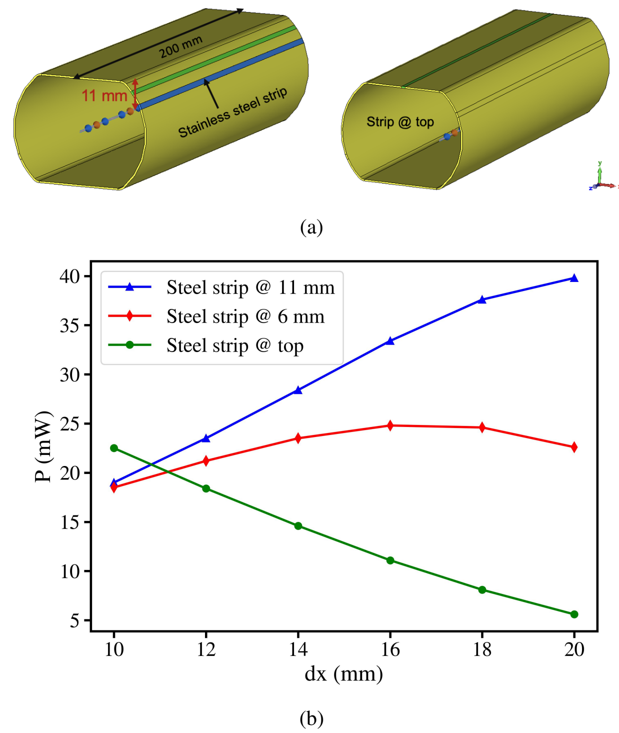

Figure 2: (a) HSR BPM screen geometry (without longitudinal slots) showing the stainless steel strip on the curved wall (left), and top flat (right). (b) RW loss comparison for the strip with horizontal beam offset across three different locations.

amount of loss. The RW loss on the outer layer (steel) of the screen and the cooling channel is in the order of micro-watts, and hence we neglected for thermal analysis.

After evaluating RW losses, we scaled them to cryogenic temperature by including the effect of residual resistance ratio (RRR = 10 for copper), magneto-resistance effect (MR), and anomalous skin effect (ASE). Figure 3 (b) depicts the variation of the RW loss per unit length with horizontal and vertical offsets at the dipole (arc) section of the HSR. The detailed calculation of the RW loss and the impedance on the HSR beam screen can be found in [6, 12].

ELECTRON CLOUD HEATING

Electron cloud formed inside the beam screen is another source of heat, if not properly suppressed. Figure 4 shows a typical heat load due to electron cloud with the horizontal beam offset for various Secondary Electron Yield (SEY) values. The maximum heat load due to electron cloud is at the center of the vacuum chamber, and decreases with the horizontal beam offset. The detailed loss calculation due to electron cloud is reported in Ref. [13]. We plan to suppress the loss due to electron cloud by amorphous carbon (aC) coating on copper. Thus, the HSR beam screen involves three layers; amorphous carbon, copper, and stainless steel.

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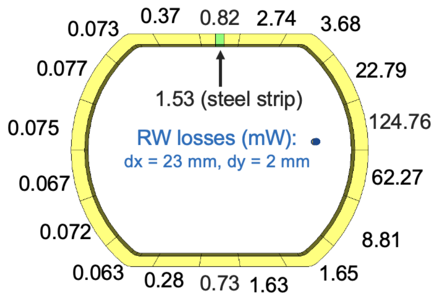
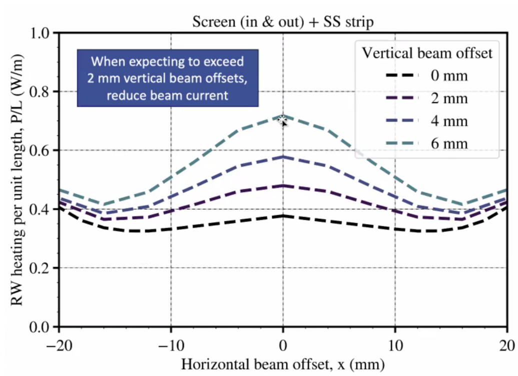


(a)



(b)

Figure 3: (a) Piece-wise RW loss (mW) around the copper beam screen profile with a length of 100 mm due to the worst-case beam offsets: horizontal offset dx = 23 mm and vertical offset dy = 2 mm. (b) Total RW loss per unit length with horizontal and vertical beam offsets.

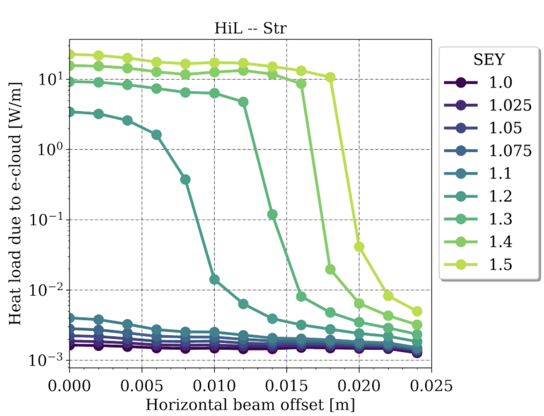
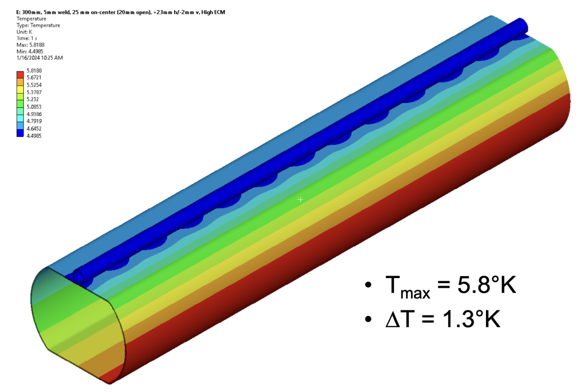


Figure 4: Heat load due to electron cloud formation by the highest luminosity beam for no field section of the nominal profile (from Ref. [13]).

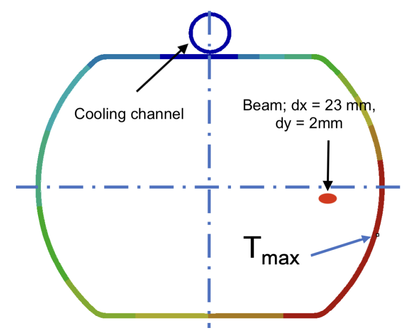
The thin layer (~ nano-meters) of the aC coating on copper showed a negligible effect on the RW heating.

THERMAL ANALYSIS

Thermal analysis for the HSR beam screen is performed with the incorporation of heat load contribution from the



(a)



(b)

Figure 5: Thermal distribution around the beam screen profile due to the worst-case beam offsets: horizontal offset dx = 23 mm and vertical offset dy = 2 mm. (b) The same thermal distribution with cross-sectional view to depict the maximum temperature location. Here, the beam screen geometry is turned over to show the cooling channel.

both RW loss and electron cloud into ANSYS code for the worst-case beam offsets. We chose a conservative value of SEY = 1.1 for the beam screen having aC coating on top of copper. With proper aC coating, study showed that the SEY value can be reduced even below one. For the heat extraction, we circulated liquid helium at the temperature of ~ 4.5 K via cooling channel of the screen. Simulation showed the maximum temperature on the beam screen is 5.8 K near the beam Fig. 5. The cross-section of the beam screen showing this maximum temperature and thermal analysis is shown in Fig. 5 (b). We are aiming to keep the screen's temperature below 10 K though we can tolerate up to 30 K in the small localized region like BPM button.

SUMMARY AND FUTURE WORKS

In this paper, we reported the beam-induced heating and thermal analysis for EIC HSR beam screen. The thermal analysis of the HSR beam screen showed a maximum temperature of 5.8 K for the beam with horizontal beam offset of 23 mm and the vertical beam offset of 2 mm. We will continue the heating and thermal analysis for other EIC components in the future.

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REFERENCES

[1] Electron-Ion Collider. `https://www.bnl.gov/eic/`

[2] C. Montag *et al.*, "The EIC accelerator: design highlights and project status," presented at IPAC'24, Nashville, TN, USA, May 2024, paper MOPC67, this conference.

[3] C. Montag, E. C. Aschenauer, *et al.*, "Design Status Update of the Electron-Ion Collider," in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 2585–2588. `doi:10.18429/JACoW-IPAC2021-WEPAB005`

[4] F. Willeke and J. Beebe-Wang, "Electron Ion Collider Conceptual Design Report," 2021. `doi:10.2172/1765663`

[5] S. Peggs *et al.*, "Large Radial Shifts in the EIC Hadron Storage Ring," in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 1443–1446. `doi:10.18429/JACoW-IPAC2021-TUPAB042`

[6] S. Verdu-Andres and M. Sangroula, "Beam-induced heat deposited in the eic hsr screens," Brookhaven National Lab.(BNL), Upton, NY (United States), Tech. Rep., 2023.

[7] S. Verdu-Andres, "Beam-impedance consideration for the eic hsr screen," Brookhaven National Lab.(BNL), Upton, NY (United States), Tech. Rep., in preparion.

[8] M. P. Sangroula *et al.*, "Localized Beam Induced Heating Analysis of the EIC Vacuum Chamber Components," in *Proc. NAPAC'22*, Albuquerque, NM, USA, 2022, pp. 833–836. `doi:10.18429/JACoW-NAPAC2022-WEPA85`

[9] M. Sangroula *et al.*, "Beam Induced Heating Analysis Update for The EIC Vacuum Chamber Components," Brookhaven National Laboratory (BNL), Upton, NY (United States), Tech. Rep., 2023.

[10] F. Micolon, D. Gassner, C. Hetzel, I. Pinayev, M. Sangroula, and S. Verdu-Andres, "Thermal simulation of the HSR arc BPM Module for EIC," Brookhaven National Lab.(BNL), Upton, NY (United States), Tech. Rep., 2023.

[11] M. Sangroula *et al.*, "Update on the beam-induced heating and thermal analysis for the EIC vacuum chamber components," presented at IPAC'24, Nashville, TN, USA, May 2024, paper MOPS21, this conference.

[12] S. Verdu-Andres and M. Sangroula, "Beam-induced Heat Deposition in the EIC HSR Screen," Brookhaven National Lab.(BNL), Upton, NY (United States), Tech. Rep., 2023.

[13] S. Verdu-Andres, "Electron cloud thresholds at the arcs of the Electron-Ion Collider hadron storage ring," Brookhaven National Laboratory (BNL), Upton, NY (United States), Tech. Rep., 2023.