Thermal engineering of the beam position monitors for the EIC hadron storage ring


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Outline

• The EIC project
• Need for this study
• System integration
• Heating sources
• Analysis results
• Conclusion
The EIC project

- The **Electron-Ion Collider (EIC)** is a project of collider using electrons to probe the hadrons nucleus

- Design based on **existing RHIC Complex in BNL** (NY, USA)

- **Hadron Storage Ring (HSR)** 40-275 GeV
  - Superconducting magnets and cryogenic infrastructure reused
  - 1160 bunches, 1A beam current (3x RHIC)
  - strong hadron cooling

- Two electron - accelerating and storage - rings will be added to the RHIC tunnel
Need for this study

A thermal analysis of the HSR BPM design was made with the following aims:

- Making sure the BPMs cable will not overheat and be a limitation to the operation of EIC (it was considered an - unexpected - bunch intensity limit for RHIC)

- Making sure the temperature reached by the button will be compatible with operation

- Making sure the added heat to the cryogenic systems would be within budget
System Integration
System Integration

- RHIC magnet interconnect (dipole – CQS)
- Magnet helium lines
- New button BPM x4
- Decommissioned RHIC BPMs (shielded)
- Signal cables heat intercept block
- BPM signal cryo cables x4
- Cryostat feedthrough
New HSR interconnect module planned for EIC
Sources of Heat
BPM Heating

**Thermal conduction through signal cables**
The cryostat feedthroughs are kept ~293 K by tunnel air convection
The cryostat heat shield is kept at 50 – 80 K by circulation of supercritical helium
The magnets will be kept at 4.5 K by circulation of supercritical helium

**RF signal propagation along BPM cables**
The propagation of the RF signal along the BPM cable will produce some resistive and dielectric heating

\[
\frac{dx \cdot \sqrt{f \cdot \rho_{i,e}(T)}}{r_{i,e}} \cdot \int i^2 \cdot dt + P_{RF} \cdot \left(1 - 10^{\frac{-\alpha \cdot dx}{10}}\right) - k(T) \cdot S_{i,e} \cdot \frac{dT}{dx} = 0
\]

- **Resistive heating**
- **Dielectric heating**
- **Conduction**

**Beam resistive wall heating and electron clouds**
The propagation of the beam wall image current on the beam chamber walls and beam-induced electron clouds will produce some heating on the pickup.
Buttons and inner conductors are well insulated. Electrically, and thermally as a byproduct.
BPM signal

EIC will operate with a radial offset of the hadron beam. This will bring an asymmetrical heating of the BPM buttons and cables.
Analysis results
What is the maximum allowable temperature?

The beamline UHV needs to be preserved.

The pickups have a aC coating to avoid e- clouds, this acts as an adsorber for residual gases.

From the amorphous carbon TDS, H$_2$ desorption will start past 40 K.

→ We will strive to stay below 40 K of beam wall temperature.

Figure 1: TDS for H$_2$, N2 and CO measured for a-C coating as a function of $\theta_0$ and $\beta$.

The button temperature is below 40 K in all cases. This will be low enough to avoid significant H₂ desorption.
Conclusion

• Engineering analysis of the new HSR button BPM has been carried out in 2023

• Although close to the limit in button temperature and cable attenuation the design is found satisfactory.

• Dedicated tests will be done to validate the thermal conduction and RF heating of the cable.
Happy to take questions !
The 0.090” is more susceptible to attenuation variations. However, in the voltage range expected, the attenuation is still stable for both cables.
Heat intercept design

Distortion by squeezing the cable will bring unwanted signal reflections

→ We have designed a heat block assembly to limit the maximum squeezing force
Heat block intercept design

Animation of the normal radial stress at the interface cable/heat block
Possible Coax Cryo-Cable Options

The plan is to use rigid coaxial cables with a low density SiO$_2$ dielectric material.

The inner conductor will be bulk copper. The outer conductor will be a stainless-steel jacket with an inner copper coating.

Compared to the current RHIC BPM cables:
- ~3x bigger thermal conductivity for the 0.141” cable
- ~lower thermal conductivity for the 0.090” cable

However the RF attenuation is expected ~1.5x higher with the 0.090” cable.
• More details on the simulation and results can be found in the BNL technical note published earlier this year:

https://www.osti.gov/servlets/purl/1969913
Copper Electrical Resistivity

Assumption for Cu conductivity = $5 \times 10^8$
Impact on Vacuum

Figure 1: TDS for H₂, N₂ and CO measured for a-C coating as a function of θ₀ and β.

Desorption of gas from an aC coated surface vs temperature - Source: R. Salemme et al. [Link]

**Fig. 7:** Saturated vapour pressure curves as a function of the temperature [13, 40, 41].

From V.Baglin [lecture on cryopumping](link)
BPM Feedthrough Temperature

A measurement campaign with thermocouples on the BPM feedthrough has started this year to validate the temperature of the warm end.

During the cold fill the feedthrough temperature has not evolved.