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CONCEPTS AND DESIGN FOR BEAMLINE HOM DAMPERS FOR eRHIC*

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Abstract

In the design of eRHIC at BNL, HOM power plays a major role for the SRF installation. Depending on the final accelerator design and choice of cavity, up to 100kW of HOM power is estimated to be generated, presenting a big challenge for the HOM damping concept. Due to this high amount of HOM power, all current concepts for eRHIC would use room temperature beam line absorbers equipped with silicone-carbide dielectrics to absorb HOM power. Concepts, designs and simulations for these beam line absorbers will be presented.

INTRODUCTION

eRHIC is an electron-ion Collider proposed by the Collider-Accelerator Department at Brookhaven National Lab. The goal is to collide polarized electron with an energy form 5 to 18 GeV with the polarized proton beam from RHIC. For this a new electron accelerator will be build in the existing RHIC tunnel.

Two concepts for the electron accelerator are being considered. The Linac-Ring (LR) version [1] uses an Energy Recovery Linac (ERL) to accelerate the electrons up to collision energy and after collision decelerate them to recover their energy and drive the Linac. The Ring-Ring (RR) version [2] uses an recirculating Linac to inject the beam into a storage ring to collide with the ion beam. Both concepts will use SRF technology in their respective RF cavities. The LR eRHIC will use 647 MHz five-cell cavities and the RR-eRHIC 563 MHz two-cell cavities. In both concepts, room temperature beam line absorbers will be utilized to extract HOM power. In addition, the LR-cavity will have waveguide HOM dampers to extract power [3,4]. The absorber will be made out of silicone carbite (SiC), similar to the absorber used in Cornells ERL [5] and ANL APS upgrade [6]. The mechanical design of the beam line absorbers for both LR and RR is set to follow the ANL path with shrink-fitting the SiC into a copper sleeve with water cooling channels.

LINAC-RING

In the Linac-Ring (LR) (schematical layout can be seen in Fig. 1), concept of eRHIC a 1.67 GeV/turn ERL accelerates the beam up to its collision energy. The 647 MHz five-cell cavity will operated at a cw gradient of 16 MV/m. Since the straight section in the tunnel is limited to 200 m, the

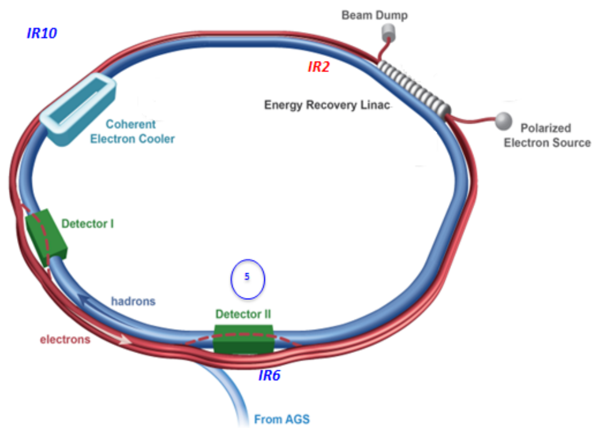

Figure 1: Layout for the Linac-Ring eRHIC with the existing "blue" hadron ring and the electron ring in red. The SRF Linac is located at IP2.

real estate needs to be conserved. For this reason most of the HOM power is extracted away from the beamline via waveguides with a SiC termination [7]. The rest of the HOM power is extracted with warm beam line absorbers between cryomodules. The cavity is designed with a beam pipe diameter of 104 mm, resulting in a cutoff frequency for TM01 modes of 2.2 GHz. As the bunch spectrum peaks at $n \cdot 2 \cdot 647$ MHz, the HOM power peaks at these frequencies too. The absorber is therefore optimized for frequencies around

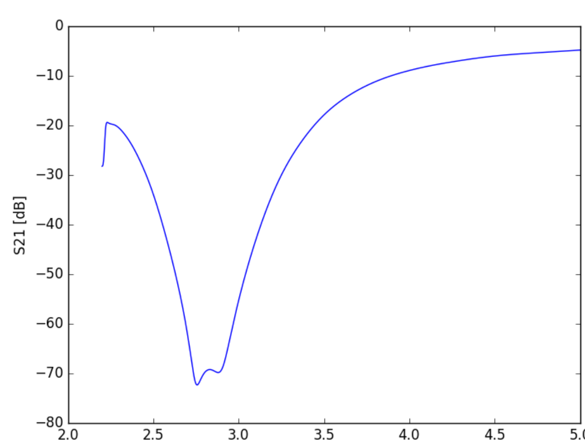

Figure 2: Tranmission simulation for the LR beam line absorber with a resonance around 2.7 GHz to cover the peak in bunch spectrum power.

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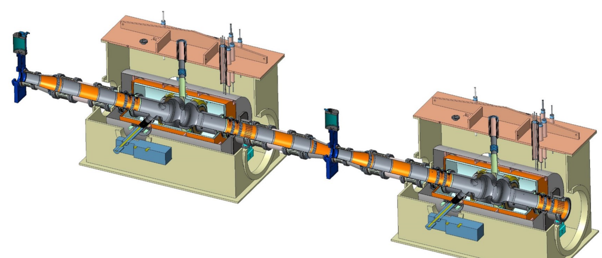

Figure 3: Conceptual drawings of the Ring-Ring eRHIC cryomodule assembly. The 2cell cavity is surrounded by a 500mm long warm-cold-transition with bellows (orange), followed by the first absorber, a section of beampipe, the second absrober and a downtaper section to a gatevalve.

2.6 GHz by using S21-transmission simulations. In these simulation a resonance can be found where the transmission is significantly lower. This depth of the resonance depends on the length of the dielectic while the frequency depends on the thickness of the dielectric. For a beampipe diameter of 104 mm, a thickness of 5 mm and lenght of 300 mm results in a transmission below -30 dB from 2.46 to 3.25 GHz. As can be seen in Fig. 2 from the cutoff frequency to 2.46 GHz the transmission is below -20 dB, providing sufficient absorbtion for HOMs.

The ANL mechancial design of their beam line absorbers is very compact as the dielectric reaches from flange to flange compared to other designs. This is helpful in preserving the real estate of the Linac as this is scarce resource in the Linac-Ring design.

RING-RING

The ring-ring (RR) eRHIC uses a high current storage ring to collide the electrons with the heavy ions instead of the ERL in the LR option. This ring will be fed by a pulsed (1 Hz) Linac based on 647 MHz SRF cavities. Since the repetition rate is so low, only a small amount of HOM power is expected and the focus of development is put on the storage ring cavity, which is expected to produce a high amount of HOM power, up to 70 kW. For the storage ring, two luminosity scenarios are planned: a medium luminosity scenario with a bunch repetition rate of 28 MHz and a maximum bunch charge of 50 nC and a high luminosity scenario with a repetition rate of 112 MHz and a bunch chare up to 25 nC. Both scenarios operate with a σ_z = 8 mm long bunch. At the time of writing, a two cell elliptical cavity operating at 563 MHz is being considered to deliver up to 670 kW of RF power to the beam to compensate for syncrotron radiation losses. At a beam energy of 18 GeV, 15 cavities are operated at a voltage up to 4.16 MV. The use of a multicell cavity for the storage ring reduces construction, installation and operating costs compared to a single cell cavity in addition to preserving RHIC IR real estate. The current concept for HOM damping utilizes room temperature beam line absorber to extract HOM power. The absorber follow a similar design as in the LR case and are made out of the same SiC. The

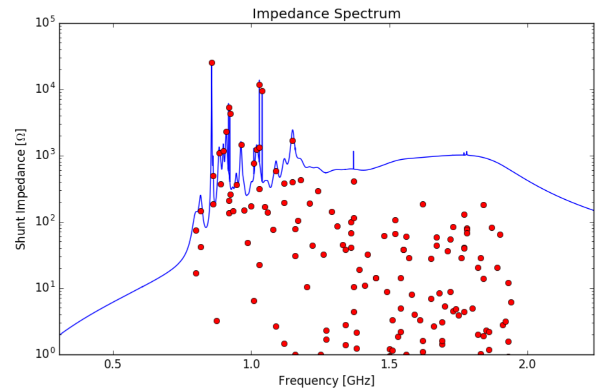

Figure 4: Eigenmode impedance results (red dots) and fitted impedance (blue line) for the Ring-Ring two-cell cavity with four beam line absorbers.

two-cell cavity features very large beam pipes with an inner diameter of 270 mm. This allows for strong propagation of HOMs into the absorber. The cavity also transitions directly into this diameter without an iris at the end of the cell. While this reduces the R/Q of the fundamental mode significantly to 147 Ω from a theoretical 200 Ω, it allows for a better propagation of HOMs. After a warm-to-cold transition two absorbers follow. A conceptual model can be found in Fig. 3. The configuration of the absorbers (lenght, thickness and distance from each other) was optimized to reduce the Q of the first dipole mode passband as these modes had a significant impact on the beam quality and are below the cut-off frequency for this beam pipe diameter. In this optimization the outer radius of the SiC has been changed. The absorber creates a pillbox-like cavity with its own resonant frequency. If this frequency matches with the cavity mode within their bandwidths, both resonant together and reducing the cavity modes Q due to the SiC. The taper section seen in the conceptual drawing is not considered in the eigenmode simulations and has yet to be optimized to minimize additional impacts on the impedance. The monopole shunt impedance with these four loads can be seen in Fig. 4. These are calculated using periodic boundary condition with 0 degree phase advance. To calculate the HOM power, the impedance needs to be multiplied with the bunch spectrum. In both medium and high luminosity scenario, there will be an abort gap in the bunch structure. In the 28 MHz case, only 330 of 360 possible bunches are in the ring and in the 112 MHz case 1320 out of 1440 bunches. The resulting bunch spectra are found in Fig. 5a) and Fig. 6a). The bunch spectrum reaches up to 15 GHz, as is expected with an 8 mm long gaussian bunch. The fine structure can be seen in Fig. 5b) and Fig. 6b) and represents the 28 and 112 MHz bunch repetition rates and is overlayed with the cavity impedance. This results in 65 kW (medium luminosity) and 70 kW (high luminostiy) of HOM power up to 2 GHz as can be seen in Fig. 5c) and Fig. 6c). Wakefield simulations with CST and ABCI using the medium luminosity bunch charge of 50 nC and a wakelength of 10 m showed a loss factor of 0.44 V/pC for

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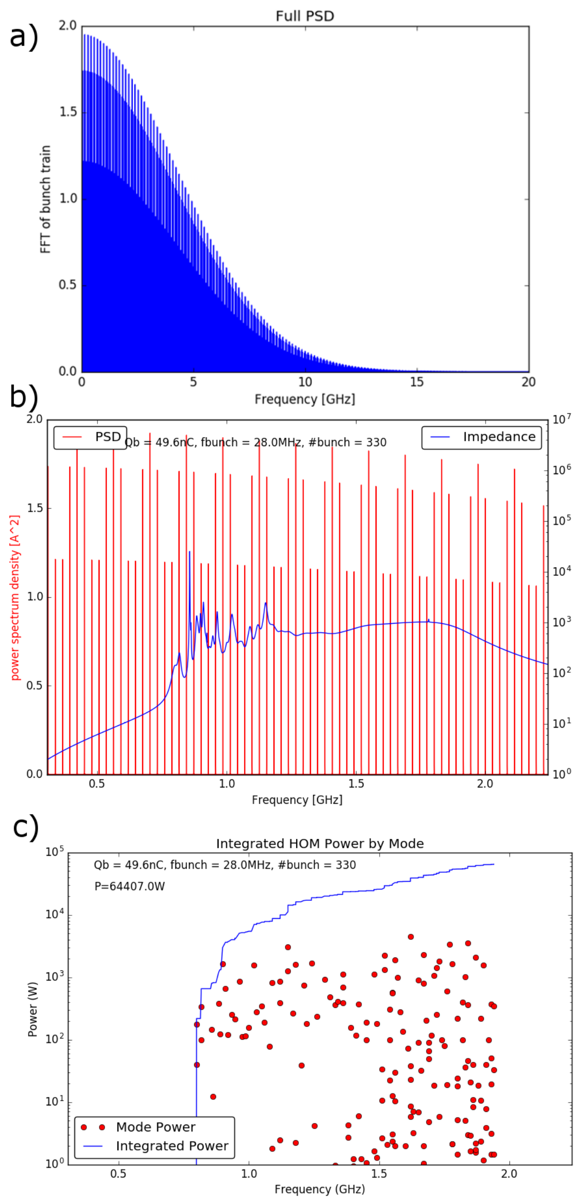

Figure 5: Medium luminosity scenario. a) full bunch power spectrum; b) bunch spectrum (red) overlayed with cavity impedance (blue); c) HOM power spectrum (red dots) and integrated HOM power (blue line).

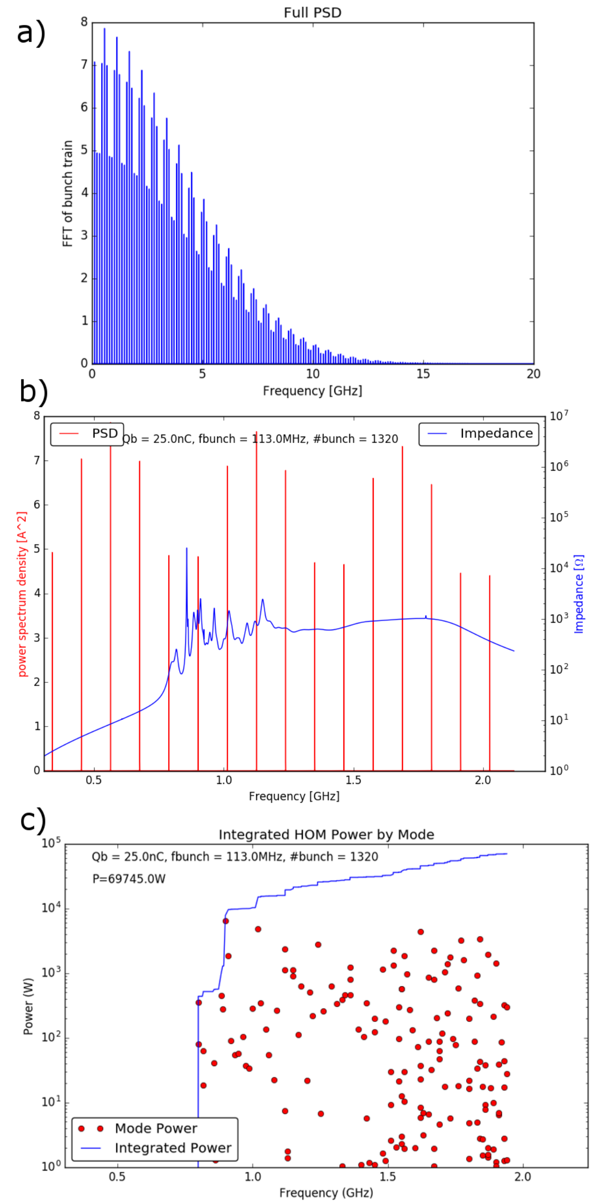

Figure 6: High luminosity scenario. a) full bunch power spectrum; b) bunch spectrum (red) overlayed with cavity impedance (blue); c) HOM power spectrum (red dots) and integrated HOM power (blue line).

the whole structure. The resulting impedance can be seen in Fig. 7. Excluding the contribution of the fundamental mode at 563 MHz, the loss factor is 0.33 V/pC. In a single bunch calculations, the HOM power is $P = kI_{ave}Q_b = 21$ kW for the medium luminosity scenario and 13 kW for the high luminostiy scenario at a beam energy of 10 GeV.

One area concern of this design are the instabilities growth rates that are associated with the longitudinal and transverse impedance of the cavity. As can be seen in Fig. 8, a couple of modes around 950 MHz have significant growth rates in the 10^4 to $10^5 s^{-1}$ range. It would be preferred to have these below $10^2 s^{-1}$. The eigenmode at 920 MHz that cause the high transverse impedance are quadrupol modes that are below the cutoff frequency of the beam pipe. Further development work is needed to reduce the impedance and with it the beam instability growth rate.

SUMMARY

eRHIC is an electron-ion collider. Two concepts for the new electron accelerator are being investigated: the Linac-Ring and the Ring-Ring concepts. Both will use beam line absorbers made out of SiC to the the Q of the HOMs.

For the LR version, a beam line absorber has been designed to cover higher frequency HOMs traveling between

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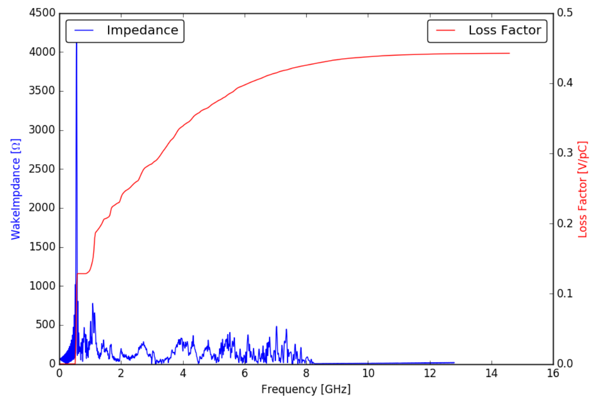

Figure 7: Wakefield impedance (blue) and integrated long. loss factor (red) calculated by CST and ABCI with a 50nC, 8mm long bunch. The loss factor is integrated to 0.44V/pC.

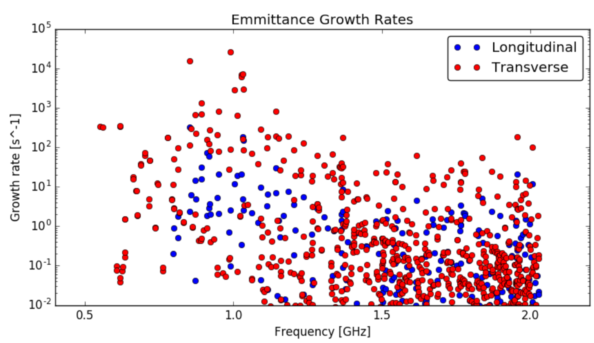

Figure 8: Beam instability growth rates are concerningly high due to the longitudinal and transverse impedance of the two-cell cavity.

two cryomodules. The beam power spectrum peaks around 2.6 GHz, so the absorber is optmized to have a transmission of <-20 dB from 2.2 to 3.2 GHz. The mechanical design is set to follow the proven ANL design by shrink-fitting the SiC dielectric into a copper sleeve with water cooling channels.

In the RR design, about 70 kW of HOM power are expected while using a two-cell cavity with four beam line absorbers. A current concern are the beam instability growth rates due to the HOM impedance from the cavity and more development work is needed.

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