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NOVEL HOM DAMPER DESIGN FOR HIGH CURRENT SRF CAVITIES*

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Abstract

The ERL-Ring eRHIC design incorporates a new high current (50 mA), multi-pass (6 passes) ERL, generating 5-18 GeV electron beams to collide with the ion beams of the existing RHIC. One critical challenge for eRHIC is to damp HOMs. The average HOM power is up to 8 kW per cavity, potentially much more if the electron beam spectrum overlaps with cavity HOM spectrum. We present a novel HOM damping scheme, employing ridge waveguides, which is able to well damp both longitudinal and transversal modes. This paper will describe the design of the HOM damping scheme, including RF design, HOM damping results, progress of prototyping.

INTRODUCTION

An Electron-Ion Collider, eRHIC, is proposed at Collider-Accelerator Department at BNL. There are two technologies are under evaluating: one is ERL-Ring [1] technology, which uses ERL technology to provide CW high current, high energy electron beams to collide with proton beams, the other one is Ring-Ring [2], which is to use pulse recirculating linac as an injector to inject electron beams into a storage ring and then collide with proton beams. The SRF requirement for ERL-Ring eRHIC and Ring-Ring eRHIC is significantly different. For ERL-ring, it requires the cavity operating CW at 16 MV/m with Q0 > 3e10, and well HOM damping for the high BBU threshold and HOM power; however, the recirculating-linac requires high gradient operation at 26 MV/m with Q0>1e10, and limited HOM damping requirement.

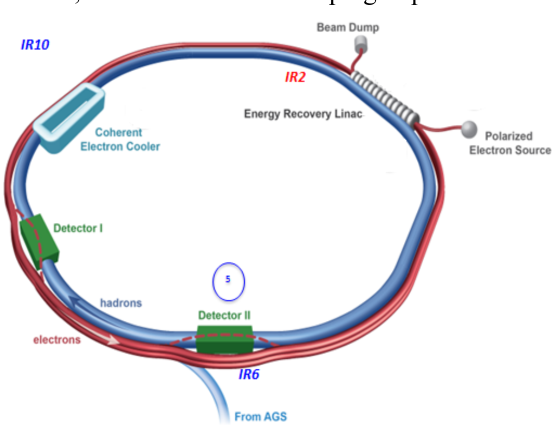

Figure 1: Layout eRHIC. Existing “Blue” hadron ring (center); Electron ring and SRF linac at IP2.

This paper is to study the HOM damping scheme for the ERL-Ring eRHIC SRF linac. As shown in Figure 1, the ERL is realized by two FFAG ring to accelerate the electron beams up to 20 GeV. The high current SRF linac is located at 2 o’clock inside the existing RHIC tunnel, where only 200 m straight section is available. The required energy gain for the linac is 1.67 GeV, so that the electron beam energy can reach 20 GeV by passing through the SRF lianc 12 times. This is the reason that a compact, igh efficient HOM damping is demanded.

This paper describes the layout of the linac and HOM damping scheme for the linac, then focuses on the high current HOM damping schemes.

ERL-RING ERHIC SRF LIANC

SRF Linac Layout

ERL-Ring eRHIC SRF linac is a high current, up to 50 mA, and mulitpasses, up to 12 passes, ERL. Depending on the number of passes, it can provide electron beams with energy of 5 to 20 GeV. The SRF linac for the ERL-Ring eRHIC contains eighty eight 647 MHz 5-cell cavities in 22 cryomodules (four cavities per cryomodule). The total length of the linac is 189 meter, which fits into the straight section of the RHIC tunnel (200 m). The main linac parameters are listed in Table 1.

Table 1: ERL-Ring eRHIC SRF Linac

Parameters	Number	Unit
Energy Gain	1.67	GeV
Beam current	50	mA
Bunch charge	5.3	nC
No. of passes	12	
Linac length	189	m
No. of cavities	88	
No. of cryomodule	22	
Real-estate gradient	8.83	MV/m

ERL Bunch Pattern

The revolution frequency of the RHIC is 78 kHz, and there are 120 RF buckets (110 proton bunches and 10 RF bucket’s abort gap), so the collision repetition rate is 9.38 MHz. This is also the repetition rate of the electron bunches from the source. However, there are 5 accelerat-

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ing bunches (at various energies) and 5 decelerating bunches (at various energies) travelling together as a macrobunch, whose repetition frequency is the same as the electron source or proton bunches, i.e. 9.38 MHz. The maximum spacing between accelerating bunches and the maximum phase difference of the decelerating bunch is limited by the RHIC tunnel. Within this limit, the bunch spacing and phase shift can be optimized to improve the beam-break-up threshold, the HOM power and other parameters. Figure 2 shows an example of the bunch pattern, where the bunch spacing is 5 RF cycles and the phase shift is -5.5 RF cycles from the last accelerating bunch.

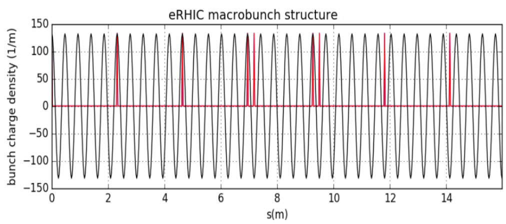

Figure 2: An example of the electron bunch pattern for the ERL-Ring eRHIC.

Cryomodule Layout

Two types of HOM dampers are planned for the HOM damping scheme: ridge waveguide HOM dampers on each side of the cavity [3] and a SiC beamline absorber [4] on each end of the cryomodule. The cavity will be operated at CW mode with an average gradient of 16.4 MV/m, and the real-estate gradient of the whole linac is 8.83 MV/m. The main parameters of the cryomodule are listed in Table 2. Figure 3 shows a schematic of the cryomodule layout.

Table 2: Parameters of a Cryomodule

Parameters	Number	Unit
Energy Gain	75.7	MeV
No. of cavities	4	
Gradient	16.4	MV/m
Q factor	2E10	
WG dampers*	16 or 24	
SiC absorbers	2	
Cavity length	1.72	m
End transition	0.5	m
Inter-cavity length	0.1	m
Valve space	1*0.1	m
SiC absorber length	0.3	m
Total length	8.58	m

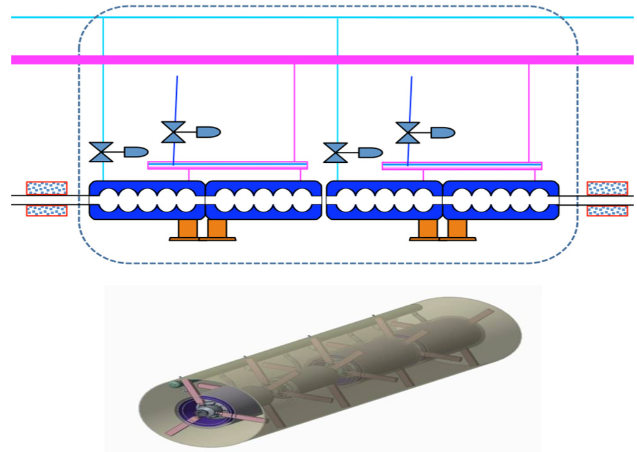

Figure 3: Schematic layout of the cryomodule.

RIDGE WAVEGUIDE HOM DAMPING

Regular waveguides have great advantages for high power HOM damping because 1) it is a natural high pass filter, so fundamental mode rejection is obtained naturally; 2) it is able to handle high power HOM, which is critical for high current and high power machines; 3) it has good coupling to the HOMs because of larger cross-section between the waveguide and the cavity beampipe; 4) it doesn't add much to the length of the cryomodule, which is beneficial for limited size tunnels, such as eRHIC. These are the reasons for the widespread use of waveguides used for HOM damping in various SRF accelerators [5, 6]. However, regular rectangular waveguide HOM damper leads to a higher heat load for the cryomodule due to its big size. This is particularly difficult at a lower frequency. A ridge waveguide resolves some of these issues for high power HOM damper because it reduce the heat load relative to a rectangular waveguide but keep the good properties that a waveguide has. Our design of the ridge waveguide HOM damper evolved from a rectangular double ridge waveguide to a rounded ridge waveguide.

H-shape Waveguide HOM Damper

Our first version [7] of the ridge waveguide HOM damper is shown in Figure 4. There are three rectangular ridge waveguides, also known as H-shape waveguide, at the each side of the cavity, and they are rotated by 90 degree from each other

As shown in Figure 5, HOM power can be from 3.6 – 10 kW depending on the bunch pattern. When the HOM spectrum aligns with bunch spectrum, the HOM power can be a factor of 2-3 higher.

The transverse component of the HOM impedance requirement comes from beam-break-up (BBU) threshold current, in which the higher is the better. The BBU simulation by GBBU code [8] shows that the threshold is a factor 3 higher than the design current of the ERL when the HOM frequency spread ($\Delta f/f$=0) among cavities in the linac is 0, and is a more than a factor 10 higher when $\Delta f/f$ =1e-3, which is a realistic number.

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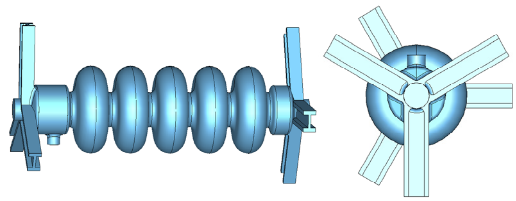

Figure 4: H-shape ridge waveguide HOM damping scheme.

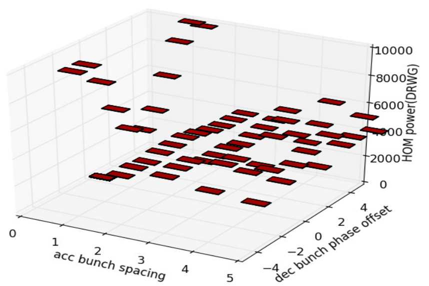

Figure 5: H-shape ridge waveguide HOM power scan.

B-Shape Ridge Waveguide

The original idea for the B-shape ridge waveguide is to supress the multipacting with rounded surface, like elliptical SRF cavity. Then, we found out that with some optimization geometry, the number of the waveguide per cavity can be reduced to four waveguides, with a coaxial coupling between waveguide and cavity. Figure 6 shows the geometry of the B-shape ridge waveguide HOM damper, and it is HOM power scan is shown in Figure 7.

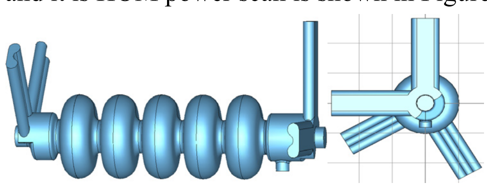

Figure 6: B-shape waveguide HOM damper.

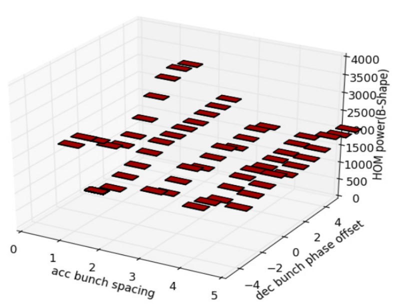

Figure 7: B-shape ridge waveguide longitudinal HOM power scan.

BBU simulation of the B-shape HOM damper with the same lattice shows that the BBU threshold current is 12.2 mA (a factor 2 higher than the design current, 6 mA) with $\Delta f/f$=0, and is 92.5 mA for $\Delta f/f$ =1e-3 (Figs. 8 and 9).

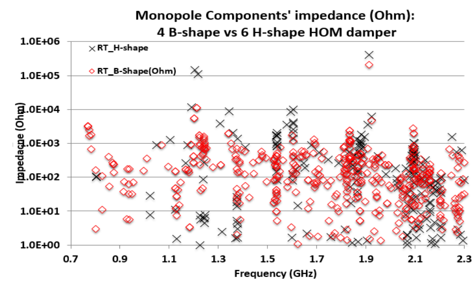

Figure 8: Impedance and HOM power comparison of the H-shape and B-shape HOM damper.

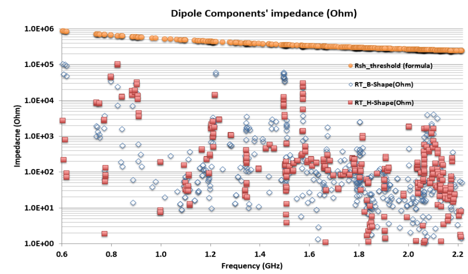

Figure 9: Impedance of Dipole components of B-shape and H-shape HOM damper.

Other Waveguide HOM Damper and Criteria for Comparison

We attempt to use the minimum number of waveguide HOM dampers per cavity to satisfy the HOM damping requirements. We have tried various configurations, as shown in Figure 10, including the number of the waveguides and the relative angles of the waveguides. It takes an enormous amount of time and effort to analyse every cases in great detail, so it is important to come up with a first order of criteria, through comparing critical parameters, which is the impedance budget of BBU threshold in a multi-pass high current ERL.

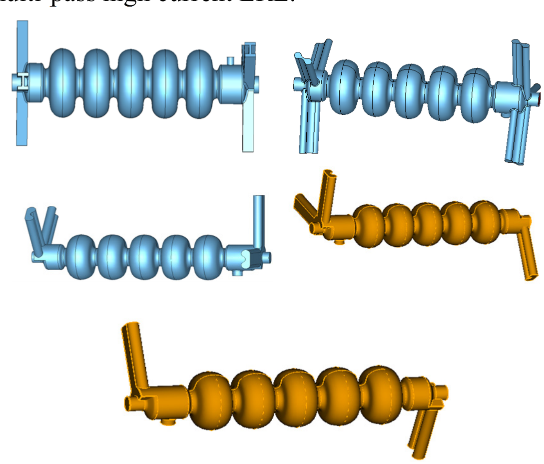

Figure 10: HOM damper configurations.

When BBU happens, one "worst" mode will trigger BBU threshold and this mode should be the one with smallest impedance budget, which is with largest ratio of BBU threshold impedance (R_{th}) over cavity transversal impedance (R_{cav}), i.e., R_{th}/R_{cav}. The R_{cav} is eignmode simulation result of different HOM damping configura-

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tions. With some simply, The R_th can be calculated by the following formula [9].

$$R_{\text{th}} = -\frac{2pc}{I_{\text{th}} Q_b k T_{12}^{*} \sin(\omega t_r)} \frac{1}{N_r (2N_r - 1)} \quad (1)$$

Where I_{th} is the beam current, N_r is the number of passes, T_{12}^* is the ERL arcs' optical matrix element, t_r is the revolution time, and k and ω are HOM wavenumber and angular frequency, p is the momentum of the particle and Q_b is the bunch charge. This expression doesn't include x-y motion coupling or frequency spread in the different cavities, which increase the BBU threshold current. One should notice that the impedance is inversely proportional to the frequency.

A comparison of different HOM dampers is shown in Table 3. Looking at the minimum R_{th}/R_{cav}, the 4 B-shape, 6 H-shape and Eight-shape waveguide HOM dampers are close, however, when the frequency normalization is taken into account, the 4 B-shape and 6 Eight-shape waveguide HOM damper are the best. The BBU simulation was carried out with the same 12 pass FFAG lattice eRHIC design, which beam current is 6 mA at 18 GeV operation mode. It shows that the higher minimum R_{th}/R_{cav}, the BBU threshold with Δf/f = 0 will be higher. The higher normalized R_{th}/R_{cav}, the realistic BBU threshold with Δf/f =1e-3 will be higher. Considering the HOM power, BBU threshold, fabrication, heat load of the cryomodule and cost, 4 B-shape HOM damper will be the choice for eRHIC ERL–SRF linac.

Table 3: Comparison of the Waveguide Configurations

Waveguide configurations	Min R_{th}/R_{cav}	F (GHz)	Normalized R_{th}/R_{cav}	BBU (mA) df/f=0	BBU (mA) df/f=1e-3
6 H-shape	6.2	0.86	5.3	20.3	67.5
6 Eight-shape	6.0	1.6	9.6	43.7	83.5
4 B-shape (30°)	5.9	1.53	9.0	12.2	92.5
3 B-shape (60°)	3.6	1.25	4.5	8	67.5
2 B-shape(120°)	3.5	1.25	4.3	9.7	43.5

Prototype Waveguide HOM Damper

The HOM damping design will eventually be verified by measurments on a copper cavity, with a detachable beampipe to allow the use the same cavity to test different damper designs. A copper 650 MHz cavity [10] was fabricated by RI [11], and recently delivered to BNL, is shown in Figure 11. We will carry out cavity's HOM measurement on the 3-D bead-pull test stand first, and then prototyped HOM dampers will be attached to the cavity for damping studies, on a test stand shown in Figure 12.

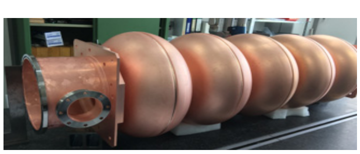

Figure 11: Copper cavity with detachable beampipe for HOM study.

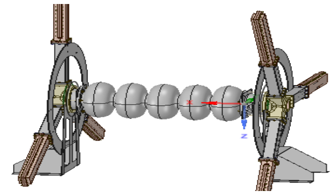

Figure 12: HOM damping measurement scheme.

SUMMARY

This paper discusses the HOM damping requirements for high current, multi-pass ERL SRF linac for eRHIC. HOM damping schemes with combinations of ridge waveguides and room temperature beam-pipe SiC HOM absorbers is being worked out. Prototypes of the ridge waveguide HOM dampers were made and characterization of the HOM dampers with a copper cavity is undergoing.

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