RF AND MECHANICAL DESIGN OF 647 MHz 5-CELL BNL4 CAVITY FOR ERHIC ERL*

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Abstract
A 647 MHz 5-cell BNL4 cavity was designed for high current FFAG lattice ERL for high luminosity eRHIC. The cavity was optimized to be able to propagate all the HOMs out of the cavity for high BBU threshold current and low HOM power (loss factor). eRHIC will collide electron beam for large energy range of proton (40 GeV to 250 GeV), which requires the cavity to be able to tune up to 170 kHz at 2K. This presents a challenge for the mechanical design of the SRF cavity. This paper will present the RF and mechanical design of the 647 MHz 5-cell BNL4 cavity. The status of the cavity fabrication and preparation for vertical test will be addressed as well.

INTRODUCTION

An FFAG based electron-ion collider, eRHIC, is proposed by Collider-Accelerator Department at Brookhaven National Lab [1]. For eRHIC, an electron accelerator will be built to provide polarized electron beams with an energy range from 5 to 20 GeV to collide with the existing polarized proton beams. The new electron accelerator will be placed in the existing RHIC tunnel and the SRF linac at IP2, where the length of the available straight section is 200m. The SRF linac, consisting of 80 5-cell 647 MHz SRF cavities with gradient of 18 MV/m, will provide 1.667 GeV of energy gain, as shown in Figure 1

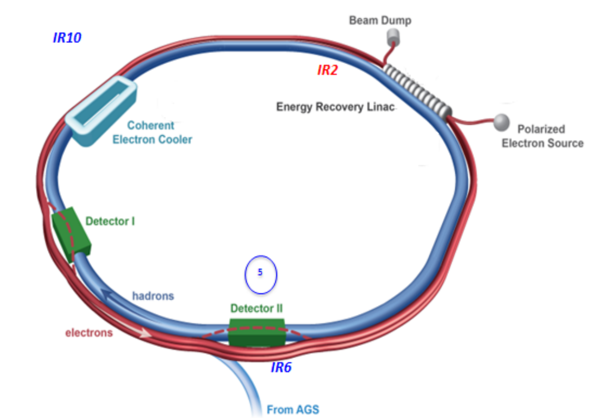

Figure 1: Layout of FFAG based eRHIC. Existing “Blue” hadron ring (center); Two electron NS-FFAG beam lines (Red) and SRF linac at IP2.

The accelerator design for producing electron with energies up to 20 GeV is based on up to 12 passes energy recovery linac (ERL). In eRHIC, the electron beams will collide with different proton energies from 40 GeV to 250 GeV, which corresponds to a frequency shift up to 174 kHz required for the 647 MHz cavity, which presents a challenge for the mechanical design of the cavity. This paper will describe the linac configuration, RF design of the cavity and mechanical design.

RF DESIGN OF THE 647 MHz 5-CELL CAVITY

The 5-cell 647 MHz BNL4 cavity uses the same idea of the previous BNL 5-cell cavities, i.e., enlarged beam tube to propagate all the HOMs but attenuate the fundamental modes. There is a taper at the each side of the cavity to reduce the cross-talk between cavities and avoid RF heating on the cavity’s gaskets. Figure 2 shows the Superfish model of the BNL4 cavity and its parameters are listed in Table 1.

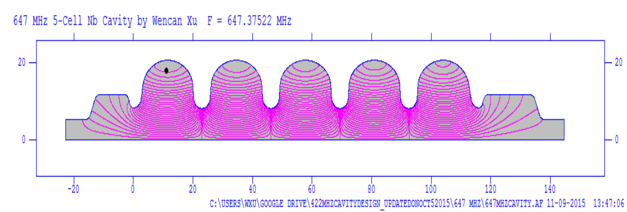

Figure 2: Superfish model of BNL4 cavity.

Table 1: BNL4 Cavity’s Parameters

Parameters	BNL4 cavity
Frequency [MHz]	647.4
Number of Cells	5
Geometry Factor [G]	273
R/Q [Ω]	502
Bpeak/Eacc [mT/MV/m]	4.42
Epeak/Eacc	2.27
Coupling factor [%]	2.8
Cavity length [m]	1.68

During the cavity design, the loss factor, HOM damping capability was optimized to generate low monopole HOM power and increase the transversal beam-break-up (BBU) at the same time. More detail of the cavity design is described in [2].

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MECHANICAL DESIGN

Up to 174 KHz tuning range is required for BNL4 cavity to matches the collision energy of the wide energy of proton energy (40-250 GeV), which corresponds to 2 mm of mechanical length. The tuning of cavity will create high local stress, whose limitation is 7000 psi for RRR>250 Nb. An example of local stress, shown in Figure 3, happens at the welding area between stiffness ring and a 3.6 mm thickness of cavity wall. After a lot of mechanical analysis, a decision was made to use 4 mm thickness and no stiffness ring. Different scenarios were simulated and are addressed below.

The first case is to tune the cavity in air. The local stress is 3090 psi, as shown in Figure 4. The cavity's stiffness is -533 lb/mm.

The second case is for the vertical test, when the maximum pressure happens during cooling down. The mechanical burst disk valve threshold pressure is 23 psi. This pressure will compress the cavity up to 4.92 mm, which makes the cavity's local stress as high as 14,001 psi as shown in Figure 5 (top). So, it is necessary to lock the cavity during the vertical test, and the required "lock" load is 2410 lb. With locked cavity, the maximum local stress is 3617 psi, as shown in Figure 5 (Bottom).

The third case is to tune the cavity for operation (after it's cooled down), where the LHe pressure is 2 K and the pressure is 14.7 psi. The maximum stress happens when the tuner is unlocked, which turns out to be 6986 psi in Figure 6 (top). Tuning the cavity requires only 205 lb, as shown in Figure 6 (bottom). This makes the design of tuner very easy.

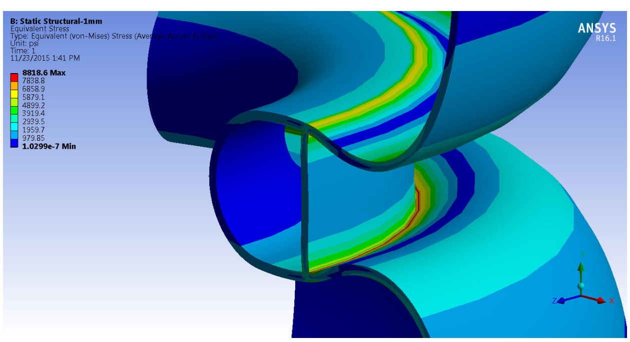

Figure 3: Example of a high local stress in the stiffness ring and cavity welding area when the cavity is tuned by 1mm.

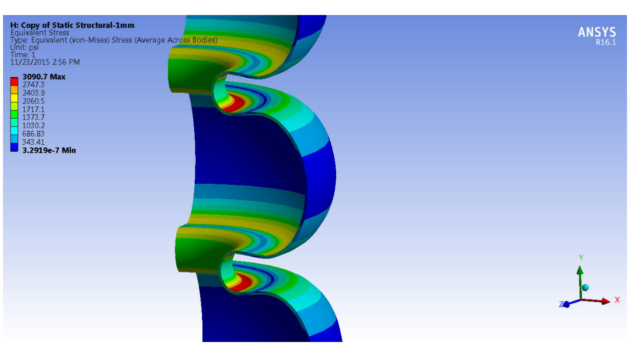

Figure 4: 4mm thickness cavity wall and no stiffness ring, cavity is tuned for -1 mm in the air.

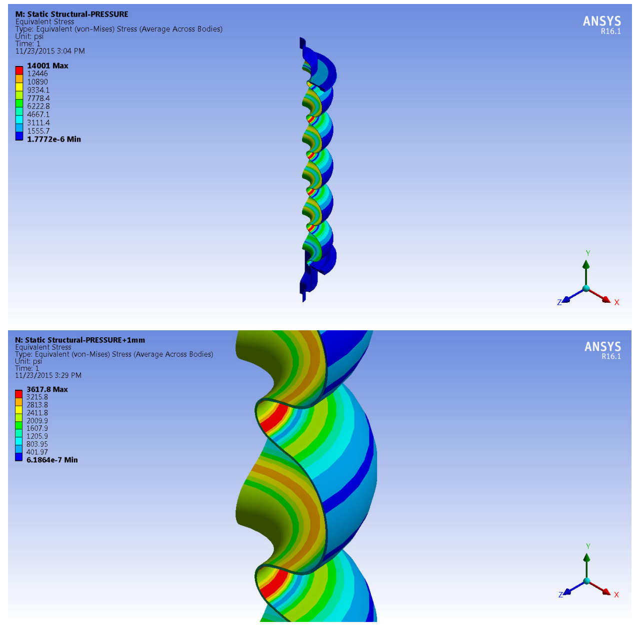

Figure 5: Vertical test scenario: (Top) 23 psi He pressure and cavity is unlocked; (Bottom) 23 psi He pressure and cavity is locked.

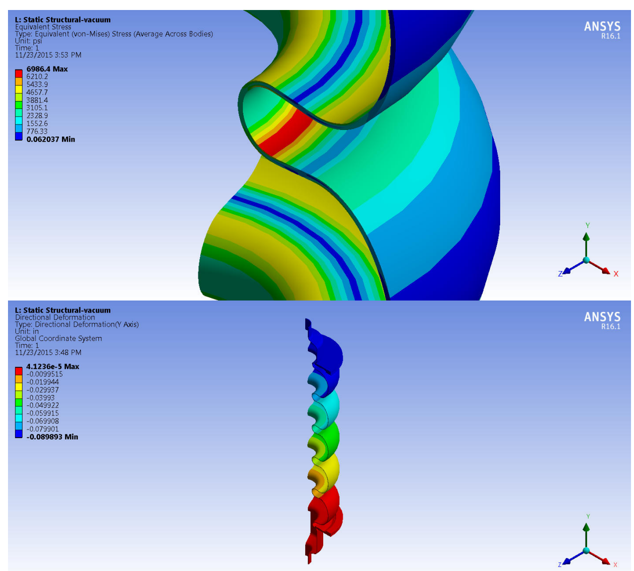

Figure 6: Cavity operation scenario: (Top) local stress with unlocked tuner; (Bottom) Tuning load.

Figure 7 shows the tuner disk and structure, where all the weld joints are fully bonded. On the fixed end, the maximum stress for NbTi in the structure is 16,719 psi, which is below the allowed limit of 69,500 psi. The total equivalent stress on the Nb cavity, including the helium pressure and tuning force is 4508 psi. And the maximum load on Ti is 5,967 psi, whose limit is 51,900 psi. On the tuner end, the Nb cavity's total pressure is similar to the fixed end and the load on the reactor grade Nb is 3,365 psi (< 10,500 psi).

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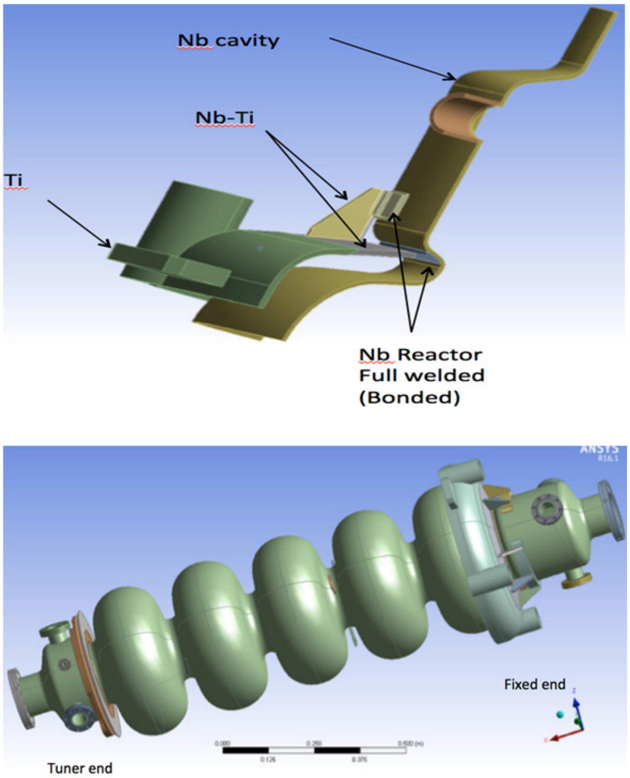

Figure 7: Mechanical design of tuner side (Top) and LHe vessel ready cavity model.

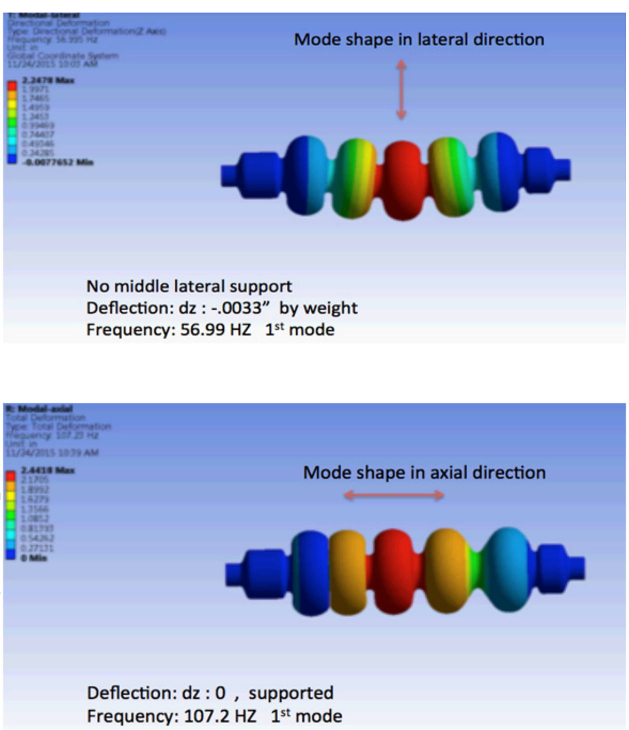

Figure 8: Modal analysis: without (top) and with (bottom) lateral support in the middle cell of the cavity.

Modal Analysis

Modal analysis is important for the cavity's microphonics suppression for operation, which usually requires the mechanical frequency to be higher than 100 Hz. Without any lateral support on the cavity, the first mechanical mode is transversal mode, at a frequency of 56 Hz. This is dangerous for cavity's operation (too close to 60 Hz). However, with lateral support in the middle cell of the cavity, the first mode is horizontal mode and its frequency is 107 Hz. The results are shown in Figure 8. The tuning load for the cavity is 533 lb for 1 mm.

STATUS OF CAVITY FABRICATION AND SCHEDULE

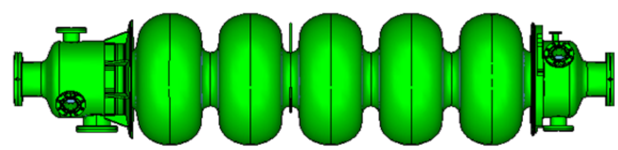

Figure 9: Engineering model of the cavity.

Figure 9 shows the engineering model of the cavity, the fabrication contract of which was awarded to RI [3]. One Nb cavity will be fabricated to study the cavity's performance and one Cu cavity will be fabricated for HOM damping study. The cavities are expected to be delivered to BNL in early 2017.

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