RF DESIGN OF NORMAL CONDUCTING 704 MHz AND 2.1 GHz CAVITIES FOR LEREC LINAC *

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Abstract

To improve RHIC luminosity for heavy ion beam energies below 10 GeV/nucleon, the Low Energy RHIC electron Cooler (LEReC) is currently under development at BNL. Two normal conducting cavities, a single cell 704 MHz cavity and a 3 cell 2.1 GHz third harmonic cavity, will be used in LEReC for energy spread correction. Currently these two cavities are under fabrication. In this paper we report the RF design of these two cavities.

INTRODUCTION

To map the QCD phase diagram, especially to search the QCD critical point using the Relativistic Heavy Ion Collider (RHIC), significant luminosity improvement at energies below $\gamma = 10.7$ is required, which can be achieved with the help of an electron cooling upgrade called Low Energy RHIC electron Cooler (LEReC) [1].

An electron accelerator for LEReC (linac) consists of the DC photoemission gun and a booster 704 MHz SRF cavity converted from the ERL SRF gun [2]. A single cell 704 MHz normal conducting cavity and a 3-cell third harmonic (2.1 GHz) normal conducting cavity will be added to de-chirp the energy spread and to compensate its non-linearity. The design of these two cavities were previously reported in reference [3]. In this paper we will focus on the progress of these two designs.

CAVITY DESIGN

The RF optimizations are performed using CST Microwave Studio®, and the final designs are simulated using ACE3P package. Thermal and mechanical simulations are also performed, which will not be covered by this paper.

2.1 GHz Cavity RF design

The design frequency is 2.112 GHz. A pillbox shape cell is adopted as a baseline bare cell in this design. The cell is set to have 10mm walls to the adjacent cell, with the length of the vacuum portion of the cell to be $\lambda/2\text{-}10$ mm. Nose cones with the height h, shown in Fig. 1(c), are used to improve the cavity shunt impedance. Cell-to-cell coupling is determined by the 1.875″ beam pipe between adjacent cells, as shown in Fig. 1(b). Cells with different height h were simulated, with h varied from 1 to 5 mm with a 0.5 mm step size. For each simulation the value of R_d is optimized so that resonance frequency can be set at 2.112 GHz for π mode. The simulations showed a maximum shunt impedance at $h = 2.5$ mm.

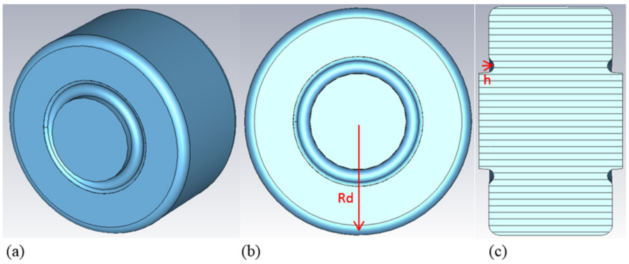

Figure 1: The 2.1 GHz bare cell: (a) perspective view; (b) front view; (c) side view.

This design provided a baseline for the 3-cell cavity. For the end cell with beam pipe, the nose cone close to the center cell side is chosen to have an $h = 2.5$ mm, same as the center cell. The height of the nose cone close to the beam pipe is h_e. Different values of h_e and R_d values are evaluated. We choose $h_e = 0$ mm to simplify the cavity construction without significant degradation on the cell shunt impedance R_{sh}. Adjusting the end cell cavity length might increase the shunt impedance of the fundamental mode. However it will also increase the R/Qs of the same order modes (SOMs) thus increase HOM induced energy spread. For example, with the end cell length increasing 10 mm, the R/Q will decrease 2.7% and the quality factor will increase 7.4%, which gives a 5% increase on the shunt impedance. However, together with this change, the R/Q of the 2.099 GHz mode increases to 9.7 Ω. This mode is not going to beat the multiple of 704 MHz since it is 13 MHz away from the working frequency at 2.112 GHz, the third harmonic of 704 MHz. However, it is possible that this mode will beat the multiple of ~9 MHz thus give a high voltage fluctuation, estimated to be ~ 4 kV, corresponding to ± 2.0e-3 dp/p peak to peak, way above the required ± 7e-4. If the beam pipe diameter is set at 1.975″, the HOMs at 4.717 GHz and 4.771 GHz will

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give 0.57 kV voltage fluctuation, corresponding to ± 2.9e-4 dp/p peak to peak. Setting the beam pipe diameter at 1.925″ will allow these HOMs propagating out of the cavity, so that both R/Qs and quality factors are suppressed. In this case we choose the length of the vacuum portion of the end cell to be $\lambda/2-10$ mm, and beam pipe to be 1.925″ to reduce the HOM induced energy spread in this cavity [4].

In this cavity we choose the cavity tuner to be a folded coaxial structure, shown in Fig 2(a). The cavity fundamental mode forms a TE$_{11}$ like mode on the coaxial, and this mode has a much higher cut-off frequency than fundamental mode, and it is not easy for this mode to match the TEM port mode. The coaxial structure can also be treated as a capacitor with a low impedance to reject the fundamental mode.

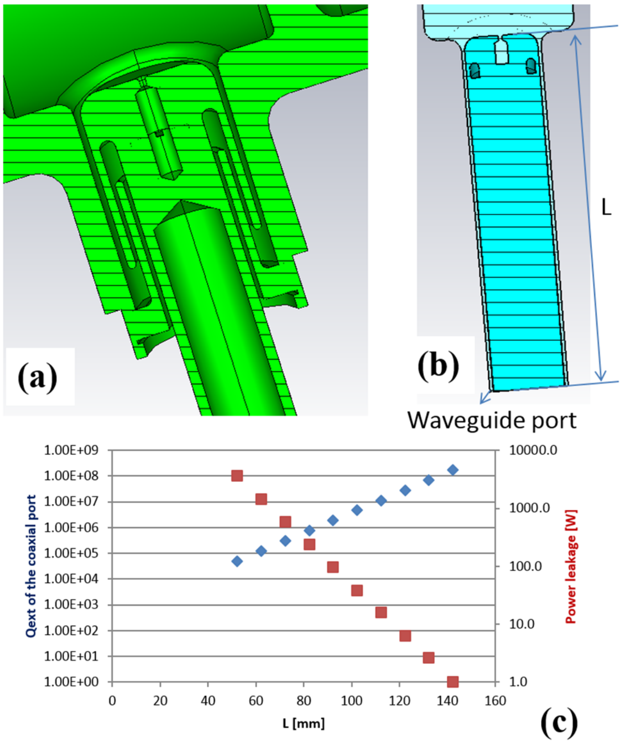


Figure 2. Coaxial tuner (a) folded coaxial tuner; (b) coaxial tuner for simulation; (c) external quality factor of the coaxial waveguide port and the power leak versus coaxial length.

For simplicity, we evaluate the case of using a straight (non-folded) tuner to estimate the length of the folded coaxial tuner, shown in Fig. 2(b). The power leakage from the coaxial cross section is calculated by treating the end of the tuner as a waveguide port and calculate the power of 5 modes leaking out of there. From Fig. 2(c) we can see we need > 140 mm tuner to attenuate the power leakage to < 1Watt. In this case for the folded design, the tuner should be roughly 50 mm in length. Additional length is needed to integrate the bellow with the Lesker motor to the tuner. Please note in this design the alignment of the tuner is important. In case the top of the tuner is shifted/tilted with 0.1 mm, about 40 Watts power is going to propagate out of the coaxial structure.

As we expected, simulation shows that multipacting will happen in this coaxial structure. We will try to condition it before considering to put TiN coating.

The FPC is critically coupled to the cavity without the beam. In this case there is no strong standing wave along the FPC waveguide, and the position of the FPC window is not critical. A JLab C100 / C50 RF window is adopted after a 90 degree 50.08mm bending to the 298mm long JLab530 rectangular waveguide with a dimension of 5.292″ × 0.986″, shown in Fig. 3. Its TE$_{10}$ cutoff frequency is 1.134 GHz and TE$_{20}$ cutoff frequency is 2.266 GHz. The cavity side of the RF window is under vacuum, with a pumping port close to the window, and the amplifier side is in the air. Two knobs that are opposite to each other are placed on the air side to optimize the match at 2.112 GHz. The waveguide is then tapered to WG340 with 4.3″ × 2.15″ dimension. Its TE$_{10}$ cutoff frequency is 1.372 GHz, and TE$_{20}$ cutoff frequency is 2.744 GHz, the working mode TM$_{010}$ at 2.112 GHz is not going to be coupled to the cavity side port (port 1) as TE$_{20}$ mode. The amplifier at 2.112 GHz is 0.6GHz away from the TE$_{20}$ cutoff of WG430 (port 2). The RF windows is going to see only TE$_{10}$ mode. The notch at ~ 2.1 GHz is sensitive to the position of the knobs, with knobs shifting 0.2 mm along the waveguide, the notch frequency shifts 26 MHz.

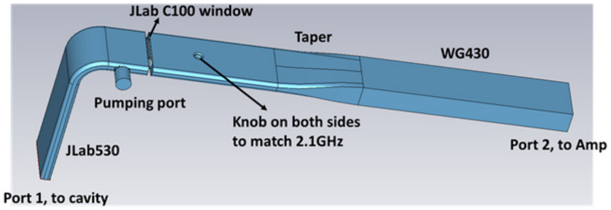


Figure 3. FPC waveguide to the cavity.

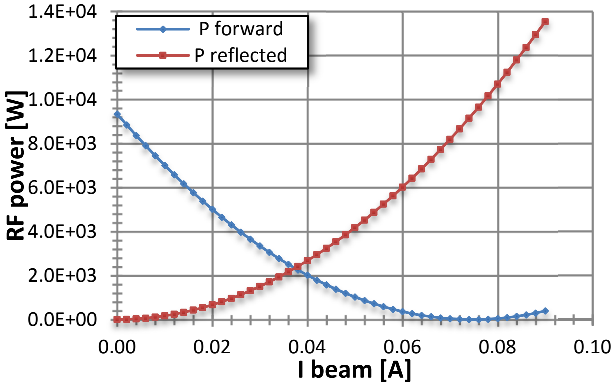


Figure 4. Forward and reflected power on the FPC versus the beam current.

By assembling the two end cells (without a vacuum port, radius R_{d_e}) and the center cell (radius to be R_{d_c}) with the tuner, and add a JLab C100/C50 RF window after a 90 degree 50.08mm bending to the 298mm long JLab530 rectangular waveguide, we get a 3-cell cavity.

0.626″ blending is applied all around the FPC. A vacuum port is added on the vacuum side of the FPC window. The design is further optimized to 2.112 GHz working frequency with 250 kV accelerating voltage, corresponding to 2.1132 GHz at cold (room temperature). The parameters used for this cavity is shown in Table 1.

Table 1. Parameters for 3-cell Cavity (length unit in mm)

	Freq [GHz]	*h*	$R_{d\,e}$	$R_{d\,c}$	WGHeight
Warm	2.1120	2.50	56.57	55.91	91.00
Cold	2.1132	2.50	56.54	55.88	91

This design is simulated for different tuner penetration, from -6 mm to 6 mm. With the tuner at 0 mm, the quality factor is 20,569. The external *Q* factor of FPC is 20,847. At $\beta = 1$, the *R/Q* is 350.7 Ω. With the tuner varying from -6 mm to 6 mm, the frequency changing range is 3.92 MHz, the *R/Q* varies from 347.2 Ω to 350.7 Ω, the quality factor varies from 19,881 to 20,825, and the FPC's external *Q* varies from 15,899 to 23,923. The reason for the FPC's external *Q* change is due to the field flatness change: with the tuner inserted deeper into the cavity, the field is pushed to the end cells, which makes the coupling weaker and thus gives a higher Q_{ext}.

This 2.1 GHz cavity is used to stretch the bunch after the SRF linac and correct the energy spread. It works at 180 degrees, decelerating the beam. In this case, while the beam current goes higher, the cavity will get more energy from the beam, thus needs less energy from the RF amplifier. Figure 4 shows the forward and reflected power on the FPC versus the beam current. The RF amplifier should provide 9500 Watts power to the cavity, and the reflected power will be less than 4000 Watts with beam current up to 50 mA. Considering the cable loss, the amplifier should be around 14000 Watts.

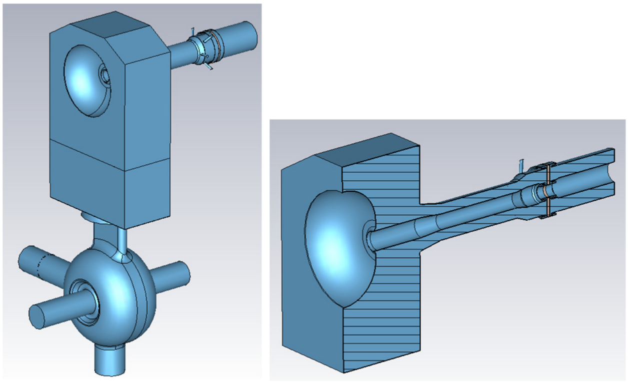
With good surface finish (surface roughness less than 8 micro-inches) on the Cu material, the cavity's unloaded quality factor can be as good as designed. In case of rough surface, the quality factor is usually scaled down by a factor of 1.3, in our case from 20,000 to 15,400. We are aiming to achieve a quality surface finish, and the FPC is designed to be critically coupled to the cavity in this case. In case the surface finish cannot achieve 8 micro-inches, or the cavity is contaminated by the brazing material, or the cavity's quality factor get degraded for some other reasons, we still want to keep the FPC to be critically coupled to the cavity. The 2 FPC tuners are designed on the neck of the FPC port to change the FPC coupling of the fundamental mode. With two 0.5″ diameter knobs with 5 mm insertion, the Q_{ext} can be degraded from 20,000 to 12,800.

8 fixed tuners are evenly distributed on the center of the end cells, with 4 on each side. The fixed tuners are designed to be tangential to the cavity inner surface on the nominal position in ideal case. With one fixed tuner inserted 5 mm into the cavity, the fundamental frequency will increase 0.36 MHz, and the total 8 fixed tuners give a 2.88 MHz frequency increase. The 3.28 GHz HOM that will give the most perturbation on the energy spread if not well controlled is sensitive to the fixed tuners. With one fixed tuner inserted 5 mm into the cavity, the frequency of this HOM will increase 2.86 MHz. These fixed tuners will be used to tune the fundamental mode frequency towards 2.112 GHz, and to tune the 3.28 GHz HOM away from the multiples of 9 MHz.

Two pickup ports are designed on the center cell of the cavity. Hook shape pickup coupler is used to get a maximum 10 Watt power out of the cavity at 250 kV. This 10 Watt power will get significantly reduced through the RF cable from IP2 to the LLRF board since cables at 2.1 GHz are normally smaller and lossier while comparing with lower frequencies, for example, 704 MHz. By simply rotating the hook coupler, the output power can be reduced.

704 MHz Cavity RF Design

To ease the fabrication procedure, the design of the 704 MHz cavity reported in [3] is slightly modified. A 213.05 mm long, 165.01 mm radius pillbox with rounded corner (rounding radius 86.09 mm) is adpoted, as shown in Fig. 5(a). The beam pipe radius is increased to 41 mm for HOM consideration [4]. A Toshiba coaxial window is used in this design, and is connected to the cavity using a doorknob waveguide to coaxial vacuum transition. Multipacting simulation of the doorknob is performed and no significant issue was found. The 2.1 GHz tuner was scaled to 704 MHz to be used in the 704 MHz cavity.



(a) (b)

Figure 5. (a) 704 MHz cavity (b) cross section of doorknob with RF window.

CONCLUSIONS

In this paper, we report the RF design of the elliptical 704 MHz and 3-cell pillbox 2.1 GHz normal conducting RF cavities. These two cavities are currently under fabrication.

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