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RF CONCEPTUAL DESIGN OF NORMAL CONDUCTING CAVITY FOR AN ERHIC RAPID CYCLING SYNCHROTRON*

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Abstract

The Rapid Cycling Synchrotron (RCS) for the eRHIC Ring-Ring design will provide on energy injection (up to 18 GeV) of high charge, polarized electron bunches to the eRHIC electron storage ring. The RF system comprises a large number of 563MHz fundamental cavities, providing up to 45MV per turn. The cavities will operate in pulsed mode with <20% duty factor, at a repetition rate of 1 Hz. In this paper we report the conceptual RF design of the cavity.

INTRODUCTION

A RCS is proposed to inject on-energy polarized electron bunches into the Electron Storage Ring. The RCS will capture single, 400 MeV, 10 nC electron bunches from the pre-Injection Linac, and accelerate them up to a maximum energy of 18 GeV, over an acceleration ramp time of 100 ms - 200 ms. The repetition rate of the RCS is 1 Hz. The RCS RF utilizes only a fundamental 563MHz system. Table 1 shows the RCS parameters relevant to the RF system design.

Table 1: RF Operating Parameters of the RCS Injector

Parameter	Units	Value
Injection Energy	[MeV]	400
Top Energy	[GeV]	18
Circumference	[m]	3842.142
Repetition rate	[Hz]	1
Acceleration Time	[ms (Turns)]	100 (8000) – 200 (16000)
Number of bunches		1
Charge per Bunch	[nC]	10
RF Frequency	[MHz]	563 (h=7200)
Peak RF Voltage	[MV]	50
Bunch length	[mm (ps)]	1.8 (6)
dp/p		7.8e-4

CAVITY OPTIMIZATION

The design of the RCS cavity started at the 200MHz SPS (197MHz RHIC) cavity [1] (Fig. 1 top-left). The SPS single-cell cavity has an R/Q (accelerator definition in this paper) of 400 Ω, and a quality factor Q of 30,000. A CST model, shown in Fig. 1 top-right, was then constructed based on the SPS cavity by parameterizing important geometric parameters without blending, with beam pipe size set at 4 cm in diameter, based on the physical beam size and the possibility to maximize R. Simulation showed that a pillbox shape (Fig. 1 bottom-left) similar to the 2.1 GHz 3-cell normal conducting cavity [2,3] for LEReC project provided high shunt impedance R. Blending are added to this cavity to get the final single cell cavity design, shown in Fig. 1 bottom-right. It has an R/Q of 413 Ω, and a quality factor Q of 33,000, with R at 13.6 MΩ. In such a pillbox structure, even with blending, multipacting might exist, which needs to be studied in depth in the future. Simulations and experiences based on the 2.1 GHz and 704 MHz normal conducting cavities for LEReC project suggest that multipacting is not a hard barrier and can be overcome by conditioning.

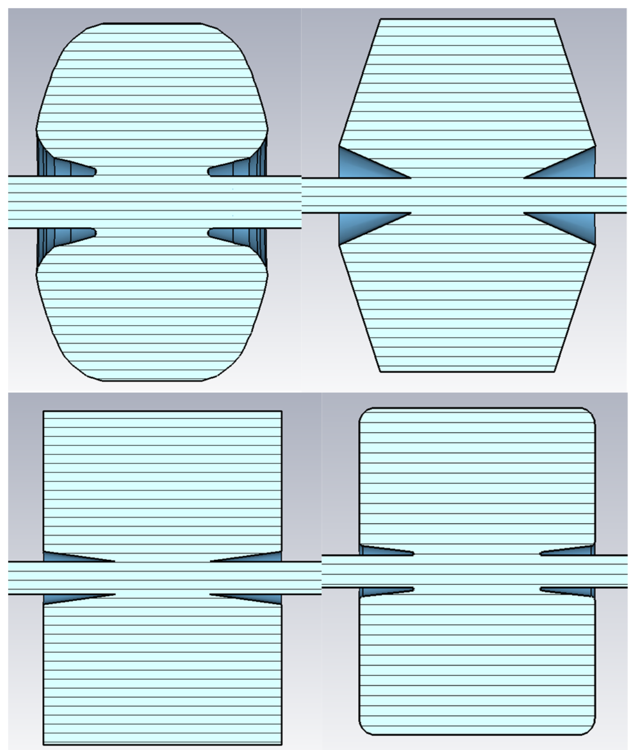

Figure 1: (Top-left) SPS 200 MHz cavity; (Top-right) parameterized SPS cavity without blending; (Bottom-left) optimized cavity without blending; (Bottom-right) optimized cavity.

TUNER AND VACUUM PORT DESIGN

The folded coaxial tuner used in the LEReC normal conducting cavities (including 704 MHz and 2.1 GHz cavities on LEReC Linac [2,3] and 704 MHz deflecting cavity on LEReC diagnose line) is scaled to fit the 563 MHz cavity, shown in Fig. 2 bottom. During acceleration from 400MeV to 18 GeV, the revolution frequency changes and with this, the harmonic frequency for the 563MHz cavity changes by 0.29 kHz, much smaller

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than the FWHM of the cavity at 19 kHz. The purpose of the tuner is not to cover the frequency change, but to simplify the conditioning and possible diagnosing.

Since the beam pipe diameter is only 4 cm in diameter, one would not prefer to put the vacuum pump on the beam pipe, which was adopted in the LEReC 2.1 GHz cavity. Similar to the LEReC 704 MHz cavity, a vacuum port is open on the cavity wall, and Cu mesh is used to block RF from leaking into the vacuum pump. The vacuum pumping port is shown in Fig. 2 top and bottom.

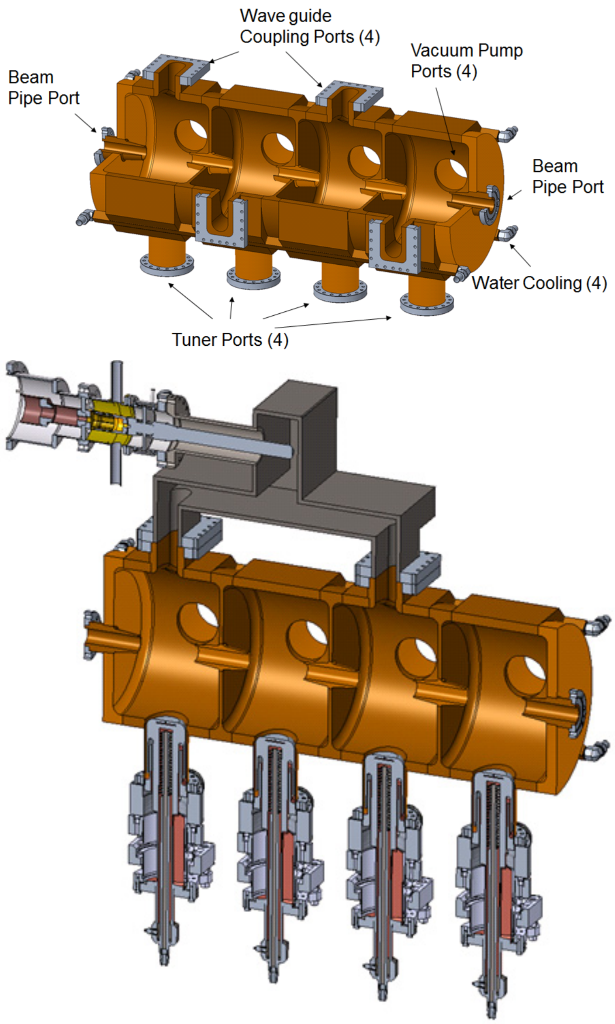

Figure 2: 563MHz 4-cell (top) bare cavity, (bottom) cavity with FPC and tuner. Cells are decoupled to each other, and every other cell are connected to one 70kW RF amplifier using waveguide to coaxial transition.

MULTICELL AND POWER COUPLING

To save cost, one would prefer to build a cavity with more cells. However there are some limitations from the fabrication procedures. For example, an 8-cell 563 MHz RCS cavity will be too big for brazing chambers. With these considerations, cavity with 4-cell is chosen.

For the RCS 563 MHz cavity, with 13.6 MΩ/cell R from the above single cell design, and 0.625 MV accelerating voltage, the peak power per cell is 28.7 kW rms. The RCS cavity accelerates electron bunches with 10 nC per bunch in a 78 kHz repetition rate from 400 MeV to a maximum energy of 18 GeV, over an acceleration ramp time of 100 ms - 200 ms. The maximum power deliver to the beam is 97.5 W per cell. With an IOT amplifier at 70 kW CW, it can provide enough power for 2 cells. This power delivery system is similar, and slightly simpler, to the 500 MHz normal conducting bunching cavities for Coherence electron Cooler (CeC) for RHIC system [4], since it does not require high power phase shifter, and the distance between adjacent cells is fixed at half of the wavelength of the working mode.

There are different choices for cell-to-cell coupling in multicell design. E-field coupling through the beampipe, H-field coupling through the slots on the wall between two cells, or some special designs. However, with E-field coupling, R/Q will get degraded, and with H-field coupling, Q will get degraded. These two coupling schemes will degrade R, thus require more RF power.

Table 2: RF Parameters of the RCS 563MHz Cavity

Parameter (each cell)	Value
Beam pipe diameter [cm]	4
R/Q [Ω in accelerator definition]	410
Quality factor	31,900
Shunt impedance [MΩ]	13
Operating voltage [kV]	625
Peak power [kW rms]	30
Duty factor	<20%
Average power [kW rms]	6
Repetition rate [Hz]	1

With the above considerations, the 4-cell cavity is designed with cells decoupled to each other, shown in Fig. 2 top. The Fundamental Power Coupler (FPC) is critically coupled to the cavity, with the consideration that maximum power to the beam can be ignored while comparing with the power dissipated on the cavity wall. Since there is a 180 degree phase difference between adjacent cells, we connect every other cell together using E-type waveguide, shown in Fig. 2 bottom, and feed it with one IOT 70kW amplifier. For the E-type waveguides, we choose not to use regular 2:1 waveguide to save cost and space, and to reduce the weight. Each amplifier is connected to 2 cells using a Toshiba SNS-type coaxial RF window, and then a coaxial to waveguide transition piece, shown in Fig. 2 bottom and Fig. 3. This design ensures that The RF window is not in the line of sight of the electron beam to avoid charging of its ceramics, which may result in arcing through and creation of pinhole vacuum leaks [5]. This design also eliminates the need of combiners and RF terminators with >140 kW power rate, which are expensive. The FPCs for two adjacent cells are shifted 90 degree to avoid physical conflicts. 180 degree shifting is also in consideration in case transverse instability due to port openings becomes an issue. For the 4-cell design, with FPC/tuner/vacuum port openings, the R/Q is 410 Ω per cell, and Q is 31,900, with R slightly decreased to 13.0 MΩ. The peak power per cell turns out to be 30.0 kW rms. The RF parameters of the RCS 563 MHz cavity are listed in Table 2.

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Four water cooling channels are added around this 4-cell cavity trying to stabilize the temperature during operation. Detailed thermal analysis will follow. With 6 kW average power dissipated on the cavity, one would expect such a simple cooling design meets the requirement.

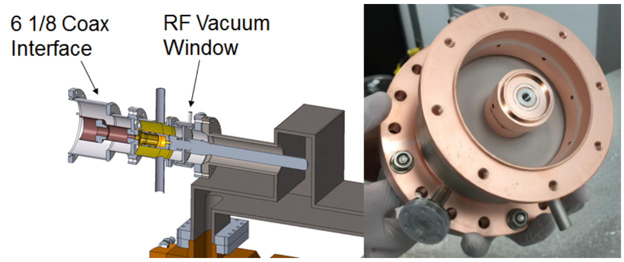

Figure 3: Waveguide to coaxial transition: (left) cross section view; (right) picture of the coaxial RF window [2,3].

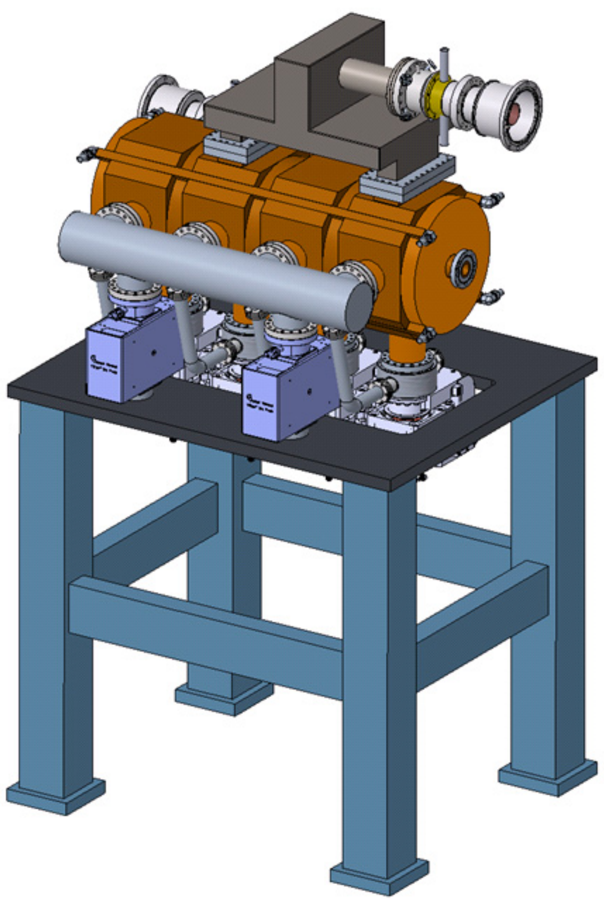

Figure 4. RCS 563MHz cavity assembly on the stand.

DIMENSION AND COST ESTIMATION

To deliver a peak RF voltage of 50 MV per turn, 20 4-cell cavities are needed, with 0.625 MV from each cell. The length of each cell is 0.266 m. With 4-cell plus the beam pipe, the cavity length is 1.2 m. For 20 cavities, the total length will be 52 m considering 1 m space between each two cavities and 20% margin. The 4-cell cavity assembly on the stand is shown in Fig. 4.

Ten IOT 70 kW amplifiers with 10 Toshiba SNS-type coaxial RF windows are used to feed these 20 4-cell cavity. As discussed previously, each cell is independently tuned with a coaxial tuner. The cost estimation is listed in Table 3. The total will be 27.0 M$, with 44.4% for amplifier, 22.2% for cavity, and 33.3% for others.

Table 3: Cost Estimation of the RCS 563 MHz System

Component	Price for each [k$]	Quantity	Price [M$]
4-cell cavity	300	20	6.0
Cavity stand	30	20	0.6
RF window	80	40	3.2
FPC power distribution box	30	40	1.2
RF amplifier	300	40	12.0
RF waveguide & circulator	50	40	2.0
LLRF	10	40	0.4
Tuner	20	80	1.6
Total			27.0

CONCLUSIONS

In this paper, we report the conceptual RF design of the 563 MHz normal conducting cavity for eRHIC RCS. This 4-cell cavity is designed with cells decoupled to each other to maximize the shunt impedance and minimize the power requirement. We connect every other cell together using E-type waveguide, and feed it with one IOT 70kW amplifier with one Toshiba SNS-type coaxial RF window. This design ensures high performance with reasonable low cost.

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REFERENCES

[1] R. Connolly, J. Aspenleiter, S. Kwiatkowski, "Modifying CERN SPS cavities and amplifiers for use in RHIC," in *Proc. PAC'97*, Vancouver, BC, Canada, May 1997, paper 2P032, pp. 2947-2949.

[2] B. P. Xiao, S. Belomestnykh, I. Ben-Zvi *et al.*, "Design of Normal Conducting 704 MHz and 2.1 GHz Cavities for LEReC Linac," in *Proc. IPAC'15,* Richmond, VA, USA, May 2015, paper WEPWI061, pp. 3634-3637, https://doi.org/10.18429/JACoW-IPAC2015-WEPWI061

[3] B. P. Xiao, S. Belomestnykh, I. Ben-Zvi *et al.*, "RF Design of Normal Conducting 704 MHz and 2.1 GHz Cavities for LEReC Linac," in *Proc. IPAC'16,* Busan, Korea, May 2016, paper MOPMY007, pp. 525-527, https://doi.org/10.18429/JACoW-IPAC2016-MOPMY007

[4] S. Belomestnykh, I. Ben-Zvi, J. C. Brutus *et al.*, "Commissioning of the 112 MHz SRF gun and 500 MHz bunching cavities for the CeC PoP LINAC," in *Proc. IPAC'15,* Richmond, VA, USA, May 2015, paper WEPWI049, pp. 3597-3599, https://doi.org/10.18429/JACoW-IPAC2015-WEPWI049

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF032

[5] M. A. Drury, E. Daly, G. K. Davis *et al.*, "Performance of the first refurbished CEBAF cryomodule, in *Proc. PAC'07*, Albuquerque, NM, USA, Jun. 2007, paper WEPMS059, pp. 2478-2480.