DESIGN AND FABRICATION OF A 5-CELL HIGH CURRENT SUPERCONDUCTING CAVITY

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Abstract

Superconducting Energy Recovery Linacs have various applications, such as hard X-ray, electron-ion colliders and electron cooler of ions. The key component for accelerating such high current beams is the superconducting radio frequency cavity. The design of a 1.3 GHz 5-cell high current superconducting cavity has been carried out under the cooperation between Peking University and Argonne National Laboratory. Radio frequency property and damping of the higher order modes of this cavity have been discussed and the final design is presented. Room temperature RF measurements are also described in the paper.

INTRODUCTION

Argonne National Laboratory (ANL) and Peking University (PKU) are both interested in developing high current superconducting cavity. ANL is planning to update Advanced Photon Source (APS) to hard x-ray to satisfy the future scientific requirement of the users [1]. For this purpose, ANL has designed a 1.4GHz prototype 5-cell high current cavity [2]. In order to meet the availability of high power RF source, ANL requests PKU to make a prototype of 1.3 GHz 5-cell high current superconducting cavity as pre-research of APS update under the cooperation between ANL and PKU. In this paper, we describe the simulation and design of this cavity.

CAVITY RF DESIGN

The TESLA like cavity is known as the typical L-band superconducting cavity for accelerators with high acceleration gradient such as X Ray FEL and International Linear Collider [3]. But the TESLA cavity is not suitable for high current ERL, because of insufficient capability of the HOMs damping. Therefore, we decide to develop a high current cavity as pre-research of APS update. In order to meet the requirement, the optimization of this high current cavity focuses on effective damping of the HOMs while maintaining appropriate R/Q of the accelerating π mode and an acceptable RF field level of B_p/E_{acc} or E_p/E_{acc}.

The optimum design of an elliptical cavity is the consequence of compromises between RF and mechanical parameters. Usually, an elliptical cavity with good RF design faces the mechanical problems such as Lorentz detune and pressure load. The geometric parameters for elliptical high current cavity (see Fig.1) are the cell length (L), the radius at cell equator (R_{eq}), the radius at cell iris (R_{iris}), the equator ellipse ratio (R_e=B/A), the iris ellipse ratio (r_i=b/a), the distance from the cavity wall to the iris plane (d), and the side wall inclination (alpha).

The final optimized parameters of the 5-cell high current cavity are shown in Table 1. We adopt the asymmetric end cups design which is beneficial for propagating the HOMs.

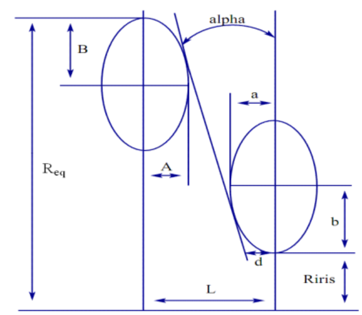

Figure 1: Geometry parameters for a half cell

The cutoff frequency of the beam pipe with 48.7mm radius is 1.81 GHz for TE_{11} mode and 2.36GHz for TM_{01} mode. The frequencies of the first two passbands of the 5-cell cavity HOMs are around 1.5GHz and 1.7GHz, which are below the cutoff frequency of the beam pipe and can`t be delivered to external easily. In order to propagate all the HOMs, we choose 60mm as the enlarged beam pipe radius.

Table 1: Geometry Parameters of the 5-cell High Current Cavity

Parameters	Mid-cell	Left end cup	Right end cup
L [mm]	57.7	57.7	57.7
$R_{iris\,[mm]}$	41.2	48.7	48.7
A [mm]	38	35.7	40.4
B [mm]	23.8	23.8	32.3
a [mm]	10.8	16.9	15.6
b [mm]	16.3	16.3	23
R_{eq} [mm]	104	104	104

Table 2: The RF Parameters Comparison of Different Cavities

parameters	f /MHz	cell	R/Q /Ω	Ep/Eacc
TESLA	1300	9	1030	2
ANL-PKU	1300	5	462	2.4
parameters	Bp/Eacc mT/(MV/m)	Coupling (%)	R_{iris} mm	R_{pipe} mm
TESLA	4.26	1.87	35	39
ANL-PKU	4.6	3.8	41.2	60

Table 2 compares the fundamental mode RF parameters of the 5-cell high current cavity with the TESLA 9-cell cavity [4]. Large iris enhances the cell to

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cell coupling which is good for HOMs propagating, but it decreases R/Q per cell. Though the E_p/E_{acc} and B_p/E_{acc} are higher than those of the TESLA cavity but they are also acceptable, since ERL high current cavity operates at the gradient of 15-20MV/m [5].

HIGHER ORDER MODES

The model for simulation is shown as Fig.2. Beam tube damper was used for coupling the HOMs. The Q_e was calculated assuming there are ideal RF absorbers at the end of the pipes and HOMs propagating through the waveguide ports will be absorbed completely.

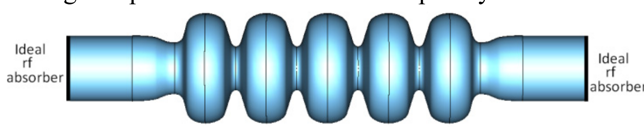

Figure 2: The Microwave Studio model for Q_e calculation

Monopole Mode

Monopole HOMs, whose frequency is close to the bunch harmonic frequency, should be avoided as the beam power loss is extremely high in that situation [6]. For a total beam current I_b (100 mA) and assuming an upper power limit of 200 W per mode, the impedance limit of the monopole mode close to 2 N 1.3GHz is[7]

$$\frac{R}{Q} \cdot Q_e < 10^4 \Omega , \qquad (1)$$

where N is an integer.

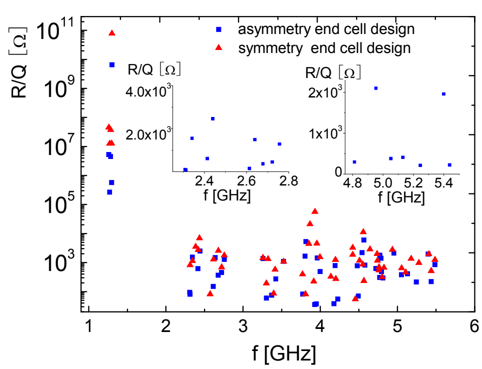

Figure 3: Spectrum of monopole mode

Fig.3 gives the simulation result of monopole modes up to 5.5GHz, where all monopole modes with frequencies close to beam harmonics are sufficiently damped with $R/Q \cdot Q_e < 10^4\ \Omega$. The asymmetric end cells design is beneficial for propagating the HOMs, especially the dangerous trapped mode. In addition, there is an trapped mode near 3.9GHz (3×1.3GHz) and its $R/Q*Q_e$ is about $10^5\Omega$ in the symmetric design. However, with the asymmetric end cups design, the mode can propagate outside of the cavity easily.

Dipole Modes and Quadrupole Modes

Dipole modes and quadrupole modes are undesirable in accelerating cavities because they will increase the bunch emmitance and energy spread, or even lead to beam breakup instability.

Typical simulation results for 100mA high current cavity calculated by Cornell university show that the dipole and quadrupole HOMs should be meet the demands of Equation(2) and Equation(3) separately [7].

For the dipole HOMs,

$$\left(\frac{R}{Q}\right)\frac{Q_e}{f} < 1.4 * 10^5 \frac{\Omega}{cm^2 GHz} , \qquad (2)$$

For the quadrupole modes,

$$\left(\frac{R}{Q}\right)\frac{Q_e}{f} < 4 * 10^6 \frac{\Omega}{cm^4 GHz} . \qquad (3)$$

Our simulation results of the dipole modes and quadrupole modes are shown in Fig.4. $R/Q*Q_e/f$ of the dipole modes and the quadurpole modes in our simulation is at least 1 order less than the demands of 100mA limit in Equation(2) and Equation(3) seperately. Therefore, 100mA BBU thresold current can be satisfied in a well designed ERL loop.

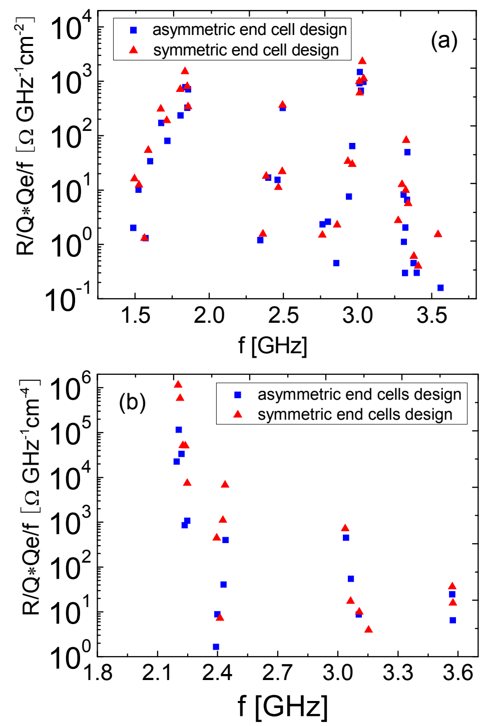

Figure 4: (a) Spectrum of the dipole HOMs, (b) Spectrum of the quadrupole HOMs

ROOM TEMPERATURE RF MEASUREMENT

A test niobium SRF cavity with no enlarged beam pipe was built to test the accelerating properties of this type high current cavity at 2K. The cavity is made of the fine grain high purity niobium sheets with RRR300.

The production procedure includes the following major fabrication steps: (1) deep drawing half-cells, (2) trim half-cells, (3) electron-beam welding (EBW) irises of two half-cells, (4)EBW stiffening rings, (5) RF measurement for dumb bell trimming, (6) dumbbell trimming to frequency, (7) grind and BCP dumbbell surfaces, (8) EBW flange to beam-tubes, (9) EBW endgroup subassemblies, (10) EBW equators. The EBW was performed at Harbin Institute of Technology (HIT).

The 5-cell cavity fabrication was finished by PKU in June 2011. A photograph of the 5-cell cavity is shown in Fig. 5. The original field flatness is 87.2% and the field flatness is 98.6% after tuning (see Fig.6).

Figure 5: 5-cell niobium high current cavity

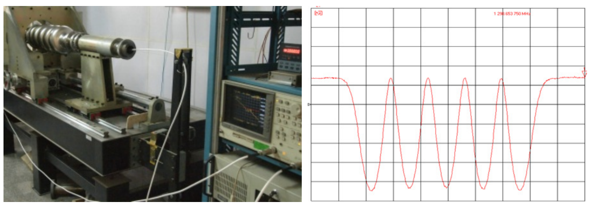

Figure 6: (a) tuning system at PKU (b) field flatness after tuning

HOMs of this cavity have been investigated with vector network analyzer. The measured monopole HOMs and the corresponding simulation results are shown in Table 3. Fig.7 shows the some monopole HOMs between the measured modes and the corresponding simulation result. The deviation of the frequency between the measured modes and the simulation are caused by the deviation of the fundamental π mode. The fundamental π mode frequency of the simulated cavity at 2K is 1.3GHz whereas it is 1.29865GHz for the test cavity at room temperature. From the comparison of the measured modes and the simulation result, the measured modes are in good agreement with the simulation results.

Table 3: Measured and Simulated Monopole HOMs

	Frequency (GHz)	
	measurement	simulation
TM011	2.31109	2.30745
	2.33566	2.32684
	2.36484	2.35494
	2.3949	2.38518
	2.42082	2.55189
TM020	2.58257	2.55432
	2.64435	2.62535
	2.69028	2.67358
	2.72689	2.70884
	2.75256	2.73684

OPTICAL INSPECTION

An inspection system of the inner surface of SRF cavity is developed at Peking University (see Fig.8). The achieved resolution of this inspection system is about 15μm/pixel. With this inspection system, we checked the inner surface of the 5-cell niobium cavity and it looks fine.

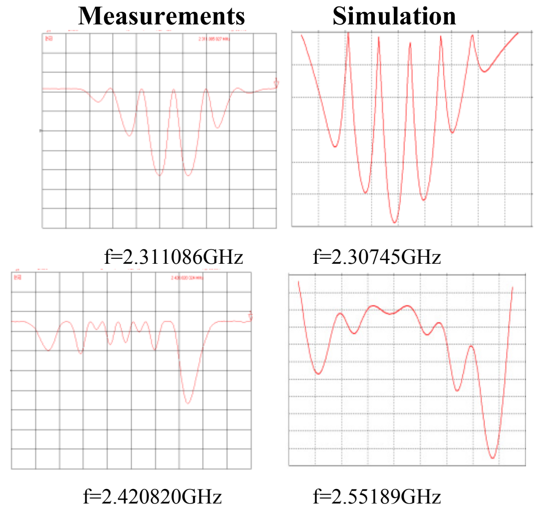

Figure 7: Comparison of some monopole HOMs in the cavity and the simulation

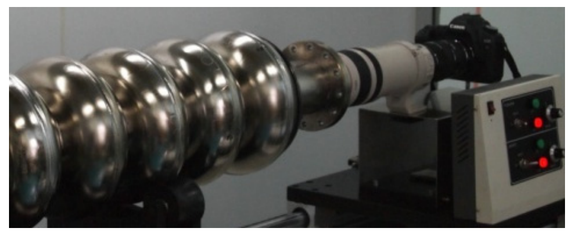

Figure 8: Optical inspection system at PKU

SUMMARY

The design of a 1.3GHz high current superconducting cavity for pre-research of APS update has been finished under the collaboration between PKU and ANL. This prototype 5-cell high current cavity has large iris and enlarged beam tube which are beneficial for HOMs propogation to the absorbing material. Compared with the TESLA cavity, it has reletive high E_p/E_{acc} and B_p/E_{acc}, but is acceptable for ERL operation at the accelerating gradient of 15-20MV/m. The fabrication of this cavity has finished. The HOMs measured in the cavity are in good agreement with the simulation results. The cavity was sent to ANL and will be tested at low temperature.

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