ELECTRO-MAGNETIC OPTIMIZATION AND ANALYSES OF ETCHING FOR HIRFL QUARTER-WAVE RESONATOR

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Abstract

A superconducting accelerating section for SSC-linac system (injector into separated sector cyclotron) is under development at the HIRFL (heavy ion research facility of Lanzhou). Two types of superconducting quarter-wave resonators (81.25 MHz, optimum beta = 0.041 and 0.085) will be used for acceleration to energies of up to 10 MeV per nucleon. The beta=0.041 QWR works at the accelerating voltage of 1 MV and beta=0.085 QWR works at 2 MV, in order to reach a record high performance, the EM design was carefully optimized for both cavities. A selected number of cavity geometry parameters were analyzed to see how they affect the electro-magnetic parameters of the cavity, and different influence levels of these geometry parameters are ranked. In this paper, we will also present how the etching thickness changes the frequency during the buffered chemical polishing processing, and the difference of the change for the two type cavities has been compared.

INTRODUCTION

The main objective of high energy accelerators is to impart a large amount of energy to the beam without a substantial loss. Reduction of the losses is directly to the reduction of the surface resistance in the cavity walls, therefore radio frequency (RF) superconductivity has become an important technology for particle accelerator. Superconducting cavities currently used for acceleration of ions with low velocity are based frequently on quarter wave resonators (QWR) due to their simplicity, accessibility and low fabrication cost [1,2]. The Institute of Modern Physics (IMP) has been doing the research of superconducting QWR cavity since 2007.

A SSC-Linac system (injector into separated sector cyclotron) is being designed in the HIRFL (heavy ion research facility of Lanzhou) of IMP. As part of the SSC-Linac, the superconducting segment will use QWR cavities of f=81.25 MHz, βopt=0.041，0.085 to accelerate beams from β~0.02 to β~0.16.The EM design and optimization of the cavities have been done and the mechanical analysis is being performed. The optimization of the cavity geometric shape and its influence on RF behavior will be presented and discussed.

ELECTRO-MAGNETIC CAVITY OPTIMIZATION

CST was used for EM simulation of the QWR cavities, in order to reach a high accelerating voltage per cavity, the shape design was carefully optimized. We mostly care about four EM parameters, they are the peak surface electric field--E_{peak}, the peak surface magnetic field--B_{peak}, the geometric shunt impedance--R_a/Q_0 and the geometric factor--G. During the optimization, we will pay attention to all the relevant geometry parameters' influence on the EM behaviors. In Figure 1, we present the most important 6 geometry parameters, they are explained below [3,4]:

1) The cavity top radius (TopR)
2) The cavity radius (CavR)
3) The stem top radius (STTR)
4) The stem bottom radius (STBR)
5) The drift tube gap width (DTGW)
6) The beam tube radius (BTR)

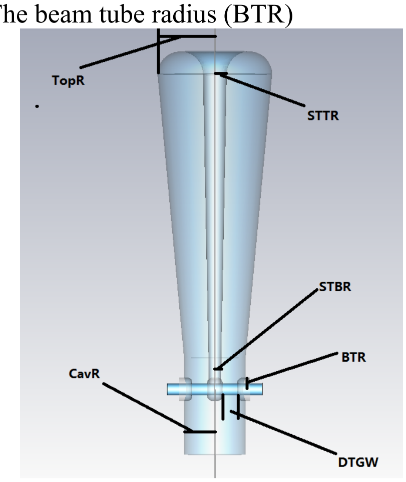

Figure 1: Parameters of the cavity geometry used in the EM optimization.

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The influence degree of the 6 geometry parameters on each EM parameters are arranged from left to right with a descending order, and the most sensitive two geometry parameters' function on the EM parameters are plotted.

QWR-0.041

Table 1：Dependence of Ra/Q_0 on the geometry parameters

STBR	STTR	CavR	DTGW	TopR	BTR
-	-	+	-	+	0

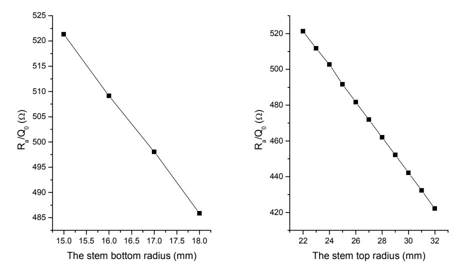

Figure 2: The two most sensitive parameters' function on R_a/Q_o.

Table 2：Dependence of G on the geometry parameters

CavR	TopR	BTR	STBR	STTR	DTGW
+	+	-	-	-	+

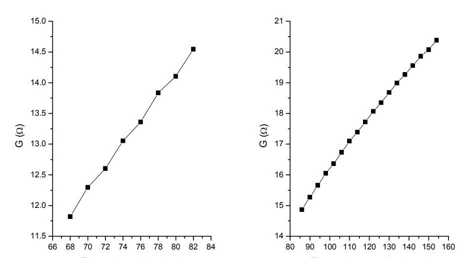

Figure 3: The two most sensitive parameters' function on G.

Table 3：Dependence of E_{peak} on the geometry parameters

STBR	BTR	DTGW	CavR	STTR	TopR
+	+	+	+	+	0

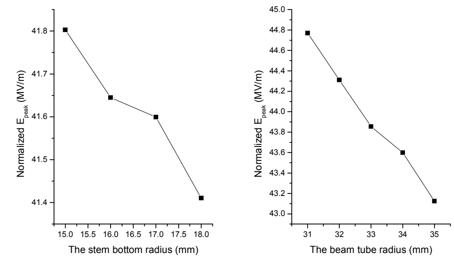

Figure 4: The two most sensitive parameters' function on E_{peak}.

Table 4：Dependence of B_{peak} on the geometry parameters

STTR	CavR	STBR	DTGW	TopR	BTR
+	+	-	-	+	0

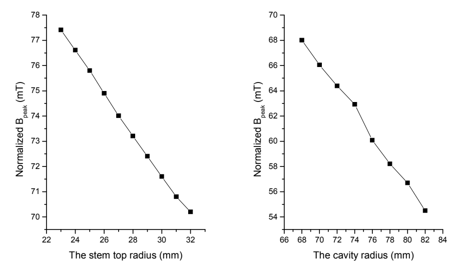

Figure 5: The two most sensitive parameters' function on B_{peak}.

QWR-0.085

Table 5：Dependence of R_a/Q_0 on the geometry parameters

STBR	CavR	STTR	DTGW	TopR	BTR
-	+	-	-	+	-

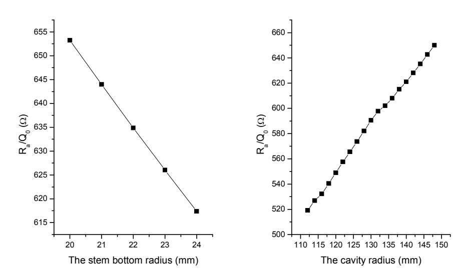

Figure 6: The two most sensitive parameters' function on R_a/Q_0.

Table 6：Dependence of G on the geometry parameters

CavR	TopR	BTR	DTGW	STTR	STBR

+	+	-	+	-	0

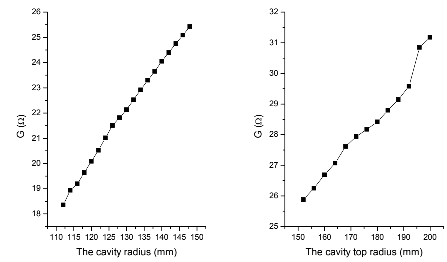

Figure 7: The two most sensitive parameters' function on G.

Table 7: Dependence of E_{peak} on the geometry parameters

CavR	DTGW	STTR	STBR	TopR	BTR
+	+	+	-	0	0

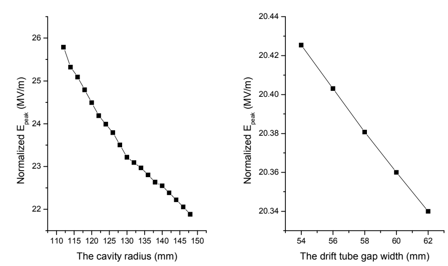

Figure 8: The two most sensitive parameters' function on E_{peak}.

Table 8: Dependence of B_{peak} on the geometry parameters

STBR	STTR	CavR	TopR	BTR	DTGW
-	+	+	+	+	0

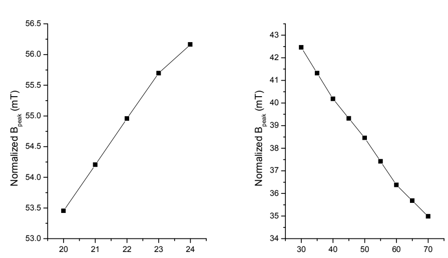

Figure 9: The two most sensitive parameters' function on B_{peak}.

The tables above means the effect of increasing every geometry parameter one at a time: + means a positive impact, - means a negative impact and 0 means no impact. After all the 6 geometry parameters' effect on the EM parameters has been checked, we finally can establish the general dependence of the EM parameters on the geometry parameters. The final cavity design will have a cylindrical shape on the bottom and a conic shape on the top for each type QWR cavity (Table 9).

Table 9: EM parameters of QWR cavities of βopt=0.041,0.085

Parameter	QWR041	QWR085
frequency	81.25MHz	81.25MHz
E_{peak}	36.7 MV/m @ V_{acc}=1MV	38 MV/m @ V_{acc}= 2MV
B_{peak}	44.9 mT @ V_{acc}=1MV	46.8 mT @ V_{acc}=2MV
R_a/Q_0	626 Ω	668 Ω
G	21 Ω	31 Ω

ETCHING EFFECT ON THE CAVITY RESONANT FREQUENCY

The surface processing is an important step in the way to a good superconducting cavity. Either the BCP or the EP is to etch proper thickness of the inner surface, which will change the frequency [5]. According to Slater's perturbation theory, a small deformation in the cavity boundary will lead to a frequency shift:

$$\frac{\delta\omega_0}{\omega_0} = \frac{1}{4U}\int_{\delta V^*}(\varepsilon_0 E^2 - \mu_0 H^2)dV \qquad (1)$$

where:

$$U = \frac{1}{4}\int_V (\varepsilon_0 E^2 + \mu_0 H^2)dV \qquad (2)$$

is the average energy stored in the cavity volume V and δv*is the volume variation caused by the distortion at the cavity wall; and in combination with the ANSYS program, it is possible to calculate the change in the frequency because of the etching.

Starting from the frequency of ~81.18 MHz for β=0.041 QWR and ~81.23 MHz for β=0.085 QWR, respectively, we are interested in the etching thickness' role in changing the cavity resonant frequency. The Figure 10 presents the quantitative dependence of the cavity frequency as a function of the etching thickness. It can be seen that, for QWR cavity, the etching of internal surface will increase the resonant frequency of the cavity, and the smaller of the cavity inner space, the larger of the frequency increment the etching will lead to.

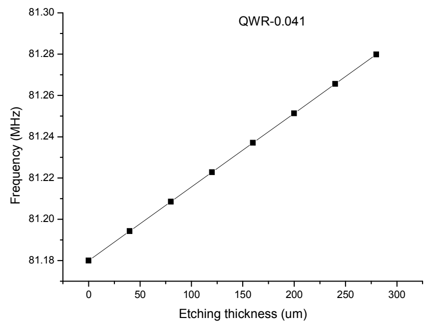

Figure 10: Quantitative dependence of the resonant frequency of the cavity on the etching thickness for QWR-0.041.

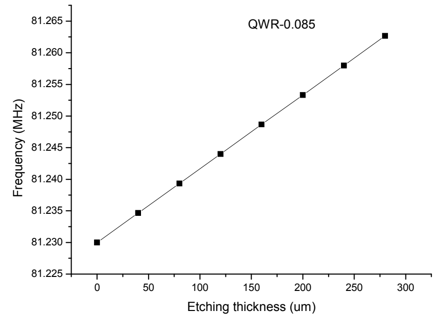

Figure 11: Quantitative dependence of the resonant frequency of the cavity on the etching thickness for QWR-0.085.

REFERENCES

[1] Panamsee H, Knobloch J, Hays T. RF superconductivity for accelerators [M]. New York: John Wiley & Sons, 1998,P.3~P.36.
[2] A. Facco, V.Zviagintsev, "Study on beam steering in intermediate- β superconducting quarter wave resonators", Proc. of the 2001 Particle Accelerator Conference, P.1095.
[3] P. N. Ostroumov, et al. A new ATLAS efficiency and intensity upgrade project", Proc. Of the SRF 2009, P218.
[4] B. Mustapha, P. N. Ostroumov, "Electro-magnetic optimization of a quarter-wave resonator", Proc. of the 2010 Linac Conference.
[5] D. Pozar, Microwave Engineering (Third Edition). John Wiley & Sons, P.256.