ELECTRO-MAGNETIC OPTIMIZATION OF A QUARTER-WAVE RESONATOR

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Abstract

The Institute of Modern Physics (IMP) has been trying to design a highly effective accelerating quarter-wave resonator (QWR) cavity which can work at a record high voltage of 2.5 MV with as low as possible peak surface electromagnetic (EM) fields. In the cavity design, we set the goal of the optimization to minimize the peak magnetic and electric fields while still keeping good values for the R over Q and the geometric factor. Take the design of the QWR cavity with frequency of 81.25 MHz and beta of 0.085 for example, from a regular cylindrical shaped inner and outer conductors, the optimization has led them to a conic inner conductor and an elliptical cylinder outer conductor. In this paper, we will present how the cavity geometry parameters evolve in order to approach optimal EM design.

INTRODUCTION

The most appealing aspect of superconducting radio frequency (SRF) accelerating cavities is that they can operate in continuous wave (CW) mode or long pulse mode while providing a high accelerating gradient due to low heat loss. The quality factor Q of SRF cavities is very high since the surface resistance of SRF cavities is 5 orders lower than that of copper cavities. The SRF cavities are refrigerated with liquid helium in order to achieve the surface resistance in nΩs. The cavities' operating temperatures are generally either above 4K or below 2K. The cryogenic load of the superconducting cavities is an important factor when we design a SRF accelerating facility.

The dynamic heat load calculation was done by calculating the cavity's RF power dissipation from fundamental cavity parameter, and the power dissipation is inversely proportional to $(Ra/Q_0)G$. Therefore, the SRF cavity optimization should include the minimization of the peak surface magnetic and electric fields while keeping favorable values for the shunt impedance and the geometry factor [1].

The large number of QWR cavities needed for the superconducting linac in IMP may exert great pressure on the cryogenic plant in the future, so it is necessary to design the superconducting QWR cavities with high geometric shunt impedance and geometry factor in order to minimize the cryogenic load.

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A NEW-SHAPED QWR CAVITY WITH AN ELLIPTICAL CYLINDER OUTER CONDUCTOR

To maximize the geometric shunt impedance and geometry factor, we tried an elliptical cylinder outer conductor of the cavity and noticed that this new shape will improve the parameters of interest significantly, including the shortening of the cavity height, approximately a ~68% increase of the $(Ra/Q_0)*G$ and a ~15mm reduction of the cavity height, compared to the QWR with a conventional cylindrical outer conductor, whose outer conductor radius is of the short axis radius of the elliptic cylinder in order to keep the same optimum β(Figure 1). The EM parameters in Table 1 show the comparison of a not optimized QWR with an elliptical cylinder outer conductor and QWR with a conventional cylinder outer conductor.

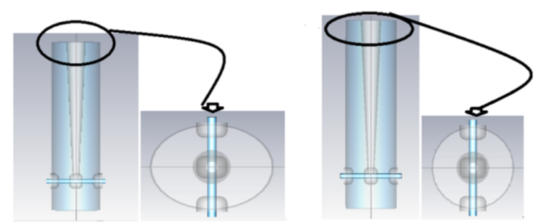

Figure 1: The comparison between QWR with an elliptical cylinder outer conductor and QWR with a conventional cylinder outer conductor.

Table 1: The EM parameters of a not optimized QWR with elliptical OC and a QWR with conventional OC

Parameter	Elliptical OC	Conventional OC
R_a/Q_0 *G (Ω^2)	~15249	~11842
B_{peak}/V_{acc}(mT/MV)	~34.4	~36
E_{peak}/V_{acc} (m^{-1})	~20	~22
Height (mm)	~895	~910

Not only can this design achieve better value of (R_a/Q_0) times G, it can also lower the cavity height which is an important factor for consideration of reasonable cryomodule size and mechanical stability; in the meantime, we use the short axis to accelerate the beam which is helpful to maintain relatively high real-estate gradient.

ELECTRO-MAGNETIC OPTIMIZATION OF THE NEW-SHAPED QWR CAVITY

The EM design of the new-shaped QWR was carefully optimized in order to reach a high accelerating voltage. In the optimization, we try to minimize the peak surface electric and magnetic fields and keep high values for Ra/Q_0 and G .

Some important geometry parameters were used during the optimization, they are presented on Figure 2 and explained below [2,3]:

(1) The cavity horizontal long radius(LongR)
(2) The cavity horizontal short radius (ShortR)
(3) The inner conductor top radius (ICTR)
(4) The inner conductor bottom radius (ICBR)
(5) The drift tube outer radius (DTOR)
(6) The accelerating gap width (AGW)

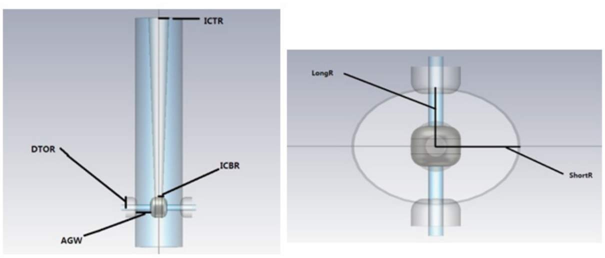

Figure 2: Parameters of the cavity geometry used in the electro-magnetic optimization.

The optimization begins from the cavity horizontal long radius (LongR) of 165 mm with an increase step of 10 mm, we notice this geometry parameter improves the Ra/Q_0 by about 5 Ω every step and leads to a final value of 706 Ω in Ra/Q_0; it also improves the G by several tenths of Ω and leads to a final value of 23.1Ω in G; it decreases the Epeak/Vacc by about 0.2 /m every step and Bpeak/Vacc by about 0.2 mT/MV every step and leads to the final values of 19.4 /m in Epeak/Vacc and 33.8mT/MV in Bpeak/Vacc. Therefore, the growth of LongR will make a positive contribution to all the parameters in which we are interested, Figure 3 shows the quantitative dependence.

With the LongR value of 195 mm, we now begin to change the inner conductor top radius (ICTR) from 50 mm with an increase step of 1 mm. This geometry parameter just has a positive effect on the B_{peak}/V_{acc}, making it lower by about 0.2 mT/MV each time; the ICTR can hardly change the E_{peak}/V_{acc}; and it plays a negative role in the R_a/Q_0 and G by lowering the R_a/Q_0 from 706 Ω to 659 Ω and lowering the G from 23.1 Ω to 22.1Ω (Figure 4).

We think the increase of the ICTR already gives us a good value of B_{peak}/V_{acc}, then we fix it and begin to change the cavity horizontal short radius (ShortR). Changing the ShortR from 115mm, we increase it by 5mm each time. This geometry parameter is very effective in the optimization of the EM parameters. We change the ShortR to 150mm, and it brings about the R_a/Q_0 of 746 Ω, G of 26.8 Ω, E_{peak}/V_{acc} of 17.1 /m and B_{peak}/V_{acc} of 24 mT/MV (Figure 5).

In the following, we want to check the impact of the left 3 geometry parameters. Their function seems not as obvious as the first three geometry parameters. The inner conductor bottom radius (ICBR) only has a very weak effect on the G; it has negative effect on the R_a/Q_0 and the E_{peak} by lowering the R_a/Q_0 to 710 Ω and increasing the E_{peak}/V_{acc} to 17.37/m,respectively; and it has no effect on the B_{peak}/V_{acc} (Figure 6).The drift tube outer radius (DTOR) can decrease the R_a/Q_0 still further and lower the E_{peak}/V_{acc} a little bit by 0.21/m, the G and the B_{peak} show no change with the increase of the drift tube outer radius (Figure 7). The accelerating gap width (AGW) helps to reduce the E_{peak}/V_{acc}, but it will decrease the R_a/Q_0 and increase the B_{peak}/V_{acc}, and it has almost no impact on the G (Figure 8).

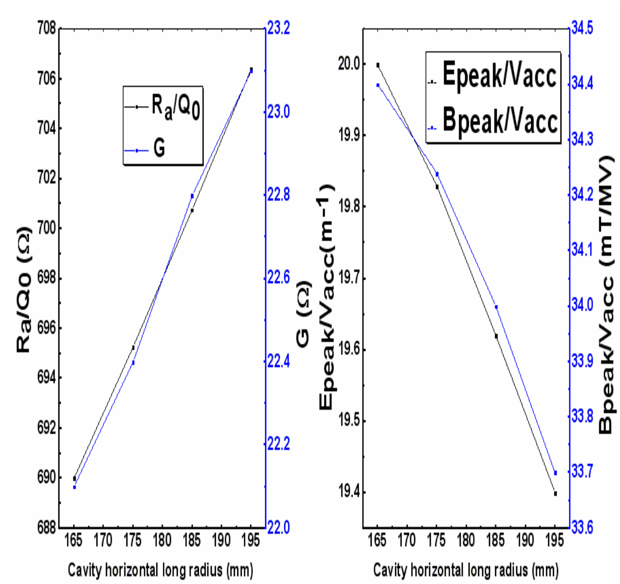

Figure 3: Quantitative dependence of the EM parameters as function of the cavity horizontal long radius.

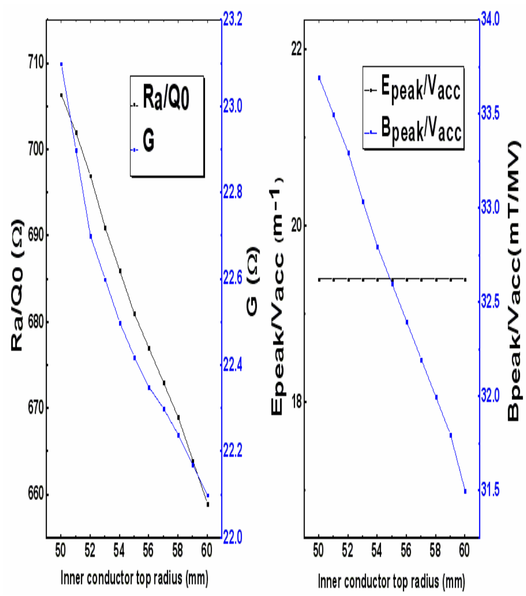

Figure 4: Quantitative dependence of the EM parameters as function of the inner conductor top radius.

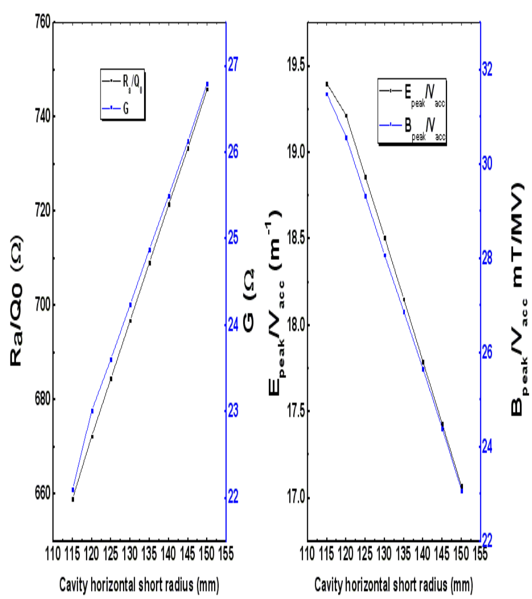

Figure 5: Quantitative dependence of the EM parameters as function of the cavity horizontal short radius.

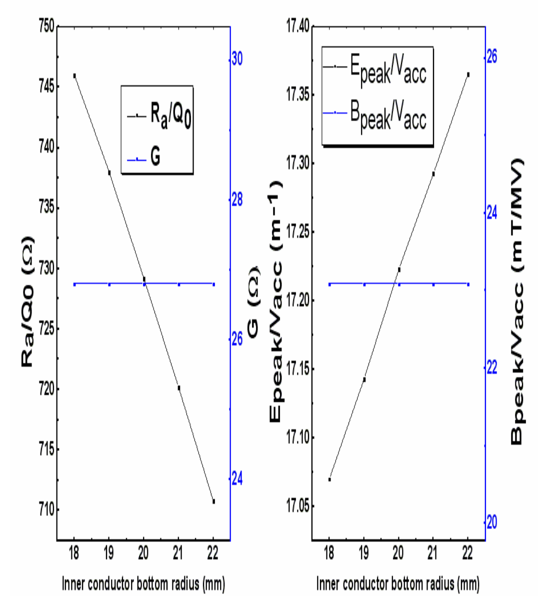

Figure 6: Quantitative dependence of the EM parameters as function of the inner conductor bottom radius.

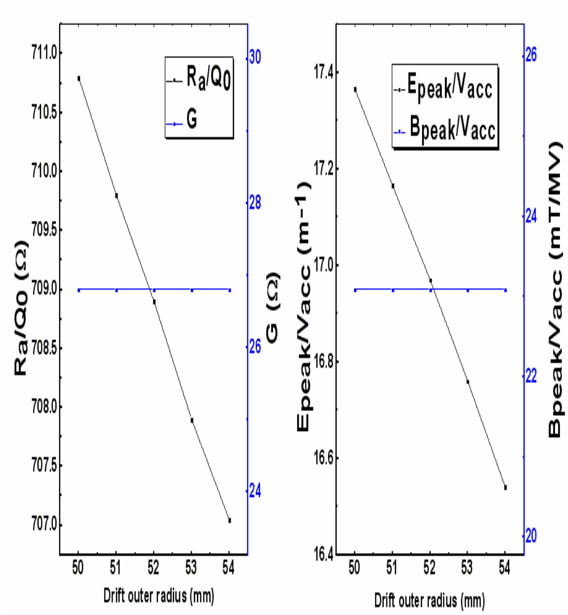

Figure 7: Quantitative dependence of the EM parameters as function of the drift tube outer radius.

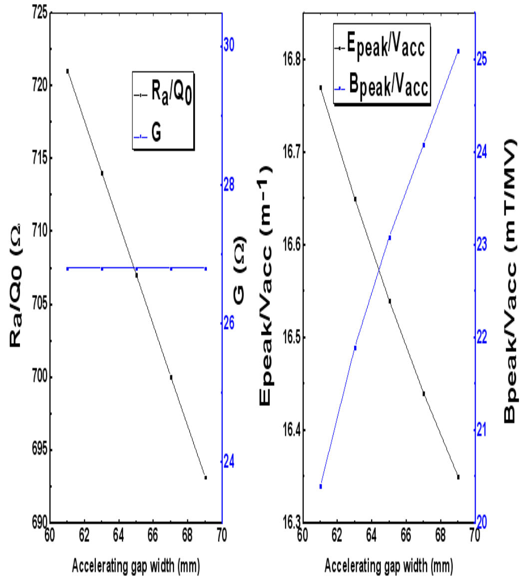

Figure 8: Quantitative dependence of the EM parameters as function of the accelerating gap width.

The impact of the 6 geometry parameters on the frequency is presented in Table 2, and the sensitive degree of the frequency to them is arranged from left to right with a descending order. During the sweep of these geometry parameters, the frequency of the cavity has been changed, we can choose to make the frequency 81.25 MHz by simply adjusting the length of the inner conductor or altering one or several of the selected geometry parameters which are not very sensitive to the EM parameters other than the frequency. In our design, we chose to adjust the frequency by regulating the DTOR and the IC length, Table 3 lists the final EM parameters of the f=81.25 MHz, β=0.085 QWR cavity.

Table 2: General dependence of the cavity frequency on the geometry parameters

ICTR	DTOR	AGW	ShortR	ICBR	LongR
+	-	+	-	-	-

Table 3: Final EM parameters of the QWR cavity

Parameter	Value	Unit
Frequency	81.25	MHz
β	0.085	
R_a/Q_0	735	Ω
G	26.8	Ω
E_{peak} @V_{acc}=2.5 MV	42.5	MV/m
B_{peak} @V_{acc}=2.5MV	57.5	mT

SUMMARY

We have made a great improvement in optimizing the geometry of an 81.25 MHz, β~0.085 Quarter-wave resonator. The optimization has led to significant refinement for all the important parameters, such as, the geometric shunt impedance times the geometry factor $(R_a/Q_0)*G$ has been increased by 66 % and the B_{peak} @ V_{acc}=1 MV has been reduced by 13 mT. Furthermore, the cavity height of this new shape can be reduced by about 20 mm which will be helpful for improvements of the mechanical stability of the cavity.

REFERENCES

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