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DESIGN AND OPTIMIZATION OF MEDIUM AND HIGH BETA SUPERCONDUCTING ELLIPTICAL CAVITIES FOR THE CW LINAC IN CIADS*

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Abstract

Superconducting technology is adopted in the main accelerating section of the CW Linac in China Initiative Accelerator Driven Sub-critical System (CIADS) to accelerate the 10 mA proton beam from 2.1 MeV up to 1.5 GeV. The medium to high energy section of the superconducting linac is composed of two families of SC elliptical cavities with optimum beta 0.62 and 0.82 for the acceleration of proton beam from 158 MeV to 1.5 GeV. In this paper, the design and optimization of the 650 MHz medium and high beta elliptical cavities are discussed, including the RF design, high order modes (HOMs) analysis, and the multipacting analysis.

INTRODUCTION

China is now developing an Accelerator Driven Sub-critical System, which is composed of a CW superconducting linac, a spallation target and a nuclear reactor operating in the sub-critical mode, to dispose the nuclear waste and solve the problems of nuclear fuel shortage. Superconducting technology is adopted in the main accelerating section of the CW Linac, including the 162.5 MHz half wavelength resonators (HWR), 325 MHz spoke cavities, and 650 MHz elliptical cavities. Two families of SC elliptical cavities are adopted with optimum beta 0.62 to accelerate the proton beam from 158 MeV to 250 MeV and 0.82 cavities for the acceleration from 250 MeV to 1.5 GeV.

RF DESIGN

The elliptical cavity can be parameterized with the geometrical parameters shown in Fig. 1. The main parameters in the elliptical cavities are the half-cell length L/2, the equator radius D, the iris radius radius r, the equator axis parameters B and A, the iris axis parameters b and a, and the wall angle alpha. Once the cavity frequency and the optimum beta (or the geometry beta) is determined, the half-cell length is also confirmed. The cavity structure can then be optimized with B, A, b, a and alpha. Here alpha is depending on A and a.

The iris radius r is mainly related to the cell-to-cell coupling. A larger r is helpful to achieve good inter cell coupling and field flatness, but will also come with the reduction of the R/Q and the increase of the Epk/Eacc and Bpk/Eacc, which will decrease the cavity properties.

The equator radius D is manly related to the cavity frequency, which can be used to tune the cavity during the optimization.

The equator axis parameters B and A will mainly change the magnetic field enhance factor Bpk/Eacc while the iris axis parameters b and a will mainly affect the electric field enhance factor Epk/Eacc.

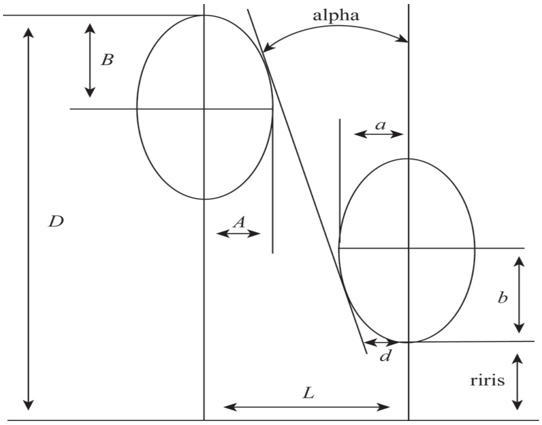

Figure 1: Geometry parameters of the elliptical cavity.

The cavity cell number is a balance of the acceleration efficiency, the cavity acceptance and the extraction of the HOM modes. Here 5 cell is adopted for the medium beta 062 cavity and 6 cell is adopted for the 082 cavity, as shown in Fig. 2 and Fig. 3. The geometry parameters and the electromagnetic parameters are list in Table 1 and Table 2.

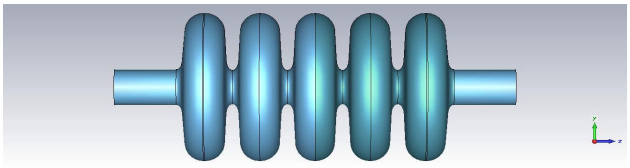

Figure 2: Cavity model of the 5 cell 062 cavity.

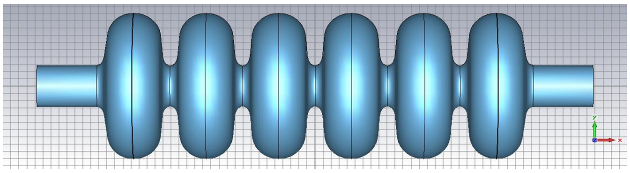

Figure 3: Cavity model of the 6 cell 082 cavity.

HOM ANALYSIS

Beam passing through the cavity, HOMs will be excited. Some of the HOMs can be efficiently been damped from the beam pipe or the HOM couplers on the beam pipe, while the others are difficult to damp since the electromagnetic fields of these modes are very weak in the beam pipe, which were called the “Trapped modes”. These trapped HOMs will have effect on the beam qualities both in the longitudinal and transverse directions, and will also result to additional cryogenic loss.

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Table 1: Geometry Parameters of the 5 Cell 062 Cavity and the 6 Cell 082 Cavity

Cavity	**5 Cell 062**		**6 Cell 082**	
Cell	**Middle**	**End**	**Middle**	**End**
Equator Dia. 2D (mm)	391.85	391.85	401.376	401.376
Iris Dia. 2r (mm)	90	94	112	115
Half-cell length L/2 (mm)	66.9	69.58	90.5	91.8
Iris b (mm)	28	23	31	33
Iris a (mm)	15	14	19	18
Equator B (mm)	48	46	67	65
Equator A (mm)	48	46	67	65
Wall Angle (degree)	2.88	4.73	4.97	7.93
End-Cell Sl (mm)		2.68		1.3
Beam pipe length Ltube (mm)		150		150
Beam pipe diameter Dtube (mm)		94		115

Table 2: Electromagnetic Parameters for the 062 Cavity and 082 Cavity

Parameter	β=0.62	β=0.82
Epk/Eacc	2.41	2.21
Bpk/Eacc（mT/(MV/m)）	4.68	4.32
R/Q(Ω)	307	542
G	185	228
Field Flatness	97.7%	99.12%
Coupling Factor K	1.02%	1.34%

These trapped HOMs are mainly determined by three factors, the cavity cell number, the end cell design and the diameter of the beam pipe. The effects of the HOMs on the beam quality and cavity are determined by the HOM frequencies and the longitudinal R/Q of each HOM. HOM analyses of two kinds of elliptical cavities are done with CST Microwave Studio [1]. Fig. 4 and Fig. 5 shows the frequency shift to the machine line of the first 120 resonant modes in the 5 cell 062 cavity and 6 cell 082 cavity.

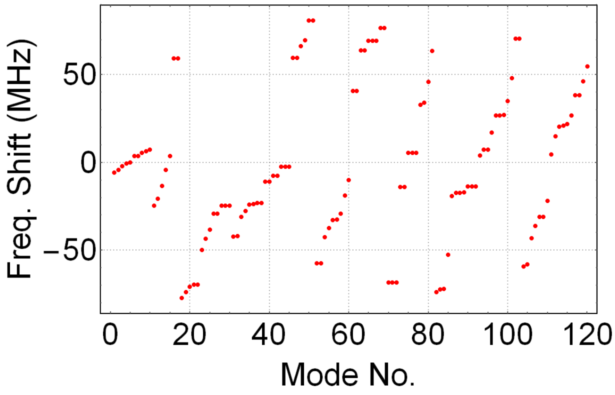

Figure 4: Frequency shift to the machine line of the first 120 resonant modes in the 5 cell 062 cavity.

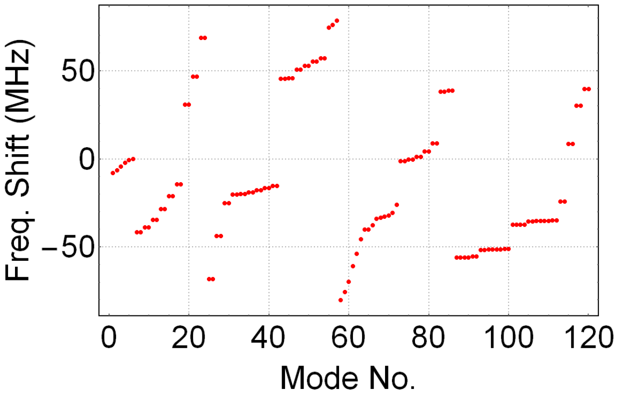

Figure 5: Frequency shift to the machine line of the first 120 resonant modes in the 6 cell 082 cavity.

For the 5 cell 062 cavity, 43th, 44th and 45th modes are mostly close to the machine line in Fig. 4. The frequency shifts are (-2.3726 MHz，-2.3662 MHz，-2.36 MHz), which are far enough away from the machine line. On the other hand, even these three modes are concentrated in the three middle cells, the electromagnetic fields distributions are far away from the beam axis, which will have no effect on the beam quality.

For the 6 cell 082 cavity, the 13th passband seems very close to the machine line in Fig. 5. The frequency shifts are（-1.3691 MHz, -1.368 MHz, -0.5776 MHz, -0.5763 MHz, 1.1236 MHz, 1.125 MHz）. This pass band is belong to the dipole modes, but the longitudinal R/Q of these six modes are very small, which will also have negligible effect on the beam and cavity.

MULTIPACTING ANALYSIS

Multipacting is a main restricts for the superconducting cavity performance. Since a great number of electrons reach resonance and absorb RF power, it will limit the cavity to achieve its design gradient, especially for the high beta cavity [2]. It is crucial to optimize the cavity to

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eliminate unexpected multipacting barriers during the design. Multipac 2.1 [3] code was used to simulate the multipacting of the 5 cell 062 and 6 cell 082 elliptical cavity. For both kind of the cavity, the multipacting analyses were done on the middle cells and end cells separately. From the simulation result, there is no hard multipacting barrier for both cavities. The straight insertion part in the end cells seem to be a potential source of two point 1st order multipacting, but the impact energy is less than 50 eV for the whole simulation range (from 0 to 60 MV/m). Fig. 6 shows the final impact energy after 20th impact in the whole simulation range for the end cell of the 6 cell 082 cavity.

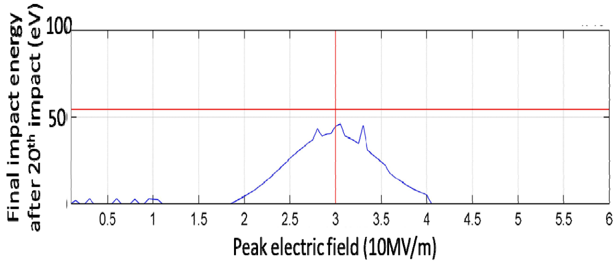

Figure 6: Final impact energy after 20th impact for the end cell of the 6 cell 082 cavity.

CONCLUSION

The RF design and optimization of the 650 MHz 5cell 062 and 6 cell 082 SC elliptical cavity is discussed in this paper for the CIADS CW linac. The RF and geometry parameters are summarized and meet the design requirements of the CIADS. The HOMs were simulated in CST and not a big concern in our designs. The multipacting was checked by the Multipac 2.1 and no hard multipacting barriers are found in both cavities. Further optimization of these two kinds of cavities include the mechanical design are still on the way.

REFERENCES

[1] `http://www.cst.com`

[2] S.H. Kim, “Overview of ten-year operation of the superconducting linear accelerator at the Spallation Neutron Source”, *Nucl. Instr. Meth.*, vol. 852, pp. 20-32, 2017.

[3] P. Yla-Oijala *et al.*, “Multipacting analysis and electromagnetic field computation by the boundary integral equation method in RF cavities and waveguides”, Ph. D. thesis, Phys., Nevanlinna Institute, University of Helsinki, Finland, 1999.