HFSS COMPUTATION OF FREQUENCY SENSITIVITY OF ISAC-II MEDIUM BETA SUPERCONDUCTING CAVITIES

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Abstract

Medium beta superconducting cavities are part of the ISAC-II project to upgrade the final energy of ISAC facility at TRIUMF. Prior to the fabrication of these bulk Niobium cavities, HFSS simulation is used to estimate the physical dimensions of the 106.08 MHz cavities and to obtain the sensitivity of the frequency variation with the lengths of the inner and the outer conductors and the beam gap. The same software is also used to calculate the rf parameters of the uniform inner and the flattened inner cavities. The sensitivity of the tuners are also computed and verified with measurements. Rf measurements of the production cavities and the simulation results are reported.

INTRODUCTION

TRIUMF is now constructing a superconducting heavy ion linac, ISAC-II facility as an extension of the present ISAC facility [1]. This will permit acceleration of radioactive ion beams up to energies of 6.5 MeV/u for masses up to 150. A first stage of the project is to construct twenty medium beta (β_o =5.7 and 7.1%) 106.08 MHz bulk niobium cavities which will be installed in five cryomodules [2]. A prototype cavity and four production cavities have been tested at TRIUMF. HFSS simulation is used to calculate the lengths of the inner and the outer conductors of the cavity prior to production of the same. The sensitivity of frequency variation with lengths of the conductors and the beam gaps are also calculated and are used as a guideline during the rf tests of the production cavities at the factory. HFSS simulation has also been used to predict the frequency variation due to a flat tuning plate and a convoluted plate design which has been manufactured and tested with the prototype Niobium cavity.

MEDIUM BETA CAVITIES

HFSS simulation is done on the prototype cavity designed in collaboration with INFN-LNL and the results of the simulation is checked with the measurements. The frequency shift of the prototype niobium cavity from room temperature to liquid helium temperature is used to determine the room temperature frequency of the production cavity. The twenty cavities of the medium beta section is composed of eight β_o =5.7% and twelve β_o =7.1% cavities. The lower beta section has an inner conductor flattened near the beam gap where as the higher beta section uses a uniform inner conductor. A vertical electric dipole field and a radial magnetic field are inherent in these types of quarter wave cavities and this produces a velocity and phase dependent vertical kick on the beam. Figure 1 shows the computed HFSS vertical component of the electric field along the beam axis and also off beam axis for the case of uniform inner conductor. The asymmetry of the Ey values give rise to the vertical electric dipole field. It has been shown that [3] for light beams an improvement in dynamic aperture can be gained by substituting uniform inner cavities by some flat cavities at the beginning of the medium beta section. Table 1 gives the rf parameters obtained from HFSS simulation for both types of cavities using copper as the cavity material.

Table 1: HFSS simulation of medium beta 106 MHz cavity with uniform and flattened inner conductor

parameters	Uniform inner	Flattened inner
Frequency, MHz	105.910	105.865
Q	6983	7037
Velocity, β	0.072	0.054
Vgap (average), V	0.019	0.018
Transit time factor, T_0	0.9	0.86
Geometric factor, RsQ	18.9	18.6
Eacc = Vgap.T_0/l, V/m	0.192	0.171
Stored energy= U/Eacc^2, Joules/(MV/m)^2	0.092	0.103
Emax/Eacc	4.74	5.56
Hmax/Eacc, gauss/(MV/m)	98	106
Rp=(2.Vgap.T_0)^2/Ploss, MΩ	4.03	3.63
For Q=3.5e08, Eacc= 6.5 MV/m, Pinput, W	7.0	7.6

Sensitivity Calculations

The sensitivity calculations with respect to the shortening of the lengths of the inner and the outer conductors and the sensitivity of the frequency to the position of the ground beam half tube are done with HFSS. In all cases, infinite conductivity of the material is chosen which enables a large number of tetrahedras to be used leading to accurate resonant frequency estimation. The length of the outer conductor is 752.3 mm and the distance of the tip of the inner conductor to the open end is 68 mm. The radii of the inner and the outer conductors are 30 mm and 90 mm respectively. The beam gap is 40 mm and the bore is 20 mm in diameter. For the β_o =5.7% cavities, the inner conductor is squeezed to a 40 mm width in the beam direction and the grounded beam ports are extended to maintain the original gap. Figure 2 shows the two configurations of the cavity. The ground beam half tubes are moved in and out from the reference position for the sensitivity calculations. The four production cavities, with uniform inner conductor, which have recently been delivered by Zanon, Italy are rf tested at room temperature at various stages of production in the factory in collaboration with INFN-LNL, Italy [4] and the sensitivity of the frequency due to length and gap are compared with the computed results and is listed in Table 2. The four cavities were chemically polished at CERN and the effect on the frequency is shown in the same table. Table 3 shows the computed sensitivity of the frequency for both type of cavities. The sensitivity at the gap for the flat inner is higher than the uniform case due to increased gap capacitance of the flat cavity.

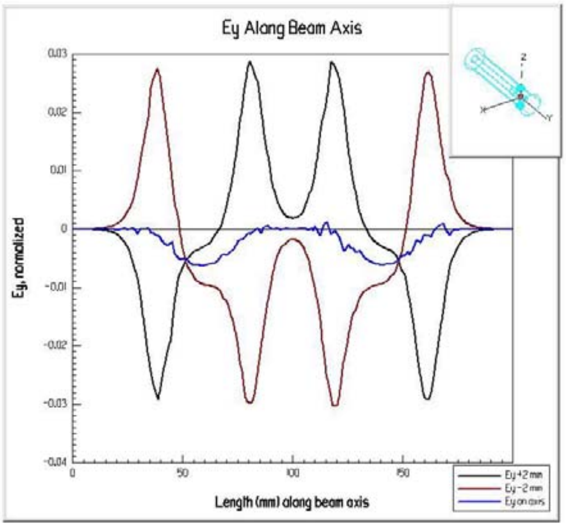
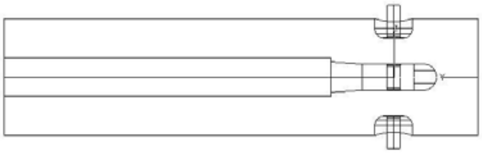


Figure 1: Vertical component of electric field along beam axis and off beam axis computed with HFSS.

Flattened inner tube



Uniform inner tube, radius 30 mm

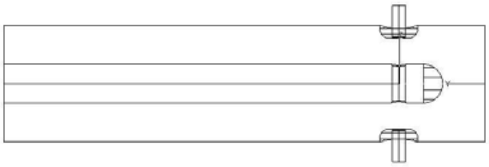


Figure 2: Flattened and uniform inner conductors for 106 MHz superconducting cavity

Table 2: Sensitivity of outer beam tube and end plates for cavity with uniform inner conductor

	Sensitivity KHz/mm		Final Frequency, MHz At room temperature	
	Inner conductor [1]	Beam gap [2]	At the factory [3]	At TRIUMF [4]
EZ01	170	- 80	105.895	105.889
EZ02	156	- 66	105.895	105.884
EZ03	129	- 50	105.885	105.866
EZ04	142	- 57	105.884	105.860
Average of EZ01 – EZ04	149	- 63		
HFSS	150	- 73		
Note 1: RF test before inner conductor shorting plate welding				
Note 2: RF test before beam port welding				
Note 3: Before chemical polishing				
Note 4: After chemical polishing and water rinsing				

Table 3: Frequency Sensitivity computed with HFSS

	Gap	Sensitivity, KHz /mm		
Inner tube	mm	Decrease / Increase Gap	Decrease length at the open circuit end	Decrease length at the short circuit end
Uniform	40	- 73 /+62	- 6.5	+ 150
Flat	40	- 120 /+84	- 8.7	+150
+ve and –ve denote increase and decrease in frequency respectfully.				

Frequency tuner

The resonant frequency, and the frequency range of the tuner plates were measured on a full scale copper cavity and the results compared with HFSS simulation. A frequency shift of 7 KHz/mm was measured with a flat niobium tuner plate mounted on the prototype cavity. A flat plate can be used but it assumes a concave shape upon cooling leading to highly non-linear response. To overcome this, a flexible tuner plate was designed and fabricated at TRIUMF. The plate, 1 mm thick RRR Niobium sheet, is spun with a single “oil-can” convolution and milled with eight radial 1 mm slots. The plate is capable of producing ±20 KHz of tuning range for a displacement of ±3 mm before yielding [5]. RF cold

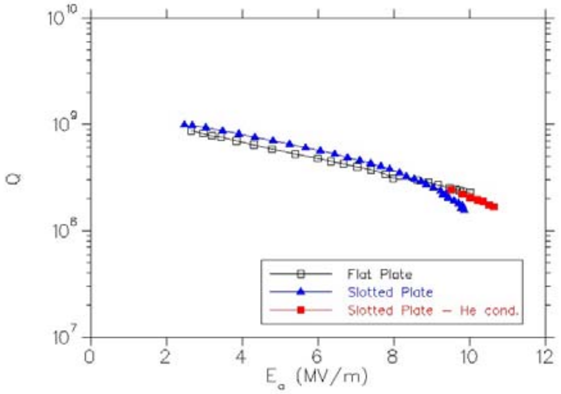


Figure 3: RF tests comparing cavity performance with a flat and slotted tuner plates

tests showed that the convoluted plate and the flat plate produce similar Q and gradient values as shown in the figure 3. In order to do these rf tests, the loop size of the coupler [6] was modified to provide maximum coupling for rf conditioning and critical coupling for Q and gradient measurements. HFSS simulation was done to verify the length of the coupling loop. The profile of the convoluted plate was optimized by using HFSS to obtain a neutral frequency (zero shift in frequency with respect to flat tuner plate). Figure 4 shows the final profile of the convoluted plate without the slots which is used for the simulation and figure 5 shows the prototype Niobium cavity with the tuner plate removed. The final tuner plate was mounted on the prototype quarter wave copper cavity and the resonant frequency is measured and compared with a flat plate. The frequency with the convoluted plate was measured to be 18.6 KHz higher than with the flat plate removed.

Figure 4: Profile of the tuner plate used in HFSS simulation

Figure 5: View of Niobium cavity with tuner plate

This however poses no problem since the slotted plate, due to its flexibility, can be held in a fixed position to achieve the coarse tuning and then move about the fixed position for fine tuning.

CONCLUSION

The simulation results obtained from HFSS have been extensively used to predict the rf performance of the quarter wave resonator. The close agreement between the measured and the computed values of sensitivity of physical dimensions of the cavity with respect to the resonant frequency have been useful in manufacturing these cavities. Also, the electric and the magnetic fields obtained from the analysis have led to the understanding and the design of the flattened inner resonator.

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