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DESIGN OF A 1.3 GHz RF–DIPOLE CRABBING CAVITY FOR INTERNATIONAL LINEAR COLLIDER*

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Abstract

The International Liner Collider (ILC) requires crabbing systems to increase the luminosity of the colliding electron and positron bunches. There are several frequency options for the crabbing cavity. We have designed a 1.3 GHz compact 1-cell and 2-cell rf-dipole crabbing cavity to compensate for luminosity degradation due to large crossing angle. This paper presents the 1-cell and 2-cell cavities designed to meet the current specifications including the fundamental power coupler and higher order mode couplers.

INTRODUCTION

The International Liner Collider (ILC) is designed to collide electrons and positrons that are accelerated in two separate linacs spanning over 20 km as shown in Fig. 1 [1, 2]. The baseline design will operate at a center of mass (CoM) of 250 GeV colliding electrons and positrons at speed of light with an upgrade planned for CoM of 1 TeV. The expected luminosity goal is ~10^{34} cm^{-2}sec^{-1}. The ILC requires crabbing cavities to compensate for the luminosity degradation due to the large crossing angle of 14 mrad [3]. Operation without crab cavities may lead to a luminosity reduction up to 80%.

The crabbing systems are installed on the electron beam line as shown in Fig. 2. The key specifications of the crabbing systems are following [4]:

- Total beam line space – 3.8 m
- Total transverse impedance specifications – Z_x < 48.8 MΩ/m and Z_y < 61.7 MΩ/m
- Minimum crab cavity beam aperture – 25 mm

The total transverse voltages are shown in Table 1.

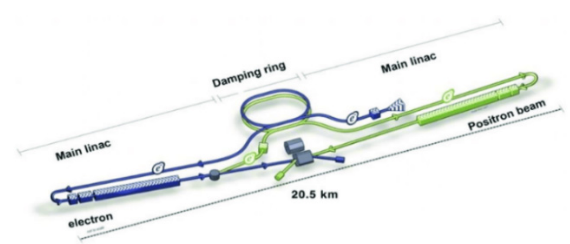

Figure 1: Layout of the Electron-Ion Collider.

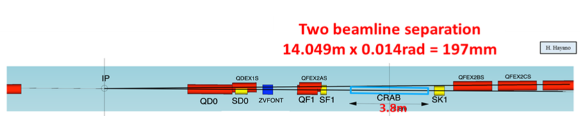

Figure 2: Beamline layout of the crabbing system.

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Table 1: Total Transverse Voltages

Beam Energy	250 GeV			1 TeV		
Frequency [GHz]	3.9	2.6	1.3	3.9	2.6	1.3
Total Voltage [MV]	0.615	0.923	1.845	2.5	3.7	7.4

The recent crabbing cavity system development for the ILC has several crabbing cavity options under study [4]. In this paper we study 1-cell and 2-cell cavity designs based on the rf-dipole design operating at 1.3 GHz [5, 6].

1.3 GHz CRABBING CAVITY DESIGNS

The 1.3 GHz rf-dipole crabbing cavity is a compact cavity design where both 1-cell and 2-cell options as shown in Fig. 3 that are viable solutions for the ILC. Both cavities are designed with a 25 mm pole separation and a 30 mm beam aperture for effective HOM extraction.

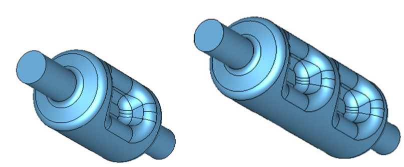

Figure 3: 1-cell (left) and 2-cell (right) 1.3 GHz rf-dipole crabbing cavities.

Table 2: RF Properties

Property	1-cell	2-cell	Unit
SOM	–	1.198	GHz
1st HOM	2.142	2.039	GHz
E_p^*	3.83	3.85	MV/m
B_p^*	6.84	6.84	mT
$[R/Q]_t$ (V^2/P)	444.8	892.7	Ω
G	129.9	132.2	Ω
R_tR_s (V^2/P)	5.78×10^5	1.18×10^4	Ω^2
V_t per cavity	1.35	2.70	MV
E_p	44.8	45.0	MV/m
B_p	80.1	80.0	mT
Cavity diameter	100.3	103.4	mm
Cavity length#	310	450	mm
At E_t^* = 1.0 MV/m		#Flange to flange	

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The rf properties of the two designs are listed in Table 2. The 2-cell cavity has a similar order mode at 1.198 GHz below operating mode. The poles in the cavity are designed to achieve balanced peak surface fields of 45 MV/m and 80 mT. 1-cell and 2-cell designs reach transverse voltages of 1.35 MV and 2.70 MV respectively at the maximum surface fields. The maximum transverse voltage of 7.4 MV for 1 TeV CoM is achieved by 6 1-cell cavities and 3 2-cell cavities that provides a total transverse voltage of 8.1 MV with a 10% margin. The cryomodule layout of the two cavity options are shown in Fig. 4. The cryomodule fits within the 3.8 m beam line space also includes the parallel beam pipe with a separation of 197 mm incorporated into the vacuum vessel as shown in Fig. 5. There is the possibility of including an additional cavity within 3.8 m for both 1-cell and 2-cell cavity options in achieving higher safety margin and preventing any single point failures.

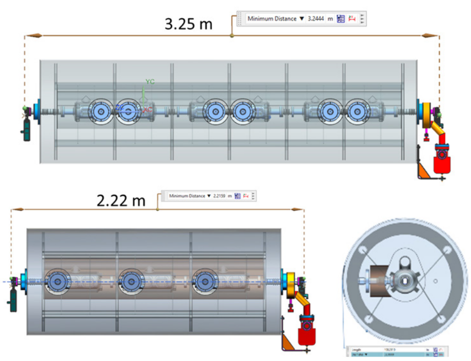

Figure 4: Conceptual cryomodule layout for 1-cell (top) and 2-cell (bottom left) cavity options with front view (bottom right).

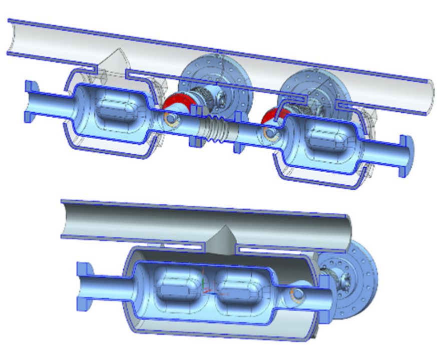
Figure 5: Conceptual He vessel layout for 1-cell (top) and 2-cell (bottom left) cavity options.

HIGHER ORDER MODE DAMPING

The higher order mode (HOM) damping is achieved by TESLA type HOM couplers as shown in Fig. 6 [7]. The HOM couplers are placed on the beam pipe in the 1-cell cavity. The 2-cell cavity requires a coupler placed at the center of the main body to suppress the modes with fields trapped between the two cells.

Figure 7 shows the transverse horizontal and vertical impedances of the 1-cell and 2-cell cavities calculated using the circuit definition. The modes are evaluated up to 8 GHz which is above the TM_{010} cut-off frequency of 7.65 GHz for the 30 mm beam pipe. The impedance thresholds per cavity are:

- 1-cell cavity: $Z_x < 8.14$ MΩ/m and $Z_y < 10.27$ MΩ/m
- 2-cell cavity: $Z_x < 16.27$ MΩ/m and $Z_y < 20.57$ MΩ/m

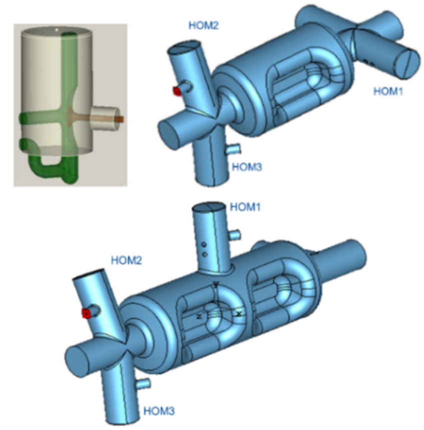

Figure 6: TESLA HOM coupler (top left), 1-cell cavity with HOM dampers (top right), and 2-cell cavity with HOM dampers (bottom).

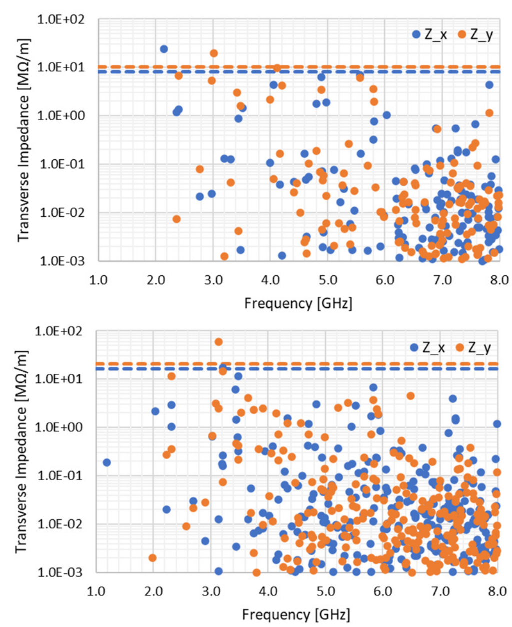

Figure 7: Horizontal and vertical impedances for 1-cell (top) and 2-cell (bottom) cavities.

In the 1-cell cavity there are two modes which is the 1st HOM at 2.142 GHz, and 3.02 GHz that requires further damping. Similarly, in the 2-cell cavity the two modes at 3.209 GHz and 3.141 GHz requires further damping. Increasing the beam aperture will allow effective propagation of these modes in lowering the impedance.

MULTIPACTING ANALYSIS

The multipacting resonances were evaluated for both 1-cell and 2-cell bare cavities using Track3P code in the SLAC ACE3P suite [8]. The secondary electrons were traced for 50 rf cycles for primary electrons with 20-2000

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eV impact energies. The location of the secondary electrons and the corresponding impact energy as a function of transverse voltage is shown in Fig. 8 and Fig. 9.

The concerning resonant particles are located on the end cap and at the beam aperture rounding surface. The low voltage resonant barrier is similar to that has been seen in the past rf-dipole cavities and is expected to be processed easily [5]. Further analysis will be carried out for any resonances in the HOM dampers.

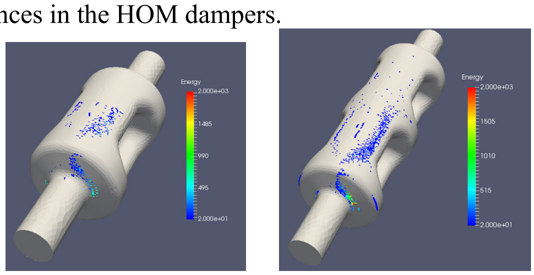

Figure 8: Multipacting resonances of the 1-cell (top) and 2-cell (bottom) cavities.

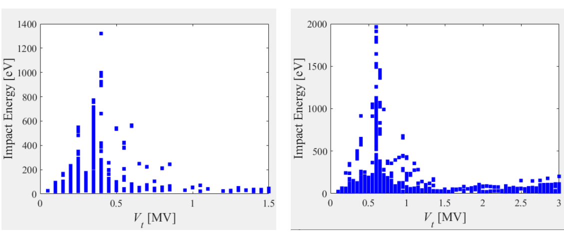

Figure 9: Impact energies of the 1-cell (top) and 2-cell (bottom) cavities.

MECHANICAL ANALYSIS

Stress Analysis

The stresses are calculated for both 1-cell and 2-cell cavities with 3 mm uniform thickness and constrained beam pipes and FPC. The analysis is carried out assuming room temperature Nb properties with an external pressure of 2.2 atm [9]. The allowable stresses require to be below 43.5 MPa. The estimated maximum stress is 25 MPa for the 1-cell cavity and 32 MPa for the 2-cell cavity that are well below the allowable as shown in Fig. 10.

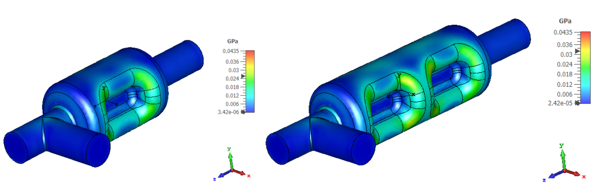

Figure 10: Stresses in the 1-cell (left) and 2-cell (right) cavities at an external pressure of 2.2 atm.

The compact size of the cavity allows the cavity to be fabricated out of bulk Nb ingot [10]. This method allows to fabricate the cavity with varying thickness at carefully selected locations in order to reduce stresses and sensitivity to pressure.

Tuning Analysis

The preliminary tuning analysis is done for both 1-cell and 2-cell cavities to estimate the available tuning ranges. The analysis is carried out for cavities with 3 mm uniform thickness assuming cryogenic temperature Nb properties with beam pipes and FPC constrained [9]. The tuning force is applied to a cylindrical tuner tab of 10 mm diameter. The peak stresses are around the tuner tab attachment and within the allowable of 43.5 MPa as shown in Fig. 11. The tuner tab geometry can be optimized to reduce the stresses. The tuning parameters for both 1-cell and 2-cell cavities are listed in Table 3.

The achievable maximum tuning range of the 1-cell cavity is 1.96 MHz for a force of ~3.2 kN. The 2-cell cavity was simulated with a dummy pipe replicating the on-cell HOM damper. The achievable maximum tuning range of the 2-cell cavity is 2.23 MHz and requires slightly higher force at the top surface with the HOM damper to achieve symmetric displacement.

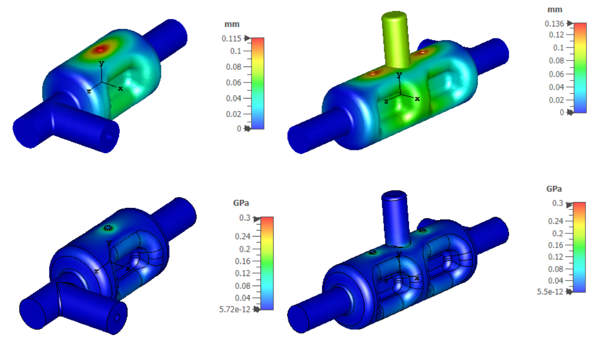

Figure 11: Deformation (top) and stresses (bottom) for the 1-cell (left) and 2-cell (right) cavities at the maximum tuning range.

Table 3: Tuning Parameters

Parameter	**1-cell**	**2-cell**
Total displacement [mm]	0.23	0.27
Tuning sensitivity [MHz/mm]	8.5	4.1
Tuning range [MHz]	1.96	2.23

CONCLUSION

Two compact 1-cell and 2-cell 1.3 GHz rf-dipole crabbing cavity options have been designed for the ILC including FPC and HOM dampers. The 1.3 GHz crabbing cavities meet the beamline space requirement of 3.8 m for both 1-cell and 2-cell cavity designs. The cavities are designed with a 25 mm pole separation and a 30 mm beam aperture to enhance HOM propagation. The HOMs are damped using TESLA type HOM couplers. The existing TESLA dampers designed for 1.3 GHz dampers simplifies the damper design used in the crabbing cavities. Further increase of beam aperture will be evaluated to suppress the HOMs that are above the impedance thresholds along with other damping methods. The compact cavity is an ideal geometry to be machined out of a Nb ingot and will be explored for prototype fabrication.

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