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STUDY OF HOM COUPLERS FOR THE C-BAND ACCELERATING STRUCTURE

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Abstract

Cryo-cooled C-band (5.712 GHz) copper distributed-coupling cavities are a new approach to the structure-based accelerators for the future multi-TeV energy range linear collider. It provides numerous degrees of freedom to optimize the cavity geometry to achieve high gradient. In this study, we analyzed the dipole modes of a C-band 20-cells cavity and calculated the wall loss Q-factors, shunt impedance, and the kick factors of transverse wakefields in the frequency range up to 40 GHz. Next, we equipped each cavity with four waveguide manifolds with damping loads to suppress undesirable higher-order-modes (HOM). In this paper, we report the results of simulations of HOM suppressions with CST Microwave studio (CST) and Omega3p.

INTRODUCTION

High gradient C-band accelerating structures have been designed and fabricated for multiple purposes [1-3]. It was recently proposed to use cryo-cooled normal-conducting radio-frequency (NCRF) cavities to construct a cost-affordable multi-TeV e^+e^- linear collider [4, 5]. The NCRF structure with distributed coupling cavities can be designed with high shunt impedance and low probability of breakdown. However, HOM suppression has never been studied in these novel structure geometries. For the multi-TeV linear collider, good HOM suppression is essential to be able to accelerate high quality electron bunches over multi-kilometer distances.

In this paper, we focus on designing HOM suppression manifold for a C-band distributed-coupling accelerating cavity. The design is performed using CST [6] and Omega3p [7]. First, we analyzed all dipole modes of a particular cavity design in the frequency range from 5 to 40 GHz and computed wall loss Q-factors and transverse kick factors. Second, we added four waveguide manifolds with HOM absorbers to the cavity design to reduce the Q-factors. We varied geometric parameters of these manifold to determine the best configuration for HOM suppressions based on the damped Q-factors and transverse wakefield kick factors.

CALCULATION FOR DAMPED Q-FACTORS AND TRANSVERSE WAKEFIELD KICK FACTORS USING CST

We started with seven different cavity geometries originally introduced in [8], and then focused on the cavity's geometry with 2 mm aperture size and 1.5 mm thickness of the iris. This geometry is illustrated in Fig. 1(a). We computed all dipole modes in the frequency range of 5 to 40 GHz using eigenmode solver in CST with periodic boundary conditions along the beam propagation to ensure resonance with the electron beam traveling with the speed of light. For each dipole mode, we calculated suitable phase advance (φ) expressed as

$$\varphi\ (rad) = \frac{\omega \times L_{cav}}{c}.$$

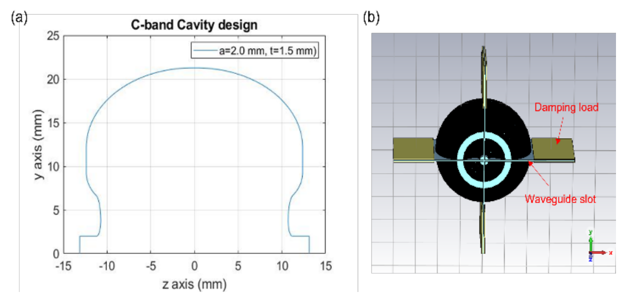

Figure 1: C-band cavity design by SLAC. Aperture size and thickness of the iris are 2 mm and 1.5 mm, respectively.

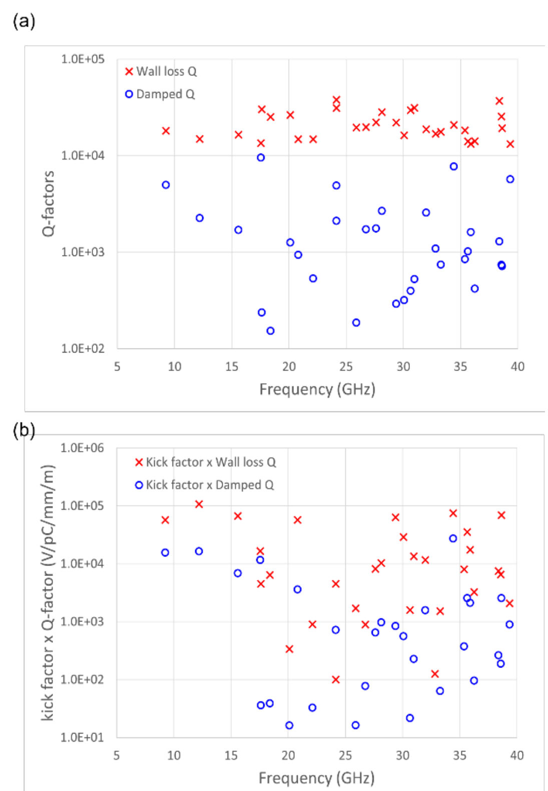

Figure 2: (a) Wall loss Q vs damped Q, and (b) Kick factor x wall loss Q vs kick factor x damped Q.

Next, we added 4 waveguide slots with SiC absorbers with the electrical conductivity of 100 S/m as illustrated in

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Fig 1(b). In these simulations, we computed wall loss Q-factors, damped Q-factors, and the transverse kick factors for each of the dipole mode identified in previous calculation. In the first simulation, the waveguide's thickness and length were fixed as 0.5 mm and 30 mm, respectively. We observed that most of the dipole modes coupled well to the damping waveguides, and Q-factors and transverse kick factors were substantially reduced in presence of the damping slots as shown in Fig 2 (a) and (b). However, three dipole modes at 9.25, 17.56, and 34.41 GHz were still seen relatively high on the plots in Fig. 2 for damped Q-factors (around 1.0E+4), and high kick factor x damped Q-factors (over 1.0E+4 V/pC/mm/m).

HOM SUPPRESSION STUDY WITH VARIATION OF CAVITY GEOMETRY

Next, we performed Omega3p simulations of a realistic 20-cell long structure with damping manifolds with three different geometries to optimize HOM suppression. Figure 3(a) shows one quadrant of the 20-cell accelerating structure designed in Cubit [9]. It has impedance boundaries on top of each waveguide slot, and xz plane and yz plane have the electric boundary plane and the magnetic boundary plane, respectively. As illustrated in Fig 3(b), the first model had a straight shape of the HOM suppression waveguide, and the length of the waveguide was varied from 30 to 50 mm with 2 mm step to optimize HOM suppression. Particularly, we focused on the modes with frequencies around 9.24 and 17.47 GHz because of their relatively higher Q-factors and kick factors.

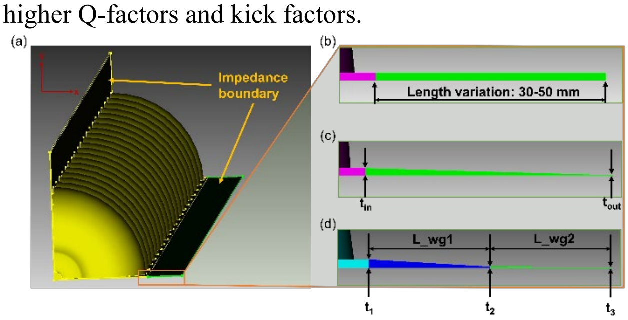

Figure 3: Schematic design of the 20-cell cavity (a) and three different waveguide slots for HOM suppression (b-d).

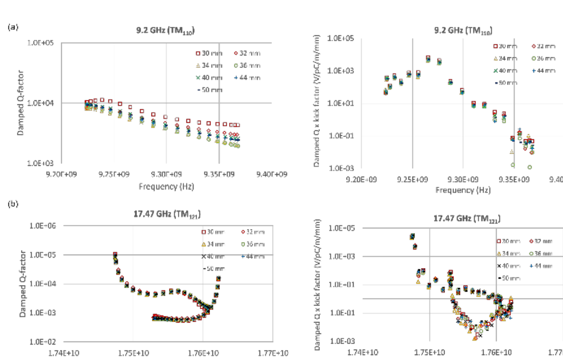

Figure 4: Suppressed Q-factors and Q-factors x kick factors at (a) 9.24 GHz (TM_{110}) and at (b) 17.47 GHz (TM_{121}).

The computed Q-factors and the Q-factor x kick factor are shown in Fig. 4. From these simulations, we observed that the case of 34 mm and 50 mm waveguide slots provided the lowest Q-factors and transverse kick factors. Therefore, we fixed the length of the damping waveguide at 34 mm and designed taper waveguides to achieve even better HOM suppression.

First, we investigated waveguide with one taper as shown in Fig. 3(c). Initial waveguide thickness (t_{in}) was fixed as 0.25 mm, and thickness of the end taper section (t_{out}) was 50 or 0.5 μm. In this simulation, the absorber material was NiCr (1E+6 S/m), which was recently designed and fabricated at SLAC.

It can be seen from Fig. 5 that 34 mm and 50 mm waveguide lengths with 0.5 μm tapers result in the lowest damped Q-factors and kick factors. These two cases provide the most efficient coupling between the higher-order dipole modes and the damping materials.

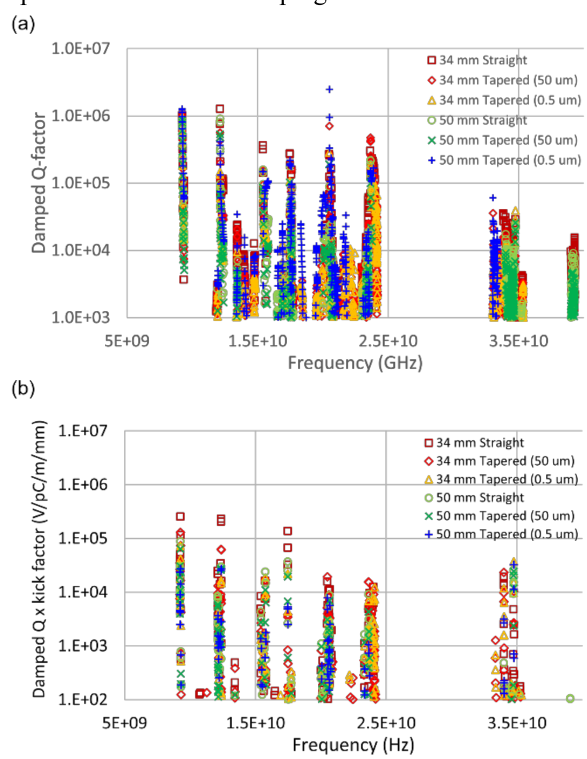

Figure 5: (a)Damped Q-factors and (b) Q-factors times kick factors with different cavity geometries. Absorber material was NiCr for all simulations.

Finally, we simulated the design of wakefield damping manifold with two tapers as illustrated in Fig. 3(d). The relevant parameters of this simulation are summarized in Table 1. Lengths of the first and second waveguide slots were varied from 2 to 8 mm and 4 to 10 mm, respectively. Thickness of the initial waveguide slot was fixed as 0.25 mm. The thickness of the end of the first taper varied from 20 to 100 μm. The thickness of the end of the second taper was fixed at 0.5 μm. It must be noted that for all these geometries, the fundamental TM_{101} mode was consistently found at 5.712 GHz, and Q-factor sustained as 13,700.

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Table 1: Parameters of Waveguide Slots

Parameter	Value (mm)
Length of waveguide slot	34
Length of 1st waveguide slot (L_wg1)	2 to 8
Length of 2nd waveguide slot (L_wg2)	4 to 10
Thickness of initial waveguide (t_1)	0.25
Thickness of the end of the 1st tapered (t_2)	20, 40, 60, 80, 100 µm
Thickness of the end of the 2nd tapered (t_3)	0.5

Figure 6 shows the simulation results for the two representative cavity designs with double-tapered waveguide slot. Each data name on the graph legend corresponds to the specific cavity geometry. For example, if the data name is 22_250_26_60_34_0.5, 22 is 22 mm in x axis which is the starting position of the first taper. 250 is 250 µm, the thickness of the initial waveguide slot (t_1). 26 is 26 mm in x axis which was the starting position of the second taper. 60 is 60 µm, the thickness of the end of the first taper. 34 is 34 mm in x axis which is the position of the end of the waveguide slot. 0.5 is 0.5 µm, the thickness of the end of the second taper. We concluded that the 34 mm with the case of 22_250_26_60_34_0.5 was the best cavity design for the compact accelerating structure with HOM suppression.

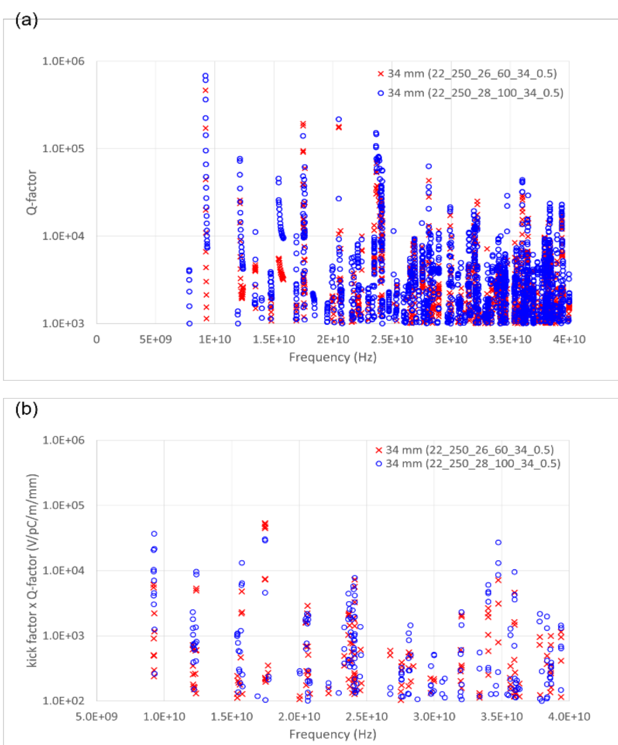

Figure 6: Calculated (a) Q-factors and (b) kick factor x damped Q from the two different geometries with two tapers.

CONCLUSION AND PLANS

We conducted computational investigation of the higher order mode suppression in a C-band high gradient accelerating structure with distributed coupling. The suppression is achieved with four damping manifolds running the length of the structure. We computed the Q-factors and the products of kick factor and damped Q-factors for the dipole modes in the frequency range from 5 to 40 GHz using CST and Omega3p. We optimized the geometry of damping manifolds to achieve the best HOM suppression. We concluded that the 34 mm waveguide length with the two tapers resulted in the lowest Q-factors and the wakefield kick factors.

In the future, we will continue optimizations of geometry and study various damping materials to provide strong absorption to all dipole modes.

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