HFSS SIMULATION OF FUNDAMENTAL MODE EVANESCENT FIELDS IN A HOM DAMPING WAVEGUIDE AND COMPARISON WITH MEASUREMENTS*

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Abstract

Higher order cavity modes (HOMs) can be damped by circular waveguides using circular-waveguide-to-coaxial transitions (CWCTs) to extract the HOM energy. The cutoff frequency of the CWCT must be chosen to be below the frequencies of all higher order modes (HOMs), but above the frequency of the 500 MHz fundamental (operating) cavity mode. The CWCT is intended to filter out the HOMs while retaining the operating mode in the cavity. However, due to the evanescent field transmitted through the finite-length CWCT, a small leakage of fundamental mode power through the coaxial port of the CWCT is unavoidable. Here, we present numerical simulation studies of the evanescent field using the HFSS code, and compare the results with recently reported measurements. Simulation results agree reasonably well with experimental measurements. This study demonstrates that the HFSS simulation can be employed as a reliable tool in subsequent studies aimed at the reduction of the evanescent field to an acceptable level.

1 INTRODUCTION

A 500 MHz HOM-damped cavity is under development, in the frame of an EC funded project with the aim to provide an acceleration cavity specifically optimised for 3rd generation synchrotron radiation sources [1]. In order to damp the first longitudinal HOM of this cavity, the cutoff frequency of the CWCT has been reduced to 650 MHz from the previous design value of 710 MHz. It is of concern that the 500 MHz fundamental mode will have too large a power leak through the 650 MHz CWCT due to the evanescent field if the total CWCT length remains as in the previous 710 MHz CWCT design [2-4]. In this paper, we study the damping effect on the fundamental mode of the EU cavity by the 650 MHz CWCT as a function of the length L_2 of an inserted double-ridged section of uniform cross-section and 650 MHz cutoff frequency as sketched in Fig. 1.

2 SIMULATION MODEL

The principal quantities of interest are the relative levels of power losses of the 500 MHz fundamental mode on the cavity wall, on the CWCT wall, and through the coaxial port of the CWCT. Power loss through the coaxial port is of particular importance because it is constrained by the power capability of the 7/8" EIA standard coaxial line and window.

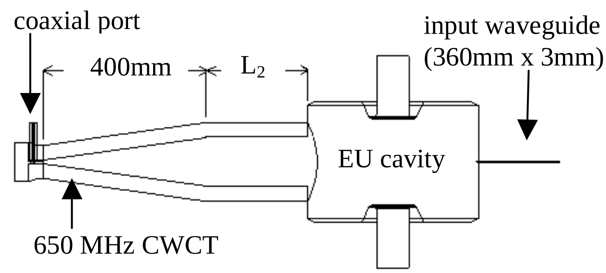

Fig. 1. Configuration of the CWCT/cavity assembly under study.

The configuration under study is a single 650 MHz CWCT attached to the cavity through an uniform doubled-ridged section of length L_2. The uniform section has the same cutoff frequency as the CWCT. The taper section of CWCT is fixed at 400 mm, while the uniform section length L_2 is varied. All calculations are performed with the HFSS code [5]. In the HFSS simulations, the test wave is injected into the CWCT/cavity assembly through a rectangular waveguide (with a large width-to-height ratio) weakly coupled to the assembly. Q_{ext} due to input coupling can be evaluated from the resonant line width and the voltage standing wave ratio in the input waveguide [2]. It has been discounted in the Q calculations for the CWCT/cavity assembly.

Figure 2 displays the Q values of the fundamental mode vs. L_2 under different conditions. Three Q values have been calculated:

Q_{cavity}: Q value of the cavity alone (with the CWCT port blocked by perfect conductor and the rest of the surface area covered by copper of conductivity 5.8×10^7 $ohm^{-1}m^{-1}$).

Q_{short}: Q value of the assembly in Fig. 1 with the coaxial port of the CWCT shorted and all surfaces covered by copper.

Q_{match}: Q value of the assembly in Fig. 1 with the coaxial port of the CWCT connected to a matched load and all surface areas covered by copper.

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Relative power losses can be inferred from these Q values through the relations:

$$P(cavity\ wall)/P_{in} = 1/Q_{cavity} \quad (1)$$

$$P(CWCT\ wall)/P_{in} = 1/Q_{short} - 1/Q_{cavity} \quad (2)$$

$$P(coaxial\ port)/P_{in} = 1/Q_{match} - 1/Q_{short} \quad (3)$$

In Fig. 2, the "cavity alone" case implies that the CWCT port on the cavity is blocked by perfect conductor (with the rest of the surface area covered by copper). This makes it possible to clearly distinguish the Ohmic losses on the cavity wall and the CWCT wall through Eqs. (1) and (2), respectively. For this "cavity alone" case, the calculated Q value is 39560. If the CWCT port on the cavity is blocked by copper instead of a perfect conductor, the calculated Q value would be 37764. The difference between these two cases indicates that, about 4.5% of the total Ohmic loss is dissipated on the copper surface area which blocks the CWCT port.

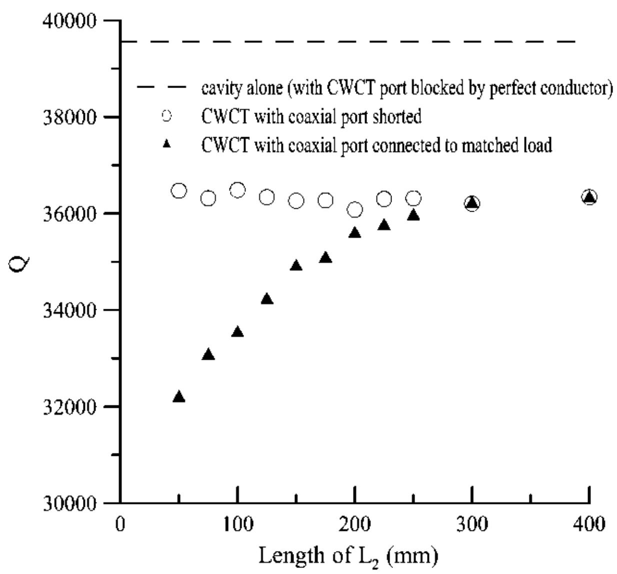

Fig. 2. Q values of the TM_{010} mode under different conditions

For an independent check, the power losses have also been evaluated based on S-parameter calculations and Poynting vector calculations. Figure 3 gives the fractional power loss through the coaxial port as a function of length L_2 calculated by the above three methods. The results are in reasonable agreement, especially those calculated by the more direct methods based on S-parameter and Poynting vector . The power is expected to attenuate in the insertion section exponentially [6] following

$$P(z+\Delta z)/P(z) = \exp(-2k\Delta z), \quad (4)$$

where Δz is the incremental length of L_2 and k is the rate of field attenuation given by

$$k = \frac{2\pi f_c}{c}\sqrt{1-(\frac{f_0}{f_c})^2}, \quad (5)$$

where f_o is the wave frequency and f_c is the cutoff frequency of the insertion section.

For comparison with the HFSS simulation data, the analytical attenuation curve for a 500 MHz wave in a waveguide of 650 MHz cutoff frequency is also plotted in Fig. 3 as a dashed line. For reality case, input power up to 100kW, the leakage through coaxial port of 1% is acceptable value which attained around L_2=200mm.

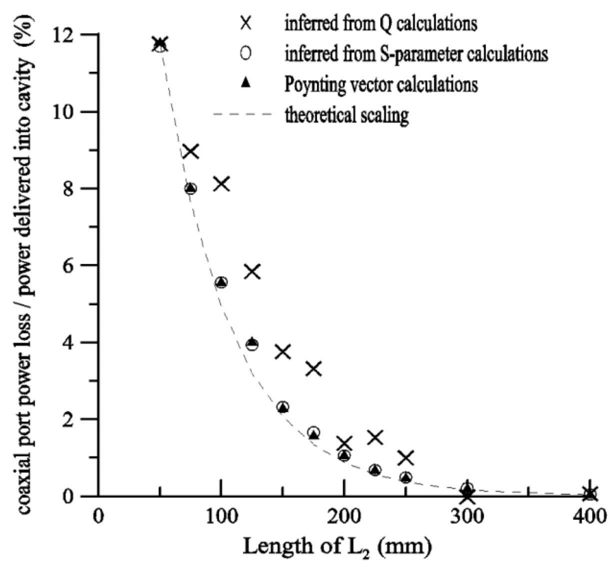

Fig. 3. Evanescent field effect on the TM_{010} mode (fundamental mode)

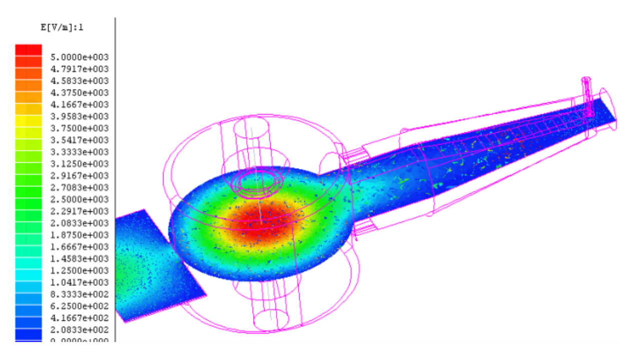

Fig. 4. Electrical field distribution in whole assembly

We see the field of fundamental mode built up inside cavity by the wave from input waveguide as well as the evanescent filed inside CWCT.

3 COMPARISON BETWEEN CALCULATED AND MEASURED R VALUES

Comparison with experimental measurements of fundamental mode power transmission have been reported recently [7] for the low power aluminium prototype cavity with 3 CWCTs as shown in Fig. 1. with a length of L_2=171.3mm and a cutoff frequency of 650 MHz. For the power transmission ratio R

$$R = \frac{\text{coaxial port output power}}{\text{total input power into cavity}} , \qquad (6)$$

a mean value of R_{exp}=0.0043 has been obtained per CWCT at the fundamental mode frequency f_{exp}=498.047 MHz, where as the HFSS calculation yield R_{cal}=0.0092 at the resonant frequency f_{cal}=494.032 MHz

The experimental set-up, due to the surface roughness of the aluminum material, has an effective conductivity smaller than the conductivity of aluminium used in the HFSS calculations (1.9x10^7 ohm^{-1}m^{-1}). With the three coaxial ports shorted the calculated and measured Q values are, respectively, 21818 and 15046 [7] from which we infer a effective conductivity σ_{exp}~0.476σ_{Al} for the experimental assembly. To compare the calculation with the measurement, this difference in wall conductivity as well as the difference in resonant frequency has to be adjusted as described below with the help of the scaling relation given by Eq. (4) and (5).

Since R is much smaller than 1, we may assume that the total input power into the cavity is almost all dissipated on the walls of the cavity and the CWCT. Hence the denominator of Eq. (6) is proportional to $\sigma^{-1/2}$. On the other hand, the rf field is exponentially attenuated in the cutoff section. Thus, the numerator of Eq. (6) is proportional to e^{-2kL}, where L= 590.5 mm is the length of the CWCT up to the coaxial line and k is given by Eq. (5). The power ratio R can therefore be scaled by

$$R = C\sigma^{1/2} e^{-2kL}, \qquad (7)$$

where C is a proportionality constant, and we finally obtain

$$\frac{C_{cal}}{C_{\exp}} = \frac{R_{cal}(\sigma_{Al})^{\frac{-1}{2}} e^{2k_{cal}L}}{R_{\exp}(\sigma_{\exp})^{\frac{-1}{2}} e^{2k_{\exp}L}} = 1.66 \qquad (8)$$

As a result of this rescaling procedure, the calculated output power at the CWCT coaxial port is 1.66 times that of the measured value. We know that the CWCTs of the low power prototype cavity used for the measurements in [6] are not perfect, but have a cutoff frequency varying slightly along the tapered section from 650 HMz at the large diameter cavity port to 673 MHz at the end of the tapered section near the coaxial transition. This is due to a constant radius of 6mm along the taper at the foot of the ridges instead of a sharp corner as used for the simulations. Thus is reality the CWCT has an effective cutoff above 650 MHz, which reduces the power transmission ratio obtained from the measurements. Assuming $C_{cal}/C_{\exp} = 1$ in Eq. (8) we obtain an effective cutoff frequency for the CWCT of 663.3 MHz. This indicates that the simulations and the measurements are in reasonable agreement within the uncertainty of the effective cutoff frequency of the CWCT.

4 CONCLUSION

We have presented details of HFSS simulations of the evanescent field effect of the 500 MHz operating mode through the CWCT based on a recently optimized configuration of the HOM damping scheme. Calculated results agree reasonably well with experimental measurements. Both of them indicate that the R value is below the actual power capability well of the 7/8" coaxial line and rf window. This exercise demonstrates that the HFSS simulation can be employed as a reliable tool in subsequent studies aimed at the reduction of the evanescent field effect. Further details are provided in [8] and [9].

5 ACKNOWLEDGEMENT

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