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COPPER PROTOTYPE MEASUREMENTS OF THE HOM, LOM AND SOM COUPLERS FOR THE ILC CRAB CAVITY

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Abstract

The ILC Crab Cavity is positioned close to the IP and delivered luminosity is very sensitive to the wakefields induced in it by the beam. A set of couplers were designed to couple to and damp the spurious modes of the crab cavity. As the crab cavity operates using a dipole mode, it has different damping requirements from an accelerating cavity. A separate coupler is required for the monopole modes below the operating frequency of 3.9 GHz (known as the LOMs), the opposite polarization of the operating mode (the SOM), and the modes above the operating frequency (the HOMs). Prototypes of each of these couplers have been manufactured out of copper and measured attached to an aluminum nine cell prototype of the cavity and their external Q factors were measured. The results were found to agree well with numerical simulations.

INTRODUCTION

A full design of the ILC crab cavity including mode dampers is currently being undertaken by Lancaster University, STFC, FNAL and SLAC. The proposed ILC crab cavity [1] is a 9-cell superconducting dipole cavity operating in the π-mode of the HE_{110} mode passband. The cavity operates at a frequency of 3.9 GHz, at the third harmonic of the main ILC linac. As the operating mode is a dipole mode it will have two polarizations, the operating mode and the Same Order Mode (SOM). These modes will be separated in frequency by a small (~3.8 mm) squashing of the cavity.

One of the current designs includes a separate coupler for the LOM, SOM and for the HOMs [2]. The desired Q factor for each of these modes was calculated [3] in order to keep the wakefield below prescribed limits. In order to verify the cavity designs a modular aluminum prototype of the cavity was constructed for a series of measurements. One such measurement was to verify the design of the couplers by measuring the external Q of each of the couplers.

The prototype, shown in Figure 1, allows the addition and removal of the couplers, and we constructed some of the possible coupler designs proposed for the ILC. The cavity was initially constructed to be azimuthally symmetric; however a series of metal disks could be bolted to the equator of the cavity polarizing the cavity by splitting the two dipole polarizations by 12 MHz.

Figure 1. Aluminum prototype 9 cell crab cavity with HOM and power couplers.

MEASUREMENT TECHNIQUE

The external Q was measured for each coupler using a transmission method [4]. This method was employed as the external Q factors were much higher than the cavity's ohmic Q, causing a reflection coefficient close to unity. In such a regime it is difficult to measure the external Q accurately using a reflection technique.

In the transmission technique, we use a probe coupler and a test coupler, which is the coupler we are testing. The probe coupler should be loosely matched so that it has a reflection coefficient less than unity and can have it's external Q accurately measured by a reflection technique. This probe coupler is simply a piece of semi-rigid coaxial cable, RG405, placed penetrating slightly into the opposite beam-pipe. This probe coupler should be chosen so that its reflection can be accurately measured but not coupled so strongly that it perturbs the cavity fields. Then the probe coupler is fixed in place and the 3 dB bandwidth, Δf, is measured to find loaded Q of the system. From S_{11} we can calculate external Q from the coupling parameters. First we must calculate the coupling parameter of the probe coupler, β_{probe}

$$\beta_{probe} = \frac{1 \pm S_{11}}{1 \mp S_{11}} = \frac{\frac{1}{Q_0} + \frac{1}{Q_e}}{\frac{1}{Q_{probe}}} \quad (1)$$

where S_{11} is the reflection at the probe coupler. The external Q of the probe coupler can then be found from,

$$Q_{probe} = Q_L \left(1 + \frac{1}{\beta_{probe}}\right) \quad (2)$$

We can then measure the transmission between the probe and test couplers. The measurement of transmission is more accurate than the measurement of reflection when the coupler is mismatched as the small signal can be amplified. From the transmission we can measure the cavity bandwidth, and hence the loaded Q factor.

In order to find the external Q of the test coupler we must measure the transmission between the probe and the test couplers S_{21}. For a lossless coupler with calibrated cables we find,

$$\frac{1}{S_{21}^{\ 2}} = \frac{P_{in}}{P_t} = \frac{P_c + P_r + P_t}{P_t} \quad (3)$$

where P_c is the power dissipated in the cavity, P_t is the power transmitted through the prototype coupler and P_r is the power reflected in the probe. This can be rearranged to show

$$\frac{1}{S_{21}^{\ 2}} = 1 + \frac{S_{11}^{\ 2}}{S_{21}^{\ 2}} + \frac{P_c}{P_t} \quad (4)$$

applying $P_c/P_t = Q_e/Q_0$ to eqn. 4 and rearranging we find,

$$\frac{1 - S_{11}^{\ 2}}{Q_e S_{21}^{\ 2}} = \frac{1}{Q_0} + \frac{1}{Q_e} = \frac{1}{Q_L} - \frac{1}{Q_{probe}} \quad (5)$$

Rearranging this equation and applying equations 1 and 2, we find the equation for the external Q of the test coupler,

$$Q_e = \frac{4Q_L^{\ 2}}{S_{21}^{\ 2}} \frac{1}{Q_{probe}} \quad (6)$$

SOM COUPLER

The SOM coupler is a simple co-axial coupler, similar to the power coupler. In is a 50 Ohm coax with an outer diameter of 27 mm. A tapered section and a vacuum feedthrough (Kyocera N-R connector GMM-87157A) was used to match the coupler to the N-type connector of the test cable. This coupler was designed to efficiently couple out the power in the vertical polarization of the dipole mode, while not coupling to the operating horizontal polarization. This was achieved by positioning the coupler at the position of minimum field for the operating mode. The coupler and the cavity polarization were adjusted until the coupling was found to be at a minimum, at which point the external Q for the operating mode was found to be 9×10^8. The SOM was found to have an external Q of 4.8×10^5, this agreed well with the simulation value of 5.5×10^5.

LOM COUPLER

The LOM coupler constructed was a hook-type co-axial coupler with a single inductive stub [5]. The coupler is also positioned at the zero field point of the operating mode ensuring that the coupler does not damp the operating mode. The avoidance of a notch filter makes the design simpler and cheaper. The same vacuum feedthroughs as were used in the SOM coupler are used to match the coupler to the N-type connector.

This coupler is designed to damp the TM010 fundamental mode passband of the cavity. The measurement of the external Q factors of each of the nine modes in this passband are shown in Figure 2 along with the simulated external Q factors from Omega3P[6] and Microwave Studio [7].

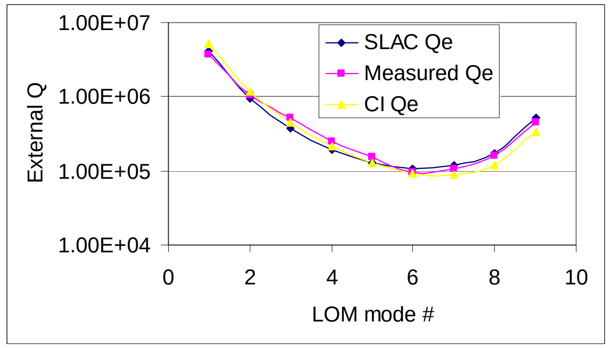

Figure 2. Comparison of the LOM coupler external Q factors for the lower order mode, between, measurements and simulations in Microwave Studio and Omega-3P.

The operating mode was found to have very weak coupling to this coupler, and as such an external Q measurement wasn't possible due to the low signal to noise ratio.

HOM COUPLER

The HOM coupler is the more complex of the three couplers. It utilizes an F-probe type design with a capacitively coupled probe to remove power from the cavity [5]. There are two capacitive gaps as well as two inductive stubs incorporated into the design in order to filter out the operating mode and to optimize the coupling to dangerous HOMs. However there is some concern over the sensitivity of these capacitive gaps to mechanical errors in the coupler fabrication. This is likely to be a major problem due to the small size of these couplers and the necessary e-beam welding in their fabrication. In order to investigate these errors the coupler was designed to have these gaps adjustable, as can be seen in Figure 3. The probe antenna was matched to RG402 semi-rigid cable using a tapered dielectric filled section of co-axial line.

Initially the coupler was placed in a section of beampipe without the cavity opposite an input coupler. The transmission between these two couplers was measured and the gap between the inner conductor and the top of the can was adjusted on the HOM coupler. It was found that the frequency of the notch filter varied as the gap was adjusted at 0.13 MHz/micron. This number was in excellent agreement with the design specification. This is a similar sensitivity to the 1.3GHz filters on the TESLA cavity HOM couplers.

Figure 3. The prototype HOM coupler, with F-probe (inset left) and adjustable can lid (inset right).

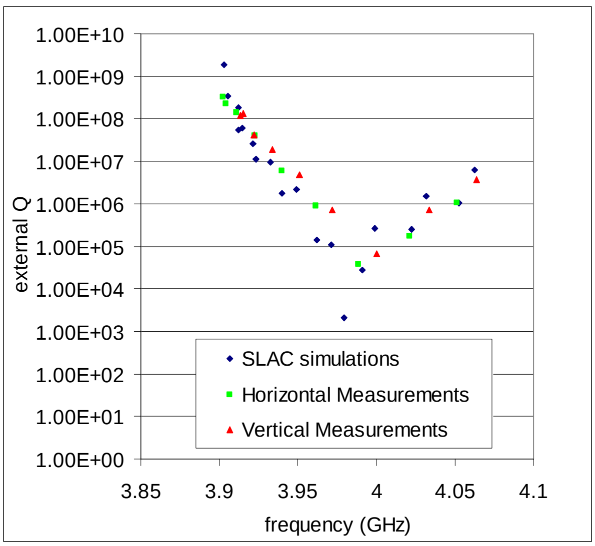

Figure 4. Comparison of the HOM coupler external Q factor for the 1st dipole passband in both planes, between measurements and Omega3P simulations.

After adjusting the notch filter to the resonant frequency of the operating mode the coupler was attached to the cavity and the external Q of a number of modes was measured. Both polarization of the 1st dipole passband were measured and were found to be in excellent agreement with the simulations as can be seen in figure 4.

Several HOM passbands were measured up to 7.67GHz, where two trapped modes were found with external Q's of above 10^8. On closer inspection of the transmission between the HOM coupler and the input coupler opposite it was found that the HOM coupler had a notch filter response at 8.04 GHz. This could be a possible problem in the future due to its close proximity in frequency to some dipole modes with high kick factors [3].

CONCLUSION

The measurements taken were found to validate the simulations undertaken in the design of the ILC Crab Cavity wakefield damping. The measurements of external Q for the LOM, and both polarizations of the 1st dipole passband were found to be in good agreement with simulation predictions.

The HOM coupler was found to have a notch filter response at 8.04 GHz which is close to some dangerous HOMs. Future work will focus on removing or moving this filter. One possible option is to use a waveguide damper instead of a co-axial coupler, removing the requirement for a notch filter. In addition in order to reduce the number of couplers required it is likely that the LOM and SOM couplers will be combined.

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