Cockcroft-06-46

COUPLER DESIGN CONSIDERATIONS FOR THE ILC CRAB CAVITY

P. Goudket, C. Beard, ASTeC, Daresbury laboratory, Warrington, Cheshire, WA4 4AD, UK
G. Burt, Cockcroft Institute, Lancaster University, Lancashire, LA1 4YW, UK

Abstract

Transverse deflecting cavities, such as the ILC crab cavity, commonly operate in the TM110 dipole mode. This means that in addition to the higher order modes (HOMs), that need to be controlled for every cavity, the fundamental TM010 mode and the other polarisation of the dipole mode also need to be damped. As the resonant frequency of the fundamental mode is much lower than the cut-off frequency of the beampipe, this mode becomes trapped in the cavity and difficult to extract using conventional HOM couplers, hence a dedicated coupler is required. The ILC crab cavities will require excellent damping of all undesirable modes in order to maintain maximum luminosity at the IP.

Presented at the Tenth European Particle Accelerator Conference (EPAC06),
Edinburgh, UK, 26-30 June, 2006

COUPLER DESIGN CONSIDERATIONS FOR THE ILC CRAB CAVITY

P. Goudket, C. Beard, ASTeC, Daresbury laboratory, Warrington, Cheshire, WA4 4AD, UK
G. Burt, Cockcroft Institute, Lancaster University, Lancashire, LA1 4YW, UK

Abstract

Transverse deflecting cavities, such as the ILC crab cavity, commonly operate in the TM110 dipole mode. This means that in addition to the higher order modes (HOMs), that need to be controlled for every cavity, the fundamental TM010 mode and the other polarisation of the dipole mode also need to be damped. As the resonant frequency of the fundamental mode is much lower than the cut-off frequency of the beampipe, this mode becomes trapped in the cavity and difficult to extract using conventional HOM couplers, hence a dedicated coupler is required. The ILC crab cavities will require excellent damping of all undesirable modes in order to maintain maximum luminosity at the IP.

INTRODUCTION

The future International Linear Collider will require crab cavities in the beam delivery system if there is to be a crossing angle. The luminosity loss from bunches not colliding head on is significant but can be compensated by applying a transverse deflection to bunches as they approach the interaction point (IP). This can be achieved using a dipole mode (or crab) cavity placed before the final focus magnets.

In order to achieve the required luminosity, the phase stability of the cavities needs to be controlled to a very high degree. One consequence of that is that the coupling of the input coupler will have to be quite high, the external Q factor being in the region of Qe 5 x 10^5. Another requirement is that effects induced on the bunch due to higher order modes (HOM) in the cavity be kept to a minimum, so very good damping of these undesirable modes is a necessity.

CKM CAVITY DESIGN

The 3.9GHz cavity originally designed at Fermilab to serve as a bunch separator for a muon machine was chosen as the baseline for the future ILC crab cavities. The current design for the CKM cavity (named after the FNAL experiment to measure the Cabbibo, Kobayashi, Maskawa matrix element) has three unwanted-mode couplers, one for lower order modes (LOM), one for same order modes (SOM) and one for higher order modes (HOM). The same order mode coupler is similar to a power coupler and couples to the unwanted polarisation of the dipole mode. The HOM coupler is a scaled down version of the welded TESLA HOM coupler, and the LOM coupler is a hook-type coupler to couple strongly to the trapped fundamental monopole mode.

Input Coupler

The CKM input coupler is a coaxial coupler placed on the same side of the structure as the HOM coupler. The current design has an external Q factor of 6x10^7 however due to the higher beam-loading in the ILC crab cavity a much lower external Q factor is required. In addition, the higher drive powers may lead to excessive heating. These requirements are likely to lead to an entirely new design of power coupler.

LOM Coupler

The fields of the fundamental mode of the CKM cavity decay sharply in the beampipe, hence this mode tends to have a high external Q. A hook type coupler is proposed to extract this mode. In order to find the external Q for this high Q coupler an eigenmode simulation, associated with the Balleyguier method [1] for calculating the external Q, was performed (see Figure 1). The 7π/9 mode, which has the highest R/Q of ~285Ω, has the lowest external Q factor ~3x10^4. When including the Q factors of all four cavity couplers, calculations of the heat dissipated in the cavity walls, assuming all modes in the fundamental passband are resonant with the beam, show the total dissipation to be less than 0.1W [2].

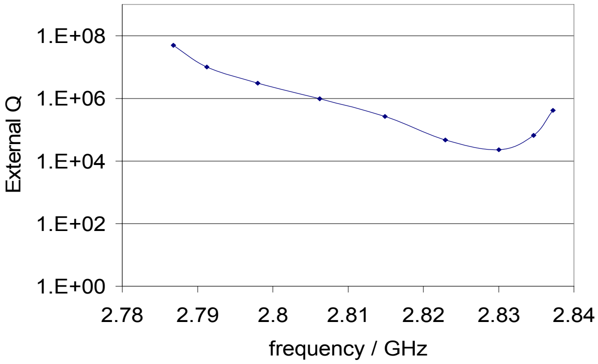

Figure 1: Qe as a function of frequency for the modes in the LOM passband.

As the fundamental mode has a high loss factor, large amounts of power will be dissipated into the cavity and extracted through the LOM coupler. The high power flow through the coupler can lead to large magnetic fields on the coupler. To simulate this, a 9-cell CKM cavity was characterised in the time-domain using Microwave Studio (MWS) [3]. The maximum magnetic field on the coupler was calculated as a function of accelerating voltage for the 7π/9 mode at 2.83 GHz, which has the highest loss factor. The highest magnetic field, 77 mT/MV, was found to be located at the first support stub nearest to the beampipe (see Figure 2).

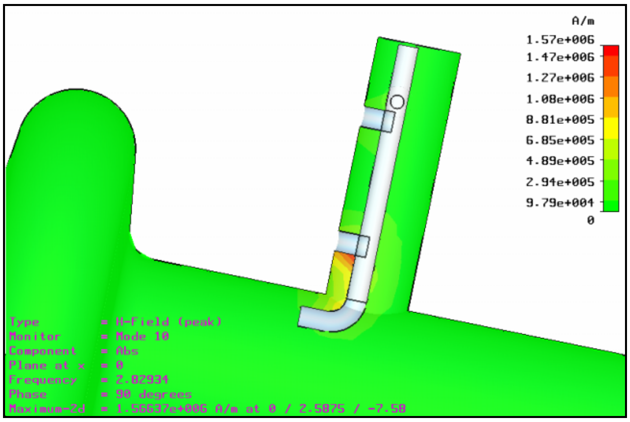

Figure 2: Magnetic field magnitude on LOM coupler

SOM Coupler

The dipole mode has two polarisations; one at which the cavity is driven, the other being an unwanted mode, known as a same-order mode. Due to the polarisation of the dipole modes we are able to design a coupler which couples strongly to one polarisation but not the other without requiring the aid of filters. This coupler is very similar to a co-axial power coupler and is placed at 90 degrees to the cavity input coupler. The probe on this coupler is adjustable in order to ensure that it does not couple to the deflecting dipole mode.

HOM Coupler

In the CKM cavity, the HOM coupler is a scaled TESLA HOM coupler. This coupler must not strongly couple to the operating mode of the cavity, hence a filter must be used. This should be a narrowband filter in order to coupler to other modes in the passband, hence the filter should be tunable. The tunability of the filter should not be too sensitive otherwise it would be difficult to adjust to the required frequency. In the HOM coupler the filter is adjusted by varying the gap between the inner conductor and a short placed in the outer conductor, hence varying the capacitance. The coupler was modelled without a cavity in MWS and the frequency domain analysis was used to find the resonances of the structure as a function of gap width (see Figure 3). It is found that near 3.9 GHz the rate of change of resonant frequency with gap width is 1.4 MHz/micron.

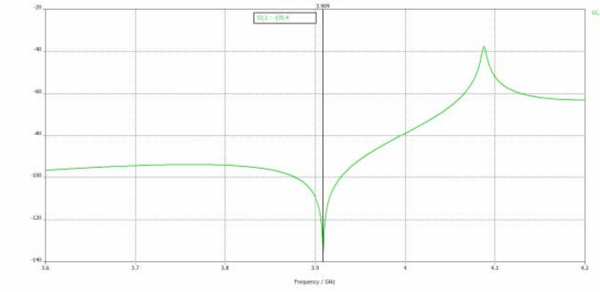

Figure 3: Transmission of the HOM coupler

ALTERNATIVE INPUT COUPLER DESIGN

Alternative designs

Waveguide coupling has been looked at for superconducting applications. Waveguide couplers are currently being investigated at various institutions including LBNL [4] and APS [5] for dipole mode cavities, with proposed use as input, LOM and HOM couplers for light source applications.

Many interesting designs are suggested, some of which combine input coupling with other functions such as coupling to LOM, SOM or HOM.

Waveguide coupler

The external Q required for the input coupler, for the ILC crab cavity, is in the region of 5 x 10^5, which is much lower than the external Q factor of the current design. It is necessary to increase the external Q without increasing the beampipe radius, and keeping the distance between the cavity and the coupler large enough to fit the helium vessel. It was decided to investigate the use of a rectangular waveguide coupler for use as an alternative to the existing input coupler on the ILC crab cavity (see Figure 4). The attractiveness of rectangular coupling is in the power handling capacity, and simplicity of fabrication. Prevention of undesirable effects such as multipactor can be slightly more complex than with a coaxial structure that can receive a bias voltage, but multipactor should not be an insurmountable problem. Cooling a rectangular coupler is also much easier than cooling the core of a coaxial coupler.

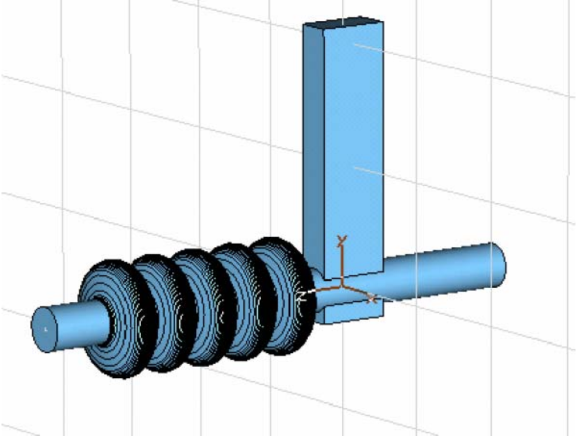

Figure 4: Rectangular coupler scheme with a 5-cell CKM-type cavity.

As an initial study, the coupling of the cavity to a rectangular waveguide of dimensions 29.08mm by 58.17mm, with a stub 25.63mm from the centre of the beampipe. The beampipe radius was kept to 18mm, as in the CKM cavity. The external Q factor was measured as a function of distance between the end of the cavity and the start of the coupler. At the desired 40 mm from the cavity the external Q was found to be 2.5 x 10^4 and as expected the Q varied exponentially with separation between the coupler and cavity (see Figure 5).

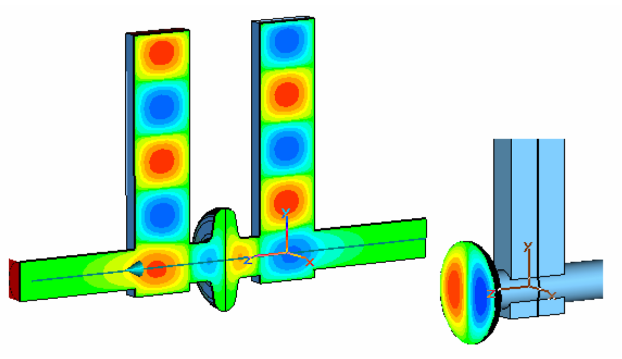

Figure 5: Ex and Ez (insert) components of the electric field in the coupler and cavity

The next study used a single cell of the CKM cavity, composed of two half endcells (see Figure 6). At the desired separation of 40 mm the external Q was found to be 3 x 10^4,which is lower than required for the ILC crab cavity.

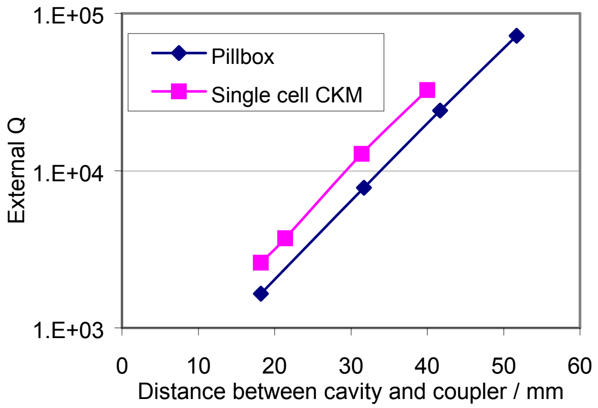

Figure 6: Effect on the cavity to coupler distance on the external Q factor

Finally the coupler was simulated attached to a 9-cell version of the CKM cavity. Early results show that a scheme such as that shown on Figure 4 can allow good coupling to the desired polarisation of the dipole mode, while leaving the other polarisation unaffected.

Early estimates of the Qe of the coupler are encouraging, showing a coupling factor of the dipole mode in the region of 4 x 10^5. A better mesh density in the simulation model should achieve better field flatness and therefore a lower Qe. The difference in Qe compared to a single cell is due to the tuned end-cells which lead to a faster decay of the fields through the beam pipes. It is encouraging that external Q factors lower than that required can be achieved without increasing the beampipe size or moving the coupler closer to the cavity.

CONCLUSION

The CKM cavity will require revised input and possibly LOM couplers for use as the ILC crab cavity. While it may be possible to effect only minor alterations to the existing design, it is also useful to look at alternative solutions, such as rectangular waveguide coupling. Given that the input coupler is placed on the same side of the CKM cavity structure as the HOM coupler, a modification of the input coupler would most probably require alterations to the HOM coupler as well. Future work will include a study into options for LOM coupling with a rectangular waveguide input coupler scheme.

REFERENCES

[1] P. Balleyguier, External Q Studies for APT SC-Cavity Couplers, 19th Linear Accelerator Conference, Chicago, 1998, p. 133.

[2] G. Burt et al., “Analysys of Wakefields in the ILC Crab Cavity”, these proceedings.

[3] CST Microwave Studio Manual,

[4] Derun Li, “Crab Cavity Progress at LBNL”, presented at the ILC Crab Cavity Workshop, Fermilab, 8 May 2006.

[5] Geoff Waldschmidt, “RF Design of a Deflecting Cavity for Short X-Ray Pulses at the APS”, presented at the ILC Crab Cavity Workshop, Fermilab, 8 May 2006.