CRAB CAVITY SYSTEM FOR THE ILC

G. Burt, A. Dexter
Microwave Research Group, Lancaster University, Lancashire, LA1 4YW, UK
L. Bellantoni
FNAL, Batavia, IL 60510, USA
P. Goudket, C. Beard, A. Kalinin, L. Ma
ASTeC, Daresbury laboratory, Warrington, Cheshire, WA4 4AD, UK

The crab cavity system requirements for the ILC are discussed in this paper. Differential phase jitter is the tightest requirement (0.066° at 3.9GHz), and will require the development of a high precision control system. A study of the integration of the cavity into the BDS suggests that the cavity should be placed close to the final focusing doublet. The Fermilab 3.9GHz deflecting mode cavity, with some modifications, has been proposed as a possible cavity design and eight 9-cell versions of this cavity could be used to provide the required kick.

1. INTRODUCTION

A possible design of the ILC is to have a crossing angle between the electron and positron lines. A consequence of having a crossing angle is the reduction in luminosity due to the geometry of the collision. Such a loss in luminosity can be recovered by rotating both bunches prior to collision with a deflecting ("crab") cavity.

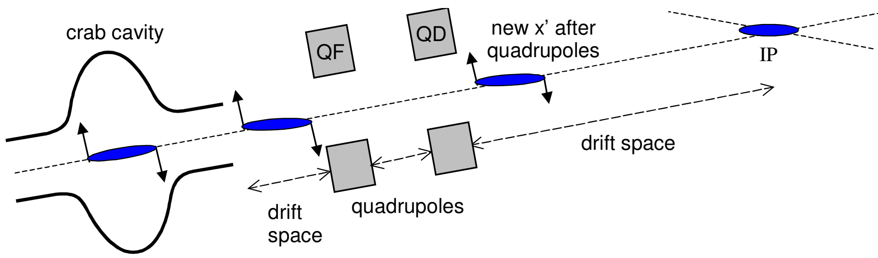

Figure 1: Bunch rotation due to a crab cavity without the quadrupoles.

A crab cavity is a RF cavity that uses the a dipole mode for its operation instead of the accelerating monopole mode. This dipole mode has zero longitudinal electric field and large transverse fields along its beam axis. The transverse fields provide a Lorentz force perpendicular to the (on-axis) velocity of the bunch.

If the phase of the RF is timed so that the centre of the bunch passes through the cavity when the magnetic field is zero (at "zero-crossing") then the head and tail of the bunch will experience equal and opposite Lorentz forces, giving the bunch angular momentum, as shown in Figure 1.

2. PHASE TOLERANCES

Precise control of the crab cavites is needed to maintain high luminosity. In particular, should there be a phase error between the cavities, the bunches would receive different amounts of transverse kick and would have a transverse offset at the interaction point. The two sets of crab cavities must be in phase with each other and the centre of each bunch must reach the centre of the cavity at zero phase. The two main sources of phase jitter are rf drive phase jitter and microphonics.

The amount each particle is deflected at the IP is

$$x_{offset} = \frac{c\theta_r}{\omega}\sin(\Delta\varphi) \quad (1)$$

where $\Delta\varphi$ is the phase at the centre of the cavity. For less than a 2% luminosity loss, the phase jitter tolerance needs to be better than 0.066° at a cavity frequency of 3.9GHz and a 20mrad crossing angle.

Some other common sources of error in accelerating cavities are not as big a concern for crab cavities. Beam loading is typically a smaller effect than in accelerating cavities. Bunch-to-cavity phase errors are not a concern as late bunches get proportionally more kick and both bunches still completely overlap such that the full luminosity is preserved.

3. BEAM DYNAMICS CONSIDERATIONS

The optics of the beam delivery system have been investigated with regards to the optimal location of the crab cavities. The final focusing quadrupole doublet can have a great effect on the transverse displacement of particles at the IP due to their focusing effect. Since crab cavities provide a momentum kick to the particles that is only converted to transverse displacement after a length of drift space, the location of the cavities with respect to the quadrupoles has a significant effect on the rotation achieved, as the quadropoles effect is a function of transverse displacement.

The relationship between the transverse kick and the position at the IP was calculated in [2] to be proportional to the ratio of the square root of the β_x at the crab cavity location and at the IP. Figure 2 shows the beta-functions for the ILC BDS for the 20mrad crossing. This shows the optimal location of the crab cavity for 20mrad to be close to the final doublet, as this configuration most reduces the focusing effect of the quadrupole QF1. The voltage required for a 10mrad crab rotation of the bunch at 1TeV was calculated at this position to be 6.1MV at 3.9GHz. The voltage required is inversely proportional to cavity frequency, and lower frequency cavities will be more difficult to locate in the beamline due to the proximity of the returning beam's line.

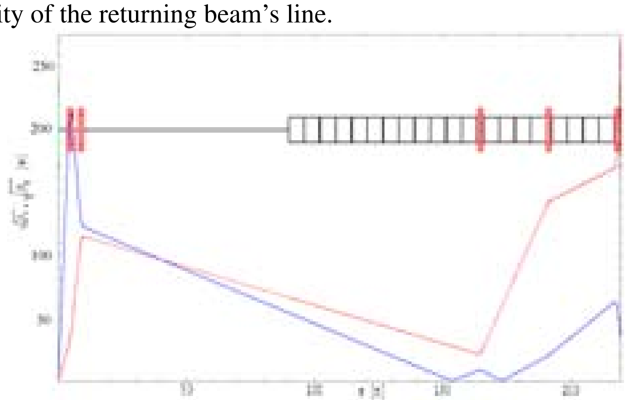

Figure 2: β_x (red), β_y (blue) for the 20mrad ILC BDS

The position for the 2mrad case has yet to be fully studied, however it is likely to be much further upstream.

4. FERMILAB CKM CAVITY

A superconducting dipole cavity is currently under development at Fermilab as a time-slicing device for studying bunch structure [3]. As first pointed out by Chris Adolphsen of SLAC, it could be used for the ILC crab cavity (with some modification). The cavity, known as the CKM cavity, is a 13-cell cavity that operates at 3.9GHz and has a beampipe diameter of 3.0cm. The maximum transverse voltage provided by this cavity is limited by the maximum surface magnetic field, which is just under 80mT at a transverse voltage of 5MV/m. Figure 3 shows the fields within the structure, which has an ID of 94.36mm. A lengthy R&D program at FNAL has shown that the cavity design is capable of reaching 7.5MV/m, in keeping with the widespread experience that small-grain BCP treated Niobium cavities can sustain a peak field of about 120mT. It has also been shown possible to weld the small structures needed to construct HOM couplers for cavities of this size.

Figure 3. Electric (left) and magnetic (right) fields within the FNAL cavity

The separation of modes in the dipole passband between the pi-mode and the next mode is ~1MHz using a 13 cell cavity. Although methods of field flatness tuning have been developed [4], the dangers of trapped modes that might be excited by the ILC beam would be reduced by the use of fewer cells per cavity. At an operating gradient of 6MV/m, four 9-cell versions of this cavity could be used on each side of the interaction region to rotate the bunch on the ILC (with 1TeV CM). This would require an active cavity length of 2m, and a total length of about 4m for the entire system (including couplers, gate valves, pumping ports). This can be split into several shorter sections if required.

In a dipole cavity the fundamental accelerating mode is unwanted but can be excited by the beam in certain circumstances. Because the resonant frequency of this mode is far below the cut-off frequency of the beam-pipe, the fundamental mode does not couple strongly to traditional higher order mode (HOM) couplers. In order to remove this mode from the cavity special LOM couplers must be designed that penetrate further into the cavity than HOM couplers. Currently hook-type couplers are planned as LOM couplers.

Recent results by A. Drozhdin [5] suggest that a beam clearance of at least 15mm should be observed to avoid photons hitting the cavity. The LOM couplers currently designed for the CKM cavity penetrate to 13mm from the beam-pipe centre. In order to have the LOM coupler to be 15mm from the centre of the beam-pipe, the aperture of the end-cells must have a larger radius than the current design. Having a larger aperture will, we expect, slightly reduce the (R/Q)' of the cavity. It may also reduce the risks of trapped modes. Design work is underway to understand these effects.

5. CONCLUSION

The phase and amplitude stability of the ILC crab cavities have been studied. The phase jitter tolerances of the crab cavity are tight. A significant effort is dedicated to solving the stability issue. It should be noted that phase stability better than that required of the ILC crab cavity has previously been demonstrated on accelerating cavities [6]. The crab cavity is likely to be placed near the final focus for the 20mrad crossing angle and is likely to be about 4m long.

The Fermilab 3.9GHz CKM cavity design is being evaluated for use as the ILC crab cavity. The current design has 13 cells per cavity but for the ILC fewer cells per cavity would probably be a better choice. The main issues of end-cell aperture size and trapped modes, are being studied at the Lancaster University and FNAL.

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