NORMAL CONDUCTING DEFLECTING CAVITY DEVELOPMENT AT THE COCKCROFT INSTITUTE

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Two normal conducting deflecting structures are currently being developed at the Cockcroft Institute, one as a crab cavity for CERN linear collider CLIC and one for bunch slice diagnostics on low energy electron beams for Electron Beam Test Facility EBTF at Daresbury. Each has its own challenges that need overcome. For CLIC the phase and amplitude tolerances are very stringent and hence beamloading effects and wakefields must be minimised. Significant work has been undertook to understand the effect of the couplers on beamloading and the effect of the couplers on the wakefields. For EBTF the difficulty is avoiding the large beam offset caused by the cavities internal deflecting voltage at the low beam energy. Prototypes for both cavities have been manufactured and results will be presented.

INTRODUCTION

Transverse deflecting cavities are required for many applications on accelerators, including crab cavities, bunch separators, emittance exchange and for bunch length diagnostics. These cavities usually operate in a TM_{110}-like mode. The Cockcroft Institute in the UK is participating in the design of several deflectors for a range of applications including crab cavities for ILC [1], CLIC [2] and LHC [3] and a bunch length diagnostic for EBTF [4]. In this paper we concentrate on the normal conducting rf deflectors for CLIC and EBTF.

CLIC CRAB CAVITY

CLIC requires a crab cavity to rotate the bunches prior to the interaction point (IP) to achieve an effective head-on collision. As the bunch size at the IP is very small (~5 nm) the luminosity is very sensitive to the crab cavities RF phase and amplitude. This means that the beamloading must be minimised and correction applied. The beamloading is dependent on the longitudinal electric field experienced by the bunch. In crab cavities the longitudinal electric field is zero on axis but has a linear variation as the bunch goes off axis. This means the beamloading could be positive or negative depending on the beam offset. As the bunch train for CLIC is short (~200 ns), the beamloading cannot be compensated for in a single bunch train, the feedback would occur over several trains. Unless the jitter on the beam offset is much less than the bunch size the compensation will not be successful, hence the beamloading must be minimised instead [5]. In order to reduce the effect of beamloading the cavity is designed with a large power flow so that any power induced by beamloading is smaller in comparison. This is achieved by using a high group velocity travelling wave structure.

Another issue affecting beamloading is the perturbation of the input and output couplers. Couplers break the symmetry of the cavity and can give rise to monopole components to the deflecting field. A dual feed coupler keeps the symmetry of the structure and avoids monopole components but is more complex coupling arrangement requiring splitters. A single feed is the simpler coupling arrangement however this gives the end cells a large monopole component of the rf field. We have investigated methods of single feed coupling without inducing monopole component.

Single-feed Couplers

In order to minimise the monopole component of rf field in the end cells while using a single-feed coupler a number of options were investigated. Initially cancelling the monopole kick from the two end cells was studied. Consider particle moving at the speed of light. If the cell is rotated the monopole component has the sign of the real part of the voltage flipped. Hence if the input and output couplers are mounted on opposite side the real parts should cancel. If the lengths of the cells are adjusted so that the voltage is entirely real then the entire monopole component is cancelled. This however is not sufficient in travelling wave deflecting structures as the power put into the output cell will be extracted through the output coupler while the power in the input cell will travel down the structure. Hence it is necessary to cancel the beamloading in each cell individually.

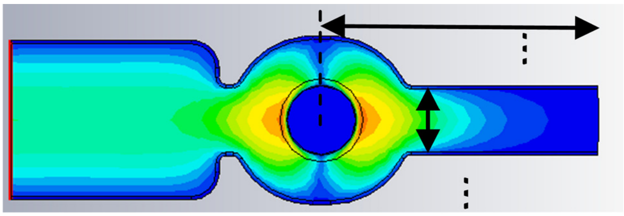

Figure 1: Dummy waveguide and input coupler on the CLIC crab cavity

In order to restore the symmetry of the cell a dummy waveguide opposite the coupler was studied. Using a dummy waveguide was found to significantly reduce the monopole component but not reduce it to zero. The real part is reduced to zero, but the imaginary component is not and hence gives the minimum voltage. The reason for this is because there must be a power flow across the cell, from the coupler to the dummy waveguide. This means that there cannot be a full standing wave in the cavity and there must be a travelling wave component.

Another method of symmetrising the cell is to couple from the side with a TE_{02} mode coupler. This allows an equal power flow to each side hence avoiding a monopole component. However the cavity is now vertically asymmetric and hence there is a small vertical kick. However this symmetry can be recovered by adding a dummy waveguide. The TE02 mode splitter must carefully be designed to avoid excitation of a TE01 mode which gives rise to a monopole component to the fields.

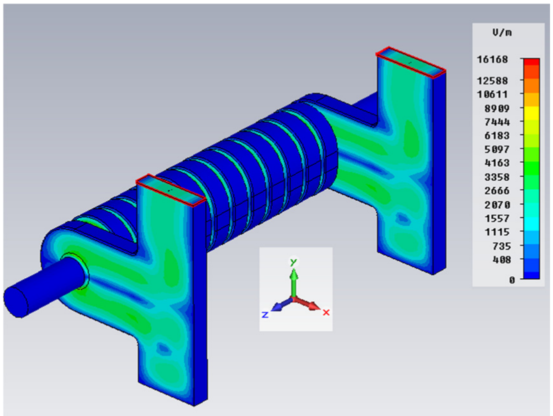

Figure 2: TE_{02} mode coupler

Wakefield Damping

As the cavity is close to the final focus magnets, where the beta function is large, it is very sensitive to transverse wakefields. It is necessary to damp any long-range wakefields within a few bunches to avoid large transverse offsets at the IP. The vertical wakefield is the most sensitive, due to the small vertical beam size, and is dominated by the opposite polarisation of the crabbing mode, known as the same order mode (SOM). As the wake is dominated by a single mode it is proposed to have this modes frequency at the zero-crossing, where the mode frequency is a half integer harmonic of the beam frequency. This means that each bunch induces a voltage 180 degrees out of phase with the previous bunch hence cancelling each other. For CLIC it is proposed that the cell has an elliptical cross-section such that the crabbing mode is at 11.99 GHz while the SOM is at 12.98 GHz. However the SOM still requires significant damping due to the very tight tolerances on vertical kicks. Choke damping and waveguide damping were both considered. Choke cavities are difficult for deflecting cavities as the choke must be polarised to damp one polarisation but not the other. Options are to use an elliptical cavity, an elliptical choke or a slotted choke [6]. The slotted choke achieved the best performance; however widening the slot to achieve better damping also reduces the Q of the crabbing mode which could be problematic due to enhanced heating. For this reason a waveguide damper was chosen for CLIC, as shown in Fig.3, as a waveguide coupler shows strong damping of the SOM without affecting the crabbing mode.

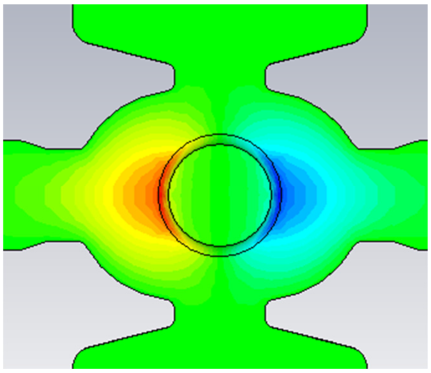

Figure 3: Damped elliptical cell of the CLIC crab cavity

Cavity Prototype

Two prototype cavities have been manufactured. One has been made by Shakespeare Engineering, a UK company, to be tested at SLAC and the other has been made at VDL, to be tested at CERN. The CERN cavity has had the parts machined and is due to be brazed soon. The SLAC cavity, shown in Fig. 4, has been fully manufactured and is currently undergoing tests at Cockcroft before shipping to SLAC.

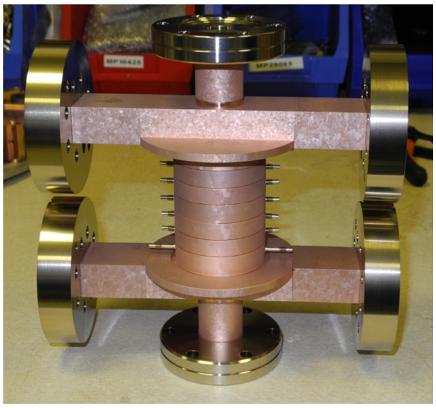

Figure 4: CLIC crab cavity prototype manufactured by Shakespeare Engineering.

EBTF TRANSVERSE DEFLECTING CAVITY

The Electron Beam Test Facility (EBTF) at Daresbury Laboratory will deliver low energy (5/6 MeV) short bunches (down to 40fs RMS) to a number of industrial experimental stations and for fundamental scientific research. In order to measure the longitudinal profile of the bunch an S-band transverse deflecting cavity will be inserted into the beamline. A transverse kick of around 5 MV is required, hence a 9 cell design has been chosen. The design of the transverse deflecting cavity has been influenced by the competing demands of high RF efficiency [7] and minimising the equal and opposite unwanted transverse kick at the entrance and exit of the cavity which causes the low energy electrons to be displaced while traversing the cavity [8]. The coupler has a dummy waveguide to minimise the on-axis longitudinal electric field.

Minimising transverse offset

As a transverse deflecting cavity has a finite size the beam experiences a range of phases as it crosses the cavity. This means for a zero-crossing it experiences a finite force, initially in one direction and then in the other such that the net transverse momentum at the centre of the bunch is the same at the start and end of the cavity. However this does result in a transverse offset as the beam travels transversely inside the cavity. It was found that due to the beampipe the electrical centre of the end cell was not at the geometric centre. This resulted in an uneven kick producing a net transverse momentum when leaving this cell, which wasn't removed until experiencing the opposite force at the other end cell. This gave a much larger transverse offset in the cavity, of 4 mm, due to the low energy of the bunch. As the beam was offset the beamloading was much higher which significantly altered the beam energy. For ultra-relativistic beam this offset is small and typically ignored. For low energy beam of EBTF is could not be ignored and has to be minimized.

In order to counteract this effect the end cells were made much shorter such that transverse kick in the end cells for a zero-crossing particle was minimised. The final cavity is shown in Fig. 5. The particle tracking simulations in GPT [9] show the transverse offset inside the cavity is minimised, shown in Fig. 6.

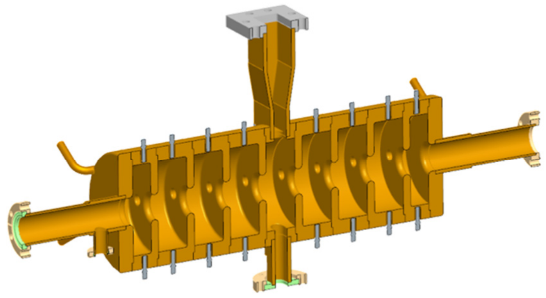

Figure 5: EBTF Transverse deflecting cavity with shortened endcells.

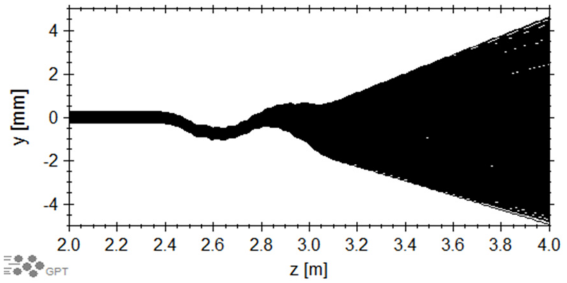

Figure 6: GPT tracking simulation of EBTF transverse motion.

Prototype Cavity

A 3-cell prototype has been produced by Research Instruments (shown in Fig. 7), to verify brazing procedure, and a contract has been placed with them for a full 9-cell structure.

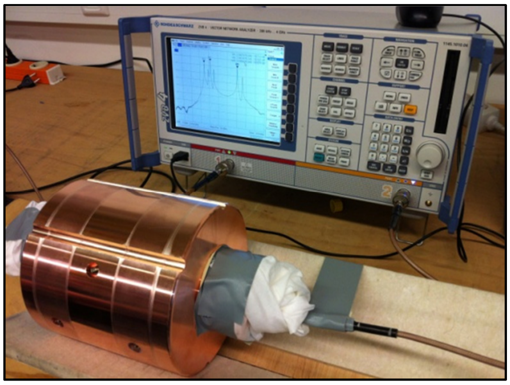

Figure 7: 3-cell prototype of the EBTF Transverse deflecting cavity.

SUMMARY

The Cockcroft Institute has a proven track record of designing deflecting cavities for numerous applications. High power testing is expected to be done on both cavities in the next few months.

ACKNOWLEDGEMENTS

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