A TRANSVERSE DEFLECTING CAVITY FOR THE MEASUREMENT OF SHORT LOW ENERGY BUNCHES AT EBTF

G. Burt, Lancaster University, Lancaster, LA1 4YR, UK
S. Buckley, B. Fell, P. Goudket, C. Hill, T. Jones, P.A. McIntosh, J. McKenzie, A. Wheelhouse, STFC, Daresbury Laboratories, Warrington, WA4 4AD, UK

Abstract

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 influence by the competing demands of high RF efficiency 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. This has led to shortened end cells to minimise the kick applied at the entrance and exit to the cavity. In order to minimise the impact of the input coupler a dummy waveguide has been placed on the opposing side of the cavity to minimise the monopole component of the RF fields in the coupling cell. The coupler is placed on the central cell of the cavity to avoid exciting the nearby modes. Tracking of the beam is performed in GPT including space charge, due to the low energy of the electrons.

INTRODUCTION

The Electron Beam Test Facility (EBTF) at Daresbury [ref] is a source of low energy (5/6 MeV), short (down to 40fs RMS), low emittance bunches. In order to accurately measure the longitudinal bunch profile, a transverse deflecting cavity will be utilised to streak the bunch onto a YaG screen converting longitudinal position into transverse offset at the screen hence allowing bunch profile measurement [1]. The deflecting cavity has been designed around the requirement to use an existing 3 GHz, 6 MW klystron as the RF source and limited space requirements of 40 cm. The system is designed to have a 10 fs resolution of a 6 MeV beam at emittances of up to 1 mm mrad requiring a deflecting voltage of 5 MV. This has required a high shunt impedance design. A competing constraint of short time from conception to delivery of the cavity has required conventional technology to be used. Taking these requirements into account, a standard standing wave cavity configuration has been chosen, similar to cavities developed at Tsinghau University [2] and SPARC [3].

As the beam energy is very low, two issues emerged early in the beam dynamics simulations; the first being the reduction of energy spread caused by the deflecting mode as this could be a significant fraction of the beam energy, secondly as the beam has a low stiffness, the deflecting field inside the cavity at zero crossing can cause large transverse offsets. The beam optics and cavity designs had to minimise both of these effects.

CAVITY DESIGN

The shunt impedance specification requires a large number of cells, however the total number, N, is limited by the separation between the π mode and the (N-1) π /N mode of the cavity. Figure 1 shows how the dispersion curves depend on the iris radius of the cavity, as simulated in CST MWS [4]. Due to the coupling between TM and TE dipole modes, the separation is maximised for iris radii between 16 and 20 mm and decreases for larger and smaller iris. The shunt impedance of the deflecting mode is largest for smaller iris radii as the hybrid mode becomes more TM-like, hence an iris radii of 16 mm is preferred. For this iris radii, the frequency spacing between the π mode and the 8 π /9 mode is 1.85 MHz which is roughly 5 times the cavity loaded bandwidth. However this mode can be avoided by coupling into the central cell hence the next excited mode is the 7 π /9 mode which is 6.5 MHz away. The maximum number of cells is therefore 9 cells.

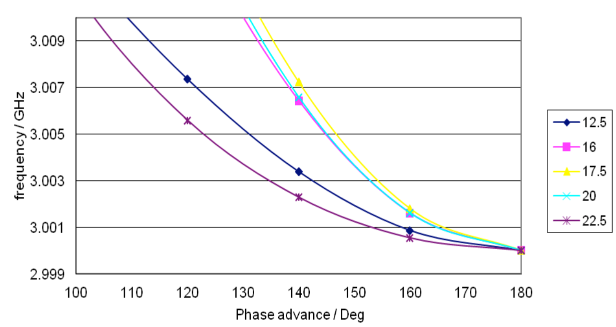

Figure 1: Dispersion diagram in cavities of varying iris radii.

Dipole cavities have degeneracy between the horizontal and vertical dipole modes, hence some method of polarisation is required to separate the frequencies of these two passbands. Typical methods for separation include coupling slots, elliptical iris apertures, parallel rods and adding distortions at the cavity equator. The most common method used is to add coupling slots in the iris walls, as this provides a large separation and simple construction, hence this option was chosen for EBTF. The slots can either couple electrically or magnetically to the vertical polarisation, increasing or decreasing the

ISBN 978-3-95450-115-1

frequency. It is beneficial to push the passband upwards as the cavity has a negative slope and the π-mode has the lowest frequency, hence electric coupling is preferred. This unfortunately means the coupling has to be close the equator, meaning that it sees a significant part of the deflecting mode field, meaning the slot has to be small enough to reduce the fields at the hole but large enough to produce a sizable polarisation. A 6.5 mm hole was chosen, shown in Fig. 2.

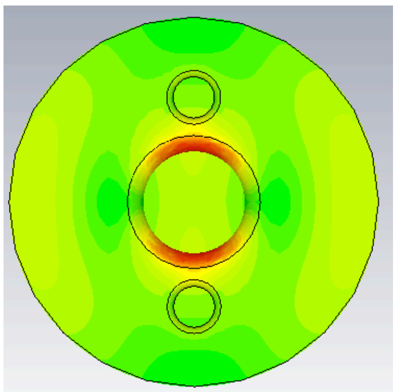

Figure 2: Magnetic field magnitude in the cavity showing low field near the coupling holes. Red is high field locations.

As the deflecting mode is a hybrid HE mode, it deflects using both the magnetic field in the middle of the cell and the electric field in the iris. This means that the total deflecting field is lower in the end cells as the beampipe aperture has significantly lower transverse electric fields than at the iris. In order to increase the kick in the end cell the beampipe is increased to 35 mm diameter, this is also beneficial as it matches the beampipe aperture for the rest of the machine.

The longitudinal electric field in a deflecting cavity is normally zero on axis and increases linearly with radial offset. This can lead to a net acceleration or deceleration to offset electrons. When a power coupler is added to the structure the centre cell obtains a monopole component to the field, causing the electrical centre of the mode to shift slightly. In order to reduce this monopole component a dummy coupler is added opposite the power coupler to symmetrise the deflecting field.

BEAM DYNAMICS

A problem that occurs in low energy deflectors is that for a particle going through the cavity at the zero crossing point, the deflecting voltage inside the cavity is non-zero. The net deflection by the cavity is zero but the electrons are kicked back and forth inside the cavity by the electric and magnetic fields. This effect is low in the mid cells as the distance between the kick and the correction is low, however in the end cells the low transverse electric field at the beampipes means that the kick imparted is not cancelled until the beam reaches the other side of the cavity. This results in a large offset of the beam inside the cavity, which is shown in Fig. 3, from modelling in GPT [5].

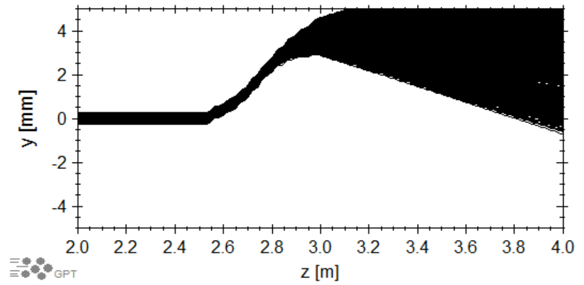

Figure 3: Vertical trajectories without correction.

As the beam is offset inside the cavity it causes the beam to experience the longitudinal electric field inducing acceleration to the beam, shown in Fig. 4.

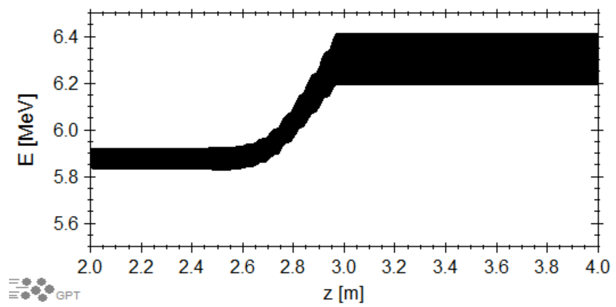

Figure 4: Particle energies without correction.

This effect can be corrected by using small steering magnets/coils before and after the cavity and can also be minimised by altering the cavity geometry slightly to minimise the kick from the end cells. A study of the fields in the end cell shows that as the field decays into the beampipe, the field maxima is shifted slightly away from the cavity, hence the beam doesn't go through the zero crossing point for this cell and the kick at the front and back of the cell do not cancel. Reducing the length of the end cell shifts the field maxima back towards the cavity centre, allowing it to be optimised so that the kick inside the cell does indeed cancel. The corrected vertical trajectories are shown in Fig. 5.

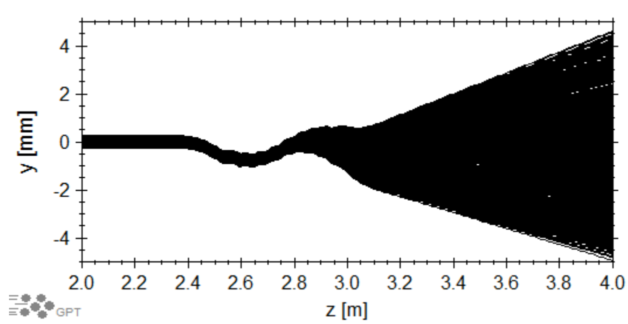

Figure 5: Corrected vertical trajectories.

Initially the concept was to have a large beta function at the transverse deflecting cavity, in order to maximise the offset at the screen for a given deflecting voltage, however this implies that the beam size is also large at the cavity. When GPT simulations were performed for the diagnostics line, it was found that as the longitudinal voltage varies linearly with radial offset, a large energy spread was introduced into the beam. For this reason it was necessary to reduce the beta function at the cavity in order to reduce the energy spread. The rms vertical beam size at the entrance to the cavity is reduced from 0.53 mm to 0.15 mm. The particle energies for the corrected optics is shown in Fig. 6.

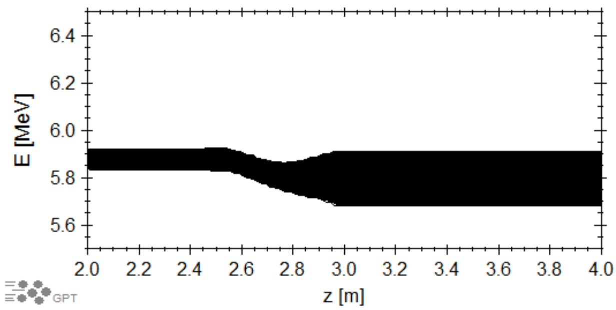

Figure 6: Particle energies with correction and small vertical beam size through the cavity.

MECHANICAL SIMULATIONS

As the bunches in EBTF will be very short and the beam is not very stiff, the beam is given a large deflection by the deflector. If the phase of the cavity varies, this will result in a large offset at the screen. In order to minimise phase errors, the cavity must be thermally stable to avoid thermal expansion detuning.

A Finite Element Analysis performed with 150 W heat uniformly distributed across the 8 irises, 15 l/min water at 35°C flowing through the cooling channels and 20°C air convection applied to the outside surfaces of the TDC, shows a 0.7°C peak temperature increase. The result in Figure 7 shows that with a reference temperature of 35°C the total deformation is 2.9 µm. The deformation across each of the 9 cavity cells is approximately 0.3 µm. To understand the effects of temperature stability, an analysis was run with a reference temperature of 35°C but a water temperature of 36°C in the cooling pipes. This result implies that a 1°C temperature fluctuation gives a total deformation fluctuation of 10 µm and approximately 1 µm deformation across each cavity cell. If the temperature fluctuations are slow (period of around 10 minutes) then the phase transients caused by this can be corrected hence this temperature rise is deemed to be acceptable.

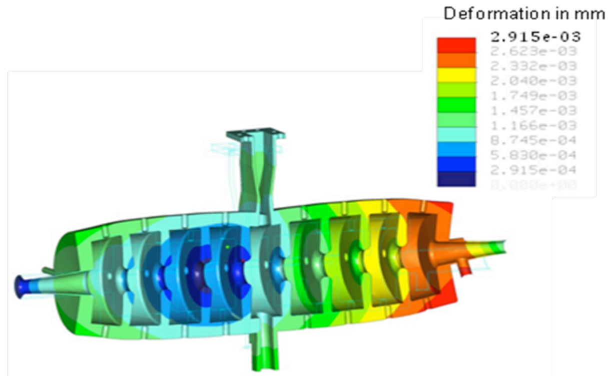

Figure 7: Deformation in the cavity due to the 0.7°C temperature rise.

CONCLUSION

A 9-cell standing wave deflecting cavity has been designed for the EBTF at Daresbury Laboratory. The cavity has overcome some major issues related to the low beam energy at EBTF to allow bunch length measurements to be made with a good resolution. The final cavity design is shown in Fig. 8.

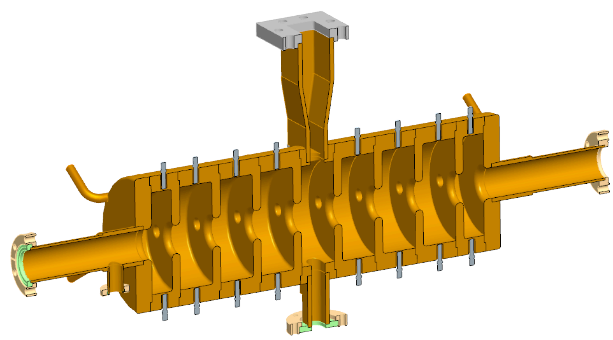

Figure 8: Final cavity geometry including tuners and cooling pipes.

A contract has been placed with Research Instruments to produce a 3-cell test prototype, followed by the full 9-cell structure. The cavity is due to be installed at EBTF towards the end of 2012.

ACKNOWLEDGEMENTS

This work has been supported by STFC via the Cockcroft Institute core grant.

REFERENCES

[1] R. Akre et al., Proc. PAC 01, Chicago, p. 2353.
[2] J. Shi et al., Chinese Physics C 32(10), (2008) 837.
[3] D. Alesini et al., NIM-A 568(2), (2006) 488.
[4] Microwave Studio, CST GmbH, Darmstadt.
[5] M.J. de Loos, S.B. van der Geer, General Particle Tracer, http://www.pulsar.nl/gpt

ISBN 978-3-95450-115-1