STATUS OF CRAB CAVITY DESIGN FOR THE CLIC

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Abstract

RF design of a crab cavity (2π/3, 11.9942 GHz) for the Compact Linear Collide (CLIC) is presented. As part of the UK-CLIC collaboration, CERN is building two copper prototypes, designed by Lancaster University / Cockcroft Institute. The first prototype to be made will be a 12 cell undamped cavity and the second will be waveguide damped cavity. The RF test at CERN will help characterisation of the dipole mode with X-band RF pulses of 15 MW peak power and pulse length of ~242 ns. Since the cavity frequency and phase advance per cell are identical to those of the CLIC main linac, the first prototype could exploit CERN's X-band cavity characterisation facilities. A fully damped cavity will be required for the actual machine in order to meet the luminosity specs. The damped prototype will use an identical coupler type as the undamped one, but the cells will have damping waveguides with / without dielectric material.

INTRODUCTION

Crab cavities are required in the CLIC beam delivery system to rotate bunches before collision. This crabbing or rotation will help regain the luminosity which would otherwise be lost when bunches collide at a crossing angle of 20 mrad [1]. The location of these cavities will be just before the final doublets (FD) on each beamline. A travelling wave cavity operating in 2π/3 phase advance and 11.9942 GHz has been proposed and is under design at the Lancaster University/Cockcroft Institute. The choice was based on considerations of achieving the required transverse voltage of 2.55 MV for 20 mrad crossing, with the known klystron peak power availability and associated beam-loading insensitivity [1]. Initially a cylindrical cell shape was considered for evaluation of approximate operating parameters such as gradient and power requirement. High power tests are required to evaluate the actual operating performance of the selected cell shape and for this purpose, a 7-cell cavity was designed with the purpose of testing at SLAC. This cavity is under manufacture at Shakespeare Engineering, UK. Wakefield analysis of a 10-cell cavity with standard waveguide couplers showed the need for tight damping of the degenerate dipole mode called Same Order Mode (SOM) of the crab cavity. Basic damping options like the waveguide and choke dampers were investigated, with waveguide showing superior performance [2]. By shifting the SOM frequency to certain harmonics of the bunch repetition rate (1.999 GHz), the multi-bunch wake could be reduced due to the cancellation of the SOM wake by the following bunch [2]. This resonant cancellation can be used to relax the tight level of damping if the SOM frequency is an integer and a half harmonic of the bunch rate. An SOM frequency of ~13 GHz was chosen and an appropriate asymmetric cell shape has to be developed.

ASYMMETRIC CELL SHAPE

Azimuthally asymmetric cell shapes such as elliptical, racetrack, rectangular, bumped cylindrical etc are well known choices. From a mechanical point of view, the racetrack shape shown in Figure 1 seems more attractive and also it preserves the operating mode for the 1 GHz shift between the dipole polarisations.

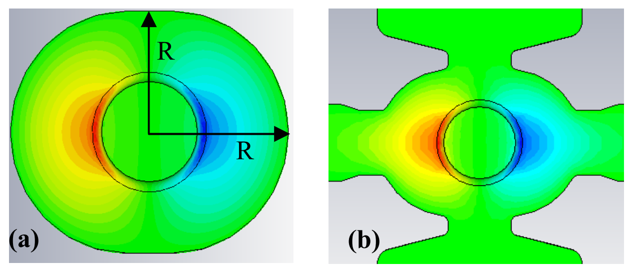

Figure 1: Race track cell shape of the (a) undamped (b) waveguide damped cavity showing the radii and electric field of the operating mode

An iris radius of 5 mm was chosen for manageable short range wakefields. The dipole frequency at 2π/3 phase advance is then fixed by radii Ry and Rx. Resonant frequency of this cell is calculated using periodic boundary conditions. Sensitivity (MHz/μm) of the resonant frequency to the radii are as follows: For Crab mode: df/dRy= −0.6, df/dRx= −0.8 and for SOM: df/dRy=,−0.2 df/dRx= −0.92. The cavity is tuned to set the crab mode at ~12 GHz and SOM at ~13 GHz. Waveguides for wakefield damping will detune the cell and retuning is required to reset the frequencies. For a comparison, RF properties of undamped and damped cells are listed in Table 1. The damping Qs are 8e5 at the operating frequency and 35 at the SOM frequencies.

Table 1: RF parameters of a single cell at 11.9942 GHz and 2π/3 periodic boundary

	Q	R_t/Q, Ohm	$-v_{gr}$, % c	E_m/E_t	H_m/E_t
Cylindrical-undamped	6396	53.66	2.94	3.497	0.0115
Racetrack-undamped	6395	54.65	2.93	3.425	0.0114
Racetrack-Damped	6022	50.57	2.63	3.676	0.0117

As shown in Table 1, RF properties of the undamped cylindrical and racetrack cells are practically the same. The damping reduces the Q and R_t/Q of the operating mode by 7 % and group velocity by 10 %. As the dipole mode has peak surface magnetic and electric fields near the iris aperture, the damping waveguides do not increase peak surface magnetic field, unlike as in the case of accelerating structures. For the cell shape in Figure 1(b), the surface magnetic field at the coupler is less than 50 % of the iris field. For a peak gradient of 100 MV/m, a manageable temperature rise (ΔT=25 K) is anticipated in the undamped or damped cells, which will mitigate surface damage issues. We note that in ongoing operation of SLAC 11.424 GHz deflectors of similar parameters, the RF breakdown is not an issue.

COUPLER DESIGN

There are several ways of coupling RF power to a cavity [3]. For CLIC main linac accelerating structure prototypes for high power testing or cavities for breakdown tests like the SLAC cavities, couplers with low field in the coupler iris/cell region are used [3]. There are two factors which make the coupler design for the crab cavity more flexible than that for the main linac cavity. Firstly, peak power requirement of the CLIC crab cavity is about a quarter of that needed for a main linac accelerating structure (P_{in} ~ 15 MW × 60 MW), consequently surface fields are lower (E_{surf} ~ 100 MV/m × 250 MV/m and ΔT ~ 25 K × 40 K) [4]. Secondly, peak surface magnetic field of the dipole mode occurs at the iris of the regular cell, whilist for the accelerating monopole mode it is at the cell equator

In a waveguide coupler the RF power is coupled to the regular structure through a matching cell. Such a design was chosen for the SLAC cavity (2π/3, 11.424 GHz) for high power test. Figure 2(a) shows the waveguide coupler design of the racetrack cell cavity. The waveguide cross section is standard WR90 and is matched to the periodic section by adjusting the matching iris radius, iris length and the matching cell radius.

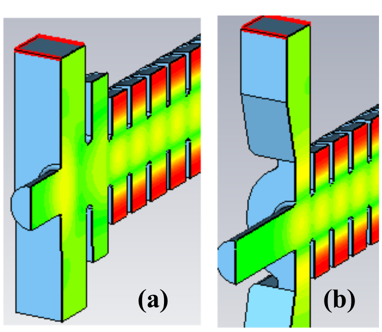

Figure 2: H field at 11.9942 GHz of (a) waveguide coupling (b) standard coupling, of undamped crab cavities

The two matching cells and waveguide (~37 mm) add to the total cavity length but provide little kick due to the TE-nature of the mode inside those regions. The matching cell will excite at TE_{111}-mode, which transforms the TE_{10} field in the waveguide to the TM_{110} in the cavity and vice versa. The extra cavity length due to matching cells can be avoided by a standard coupling method shown in Figure 2(b). Here the waveguide TE_{10} is inductively coupled to the TM_{110} of the cavity through a slot between the narrow wall of the waveguide and the equator of the end cell. The primary matching dimensions are the slot height, slot width and the end cell radius.

Such designs assume a dual-feed to the cavity whereby the cavity is fed using an E-plane hybrid Tee to split the input power into equal amplitudes and 180° out of phase as shown in Figure 3. This particular feeding method prevents any chance of exciting the monopole mode by the coupler, provided the mechanical tolerances are met. As Figure 3 shows, the standard coupler is transversely larger than the waveguide coupler when the splitter size is considered. Tuning the end cells is more difficult with the standard coupler, unless the waveguide arm is longer to provide sufficient room.

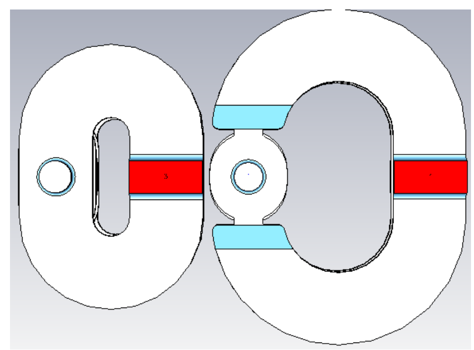

Figure 3: Transverse size comparison of structures of Fig.2 with hybrid Tee junction.

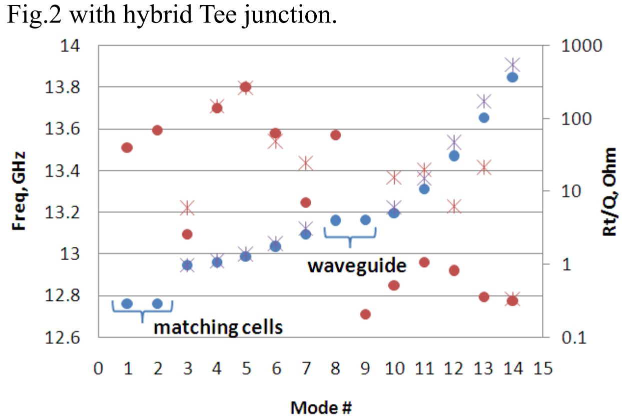

Figure 4: Frequency (blue) and transverse shunt impedance (brown) of modes in the SOM passband for waveguide coupled (dot) and standard coupled (asterisk) cavities

Enhancement of multibunch wakefield mainly depends on the effective cavity length. For a comparison, eigenmode frequencies and transverse R/Qs of a 10-cell structure with both couplers is shown in Figure 4. For a waveguide coupled cavity, significant contributions are from the matching cells and the waveguides. In practice, higher order modes, including trapped modes will also add to the wakefield. As the crab cavity has tight wakefield tolerances, the above comparison suggests a larger wakefield for the waveguide coupler, the remedy being to put dampers in the matching cells and coupling waveguides, which will make the structure somewhat more complex than the structure with the standard couplers. These extra dampers could be avoided by increasing the damping level in the regular cells. Consequently from a damping point of view, the standard coupler is preferred for the CLIC crab cavity.

FEED GEOMETRY

The well-known advantage of using the dual-feed coupler geometry for dipole cavities is that it excites only the dipole mode and also that it centres the mode null in the cavity centre. Mode symmetry could also be achieved with a single-feed coupler combined with a dummy-waveguide, but the field on-axis does not reduce to zero, resulting in on-axis beam loading. Rotating the couplers by 180^0 with respect to each other will however reduce the above effect. For low power dipole cavities, the only function of dual-feed coupler is to centre the mode null in the end cells, whereas the use of a single-feed avoids a splitter, hence resulting in a more compact structure. For the high power test cavity, a single-feed coupler as shown in Figure 5(b) or (c) is preferred to the dual-feed coupler; finalisation is yet to be done.

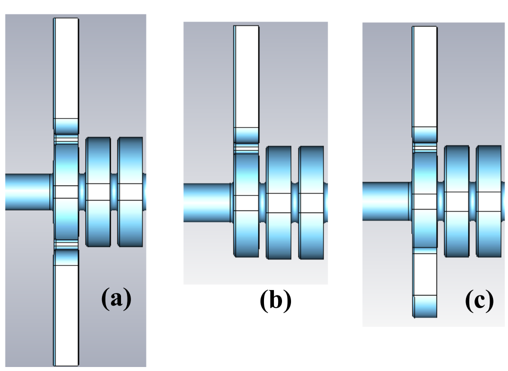

Figure 5: Feed geometry (a) dual-feed (b) single-feed (c) single-feed with dummy waveguide

A taper waveguide section will match the coupler waveguide to the standard WR90. For thermal stability, water cooling channels will be added on either side of the disk on the shorter diameter of the racetrack cell. Four tuning pins will be fitted at 90^0 from each other, and at 45^0 from the coupler plane.

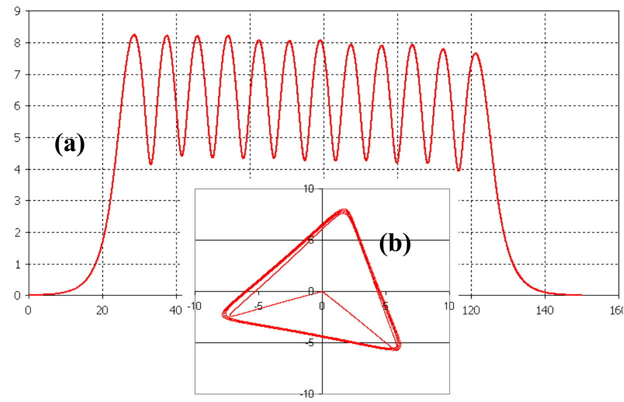

Figure 6: Hx field at 11.9942 GHz for the cavity in Fig. 5(b) (a) amplitude versus length (b) complex field assuming 1 W power at the port.

With a single-feed geometry, which is matched to 10 cells, the on-axis magnetic field distribution is shown in Figure 6. This corresponds to 1 W peak input power and a return loss of −50 dB at 11.9942 GHz. With a peak input power of 13.35 MW, the cavity gives 2.55 MV kick required for 20 mrad crossing angle of the CLIC scheme. The above power level corresponds to a peak surface electric field of 103 MV/m and peak pulsed surface heating of 26 K for 242 ns pulse which are well within the limits set for X-band structures (250 MV/m, 40 K) [4]. Pulsed surface heating on the coupler slot was about 16 K for 0.5 mm rounding of the of the rectangular waveguide iris slot which is reduced to about 10 K with 1 mm rounding.

CONCLUSION

A crab cavity with 12 undamped racetrack cells is considered as the first prototype to be made by and tested at CERN. Preference of standard (compact) coupling to waveguide coupling for the cavity is driven mainly by size and wakefield requirements. A single-feed waveguide coupler is preferred for cold testing the 1st prototype. Less than 15 MW peak power will provide the required crabbing fields, which could easily be drawn from CERN's X-band Klystron.

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