

PROTOTYPE DEVELOPMENT OF THE CLIC CRAB CAVITIES

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Abstract

CERN's Compact linear collider (CLIC) will require two crab cavities to align the beams to provide an effective head-on collision with a 20 mdeg crossing angle at the interaction point. An X-band RF system has been chosen for the crab cavities.

Three prototype cavities have been developed in order to test their high power performance. The first cavity has been made by UK industry, while the second cavity has been made using the same process as the CLIC main linac in order understand potential differences in RF breakdown behaviour between deflecting and accelerating cavities. The third cavity incorporates wake-field-damping waveguides on each cell which will eventually contain RF absorbers. This paper details the design, manufacture and preparation of these cavities for testing and a report on their status.

INTRODUCTION

CLIC [1] will require a set of crab cavities to align the bunches to provide an effective head on collision in the presence of the finite crossing angle. These cavities will be X-band travelling wave dipole structures. While the voltage required is quite small a large group velocity is desired to minimise beam-loading effects. Due to very tight phase specifications (18 mdeg) both structures must be driven by a single klystron without a pulse compressor hence to keep the power required below 15 MW the group velocity is limited to 3% of the speed of light [2].

A programme of prototyping and testing these structures has been undertaken, with three structures currently being manufactured and tested. The first cavity was an early prototype designed to be very similar to the SLAC LCLS deflector [3], and was to be tested at SLAC. The purpose of this cavity was to understand breakdown limits in dipole cavities, with the structure being autopsied (cut apart after testing to inspect damage caused by breakdown). This structure would also be made by UK industry to develop local capabilities. The second cavity was made with the structure geometry chosen for the CLIC crab cavity. This structure would be made in close collaboration with CERN, utilising CERN facilities and expertise to compare results between accelerating and deflecting structures made by the same manufacturer to the same standards. The third cavity also includes the damping waveguides, however they will not be loaded with SiC absorbers, as the purpose of this prototype is to test the breakdown performance of the waveguide loading on the cells.

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CAVITY #1

The first cavity was manufactured by Shakespeare Engineering in the UK. Shakespeare has experience in manufacturing high power RF components but not accelerator cavities hence this cavity was seen as strategically important to build local capability. The structure is fed from the RF source using a dual-fed waveguide coupled through an iris to a TE11-like coupling cavity, which is then coupled to the TM11-like structures. This type of coupler was developed at SLAC for accelerating structures to reduce surface electric and magnetic fields and used in deflectors to reduce unwanted multipole components and mitigate manufacturing risks. A prototype cavity was delivered in 2013, shown in Fig. 1, and its S-parameters were measured. The scattering parameters were found to be very close to simulations. Unfortunately this cavity developed a significant vacuum leak and hence has been returned for repair.

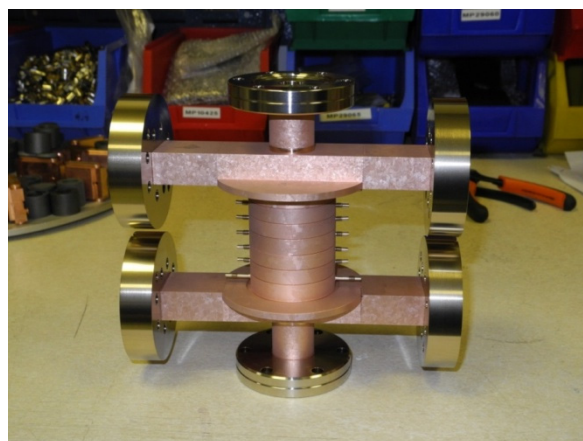


Figure 1: Cavity #1, manufactured by Shakespeare Engineering.

CAVITY #2 DESIGN

The second cavity was designed to use the same cell geometry as the CLIC crab cavity and a similar coupler. Dipole cavities have two polarisations, vertical and horizontal. While the horizontal polarised mode is used for deflecting the vertical polarised mode, the so called same order mode (SOM), can be excited by the beam leading to large unwanted deflections. In order to reduce the effect of this mode on the beam, the highest impedance is designed to be at 13 GHz which is a half integer resonance with the beam. To achieve this without increasing peak surface electric and magnetic fields a racetrack shape is chosen.

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COMPARISON WITH ACCELERATING STRUCTURES

The surface fields for a deflecting cavity is very different from that of an accelerating cavity hence a systematic study of breakdown in a deflecting structure followed by a post-mortem may provide interesting insights into the physics of RF breakdown. While like an accelerating cavity the peak electric field is on the iris, the peak magnetic field is also on the iris. However the peak E and B fields are separated azimuthally around the iris by 90 degrees. This means that the poynting flux is maximised at an azimuthal angle of 45 degrees from the electric field peak, shown in Fig. 2. Microscopic inspection of the damage distribution on the iris, may provide information about the role of the surface RF magnetic field and surface Poynting vector in RF breakdown.

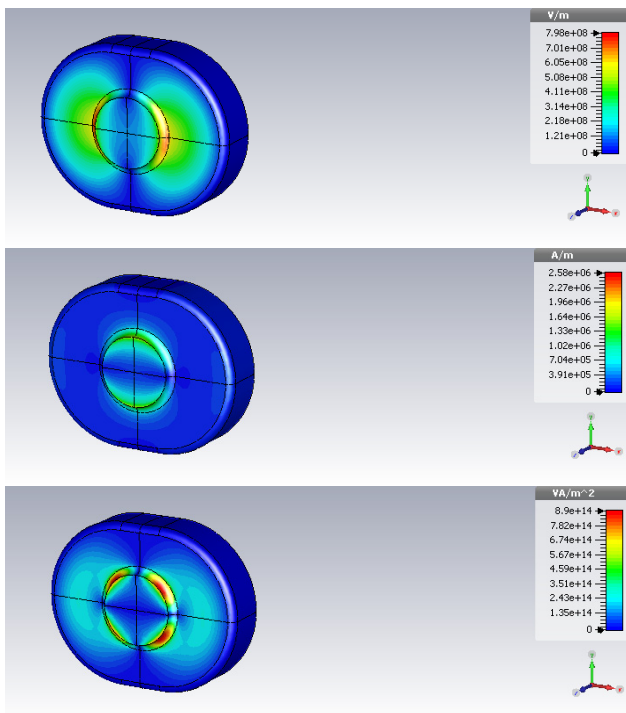


Figure 2: Surface electric (top), magnetic (middle) and Poynting flux (bottom) for the crab cavity.

If we compare two accelerating and deflecting cavities with a 5 mm aperture radius and wall thickness of 2mm we find for the same accelerating/deflecting gradient the deflecting cavity will have a 40% higher peak electric field, and a 130% larger peak magnetic field. This results in a modified poynting vector, Sc [4], that is 2.4 times higher, as shown in Fig. 3. If we compare the two structures at the same peak surface electric field the peak magnetic field is 60% larger and an Sc which is 18% larger.

However a 5mm radius aperture is quite large for an accelerating structure resulting in a group velocity of 7% c as opposed to 2.75 % c for the deflecting structure. If we

compare the crab cavity to an accelerating structure with a group velocity of around 2.75% c (3.7 mm aperture radius), then the peak fields are higher by 56% and 184% for the electric and magnetic fields respectively and Sc is higher by a factor of 4.4. If we again compare for the same peak electric field then both the peak magnetic field and Sc are 80% larger in the crabbing structure. This would mean that a deflecting structure should have a maximum gradient of half that of an accelerating structure. Most deflecting structures operating run at a deflecting voltage of around 25 MV/m which is hence rather conservative.

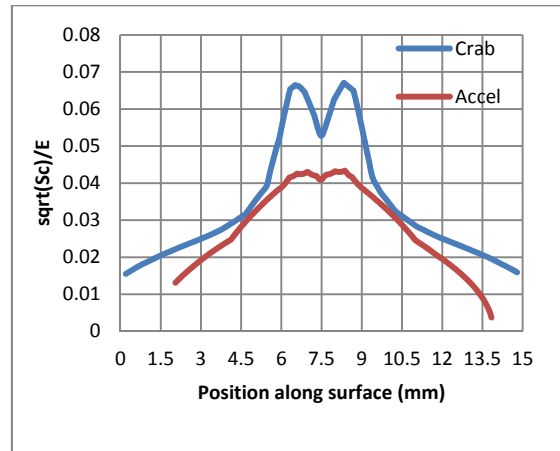


Figure 3: Comparison of \sqrt{Sc} divided by the cavity gradient along the aperture and wall surface for a crab cavity and an accelerating cavity with the same aperture radius and thickness.

MANUFACTURE

Cavity #2 was machined at VDL in the Netherlands. The surface roughness specification was $Ra=24$ nm which was achieved on all cells. Unlike cavity #1 this structure was diffusion bonded rather than brazed, which was performed in Bodycote in France. The final structure is shown in Fig. 4.

TUNING AND MEASUREMENT

The tuning of the 12-cell prototype crab cavity was done in a pragmatic way [5]. Going from the output to the input, firstly a bead-pull measurement was performed, then the electric field pattern (of E_y) was calculated and finally the cell under consideration was tuned via a brazed tuning pin (allowing both, a frequency increase and decrease) while observing ΔS_{11} . Thereafter the bead-pull measurement was repeated and the effect of the performed tuning evaluated. The tuning of each cell was repeated until the electric field pattern was satisfactory.

Subsequently the next cell towards the input was tuned. Occasionally, a cell already tuned had to be revised. After 26 steps the phase advance per cell of all ten regular cells was in average within $120^\circ \pm 0.1^\circ$ and did not vary more than $\pm 1.0^\circ$ over all cells so that the tuning could be finished. The final bead-pull measurement is shown in Fig. 5.

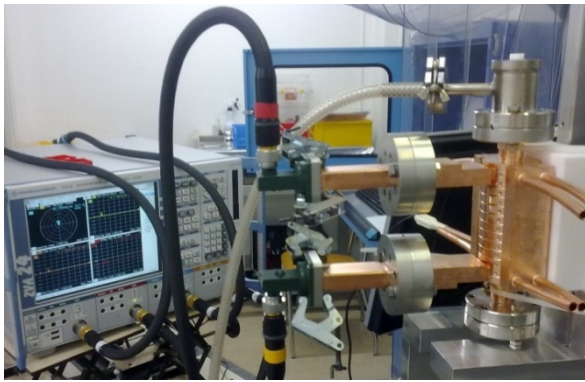


Figure 4: Cavity #2, manufactured by VDL.

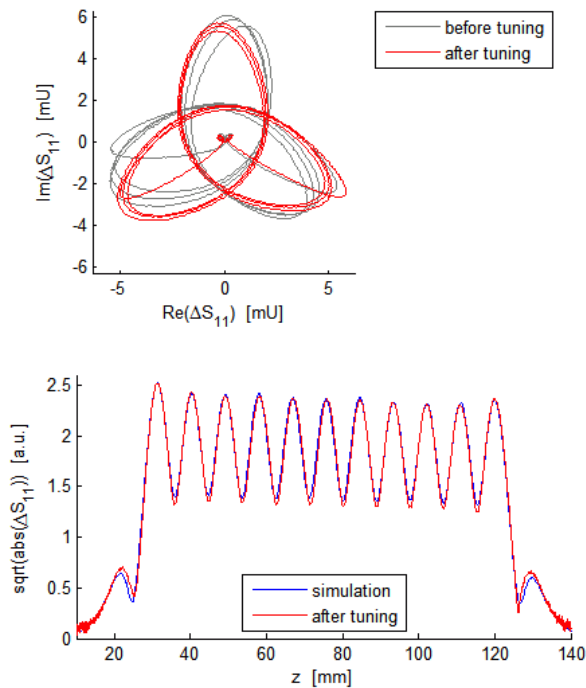


Figure 5: Bead-pull measurement results before (grey) and after (red) tuning compared to simulations (blue).

The cavity will be tested at XBox2 (CERN's high power X-band test station). The test will start without the pulse compressor. The available klystron power is 20 MW which is almost twice the operating power of the cavity. If a steady state breakdown rate cannot be measured up to 20 MW, we will use an rf pulse compressor.

CAVITY #3

To provide damping to the HOMs we add four waveguides to the cavity which will eventually be loaded with RF absorbing material. One complexity with dipole cavities as there also exists, in addition to the SOM, an accelerating mode at a lower frequency than the dipole

mode, known as the lower order mode (LOM). For this reason two of the damping waveguides must have a cut-off frequency below the crabbing mode in order to extract the LOM. These are orientated in the vertical plane so that the crabbing mode doesn't couple to the TE₁₀ mode in the waveguide, however it does couple to the TE₂₀ mode so the width must be carefully chosen. We have selected a width of 22.86 mm which has cut-off frequencies of 6.56 GHz and 13.12 GHz for the TE₁₀ and TE₂₀ modes respectively [6]. The horizontal waveguides have a cut-off at 14 GHz.

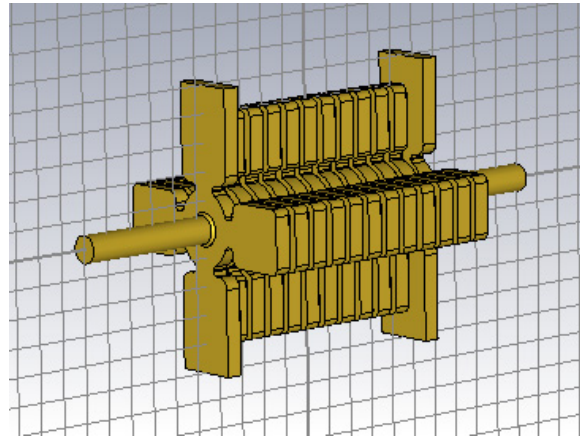


Figure 6: The geometry of cavity #3 with damping waveguides.

Due to the high magnetic and electric fields on the aperture of dipole mode cavities the fields on the equator are far lower. Hence the waveguides do not change the peak fields, shunt impedance or group velocity of the structure greatly and values degrade by less than 5%. The cavity is uses a traditional dual-feed power coupler to symmetrise the fields [7]. The final structure geometry is shown in Fig. 6.

CONCLUSION

Three prototype CLIC crab cavities have been designed and two have been manufactured. We plan to study their breakdown performance and compare it with that of accelerating structures. A dedicated test of a crab cavity structure is due to start at CERN in the coming months.

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