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TESTING AND DRESSED CAVITY DESIGN FOR THE HL-LHC 4R CRAB CAVITY

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Abstract

The High luminosity upgrade to the LHC (HL-LHC) calls for crab cavities to reduce the luminosity loss due to the crossing angle and help provide luminosity levelling. The 4 Rod Crab Cavity (4RCC) is one of three proposed options under consideration. A bare cavity has been prototyped and has undergone recent vertical tests and the results are presented. The dressed cavity includes a power coupler, a lower order mode coupler and three HOM couplers will be presented and discussed.

INTRODUCTION

The LHC luminosity upgrade requires a crab cavity in order to align the proton bunches prior to collision to avoid geometric luminosity loss. In order to get a linear deflection with time a frequency of 400 MHz is required, however there is insufficient space available to fit a 400 MHz pillbox cavity.

A four rod crab cavity has been proposed for HL-LHC. The design utilises four quarter wave resonant sections each in a different quadrant of an outer vacuum can. Each rod has the opposite polarity to both its opposing neighbours.

POP CAVITY TESTS

A prototype cavity was manufactured by Niowave [1] as a proof of principle. The design has narrower rods than the final cavity as it is based on an earlier prototype, though the peak surface fields are roughly equivalent. The cavity was initially designed to have no welds on the rods and they were machined out of bulk niobium, however a manufacturing issue meant that all four rods needed to be remade and welded on to the base-plate.

The cavity has been vertical tested at CERN in their SM18 test facility. The cavity underwent initial testing after a bake, but before final Buffered Chemical Polish (BCP) and reached a transverse gradient of 1.35 MV/m [2].

The cavity then underwent BCP and High pressure rinse (HPR) and was retested. The cavity was found to quickly reach a transverse voltage 3.3 MV (E_{pk}= 37 MV/m, B_{pk}= 65 mT) where it was found to quench. Thermometry and second sound signals identified the quench location to be on the side of one of the rods at the location of one of the welds. An endoscope inspection also found traces of dirt in this region, so another HPR is to be performed before further testing.

The cavity Q_0 was limited by losses on the stainless steel antenna and an accurate measure of residual resistance, R_{res} was not possible; the measurement will now be retaken with the antenna remade from copper and slightly withdrawn to increase the external, Q_e. The final Q versus deflecting voltage curve is shown in Fig 1.

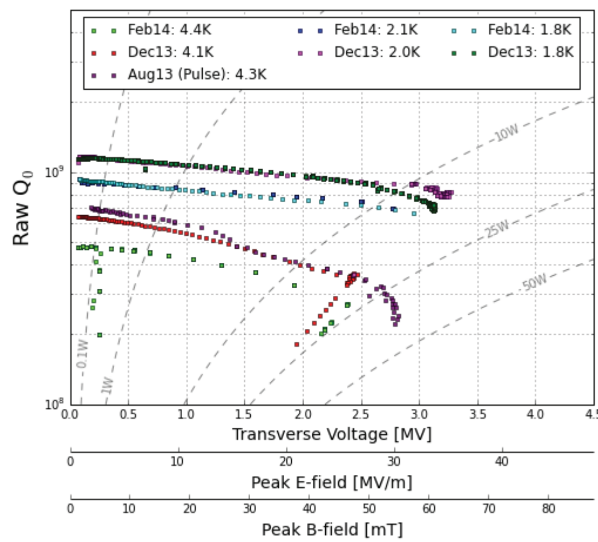

Figure 1: Q versus transverse voltage curve for the vertical test of the 4 rod crab cavity, along with constant power curves.

NEW CAVITY SHAPE

The original cavity shape was found to be very stiff which meant a very large force was needed to tune the cavity. It was found that having a wider cavity reduced the force required so the vertical width of the cavity was increased to 280 mm from 180 mm.

The external Q of the lower order mode (LOM) is strongly dependant on the vertical distance between the rods and the outer can, hence making the can wider requires the rods also become wider, which has the benefit of reducing the R/Q for both the crabbing mode (which was high and hence problematic for beam-loading) and the LOM. The multipole components [3] are also strongly dependant on the rod width and the wider rods were found to have far lower sextupole components of the deflecting mode.

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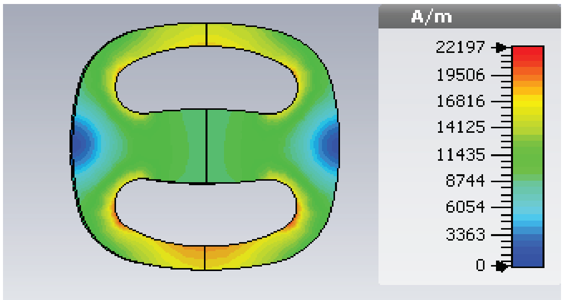

Figure 2: New cavity shape cross-section with the magnetic field amplitude near the base of the rod.

The final cavity shape is shown in Fig 2. The cavity has a peak electric and magnetic field of 32.7 MV/m and 77.5 mT respectively at a voltage of 3.4 MV and a transverse R/Q of 580 Ohms. The new cavity shape is very resilient to Lorentz force with a frequency shift of less than 500 Hz.

POWER COUPLER

The power coupler is electrically coupled and is mounted directly on to the cavity body. The coupler is orientated to come out of the top of the cavity and is slightly offset from the centre so that it faces the tip of one of the rods to increase coupling. CERN have proposed that the cavity is supported via the power coupler, as was proposed for the SPL cavities [4] hence having the coupler roughly central balances the forces on the coupler. As the coupler is far from the cavities magnetic fields the losses on the coupler tip is only 35 W which keeps the temperature of the tip to tolerable levels.

LOM COUPLER

As the 4 rod crab cavity is constructed from four quarter-wavelength long rods there are four different modes close to 400 MHz, two dipole and two monopole modes. One of the monopole modes is at a frequency lower than the crabbing mode, at 370 MHz and has a high R/Q. As this mode is close to the frequency of the crabbing mode and it needs to be damped to a Q_e of around 100, a separate coupler is required to damp this mode. The crabbing mode is rejected using both symmetry and a notch filter. As the crabbing mode is a dipole mode it has no field in the vertical plane, by placing the LOM coupler in the vertical plane it avoids coupling to the crabbing mode. In case of misalignment a notch filter is also used. The coupler is a loop to couple to the high magnetic field in the LOM at the base of the rods. The length of the inner conductor between the filter and the tip of the loop, and the length between the filter and the feed-through are both chosen to increase coupling at 370 MHz. The final coupler is shown in Fig. 3. This coupler was also found to damp all monopole modes up to 2 GHz.

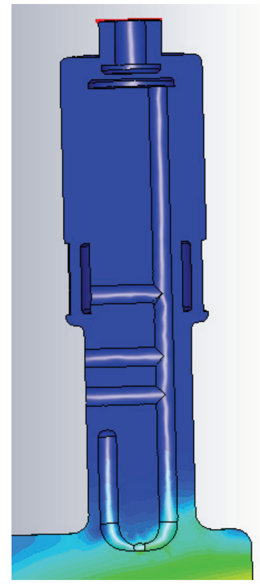

Figure 3: LOM coupler with the magnetic field of the crabbing mode.

As this coupler is placed in a field null of the crabbing mode the RF losses on this coupler is very low. The heat load due to the LOM itself is less than 100 mW.

HOM COUPLERS

The HOM couplers are needed to damp all the dipole modes above 400 MHz. One complication is the dipole mode at 440 MHz. This mode has the longitudinally opposite rods with the same polarity. It was chosen to have three HOM couplers, one for vertical modes, one for horizontal modes and one for the 440 MHz mode. The other option is to damp the 440 MHz mode with the horizontal HOM couplers but the coupler design becomes very complex.

The 440 MHz mode couple is a simple probe with a notch filter to reject the crabbing mode. This coupler would be placed at the longitudinal centre of the cavity so that it does not couple to the crabbing mode but does couple to the 440 MHz mode, so the notch filter is only to protect against coupler misalignment.

The coupler for damping vertical HOMs is a probe type coupler and the coupler for horizontal HOMs is a loop type coupler at the base. Both couplers are mounted on the bottom of the cavity and have right angled bends so the cables run longitudinally due to space limitations. Both couplers have a notch filter created by an annular ring connected to the inner conductor near the tip of the coupler, shown in Fig 4, this shields the flange/gasket from the crabbing modes magnetic fields allowing the couplers to be demountable. This notch filter is used on all four couplers (including the LOM). The HOM couplers incorporate a high-pass filter in the right angled bend in case the notch filters centre frequency is moved during assembly or cool-down.

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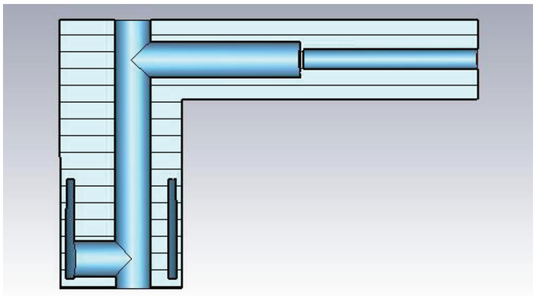

Figure 4: Filter design for the vertical and horizontal HOM couplers.

The combination of all four couplers is found to damp all modes up to 2 GHz to the longitudinal and transverse impedance limits of 2.4 MΩ and 1.5 MΩ/m total over 16 cavities per beam [3].

DRESSED CAVITIES

Figure 5 shows the complexity of the vessel required due to the number and position of ports on the cavities, and the stringent pressure requirements. The dressed cavity has been designed to meet EN13458-2:2002 Cryogenic Vessels – Design, fabrication, inspection and testing. The pressure sensitivity of the stiffened cavity is 18 Hz/mbar. Lorentz force de-tuning of the stiffened cavity at full deflecting voltage (3.4 MV) is only 408 Hz, which is much lower than the other two cavity designs due to the inherently stiff design of the 4-Rod [5].

The design of the helium vessel for the 4-Rod is also optimised to minimise the stress on the coupler ports experienced during tuning. This is achieved by incorporating a novel technique of welding ribs to the cavity which are then also welded to the helium vessel. These ribs then become the fixed points when tuning as opposed to the coupler ports. The ribs can also incorporate fiducial markers to give a positional reference from the electromagnetic centre of the cavity to outer vacuum chamber of the cryomodule.

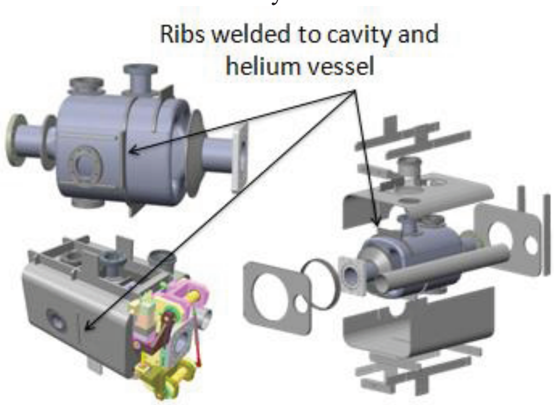

Figure 5: Components of the 4R dressed cavity.

The system uses a modified Saclay II style end lever tuner which has previously been developed as a part of International ERL Cryomodule Collaboration [6]. This tuner has an increased stiffness of 320 kN/mm. Taking 7 kN as the limit for this tuner gives a total tuning range of +188 kHz for the cavity, with the lateral deflection shown in Fig 6. This is more than the required range of ±60 kHz. Stress at end of range is 118 MPa which is well below allowable for Niobium at 2 K.

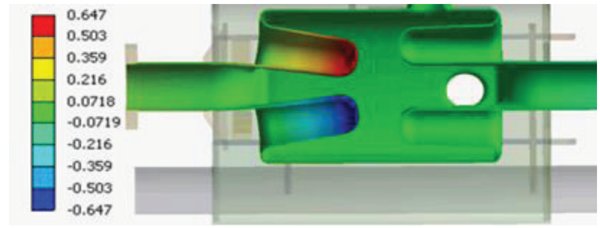

Figure 6: 4-Rod lateral deflection (mm) under 7 kN tuning load.

CONCLUSION

The 4 rod crab cavity is a viable option for HL-LHC. A complete design for the cavity and cryomodule [5] exist which meets all specifications. The filter designs for the HOM couplers result in very low losses on the demountable coupler gaskets.

Initial test results show the cavity is capable of reaching a voltage of 3.3 MV, but was limited by a quench on the welds. Future cavity design would not have a weld on the rods and hence should reach higher gradients.

In addition the cavity is capable of operating at lower frequencies without increasing the transverse size by lengthening the rods. This would allow 200 MHz operation if the LHC were to utilise longer bunch lengths.

ACKNOWLEDGMENT

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REFERENCES

[1] G. Burt, "Manufacture of a compact prototype 4R crab cavity for HL-LHC", IPAC'13, Shanghai, May 2013; http://www.JACoW.org
[2] P. Ambattu, "FIRST TEST RESULTS OF THE 4ROD CRAB CAVITY", IPAC'13, Shanghai, May 2013; http://www.JACoW.org
[3] P. Baudrenghien et al., Functional Specifications of the LHC Prototype Crab Cavity System, CERN-ACC-NOTE-2013-003, 2013.
[4] E. Montesinos, "Conceptual SPL RF Main Power Coupler design", CERN-sLHC-PROJECT-Report-0052.
[5] S. Pattalwar et al., , "Key design features of the crab cavity cryomodule for Hi-Lumi LHC", IPAC 2014, Dresden, Germany.
[6] P.A. McIntosh et al., "Realisation of a prototype superconducting CW Cavity and Cryomodule for Energy recovery", SRF 2007, p545 (2007).