ANALYSIS OF THE FOUR ROD CRAB CAVITY FOR HL-LHC

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Abstract

The Hi-Lumi Upgrade to the LHC will utilise crab cavities to increase the peak luminosity and provide luminosity levelling at the increased crossing angle. A transversely compact design is required to fit within the limited space between opposing beamlines. In this paper, further design work for a four rod TEM deflecting cavity (4RCC) is shown to be suitable for LHC. The variation of the deflecting voltage with radial offset has been minimised by careful design. An aluminium prototype has been constructed and the bead pull measurements are compared to simulations. Multipacting can be a major problem for any RF cavity and simulations have been performed to ensure the shape chosen has a lower chance of strong multipacting, and weak multipacting can be processed through. The final niobium cavity is expected to be held in a helium bath at 2 K, pressure variations can result in deformation of the complex shape which will alter the resonant frequency. Mechanical simulations have been performed to assess the sensitivity of the frequency to cryogenic pressure fluctuations, which are presented. In order to reduce the impact of these cavities on the LHC beam, a low impedance is required for the HOMs as well as the fundamental monopole mode. The couplers for the 4RCC cavity have been optimised to provide effective damping of these modes while rejecting the operating mode.

INTRODUCTION

The LHC high luminosity upgrade (HL-LHC) requires a crossing angle to reduce long-range beam-beam effects. In order to avoid a geometric luminosity loss, the bunches must be rotated prior to collision using special crab cavities [1]. As the transverse space is limited due to the opposing beamline, the cavity transverse dimension must be less than 142 mm radius, which is less than a quarter wavelength at 400 MHz A 4 rod crab cavity has been proposed as a suitable crab cavity for HL-LHC [2]. This cavity confines the RF fields between four longitudinal quarter-wave rods.

ALUMINIUM PROTOTYPE

To verify the electromagnetic fields inside the cavity an aluminium prototype has been manufactured and bead-pull measurements performed to validate the simulations and show that the transverse kick is uniform across the aperture. A 30 mm long, 1 mm diameter metallic needle was chosen as a compromise between the polarisability of the needle, the ability to thread the needle and the averaging effect over the needle length. The effect of the transverse electric and magnetic fields are cancelled by subtracting an on-axis and off-axis measurement, as the transverse fields do not vary significantly over the aperture. The fields were measured by observing the phase shift in the cavity due to the perturbation of the needle. A sample measurement is shown in Figure 1.

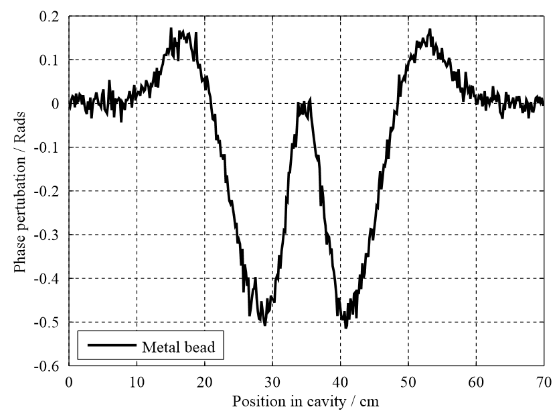

Figure 1: Bead-pull measurement of cavity phase shift versus longitudinal "bead" position

The transverse magnetic field causes an upwards phase shift at the start and end of the cavity, while the two large negative phase shifts are caused by the longitudinal electric field. The transverse electric field on the needle does not perturb the cavity frequency greatly.

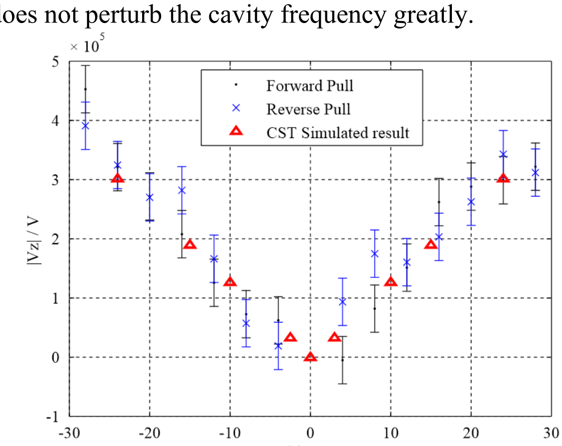

Figure 2: Measured longitudinal voltage at 1 J stored energy from bead-pull versus offset of measurement.

The longitudinal electric field measured can be integrated along the cavity length to measure the longitudinal voltage. The transverse voltage is

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proportional to the transverse gradient of the longitudinal voltage, hence for a uniform transverse voltage the longitudinal voltage should vary linearly with radius. Measurements were performed at various transverse offsets. Figure 2 shows that the longitudinal voltage varies approximately linearly with radial offset, hence the transverse kick will be constant across the aperture and giving excellent agreement with the CST simulations [3].

MULTIPACTOR SIMULATIONS

In order to verify that the cavity will not be limited by multipactor, CST Particle Studio was used to simulate electron dynamics in the RF field, hence simulating multipactor if it is present. Electrons are launched across the cavity surface over a range of RF fields and phases. When the electrons strike a wall, Furman-Pivi models are used to estimate how many secondaries are produced (also including reflected and rediffused electrons) and these secondaries are also tracked in the RF fields. The likelihood of multipactor occurring is estimated by calculating the averaged secondary emission yield, <SEY>, as the total number of secondaries produced divided by the total number of electron impacts. A <SEY> above 1 suggest multipactor may occur, while less than one suggests multipactor is unlikely. Figure 3 shows <SEY> as a function of the transverse voltage of the cavity.

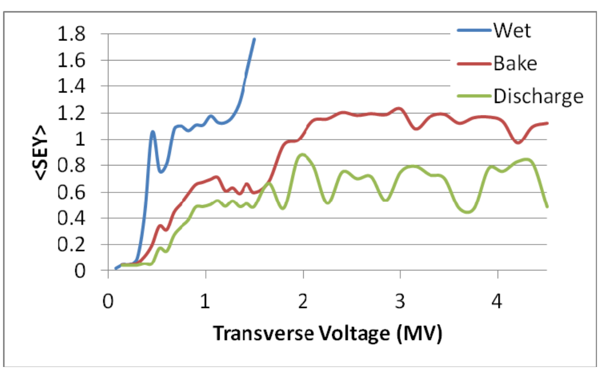

Figure 3: <SEY> versus transverse voltage for three different surface emission models.

Three different secondary models are used in seperate simulations corresponding to different levels of sample cleanliness. This represents multipactor processing as multipactor cleans the surface as it progresses. If a "dirty" sample exhibits multipactor but a "clean" sample does not, it suggests that the multipactor can be processed through and is referred to as a "soft" multipactor barrier. While "soft" barriers are not ideal they do not prevent operation of the cavity beyond that level. "Hard" multipactor barriers occur when multipactor persists on clean samples, and this can limit cavity operation. For the LHC crab cavity, "soft" multipactor barriers were found above 0.5 MV, however no "hard" barriers were found.

PRESSURE SENSITIVITY

Pressure sensitivity of a SRF cavity should be less than 50 Hz/Torr to prevent large frequency shifts due to LHe bath pressure fluctuations. Simulations were performed in Solidworks Simulation Xpress [4] to calculate the deformation of the cavity walls due to changes in pressure. The deformed cavity shape was imported into CST Microwave studio to calculate the change in frequency due to this deformation. The simulations show that the rods themselves do not deform appreciably, while the outer can deforms significantly at the flat section, as can be seen in Figure 4. This wall could be stiffened by introducing bracing along this surface, however this weak point may instead be an ideal location for a tuner.

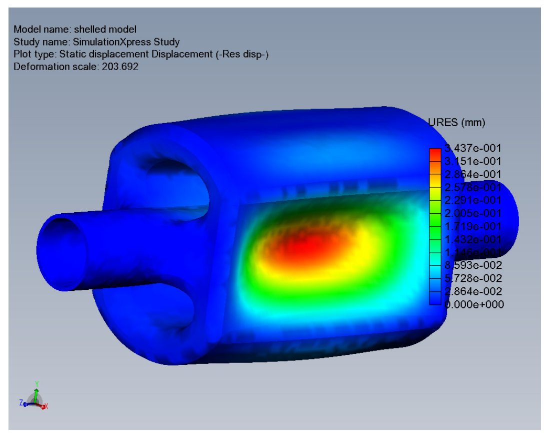

Figure 4: Cavity deformation due to atmospheric pressure difference.

The pressure sensitivity as a function of wall thickness is shown in Figure 5. A wall thickness of at least 4 mm should be used to reduce the pressure sensitivity.

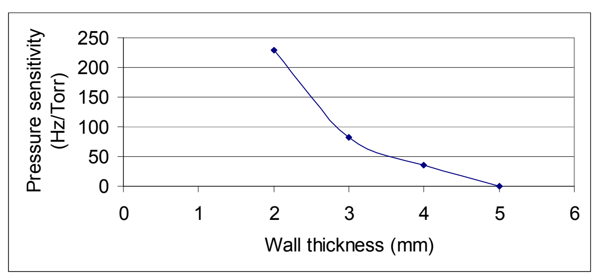

Figure 5: Pressure sensitivity of the cavity versus wall thickness.

LOM COUPLERS

The 4RCC has a monopole like mode at a lower frequency than the operating mode (360-370 MHz), known as the lower order mode (LOM). This mode has a fairly large R/Q and hence must be damped strongly to a Q of around 100. As the fields are fairly low near the beampipe, strong coupling is best achieved with couplers on the cavity body. A loop type LOM coupler is proposed to couple to the high magnetic fields of the LOM on the cavity baseplate equator at the location of zero field in the operating mode.

NIOBIUM PROTOTYPE

A Niobium prototype has been manufactured by Niowave inc (USA). Due to the complexity of the e-beam weld required if the rods were to be deep drawn, it was decided to machine the rods and baseplate from a solid Niobium ingot. To reduce the amount of material required the rods are designed to interleave allowing both baseplates to be cut via a wire EDM process from a single ingot (RRR>200), as shown in Figure 6.

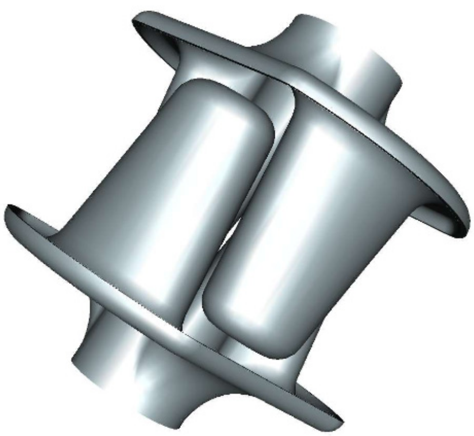

Figure 6:. Interlaced rods during wire EDM of the baseplate from Nb ingot.

The cavity was chosen to have a 4 mm wall thickness at the cavity body. Three coupler ports are pulledout from the cavity body to allow better access for the cavity for high pressure rinse purposes. All three ports correspond to the current locations of the LOM, HOM and input couplers in the cavity. Simulations show that the losses on the flanges of these ports are acceptable compared to the ohmic Q of the cavity. The manufactured cavity can be seen in Figure 7.

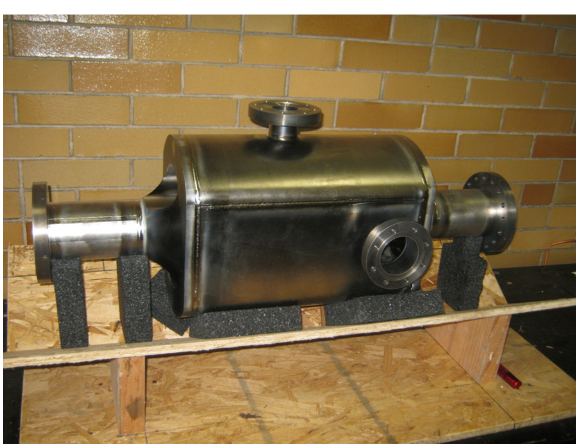

Figure 7: Manufactured Niobium cavity at Niowave.

CONCLUSIONS

A 4RCC has been manufactured in both Aluminium and Niobium. The aluminium cavity measurements verify that the deflecting field is uniform across the cavity aperture.

The Niobium prototype has been manufactured by Niowave .and simulations show that the cavity is unlikely to be limited by "hard" multipactor barriers. Processing of this cavity is due to commence shortly and testing will take place later this year.

ACKNOWLEDGEMENTS

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