ESS MEDIUM BETA CAVITY PROTOTYPES MANUFACTURING

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Abstract

The ESS elliptical superconducting Linac consists of two types of 704.42 MHz cavities, medium and high beta, to accelerate the beam from 216 MeV (spoke cavity Linac) up to the final energy at 2 GeV. The last Linac optimization, called Optimus+, has been carried out taking into account the limitations of SRF cavity performance (field emission). The medium and high-beta parts of the Linac are composed of 36 and 84 elliptical cavities, with geometrical beta values of 0.67 and 0.86 respectively. We describe here the procedures and numerical analysis leading from half-cells to a complete medium cavity assembly, which take into account not only the frequency of the fundamental accelerating mode but also the higher order modes near the machine line. The half-cell selection process to form dumb bells will be described, as well as the reshaping and trimming procedure.

INTRODUCTION

ESS [1] aim to be the most powerful neutron spallation source. It will be equipped with a 5MW proton linear accelerator [2] composed by a 50m long warm section (up to 90MeV of energy) and a 312m long cold section to reach 2GeV. In the cold section will be inserted spoke cavities and elliptical cavities, the former operating at 352.2MHz the latter at 704.4MHz. The elliptical cavities are present in two different families, one installed just after the spoke cavities section and designed to operate with proton at β=0.67 (medium beta) followed by a second group designed to operate at β=0.86 (high beta).

In this paper we will focus on the manufacturing of the medium beta cavities as designed to be installed in the Elliptical Cavities Cryomodule Technology Demonstrator (M-ECCTD) [3]. We are currently manufacturing 6 medium beta cavities, 4 of them will be installed in the cryomodule demonstrator.

Figure 1 shows a 3D drawing of the medium beta cavity model housed in the helium tank. The cavity has 6 cells, with two specific geometries, one for the central part (5 dumbbells) and one for the end groups. In table 1 are shown parameters relative to the designed cavity parameters obtained from RF calculations (COMSOL).

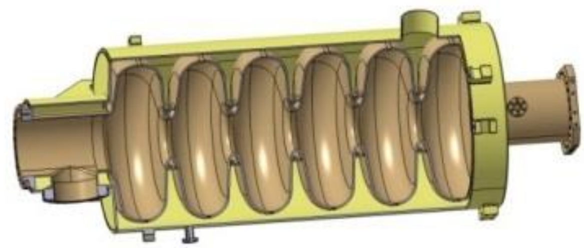

Figure 1: Medium beta elliptical cavity with helium tank.

Table 1: Medium Beta Cavity Design Parameters

Parameter	Value
Frequency	704.4 MHz
Length	1258.8 mm
# of dumbbells	5
Dumbbells length	142.8 mm
DB Trimming sensitivity	907 KHz/mm
Cavity tuning sensitivity	211 KHz/mm
Cell to cell coupling	1.2%

DIMENSIONAL & RF MEASUREMENTS SETUP

During the manufacturing the cavity components were controlled at each production step, from half cells to the complete cavity. Inspections are carried out by means of a 3D coordinates measuring machine (CMM) and RF measurements as shown in figure 2 and 3.

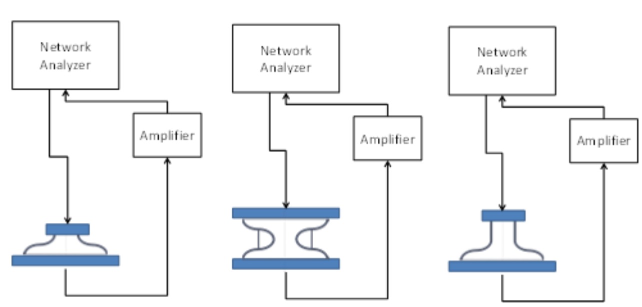

Figure 2: RF measurements set up scheme.

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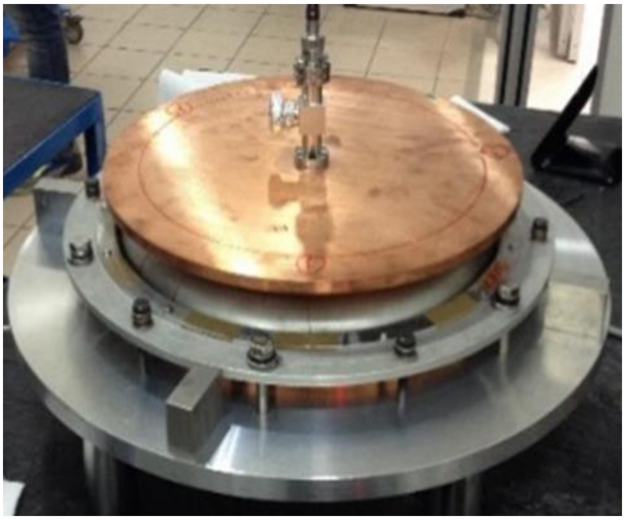
Figure 3: RF measurements system (on half cell).

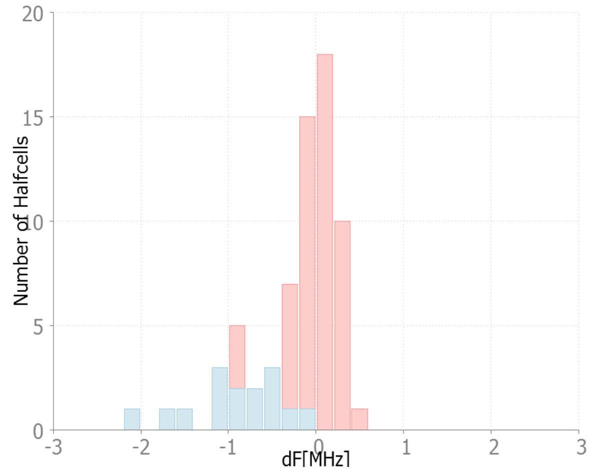

Figure 4: 0-mode frequency shift between design value and measure on central halfcells (red) and end group (blue), each bin has 0.2MHz width.

The RF measurements system is equipped with two copper plates machined to have a planarity in the range of 0.1mm. This equipment is used up to the dumbbell trimming before welding. Then Niobium plates are substituted to avoid any contamination on the contact surface. This system is used for measuring halfcells, dumbbells and end groups, the antenna penetration being optimized to reduce perturbation while keeping a good signal to noise ratio.

EXPERIMENTAL RESULTS

HALF CELLS MANUFACTURING

A total of 73 half cells (60 central shape and 13 end groups shape) were manufactured by deep drawing process from 4.5mm high purity Niobium sheet (RRR>250). Each halfcell is manufactured with extra length at iris and equator side. The extra material is removed during the trimming and welding processes.

RF and 3D Measurements

In figure 4 are shown the RF measurement results compared with the expectation value from design. The central half cells are grouped around the design value with a bandwidth of 500kHz. On the other hand the end group half cells are shifted to lower frequency about 1MHz. Only 13 cells have been manufactured, reducing the statistical significance.

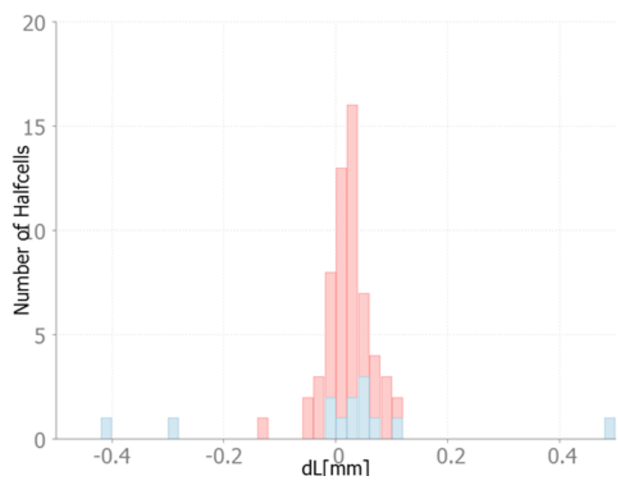

Figure 5: Length difference between simulated and measured values on central group (red) and end group (blue) halfcells, each bin has 0.02mm width.

The length difference (figure 5) among the central cells has a FWHM about 0.1mm, while for the end groups the distribution is less uniform. The measured length show a good agreement with the design value and good reproducibility. In figure 6 is shown a result from the 3D CMM apparatus, relative to a central half cell.

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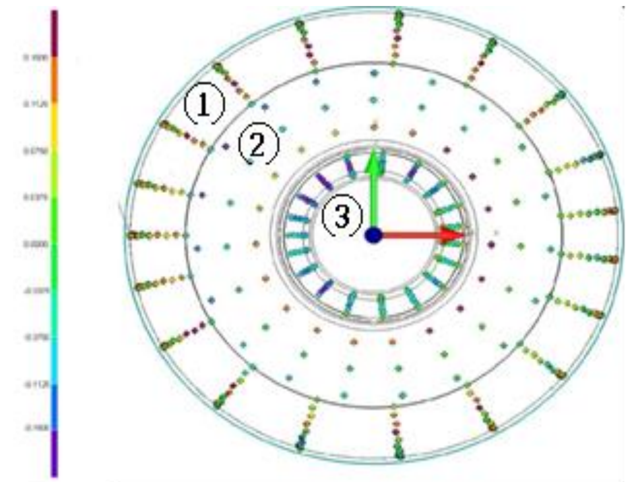

Figure 6: 3D CMM result on a central half cell, red +0.15mm, purple -0.15mm.

The data in figure 6 are obtained just after the deep drawing process. The required tolerance is 0.3mm on shape, whereas the real shape shall be within ±0.15mm the design value. On average we observe a deformation pattern depicted (not in scale) in figure 7.

More precisely we observe an expansion near the equatorial region (1), a change in the angle of the lateral wall (2) and a reduction in the iris diameter (3).

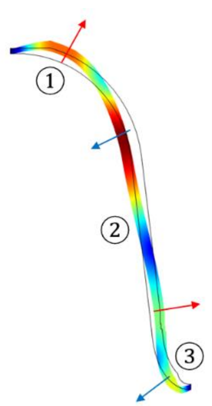

Figure 7: Scheme of average deformation observed on central half cell (not in scale).

Half Cells Coupling

We decide to assemble dumbbells from halfcells with similar geometry and frequency. The expected frequency on the dumbbell is estimated by using (1) from [4].

$$f_{DB}^2 = \frac{1}{2}(f_a^2 + f_b^2) - K f_0^2 \pm \sqrt{\frac{1}{4}(f_a^2 - f_b^2)^2 + K^2 f_0^4} \quad (1)$$

Where f_a and f_b are the frequency of the halfcells, K is the coupling factor, f_{DB} is the frequency of the dumbbells and f_0 is the design value. The plus sign is to compute the π-mode and the minus for the 0-mode. From (1) it is possible to evaluate that the frequency shift on the dumbbell is minimum when the frequency shift on the two halfcells have the same magnitude and opposite sign.

DUMBBELLS MANUFACTURING

Dumbbells are formed by joining two halfcells with an electron beam welding on the iris region, subsequently also the stiffener ring was welded by means of electron beam.

Figure 8: Dumbbells after welding in the control area.

RF and 3D Measurements

The RF measurements are performed using copper plates, the average Q0 was about 5000. The frequency spreading (FWHM) has the same magnitude as in the halfcells measure (~400 KHz). In figure 9 are shown the 0-mode and π-mode frequencies distribution for all the dumbbells (30).

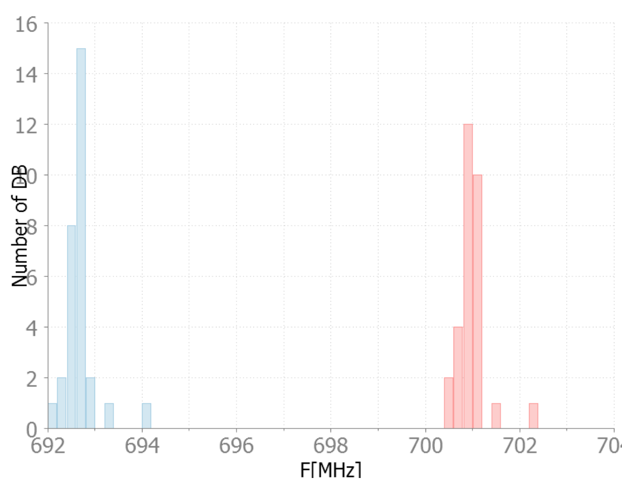

Figure 9: Dumbbells RF measurements for 0-mode (blue) and π-mode (red). Each bin has 0.2MHz width.

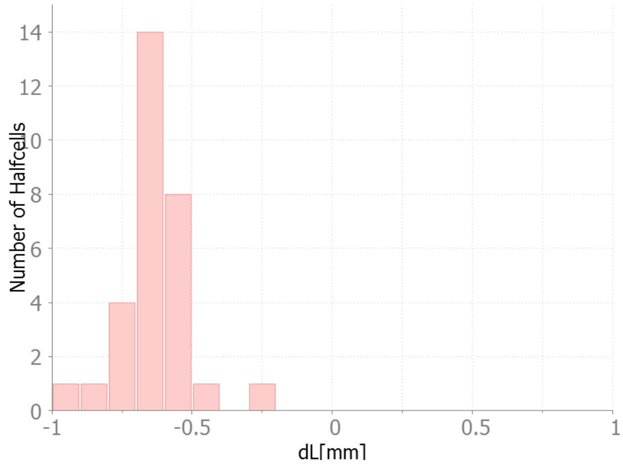

Figure 10: Dumbbells length difference with design value, each bin has 0.1mm width. Measure performed after welding and reshaping.

In figure 10 is reported the distribution of lengths as differences between manufactured and design values for dumbbells. The average value is about -0.6mm and the FWHM is about 0.2mm. It is possible that the reshaping process pressed too much the dumbbells resulting in a shorter total length.

Finally in figure 11 is shown a result from 3D CMM for a dumbbell after the welding of iris, stiffener ring and reshaping.

The average deformation on the dumbbells has the same magnitude and location as the halfcells. In particular the top part of the cell wall is displaced inside the cell by an average value of 0.24mm. This value will be relevant for 5th harmonic HOM mode frequency, more details can be found in the appendix.

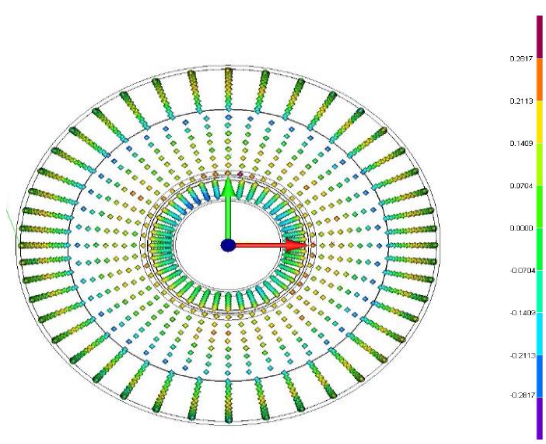

Figure 11: Dumbbells upper cell 3D measure, red +0.28mm, purple -0.28mm.

Trimming Strategy

The trimming process allows to shorten the dumbbells and consequently rises their frequency. The final goal is to obtain a cavity with the designed length and π-mode frequency. Our strategy is to trim each dumbbells taking into account the welding shrinkage and the cavity tuning sensitivity. We plan to obtain a dumbbells with an intermediate length and frequency that will lay on the cavity tuning curve as shown in figure 12. The starting distribution is spread in length and frequency (red dots) while the expected length and frequency after trim and weld shrinkage (blue dots) lay on a line.

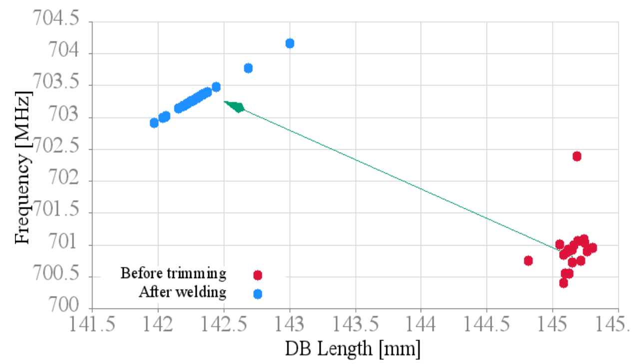

Figure 12: Dumbbells length and π-mode frequency before trimming as measured (red dots) and computed values with trim and weld shrinkage (blue dots).

In figure 13 is shown the expected evolution of π-mode frequency at different manufacturing stages. The red histogram is the starting distribution as measured after iris and stiffener ring welding, the blue one represents the computed value just after the trimming operation and the green one corresponds to the expected value taking into account the welding shrinkage. The distance between the green histogram and the vertical red line (target frequency) will be recovered by cavity tuning.

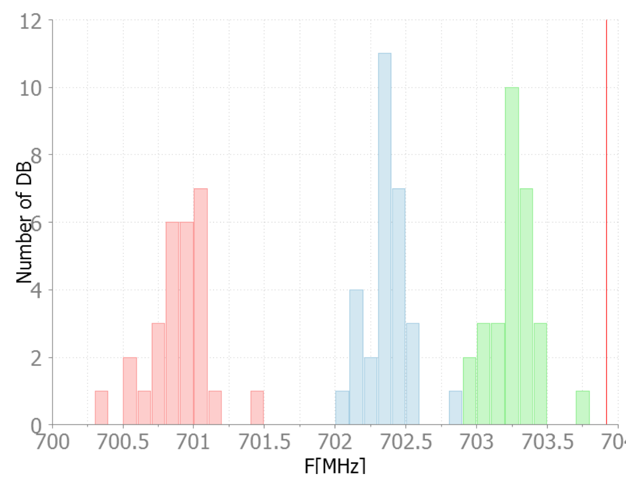

Figure 13: Dumbbells π-mode frequency evolution from welding (red), trimming (blue) and trimming+welding shrinkage (green). The vertical red line corresponds to the target value.

Dumbbells Selection for 1st Cavity

For the first prototype we decide to select 5 dumbbells having similar frequencies (ΔF~200 KHz). At the centre

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of the cavity will be placed the dumbbells with less deformation on the top part of the wall (~0.2 mm) in order to mitigate the increase on HOM frequency (appendix).

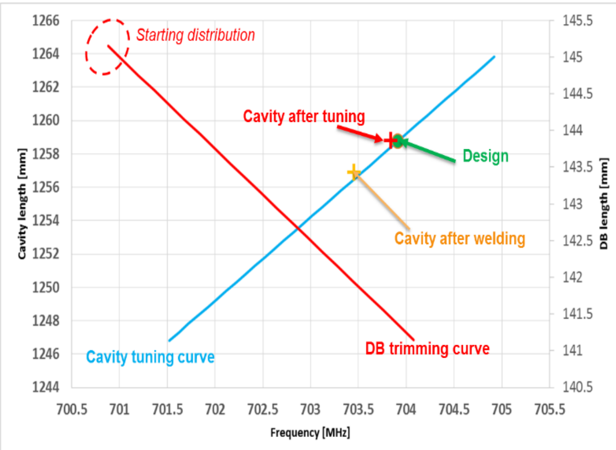

Figure 14: Dumbbells and cavity length vs. frequency plot. Red line represents the dumbbell trimming curve, blue line the cavity tuning curve, the yellow cross represents the expected value for the 1st manufactured cavity just after welding, red cross after tuning and the green dot the design value.

In figure 14 is shown the length and frequency plot for dumbbells and cavity. The dumbbell trimming curve (red line) has been obtained by RF measurements during trimming, the tuning curve has been computed with an FEM model with a coupling between RF and mechanical system. For the first cavity we expect to obtain the length and frequency corresponding to the yellow cross just after welding, the red cross represents the expectation value after tuning while the green dot is the design value.

SUMMARY

Six medium beta cavities will be manufactured for the Elliptical Cavities Cryomodule Technology Demonstrator, we expect to be able to test the first bare cavity by the end of October 2015. CEA puts in place a detailed test procedure in order to inspect, by means of RF and dimensional measurements, all the cavity subcomponents at different manufacturing steps. The subcomponents are manufactured reliably close to the designed values. A specific plan for dumbbells trimming and cavity tuning has been studied by means of RF measurements and computations.

APPENDIX

HOM Near to 5th Harmonic

The ESS specification for elliptical cavity requires that the minimum distance, in frequency, between cavity's HOM and machine line should be at least 5MHz [5]. The medium beta cavity has been designed with the closest HOM at 11MHz from the machine line at 1761.05 MHz .

Nevertheless from the experience gathered during the first high beta cavity prototype [3] we learned that it is necessary to be careful about even small systematic shape errors, especially in the region that can strongly influence the HOM frequency.

Specifically in the medium beta cavity the closest mode is the $\pi/6$ of the 3rd passband, this mode has a strong EM field in the two central cells (figure 15).

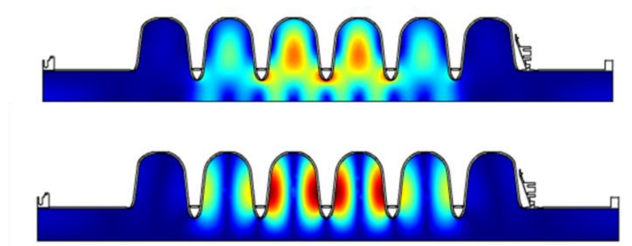

Figure 15: Electric field (above) and Magnetic field (below) for $\pi/6$ mode for HOM 3rd passband.

Using Slater perturbation theory it is possible to determine that the HOM mode frequency can be increased by moving the cell wall toward the inside of the cavity. The most sensitive region is coloured in red in figure 16.

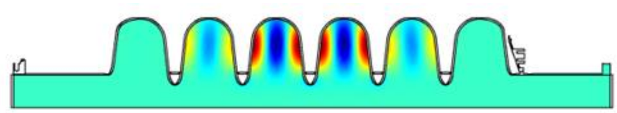

Figure 16: Medium beta cavity, computation of Slater perturbation on $\pi/6$ mode for HOM 3rd passband.

In figure 16 it can be seen that the $\pi/6$ mode is more sensitivity to deformation in the wall upper part of the two central cells (red region). For this reason we plan to allocate the best dumbbells, in terms of wall deformation, in the centre of the cavity.

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