INVESTIGATION OF HOM FREQUENCY SHIFTS INDUCED BY MECHANICAL TOLERANCES

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Abstract

We present Higher Order Mode (HOM) studies on ESS Medium-Beta cavity, designed in INFN-LASA, including both simulation and measurement results. Mechanical tolerances of the fabrication process might shift HOMs frequencies toward harmonics of the bunch frequency. Both simulation and measurements at room and cryogenic temperature show that the design is fully compatible to requirements.

INTRODUCTION

As a first step in the ESS cavity fabrication, Nb sheets are shaped using deep drawing to half-cells. Couple of half-cells are then welded at the iris to form dumbbells. The dumbbells and the end-groups, after proper trimming to reach required length and frequency, are welded together at equator to form the 6-cell cavity. Even if the cavity fabrication process is a precise procedure, tolerances in the order of 0.2 mm in deep drawing shaping and 0.1 mm in length are inevitable for an industrial fabrication, to keep the cavity price low. Based on the above mentioned cavity fabrication process and existing tolerances, it is unavoidable to have some frequency spread in cavity fundamental mode and HOMs. After cavity fabrication, accelerating mode frequency and its respective E-field profile is tuned by means of bead-pull measurement and stretching or squeezing cavity cells individually. As it will be reported later in this article, variation in geometrical parameters of cavity cells from their nominal value have different effect on accelerating mode and on HOMs and, for some geometrical parameters, the effect on HOM and fundamental mode frequency are opposite.

To fulfill the performance requirements of the ESS, the medium beta (MB) cavity should be designed such that all cavity HOMs are at least 5 MHz away from machine lines. If a monopole mode is resonantly excited by lying on a machine line, the induced voltage can degrade the beam quality and also increase the cryogenic losses. The ESS elliptical cavities have no HOM damping antenna so, for a reliable machine operation, it is mandatory to have a cavity design where HOMs are not only away from machine lines by design but also where the fabrication tolerances will not shift HOMs near to these lines. HOM study on LASA design for ESS MB cavity [1] is performed using HFSS [2]. Table 1 shows nominal frequencies of the 5π/6 mode (of the first cavity passband), accelerating mode and the closest cavity modes to ESS machine lines which have probability of being trapped inside the cavity. The most possible dangerous HOM is a monopole mode of 3rd passband which ideally it is supposed to be in 1742.5 MHz, 19MHz away from 5th machine line.

Table 1. Cavity HOMs Close to Machine Lines

FREQUENCY (MHZ)	**COMMENTS**
703.61	>0.8 MHz from accelerating mode
704.42	Accelerating mode
1029.6	>26MHz from 3rd machine line, Dipole mode
1376.7	>32MHz from 4th machine line, Quadrupole mode
1742.5	>19MHz from 5th machine line, Monopole mode

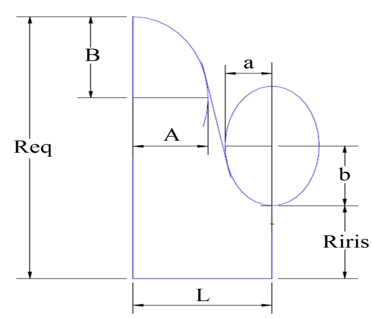

Figure 1: Schematic of 7 independent geometrical dimension in an elliptical cavity.

Table 2: Frequency Shift of 1st and 3rd Modes in a Single Cell Elliptical Cavity

	1st monopole band (MHz / mm)	**3rd monopole band (MHz / mm)**
A	-3.2	-18
B	0.9	2.7
L	2.2	-8.1
a	-2.3	7.3
b	0.4	-0.5
Req	-4.3	-3.1
Riris	1.4	1.3

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CELL FREQUENCY SENSITIVITY

As mentioned before, shift in the HOM frequencies of the 6-cell cavity is inevitable. In order to prevent confluence of the 1742 MHz monopole HOM with 5th machine line, it is important to know the possible frequency shift of this HOM due to mechanical tolerances during cavity fabrication process. To achieve this goal, in the first stage of this investigation a single cell elliptical cavity is explored through possible changes in its fundamental mode and third mode due to mechanical tolerances then in the second stage the 6-cell cavity, based on INFN-LASA design [1], is investigated through possible variations of the 1742 MHz mode.

In the first assessment stage for a single cell elliptical cavity, each of its 7 independent geometrical parameters (shown in Fig. 1) are changed to evaluate their effect on the frequency shift of the 1st and 3rd modes. In each step of frequency sensitivity evaluation just one of the 7 geometrical dimensions is altered and others are kept fixed. Based on performed simulation results, the frequency shift to the geometrical parameters are linear, results are summarized in Table 2. As it is clear from the results, parameter A has the most significant effect on 3rd mode frequency change and for some geometries (L, a, b) the direction of frequency change for the 1st and 3rd modes are in opposite, in agreement with results reported in [3].

The individually stretching or squeezing of cavity cells, to have a flat E-field profile and proper accelerating frequency, is a significant tool to compensate mechanical tolerances effect on multi cell elliptical cavities. In the 6-cell cavity, there are large numbers of degrees of freedom in the geometry of the full structure so it is important to provide few routines to simplify the full structure assessment. To provide a routine to assess frequency change of the 1742 MHz mode due to errors in different geometrical parameters of the 6-cell cavity, at first the error is inserted in one of the independent geometrical dimensions, except L, of a single cell elliptical cavity illustrated in Fig. 1. As each dimensional error will lead to some change in accelerating mode frequency of the single cell, as a second step the single cell is tuned back to 704.42 MHz just by tuning its length and none of other geometrical parameters are altered, similar to the squeezing or stretching cells by real tuning machine. In the third step the single cell cavity generated in the previous step is placed as the first cell of the 6-cell cavity and the other 5 cells of the cavity remain the same. Even if the mechanical error is in the first cell, this cell has been then tuned back to the nominal frequency and the new 6 cell cavity has no significant change in its accelerating mode frequency and in its respective E-filed profile on cavity axis (as verified by simulation). Also accelerating mode is still on its nominal frequency but inserted error in the first cell will show its effect in frequency change of cavity HOMs. As our focus in this paper is on frequency change of 1742 MHz mode, by this procedure we are considering frequency change of this mode due to the above mentioned error inserted in the first cell by considering cavity length tuning, an operation that is performed typically on multi cell elliptical cavities. As the next step, changing position of the modified cell with other cells of the 6-cell cavity will give us the amount of frequency change of the 1742 MHz mode due to the considered mechanical error by each cell of cavity. This process is performed for all the geometrical dimensions illustrated in Fig. 1, except L.

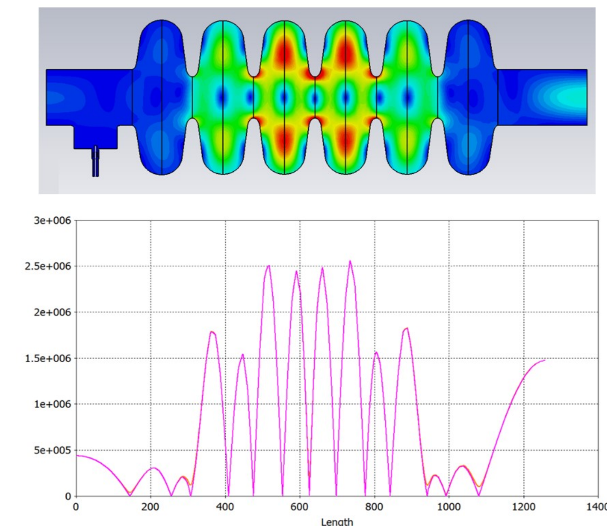

Figure 2: (Upper) simulated E-field concentration in cavity for mode at 1742 MHz; (lower) its simulated E-field profile on cavity axis.

Table 3: 6-Cell Cavity 3rd Passband Monopole HOM Frequency Shift vs. Errors in Cavity Geometry (kHz/mm)

	cell 1	cell 2	cell 3	cell 4	cell 5	cell 6
R_{eq}	-40	-3300	-7200	-7300	-3500	-100
R_{iris}	80	940	2100	2100	1000	100
A	-150	-2800	-7800	-8000	-3000	-290
B	50	960	2200	2200	1000	70
a	-35	-190	-400	-400	-200	-40
b	20	110	250	250	120	30

Because the 1742 MHz mode E-field distribution in different cells is not uniform, we expect that any non-conformity will produce different frequency shifts in different cells. Fig. 2 shows simulated E-field profile on cavity axis for the 1742 MHz mode compared with the field distribution in cavity cells. Based on this, most of E-field concentration is on 3rd and 4th cells so mechanical errors on these two cells will have the strongest effect on the 1742 MHz mode frequency change. There is not much field in 1st and 6th cells so mechanical errors on these two cells will have the weakest effect. Table 3 shows the 1742 MHz mode frequency shift based on different geometrical errors that might happen in each of cavity cells separately. Considering 0.2 mm shape tolerance on

A, B, a, b and 0.1 mm error on R_{eq}, R_{iris} and adding the numbers in table 3 as absolute values, the 1742 MHz monopole mode frequency shift is less than 9 MHz.

HOM MEASUREMENT RESULTS

Two 6-cell cavities prototypes have been fabricated using INFN-LASA design with fine grain (FG) and large grain (LG) [4] Nb material, before starting the series production of 36 MB cavities as part of Italian in kind contribution to ESS project. In this section measurement results related to 1742 MHz HOM of FG cavity is presented. Measurements related to LG cavity are still under investigation.

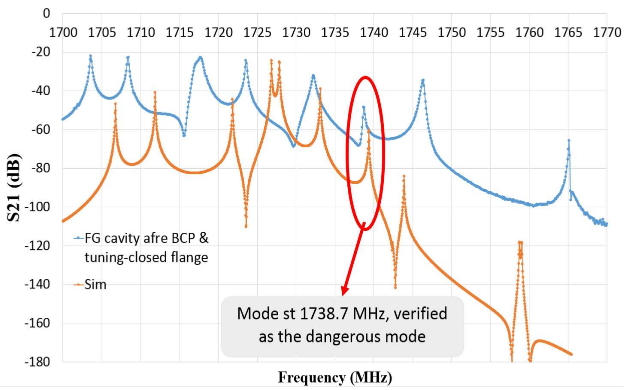

Figure 3: Simulation and measurement result comparison around 5th machine line at 300 K.

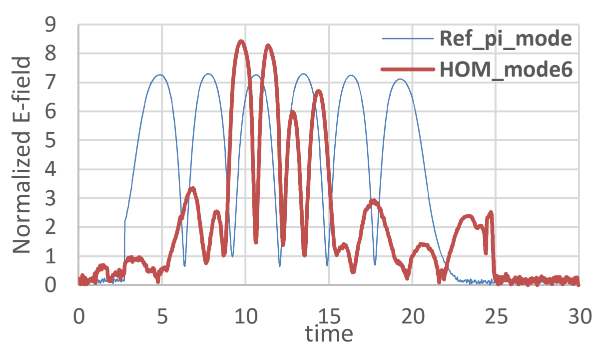

Figure 4: E-Field profile measured on cavity axis by bead-pulling for mode at 1738.7MHz at 300 K.

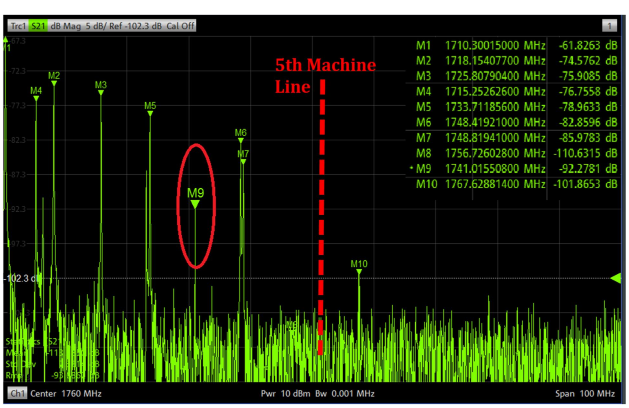

Figure 5: 6-cell cavity with FG Nb HOM measurement result at 2K with tank around 5th machine line.

HOM tracking is performed in different steps of cavity fabrication process. Fig. 3 shows S21 Simulation and measurement comparison around 5th machine line at 300 K. The red ellipse shows the spectral lines of the monopole verified as dangerous mode. The axis field profile taken via bead pull measurement, confirms that this is the trapped mode under investigation. Fig. 4 shows E-Field measurement on cavity axis by bead-pulling for this HOM mode at 300 K. Fig. 4 also illustrates comparison between the measured HOM E-field profile with the nominal accelerating mode E-field on axis, in order to better understand to which cell the measured HOM E-field peaks belong. It is possible to conclude that the detected HOM is the dangerous one and as it is expected there is E-field concentration in 3rd and 4th cells. Fig. 5 shows HOM measurement results for the 6-cell cavity at 2 K and with tank around 5th machine line. In wide band spectrum the dangerous HOM is distinguished by a red ellipse. In Fig. 5 there are three other modes around 5th machine line which are closer to machine line than distinguished mode with red ellipse but they are not monopole modes and based on simulation results will not trap inside the cavity. There is less than 1.5 MHz frequency change between simulation and measurement results and this mode is measured to be 20 MHz far from 5th machine line.

CONCLUSION

Construction and measurement process of a FG 6-cell cavity is performed by INFN-LASA as a prototype for the in kind contribution to ESS. After detection of the possible dangerous HOM which has the highest probability to overlap with machine lines, the dangerous HOM frequency shift is assessed. It is illustrated that the HOM will not lead to instability grows based on considered 19 MHz frequency difference between the 1742 MHz HOM and closest machine line in cavity design. HOM study revealed that accepted mechanical tolerances for cavity fabrication will lead to less than 9 MHz frequency change in worst case.

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