MODELING IMPERFECTION EFFECTS ON DIPOLE MODES IN TESLA CAVITY*

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Abstract

The actual cell shapes of the TESLA cavities differ from the ideal due to fabrication errors, the addition of stiffening rings and the frequency tuning process. Cavity imperfection shifts the dipole mode frequencies and alters the Qext's from those computed for the ideal cavity. Qext increase could be problematic if its value exceeds the limit required for ILC beam stability. To study these effects, a cavity imperfection model was established using a mesh distortion method. The eigensolver Omega3P was then used to find the critical dimensions that contribute to the Qext spread and frequency shift by comparing predictions to TESLA cavity measurement data. Using the imperfection parameters obtained from these studies, fiducial cavity imperfection models are generated for the studies of wakefields.

INTRODUCTION

In the production process of the TESLA TDR cavity (as shown in Figure 1), half-cells are normally built with a few tens of microns longer at the equator than the designed dimension. Two half-cells are then electron-beam welded at the iris to form a "dumbbell". To ensure same frequency for the two half-cells, trimming at the equator is required before the welding of the stiffening ring. The stiffening ring causes deformation of the dumbbell disk which results in frequency change of the cell. To compensate for the deformation, each half-cell has to be stretched by a similar amount near the dumbbell top. Eight dumbbells and the end-groups are assembled to complete the TESLA 9-cell cavity. In the final step, the 9-cell cavity will be tuned slightly for the correct operating mode frequency and the field flatness [1-2].

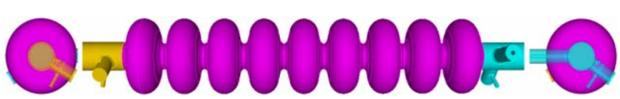

Figure 1: The model of the TESLA TDR cavity.

The actual cell shapes of the TESLA cavities differ from the ideal one due to fabrication errors, welding of the stiffening rings and the frequency tuning process for the operating mode. This procedure will also affect the dipole mode properties. It is found from simulation using Omega3P that the calculated dipole mode spectrum assuming an ideal cavity differs from measurements. For example, Figure 2 shows the comparison of the spectrum for the first two dipole bands with measurements from the TTF module 5 [3].

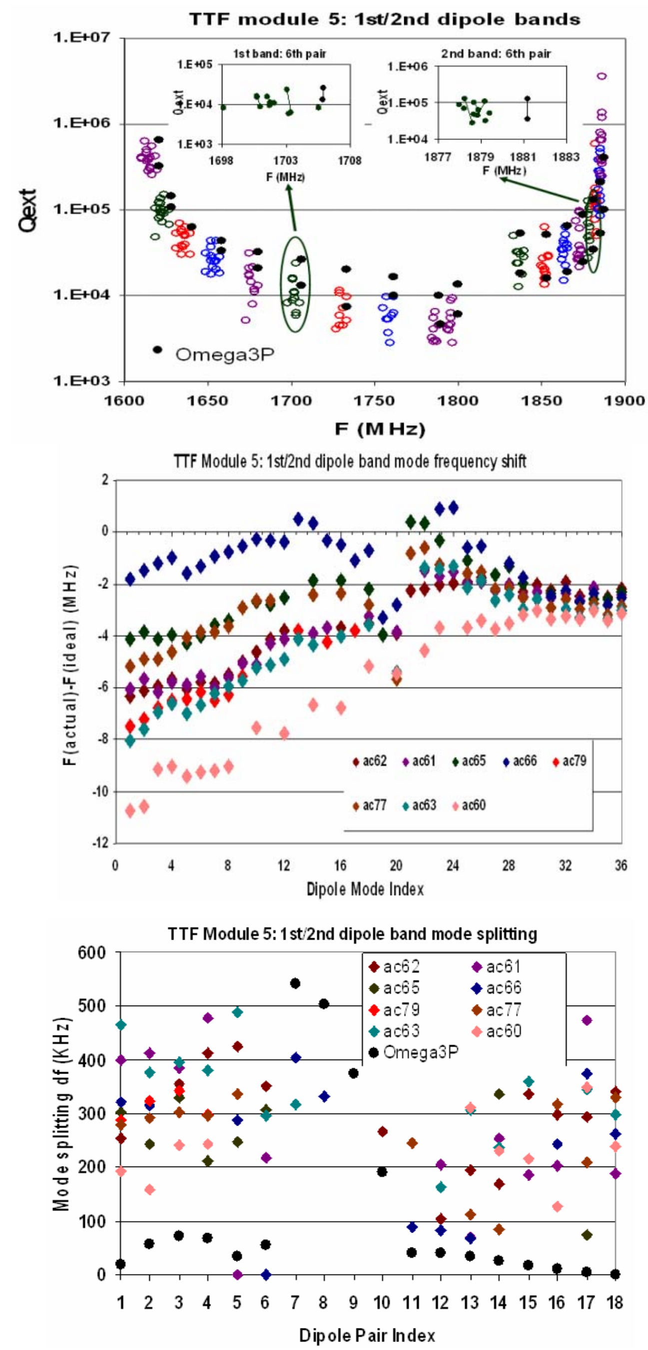

Figure 2: Comparison between ideal cavity results from Omega3P (in black) and measurements from 8 cavities in TTF module 5 (in color) – (top) damping, (middle) frequency shift from ideal cavity, and (bottom) mode splitting.

* Work is supported by DOE ASCR, BES, HEP Divisions under contract DE-AC02-76SF00515. The work used the resources of NCCS at ORNL which is supported by the Office of Science of the U.S. DOE under Contract No. DE-AC05-00OR22725, and the resources of NERSC at LBNL which is supported by the Office of Science of the U.S. DOE under Contract No. DE- AC03-76SF00098.
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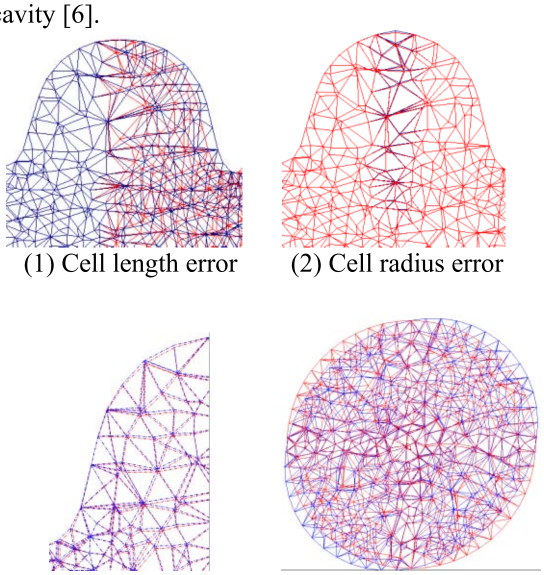
In general, for a dipole pair in the real cavities, its frequencies are shifted to lower values, the mode splitting is larger and the Qext scattered. The scatter of Qext may be detrimental to the beam quality. The trapped mode with highest R/Q in the 3rd dipole band has an unacceptable Qext exceeding 10^6 in some measured TDR cavities [4-5]. Studies of cavity imperfection will be useful to determine the tolerance requirements for the cavity shape during the fabrication process.

MODELS OF CAVITY IMPERFECTION

All TESLA cavities were fabricated and prepared following the same procedure and the nature of imperfection was similar. In this paper, the deformations from the ideal cavity shape (as shown in Figure 3) are classified as: (1) cell length error at the equator, (2) deformed cell surface due to the welding of stiffening ring and the tuning process, (3) cell radius error at the equator due to electron-beam welding and chemical polishing, (4) elliptically deformed cell shape. The effects of each type of these shape deformations on the dipole modes allow us to determine the parameters that contribute to the variations of measured data and their deviations from the ideal values. In facilitating the process of modeling deformed shapes, a mesh distortion method has been developed to generate the imperfect cavity [6].



(1) Cell length error (2) Cell radius error

(3) Deformed cell surface (4) Elliptical cell shape

Figure 3: Meshes for imperfect models with ideal cell in red and deformed cell in blue.

In Table 1, the sensitivities of the operating mode frequency to various shape deformations are listed from Omeag3P calculations. The calculated cell length sensitivity is very close to the measured value of 5.4 MHz/mm. It can been seen that the shift in frequency from a deformed shape needs to be compensated by that from another deformed shape so that the correct mode frequency and field flatness are maintained, as this is achieved during the tuning process. This constraint will be imposed for the analysis of cavity imperfection on dipole modes in the next section.

Table 1: Sensitivity of the π mode frequency to different types of deformation for the half-cell.

Deformed parameters	df (MHz)/mm
Cell length increase at the equator	-5.5
Cell radius increase within 6mm width at the equator	-1.6
Top surface stretch	-8.1
Iris surface stretch	2.9

SIMULATION OF IMPERFECTION ON DIPOLE MODES

As mentioned in the introduction, the major effects of cavity imperfection on dipole modes are frequency shift, increase in dipole pair frequency separation, and Qext scatter. In the following, we will determine the shape parameters that are responsible for each of these effects.

The process of welding the stiffening ring is modeled by deforming the cell surface at the iris. In order to keep the π mode frequency right and the field flatness (> 98%) during the tuning process, the surface above the stiffening ring needs to be stretched to compensate for the frequency change. In Figure 4, the results for the first and second dipole bands are shown for a deformation of 607 um and 200 um at the iris and the surface above the stiffening ring, respectively. The calculated frequencies of the dipole modes for the deformed cavity agree well with measurement data. While cell surface deformation causes dipole mode frequency shift, it has negligible effects on damping as the Qext remains essentially the same.

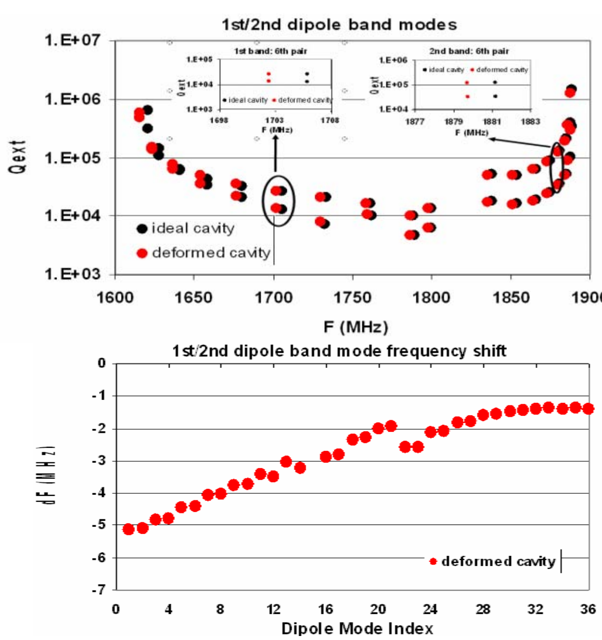


Figure 4: (Top) Dipole mode spectrum; (bottom) dipole mode frequency shift for the imperfect model with deformed surfaces.

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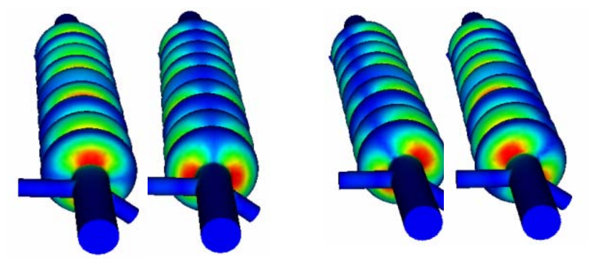
Cavity imperfection can also change the dipole mode polarization, as mentioned in Ref. [7]. It was found that by rotating the 9-cell cavity while keeping the end-groups fixed, the measured dipole mode properties was dependent on the angle of rotation, indicating that the cell shapes in the cavity are not cylindrically symmetric. Assuming elliptical cell shapes, the polarizations of the 6th dipole pair in the 2nd dipole band are compared with those for the ideal cavity with a circular cell shape (see Figure 5). It can be seen that the polarizations of the dipole pair are quite different for the two cases, and their changes in the deformed cavity could lead to enhancement of x-y coupling for wakefield effects. In addition, elliptical cell shape contributes to larger mode separation for the dipole pair.



(a) Ideal cavity (b) Cavity with elliptical cells

Figure 5: Field patterns of the 6th dipole pair modes in the 2nd dipole band.

While the cell shape affects mostly the frequency shifts and mode separations of dipole pairs, the scatter in Qext is more sensitive to the variation of the pickup gap in the HOM coupler. Figure 6 shows the variation of Qext for the first and second dipole bands for different pickup gap widths, showing that Qext can vary by a factor of 5 for some dipole modes when the gap width changes from 0.1 mm to 0.5 mm.

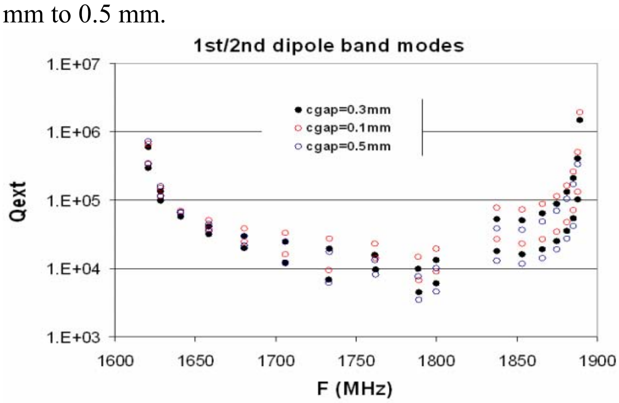


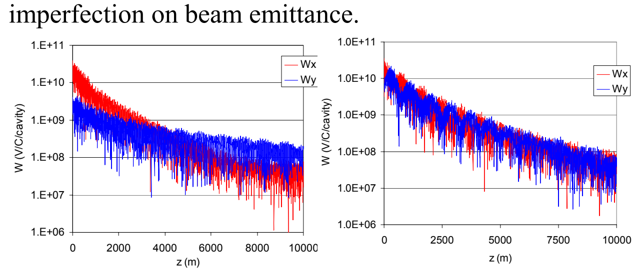
Figure 6: Damping results for various deformed HOM couplers.

Actual cavities will include all the imperfections mentioned above. A shape determination program based on least-squared minimization is being developed to automatically generate a set of deformed cavities by fitting to measured data.

WAKEFIELD IN DEFORMED CAVITY

The main concern of cavity imperfection is its effects on wakefields. Figure 7 shows the transverse wakefields in the x and y directions for a beam offset of 0.5 mm in the x direction. For the ideal cavity, the transverse wakefield in the y direction arises from the 3D asymmetry of the coupler configurations in the end-groups. For the deformed cavity with one deformed elliptical cell, the transverse wakefield in the y direction increases by almost an order of magnitude. Thus, the effects on x-y coupling are more significant for deformed elliptical cell shape than for couplers.

The x-y coupling effects in actual cavities will be further evaluated by computing the wakefields in deformed cavities determined by fitting to measured data. The resulting wakefields will be used as input to the beam tracking code Lucretia to study effects of cavity imperfection on beam emittance.



(a) Ideal cavity (b) Cavity with elliptical cells

Figure 7: Transverse wakefields in x and y directions.

ACKNOWLEDGMENTS

We would like to thank G. Kreps, M. Dohlus and J. Sekutowicz for many useful discussions on the DESY measurements of the TDR cavities.

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