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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 ones due to fabrication errors, the addition of stiffening rings and the frequency tuning process. Cavity imperfections shift the dipole mode frequencies and alter the Qext's from those of the ideal cavity. The 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, cavity imperfection models will be generated for the study of wakefield impact on beam transport.

INTRODUCTION

When fabricating the TESLA TDR cavities (as shown in Figure 1), half-cells are made initially that are a few tens of microns longer at the equator than the nominal dimension. Pairs of half-cells are then electron-beam welded at the irises to form "dumbbells," and the equators trimmed to match the half-cell frequencies. Stiffening rings are then welded on each pair, which deforms the dumbbell disks and changes the cell frequencies. To compensate, each half-cell is stretched by a similar amount near the dumbbell outer radius. Eight dumbbells and the end-groups are then electron-beam welded to complete each TESLA 9-cell cavity. In the final step, the 9-cell cavity is tuned slightly to adjust the operating mode frequency and to flatten the field [1-2].

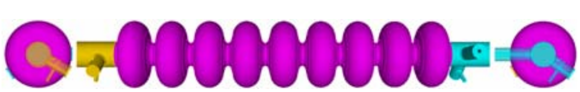

Figure 1: The model of the TESLA TDR cavity.

As a result of this assembly process, the actual dipole mode properties differ from those of cavities with the nominal dimensions. To quantify this, the mode solver program Omega3P was used to compute the nominal dipole properties. Figure 2 shows an example of how these results compare with actual frequency and Qext data for the first two dipole bands in the eight cavities in TTF Module 5 [3]. Note that there are 18 modes in each band (i.e., 9 cells times 2 polarizations), and the 'mode splittings' refer to the frequency differences between the polarizations.

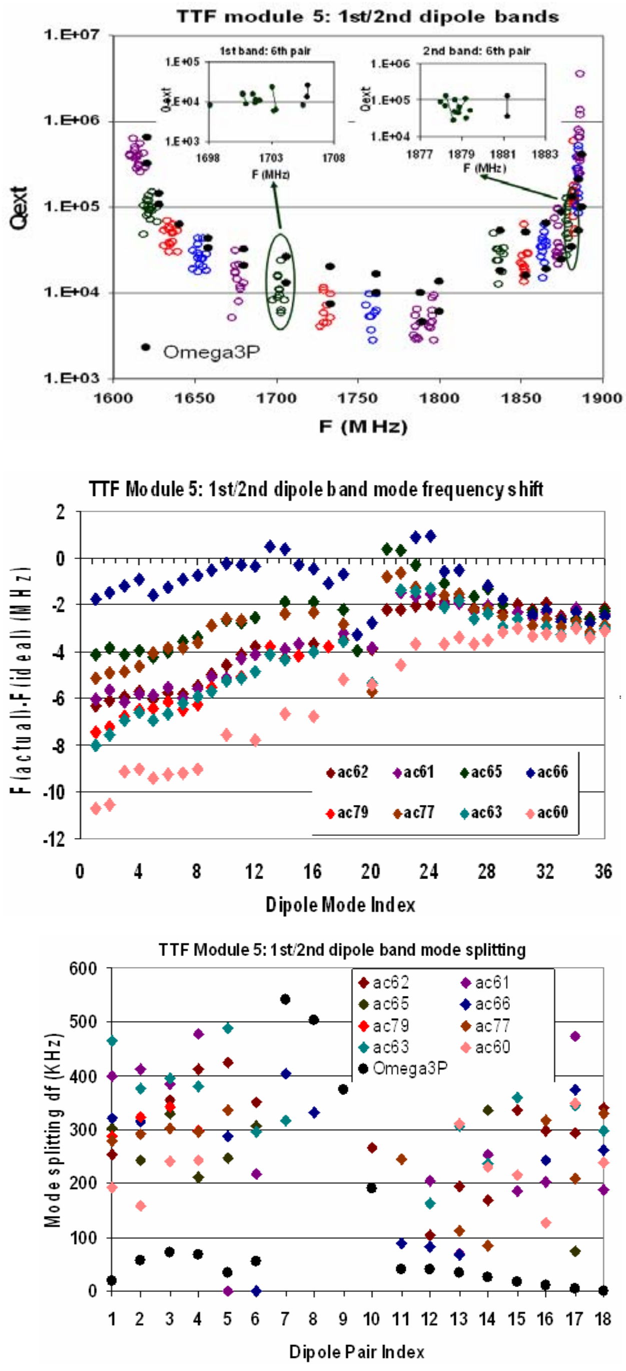

Figure 2: Comparison between ideal cavity results from Omega3P (black circles) and measurements from 8 cavities in TTF Module 5 (in color) – (top plot) Qext, (middle plot) frequency shift from ideal cavity, and (bottom plot) mode splitting.

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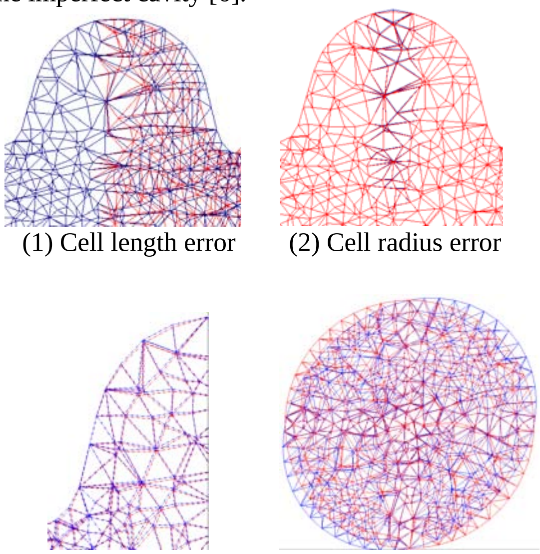
In general, the dipole mode frequencies are shifted to lower values, the mode splittings are larger than expected and the Qext's have a large scatter, which may be detrimental to the beam quality. The trapped mode with highest R/Q in the 3rd dipole band has an unacceptable Qext exceeding 10^6 in some measured TDR cavities [4-5]. Studies of cavity imperfections are thus useful to determine the tolerances on the cavity shape during the fabrication process.

MODELS OF CAVITY IMPERFECTION

All TESLA cavities were fabricated and prepared following the same procedures and the nature of the imperfections are similar. We have modeled four types of deformations as shown in Figure 3: they are (1) cell length error at the equator, (2) cell radius error at the equator due to electron-beam welding and chemical polishing, (3) deformed cell surface due to the welding of the stiffening ring and the tuning process, (4) elliptically deformed cell shape. The effect of each of these shape deformations on the dipole modes allows us to determine the parameters that contribute to the variations of measured data and their deviations from the ideal values. To facilitate 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.

Table 1 lists the sensitivities of the operating mode frequency to various shape deformations as computed with Omeag3P. The calculated cell length sensitivity is very close to the measured value of 5.4 MHz/mm. For the actual cavities, the net effect of the deformations on the fundamental mode is removed during the tuning process to achieve field flatness at the 1.3 GHz operating frequency. When modeling the effect of the deformations on the dipole modes, the consequences of this tuning were also included.

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

Table 1: Sensitivity of the π mode frequency to different types of deformations.

SIMULATION OF THE EFFECT OF IMPERFECTION ON DIPOLE MODES

As mentioned in the introduction, the major effects of cavity imperfections on dipole modes are frequency shift, increase in mode splitting, and Qext scatter. In this section, we describe the shape parameters that can produce each of these effects.

The process of welding on the stiffening ring is modeled by outward deformation the cell surface near the iris. In order to keep the π mode frequency constant and the field flat (> 98%) during the tuning process, the surface outside of the stiffening ring needs to be moved outward (as shown in illustration 3 of Figure 3). In Figure 4, the effect on the first and second dipole bands are shown for outward deformations of 607 μm and 200 μm near the iris and outside the stiffening ring, respectively. The frequency shifts of the dipole modes for the deformed cavity agree well with measurements on average (compare bottom plot of Figure 4 to middle plot of Figure 2). The surface deformations however have negligible effect on damping as Qext remains essentially the same.

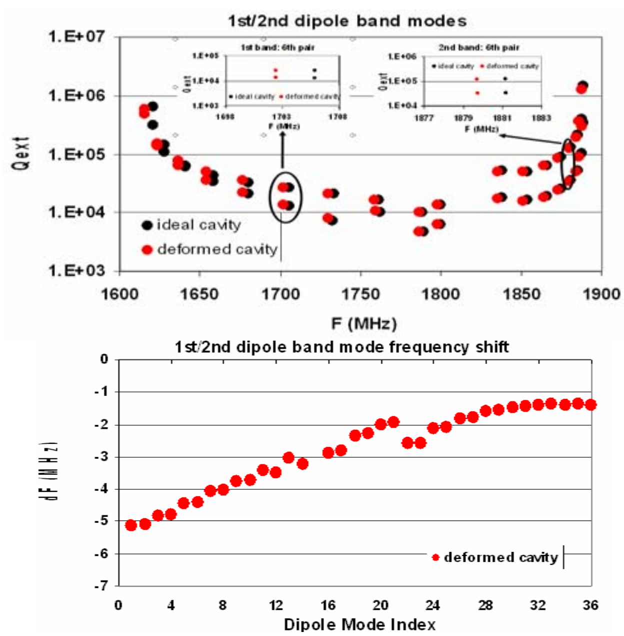


Figure 4: (Top plot) Dipole Qext, (bottom plot) dipole mode frequency shift for the model with deformed surfaces.

Cavity imperfections can also change the dipole mode polarization, as discussed in Ref. [7]. It was found that by rotating the 9-cell cavity while keeping the end-groups fixed, the measured dipole mode properties changed with 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 the 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.

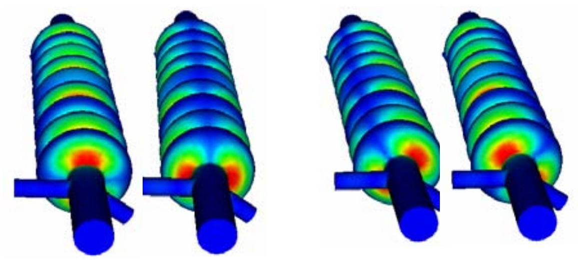


Figure 5: Field patterns of the 6th dipole pair modes in the 2nd dipole band: (left plot) ideal cavity, (right plot) cavity with elliptical cells

While the cell shape affects mostly the frequency shifts and mode separations of dipole pairs, the scatter in Qext is particularly 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.

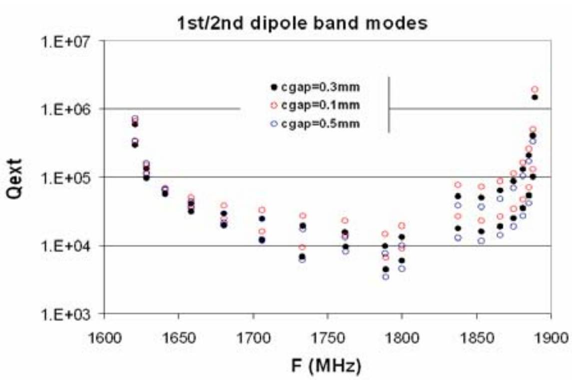


Figure 6: Damping results for various HOM pickup gap distances.

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 A DEFORMED CAVITY

The main concern with cavity imperfections is the effect on the wakefield. 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 a cavity with one elliptical cell (+/- 200 μm radius at +/- 45 degrees), the transverse wakefield in the y direction increases by almost an order of magnitude.

We plan to continue simulating x-y coupling effects in deformed cavities and resulting wakefields will be used as input to the beam tracking code Lucretia to study the effect on the beam emittance.

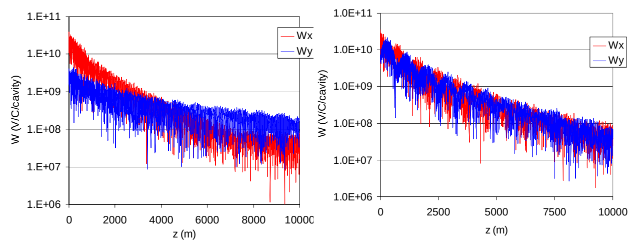


Figure 7: Transverse wakefields in x and y directions: (left plot) ideal cavity, (right plot) cavity with one elliptical cell.

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REFERENCES

[1] A. Matheisen, “Cavity fabrication and preparation sequences for the TESLA/TTF cavities at DESY”, 1st ILC workshop at KEK, Japan

[2] G. Kreps, “1.3 GHz TESLA Cavity Production and Tuning at DESY”, DESY 2006

[3] http://tesla.desy.de/oracle/6i/CavityDB/GUI/view config=app_hom_meas

[4] N. Baboi, et al., “Investigation of a High-Q Dipole Mode at the TESLA Cavities”, EPAC2000

[5] W.F.O.Muller, W. Koch, T. Weiland, “Numerical Calculation of Trapped Modes in TESLA Cavities Considering Production Tolerances”, EPAC2002.

[6] L. Lee, et al., “Shape Determination for Deformed Cavities”, SLAC-PUB-12141.

[7] M. Dohlus, V. Kaljuzhny, S.G. Wipf, “Resonance Frequencies and Q-factors of Multi-Resonance Complex Electromagnetics Systems”, TESLA2002-12.