TEMPERATURE DEPENDENT HIGHER ORDER MODES (HOM) IN THE SRS CAVITIES

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Abstract

Higher Order Mode (HOM) characteristics of accelerating cavities in modern light sources are of great importance since they can limit the ultimate source brightness. One method to reduce this effect is to control the cavity operating temperature. Finite Element Analysis (FEA) of the geometry of the Daresbury SRS cavity has been performed to predict the changes in dimensions as the cavity temperature is varied. The results of this analysis have been compared with measured results on the SRS test cavity.

1 INTRODUCTION

Longitudinal coupled-bunch (LCB) instabilities on the SRS have lead to a detailed programme of work to assess the SRS RF cavities in terms of their HOM content, with a view to operating the cavities in a regime that does not enable instability growth.

Such instabilities have been observed on the SRS. Above a certain current threshold the electron beam profile is blown up, and as the beam naturally decays the profile relaxes back into a more stable condition. This instability has been identified as a cavity induced HOM, operating at 1390MHz, which couples longitudinally with the passing electron beam, causing the bunch length to increase[1]. These coherent longitudinal oscillations are observed as beam position movements on the beam line tungsten vane monitors (TVM)[2].

FEA of the cavity geometry was performed in order to predict the deformation of cavity geometry as a function of cavity temperature. This deformation could then be input to a suitable RF cavity design package to predict the corresponding change in frequency for the potentially dangerous HOM’s.

Practical measurements of the SRS test cavity were performed which enabled confirmation of theoretical prediction results.

2 FEA OF CAVITY GEOMETRY

FEA of the Daresbury SRS cavity has been performed to predict the changes in dimensions of the cavity as the cooling water temperature is varied. The cavity was modelled using 2D axisymmetric p-type elements in MECHANICA™[3].

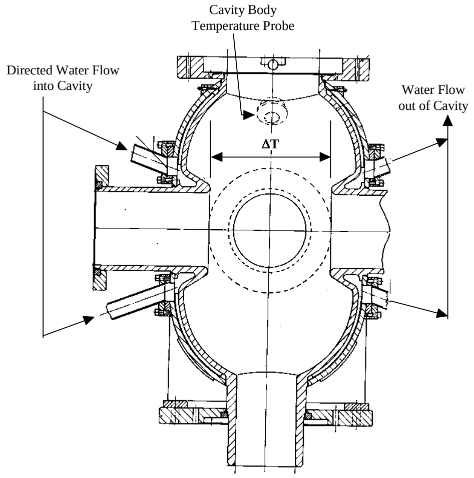

Figure 1: SRS Cavity Cross-section, Showing Water Flow Through the Cavity

Five cavity conditions were analysed; one nose-cone remained fixed at 50°C, the other nose-cone was varied between 40°C and 60°C, in 5°C increments. This was to model the action of cooling water through the cavity (see Figure 1).

2.1 Thermal Analysis

RF power loads were obtained from the 2D RF simulation code URMEL-T[4] and applied to the model. Cavity cooling is provided via demineralised water flowing through finned channels, which was modelled using convection conditions. The bulk temperature of the liquid was considered to be the same temperature as the nose-cone and the film coefficient set to 0.02W/mm^2/°C.

For a dissipated cavity power of 12.5KW, all analysis showed a maximum temperature rise of approximately 2.5°C elsewhere in the cavity walls.

2.2 Structural Analysis

The structural model was considered to be rigidly fixed at both flanges. The temperature gradients obtained in each case from the thermal analysis were applied to the structural model. The reference temperature was assumed to be equivalent to the cold nose-cone. For each case deflections were recorded to enable the new cavity geometry to be inputted into URMEL-T for analysis. Stresses were considered negligible in all cases.

2.3 *Predicted Nose-cone Deformation*

Figure 2 shows the linear relationship between FEA predicted nose-cone deformation and cavity differential temperature (ΔT) across the cavity.

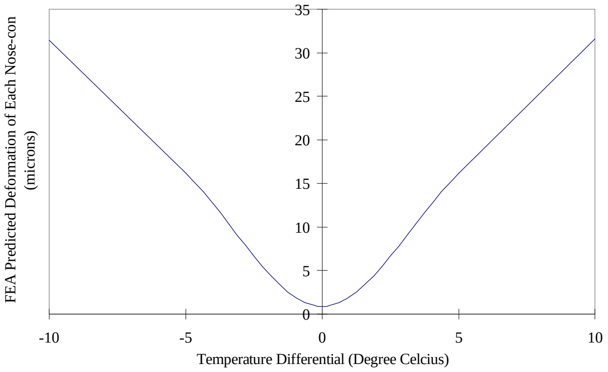

Figure 2: FEA Predicted Nose-cone Deformation vs. Temperature Differential

3 COMPUTER SIMULATION OF FEA RESULTS USING URMEL-T

The FEA results show that as the cavity temperature increases, the nose-cones expand linearly, with about 3.1µm/°C movement. This means that the nose-cones become closer together, the capacitance increases, therefore reducing the fundamental frequency[5].

Simulation of the cavity geometry with the predicted deformation due to increased temperature is currently ongoing and is hoped to confirm the linear relationship observed in practical measurement.

4 PRACTICAL MEASUREMENT

The SRS test cavity is identical to the four cavities used routinely on the SRS. It is powered by a 40KW TV transmitter and is generally used to test out new control/monitoring instrumentation prior to installation on the operational cavities. The cavity was therefore used to characterise all of the longitudinal HOM's as a function of cavity temperature and tuner position. This would then enable prediction of a cavity temperature which would force the potentially unstable 1390MHz HOM into a frequency region that the beam spectra could not excite.

4.1 *HOM's vs. Temperature*

The measurements were performed over a wide temperature range (30°C to 60°C), in order to simulate the typical range of temperature that the SRS cavities can be operated at. As the temperature was varied all strong, potentially unstable HOM's were monitored to determine the variation in frequency as a function of the small geometry change due to increased temperature.

Figure 3 shows the variation of the fundamental accelerating mode frequency as the temperature is increased, together with the 1390MHz longitudinal mode. It is this HOM that has caused beam blow up on the SRS[1] and consequent adjustment of cavity 2 temperature has successfully increased the current threshold at which this mode is excited.

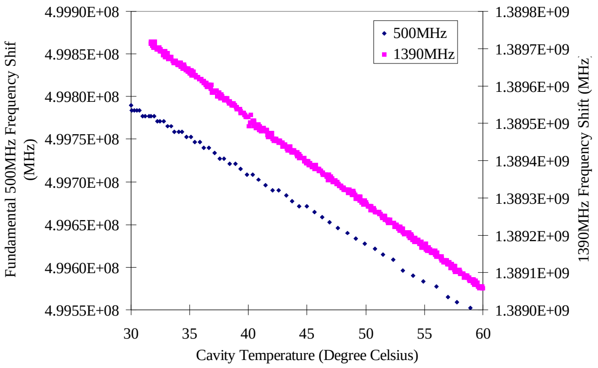

Figure 3: Frequency of 500MHz and 1390MHz HOM vs. Temperature.

Table 1 lists all significant longitudinal (monopole) and transverse (dipole) acting HOM's and their associated frequency shift as a function of raising the cavity temperature from 30°C to 60°C.

Table 1: HOM Frequency Shift as Temperature Varied from 30°C to 60°C

Frequency		R_s (MΩ or MΩ/m)	Freq/ΔT (kHz/°C)
Monopole	Dipole		
499.79		4	-7.9
1333		0.8	-5
1390		0.7	-92
	790	20	-1.4
	1060	24	-21.4
	1286	4	-5.2

4.2 *HOM's vs. Tuner Position*

It is clear that operating each cavity on the SRS at different temperatures will produce different cavity spectra characteristics. This is inevitable anyway, as the manufacture of such complex, spherical structures cause slight discrepancies in the geometry from cavity to cavity. Each cavity will therefore already have its own unique HOM spectra. The higher the Q of the HOM's the better, since then they exist in a very narrow region of the frequency spectrum, and small adjustments of the cavity geometry will shift the mode away from known beam resonances. The high Q however leads to strong e-m field components, giving these modes high impedance and large growth rates. On machines such as the SRS, where the electron beam is ramped to its final operating energy in the storage ring, the action of the cavity tuner, compensating for the increased beam loading, will cause these high Q modes to be excited and the beam would blow up, or may even be lost.

Figure 4 shows the shift in frequency of both the 500MHz and 1390MHz modes as the tuner position is varied from 15mm to 55mm into the cavity.

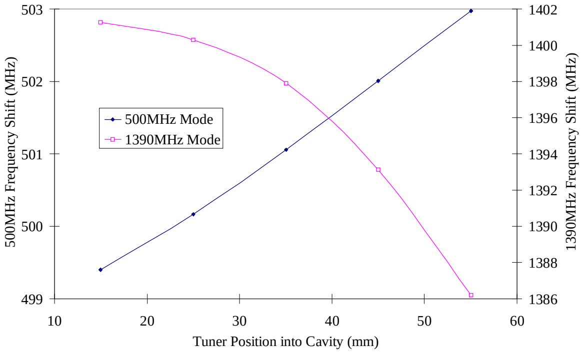

Figure 4: Frequency of 500MHz and 1390MHz HOM vs. Tuner Position into Cavity.

Table 2 lists all strong monopole and dipole modes and their associated frequency shift as a function of tuner position.

Table 2: HOM Frequency Shift as Tuner Position Varied

Frequency		Freq/Tuner position (kHz/mm)
Monopole	Dipole	
499.79		+51.4
1333		-138
1390		-215
	790	+82.8
	1060	-0.7
	1286	+0.5

Considering the 1390MHz HOM, the action of increasing the cavity temperature over a wide range had the effect of reducing the frequency of the mode by 92kHz/°C, whereas inserting the tuner has the effect of reducing the mode's frequency by 215kHz/mm.

Changing the cavity temperature has a much smaller effect on the 500MHz accelerating mode, reducing its frequency by only 7.9kHz/°C. Comparison of this magnitude deviation to that experienced when the tuner is inserted (51.4kHz/mm) makes it clear that adjustment of the cavity tuner position is a *coarse* means of altering the cavity geometry, used to shift modes away from dangerous beam resonances. Adjusting cavity temperature however, is a much more *fine* and controllable method of shifting HOM's. The action of altering the cavity geometry by changing its temperature also gives a more linear relationship between mode frequency shift and temperature, whereas applying the cavity tuner is less predictable and is certainly not linear.

5 EFFECT OF INCREASING CAVITY TEMPERATURE

Experimental measurement shows that as the cavity temperature is increased, the 500MHz mode frequency reduces by 7.9kHz/°C. Therefore, increasing the cavity temperature from 50°C to 53°C will have the effect of reducing the fundamental by 23.7kHz. For the cavity to operate effectively, the tuner plunger must compensate for the geometry change and consequently moves further into the cavity. The effective change in tuner position, to compensate for the reduction in frequency, is ~0.5mm. The corresponding effect for the 1390MHz HOM is to reduce its frequency by 276kHz due to the increase in cavity temperature, and then a further reduction of 107kHz owing to the tuner position movement. This combined modification of the cavity geometry shifts the problematic mode by 383kHz into an area of frequency space relatively free of beam harmonics.

6 CONCLUSIONS

Applying FEA design tools to predict very small deformations of internal cavity dimensions has proved invaluable to determine how the cavity HOM's react to large temperature variations.

Practical measurement of how the HOM's vary with temperature concludes a near linear relationship for all significant HOM's investigated. The corresponding response of these modes, as the cavity tuner plunger is inserted into the cavity, is clearly not linear and the modes, because of their unique e-m field orientation, will not all move in the same direction.

Evidence of LCB instability behaviour on the SRS has identified a cavity HOM as the principal cause. Characterising this mode as a function of cavity temperature and tuner position has enabled the mode to be shifted in frequency space, away from dangerous beam resonances that inherently exist in the electron beam .

REFERENCES

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