

THE TUNING OF THE CAVITY OPTIONS FOR DIAMOND

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Abstract

The RF group is considering both normally conducting [1] and super-conducting [2] cavity systems for DIAMOND. This paper will discuss using temperature and longitudinal deformation as methods of tuning for a normally conducting cavity. The longitudinal deformation of a super-conducting cavity is also discussed with its added technical difficulties of nanometer resolution and its cryogenic environment. Finite Element Analysis and URMEL-T [3] software has been used extensively to predict cavity geometry changes and the associated frequency shift.

1 INTRODUCTION

The current method of RF cavity frequency tuning on the SRS uses a non-contacting plunger. Recent experience at Daresbury has shown that normal plunger movement over a stored beam decay causes beam movement of $>20\mu\text{m}$ horizontally and $>10\mu\text{m}$ vertically. This movement is accommodated by the SRS, due to its relatively large source size, but must be avoided in DIAMOND.

Superconducting and warm systems are currently being considered, as a result tuning techniques for both systems are being assessed.

2 NORMAL CONDUCTING RF

At present, the normal conducting RF system for DIAMOND has been based on a frequency of 500MHz. The storage ring RF system will consist of six 250 kW klystrons feeding six normal conducting cavities.

2.1 The RF Cavity

Following investigation and optimisation of the three most common geometry configurations (nose-cone, pill-box and bell-shaped) an optimised nose-cone cavity was selected for DIAMOND [4], shown in figure 1. The investigation of a tuning mechanism for a normal conducting system has been based on this geometry.

2.2 Finite Element Analysis (FEA)

FEA of the DIAMOND Cavity was performed using the AnsysTM Version 5.1 [5] Code. Cavity modelling is required to predict the dimensional changes that occur when the cavity temperature is changed, the force required to axially deform the cavity and to determine the stresses in the cavity, due to tuning techniques.

A 2-D axisymmetric model was constructed using Plane 55 thermal elements, which were switched to Plane 42 structural elements for structural analyses. The cavity

will be manufactured and installed at room temperature, therefore a reference temperature of 20°C has been assumed for thermal strain calculations. The distribution of the RF power fluxes was calculated using URMEL-T and applied to the model. Each cavity will be required to dissipate 105 kW of RF power.

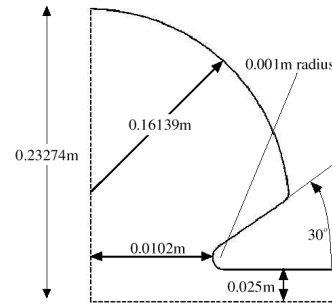


Figure 1. DIAMOND Cavity

2.3 Tuning using Cooling Water Temperature Variation

Operating the cavity at different temperatures changes the fundamental frequency of the cavity and the frequency of High Order Modes (HOM's). The temperature of the cavity can be changed by altering the temperature of its coolant. This technique has been used at many laboratories, including the SRS [6] and ELETTRA, to fight multi-bunch instabilities [7].

To confirm that the relationship between cavity geometry and temperature is linear, three analyses have been carried out. Analyses were carried out for bulk temperatures of 40°C, 50°C and 70°C. A convection boundary condition was added to the model to simulate the water flow around the cavity with a film coefficient of $0.02\text{W}/\text{mm}^2/\text{°C}$. A typical temperature contour result is shown in figure 2.

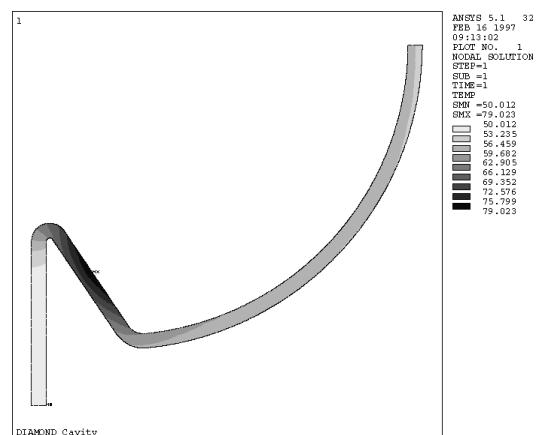


Figure 2. Temperature Contour Plot

The area of maximum temperature rise is indicated on the diagram. In all three analyses the minimum cavity body temperature is the same as the temperature of the coolant and the maximum temperature is equal to the coolant temperature +29°C. This large deviation between the minimum and maximum temperatures can be reduced by careful design of the cooling channels.

Structural analyses were then carried out on each model to determine the cavity dimensional changes.

Water Temp	Max Cavity Temp	Movement per nose-cone into the cavity
40°C	69.023°C	41.7µm
50°C	79.023°C	69.9µm
70°C	99.023°C	99.5µm

It is clear that this is a linear relationship, for each 1°C change in cavity temperature there is 1.92µm nose cone movement. Figure 3 shows typical cavity deformation.

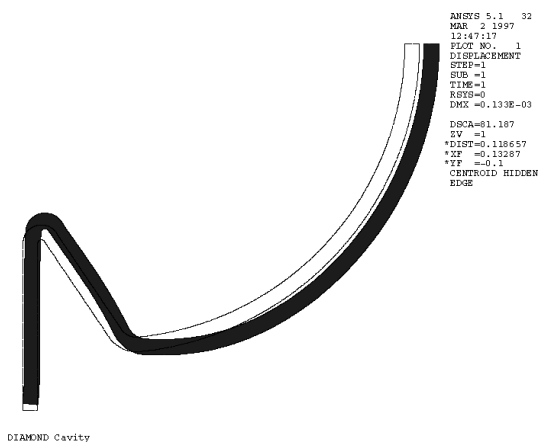


Figure 3. Deformed Cavity Shape

2.4 URMEL-T Results

This information was inputted into URMEL-T. Due to the geometry of the nose-cone cavity, the most significant frequency shift is due to the movement of the nose-cones along the axis of the cavity. For 1°C rise in temperature the fundamental frequency shift of the cavity is 6.824kHz. Using similar techniques to those used at other 3rd generation sources, cavity temperature can be controlled to ±0.1°C, giving a frequency resolution in the region of 682Hz.

2.5 Tuning by Longitudinally Squeezing the Cavity

If cavity temperature is used to prevent HOM instabilities, the fundamental frequency will also shift in addition to the troublesome HOM frequency. Therefore, a second tuning system is necessary to return the cavity to its fundamental frequency. The technique of squeezing the cavity on axis is being investigated. To prevent any waveguide sealing problems due to the squeezing of the cavity it is essential that the cavity is designed with all ports on the cavity centre-line. From URMEL-T calcula-

tions, a 1µm movement of the nose-cones corresponds to a frequency shift of 3.554kHz. The frequency range should be in the order of 200kHz. A closed loop controls system with a frequency resolution of 500Hz or better is required.

It is desirable to restrict the cavity movement so that it remains within the elastic region of the material to prevent any work-hardening of the cavity, ultimately leading to fatigue failure. This is achievable in the DIAMOND nose-cone cavity, as frequency shifts are relatively large for small nose-cone movements, but this produces a challenging mechanical resolution for the mechanism. A mechanical resolution of 0.14µm is required for a 500Hz frequency resolution. If the option to select a 100Hz frequency resolution is added, the mechanical resolution would need to be in the order of 28nm.

Using the 2-D model, it is anticipated that the force required to deform the cavity ±40µm on axis will be in the region of 2kN. The equivalent maximum stress in the cavity is 48.1MN/m², just below the 0.1% Proof Stress of Oxygen Free High Conductivity (OFHC) Copper, which is given in most texts to be 49-78MN/m². This will give a frequency range of 284.32kHz.

Two methods of squeezing the cavity are currently being investigated, a hydraulic system and a left/right handed leadscrew system.

Hydraulic drives can produce large forces for the size of actuator and have an excellent power to weight ratio. Actuators are available with a 100µm range and a resolution of up to 1nm. However, the unit required to generate the hydraulic pressure is large and expensive. It is also difficult to prevent the vibration from the equipment being transmitted through the hydraulic fluid to the cavity [8].

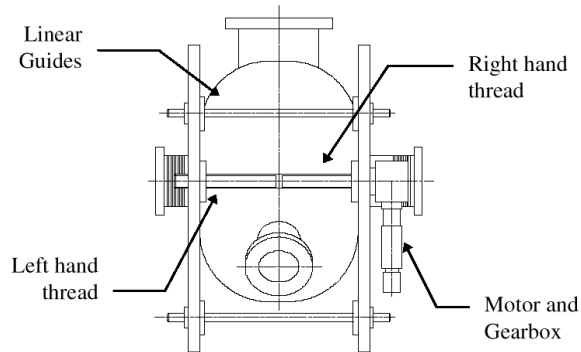


Figure 4. Leadscrew System

The left/right handed leadscrew, as shown in figure 4, is a relatively low cost solution, but there are some disadvantages. The use of a leadscrew of any description means that the system will display backlash and thermal properties are poor. Most of these problems can be overcome by careful design and choice of leadscrew. A ball screw has very low backlash and high accuracy, but due to its low friction motor brakes would need to be fitted to prevent the cavity reactive force winding the ballscrew

back. However, by deforming the cavity using frequency feedback, the accuracy of the leadscrew is less important and a conventional leadscrew could be used and the need for motor brakes eliminated. Thermal problems are not anticipated due to the environmental control of the DIAMOND tunnel. The main disadvantage with this system is the very high gear ratio required to obtain the specified resolution.

3 SUPERCONDUCTING RF

If superconducting technology is used, it is likely that DIAMOND will move to a 350MHz system, to take advantage of the development work of other sources in this area. Work has recently started on the super-conducting system and the development of the tuning system is much less advanced. This section will describe some preliminary thoughts on the subject.

3.1 Additional Problems Associated with Tuning Super-conducting Cavities.

There are more problems to be overcome when designing a tuning mechanism for a superconducting cavity. The cavity is housed in a helium cryostat and all components should be accessible for maintenance. Any mechanism used to modify the cavity geometry must make the transition from atmospheric to cryogenic temperatures. The geometry deformations required for tuning are in the nanometer region and speed of response is critical as the system must be capable of combating the frequency shifts and oscillations which can occur, due to changes in pressure in the cryostat.

3.2 Methods of Super-conducting Cavity Tuning

Two methods of tuning are usually required, a coarse tuner with a range in the order of 500kHz and a fine tuner working over approximately 10kHz. There are several actuators available which are capable of nanometer resolution, three of the most common are discussed [9] here.

Piezoelectric materials experience a dimensional change on application of an electrical potential. Devices based on these materials are commercially available, with a range/resolution ratio of 10,000:1 and are capable of high response speeds. However, they are prone to hysteresis and creep, which limit the achievable accuracy. Actuators are available with a traverse of up to 100mm in step sizes of 2nm or less. However, in devices of this length, stiffness and response speed are compromised.

Electrostrictive devices are very similar to the piezoelectric actuator. However they exhibit reduced hys-

teresis and have a low thermal expansion coefficient making them ideal for high accuracy applications. Simpler electrical drives may make them cheaper than the equivalent piezoelectric system. The main disadvantage is they are distinctly non-linear, but this is readily overcome with modern computer controls. In many cases the range is compromised to remain in a relatively linear portion of the working range. Hysteresis increases rapidly when operated below 273K, making any benefit over piezoelectric materials negligible.

Magnetostrictive devices are again very similar to piezoelectric actuators, but the strain is caused by the presence of a uniform magnetic field. The displacement per unit field is a linear relationship. They are ideal for heavy duty actuators working in the 100 μ m range. However, they are subject to hysteresis and creep.

4 FUTURE WORK

Work is progressing steadily on both systems, but there is a significant amount of work to do before comprehensive design schemes are available. The majority of the work on the warm system has been based upon the results taken from a 2-D axisymmetric model. The results must be confirmed on a complete 3-D cavity. Preliminary calculation work is to be started on the super-conducting cavity.

5 ACKNOWLEDGMENTS

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