MECHANICAL AND THERMAL LAYOUT OF A 500 MHZ HOM-DAMPED CAVITY

C.L. Hodgkinson, D.M. Dykes, Daresbury Laboratory, Warrington, UK.
V. Duerr, F. Marhauser, E. Weihreter, BESSY, Berlin, Germany.

Abstract

A European Union funded project to develop a normally conducting 500MHz accelerating cavity for electron storage rings with significantly damped high order modes (HOM's) is being carried out by a collaboration between BESSY, Daresbury Laboratory, DELTA, MAX-Lab and NTHU. This paper will describe some of the mechanical engineering aspects of the project. Finite element analysis using the high frequency electromagnetic module in ANSYS has been used to calculate the thermal and structural stresses and to determine the cooling requirements during operation at 100kW. These results have then been used to improve and finalise the mechanical layout. Methods of fabrication have been chosen with a view to minimising cost and complexity.

1 INTRODUCTION

The result of this project is to develop a normally conducting 500MHz accelerating cavity for 3rd generation electron storage rings. Many storage rings worldwide operate at this frequency and therefore the cavity has the potential for widespread application.

A prototype cavity will be manufactured during 2002, tested and installed in DELTA during 2003 for evaluation.

Computer aided design tools have been used extensively throughout the design of this cavity to determine the optimum mechanical design. The result of this work is presented in this paper.

2 THE MECHANICAL DESIGN

The cavity will be made from oxygen free copper (OFHC). As shown in Fig.1 three circular waveguide to coaxial transitions (CWCTs) with a cut-off frequency of 615 MHz are fitted to the cavity body in radial direction to couple to the HOMs and absorb the energy in external loads [1,2]. The cavity is of re-entrant type with a cylindrical shape and nose cones (see Fig. 2) to optimise the fundamental mode shunt impedance. Conceptual simplicity and a compact layout with a short insertion length were the essential criteria for the mechanical design in order to allow the installation of such cavities in existing storage ring tunnels.

The cavity body consists of two endplates and a centrepiece of cylindrical inner shape. Three large ports with NW 200 CF flanges are foreseen to mount the CWCTs. Additional ports are provided to house the RF coupling window, the tuner, and the field probes. A transverse and a longitudinal cut through the cavity showing schematically the cooling water channels in the main body are given in Fig. 2.

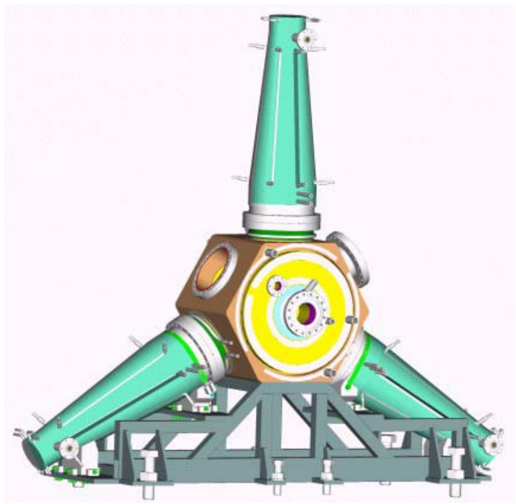

Figure 1: High power HOM damped cavity, with 3 CWCT's and test support

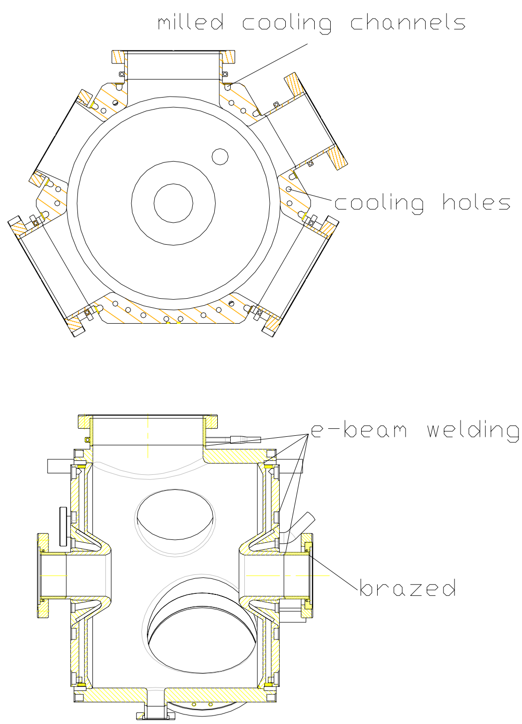

Figure 2: Two cuts through the cavity

Holes of 10mm diameter are drilled in axial direction through the cavity body, and a special inset is used for adequate distribution of the cooling water in the nose cone area.

The CWCTs (see Fig. 3) will be fabricated in two half shells mainly by milling and partly by electrical discharge machining, and the two halves will then be fitted together by vacuum brazing.

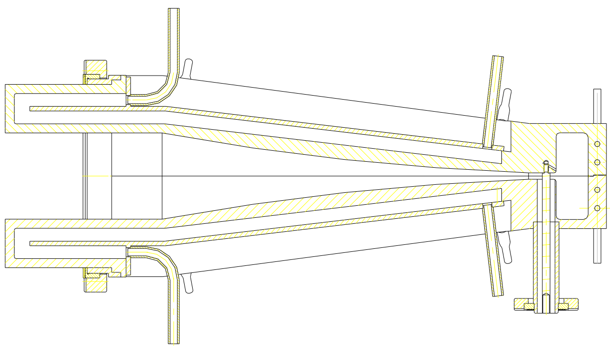

Figure 3: CWCT cross section

3 FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) was carried out using the ANSYS Multi-Physics© software package. The software was selected as it contains an electro-magnetic module with high frequency elements. Therefore the same mesh can be used throughout to determine thermal and mechanical stresses, greatly simplifying the analysis and reducing possible error transferring data between different packages [3]. Within ANSYS there is also an optional module to import ProEngineer parts which significantly reduces the amount of modelling necessary to transfer from CAD to FEA.

To reduce processing time the analysis is carried out on a 1/6 model of the cavity, shown in figure 4, with details such as flanges and weld preparations removed. The section should contain all major features as HOM dampers and input coupler ports.

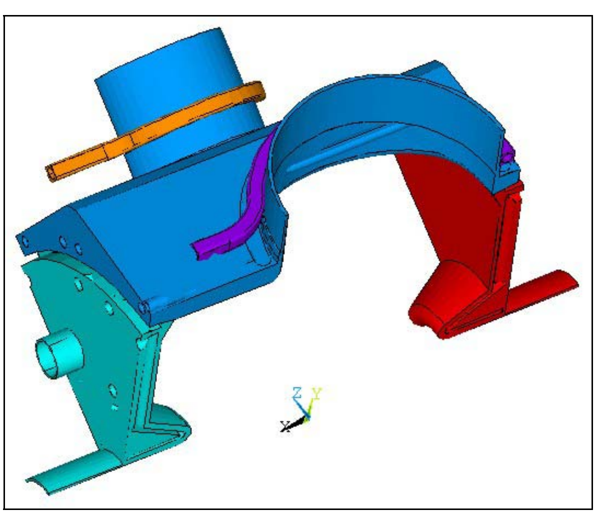

Figure 4: 1/6 Model of cavity

The cavity will be manufactured from OFHC Copper, table 1 below shows the critical parameters.

Table 1: OFHC Copper Properties

Young's Modulus (GPa)	126
Coefficient of Thermal Expansion (/K)	1.67x10-5
Thermal Conductivity (W/mK)	392
0.2% Proof Stress (MPa)	124
Relative Permittivity	1
Relative Permeability	1

3.1 High Frequency Analysis

The cavity vacuum space is modelled with high frequency elements. An electric wall boundary condition is applied to the internal surfaces of the cavity. The analysis calculated the frequency of the cavity to be 497MHz. This is a 3MHz discrepancy, which equates to an error of approximately 0.6%. This is caused primarily by the use of a 1/6 model, which has the effect of lowering the fundamental frequency. The refinement of the mesh in critical areas such as nose cones also affects this parameter. Plotting the magnetic and electric fields along beam axis can evaluate the quality of the mesh. These plots should have be a smooth curve, as illustrated in Figure 5 below.

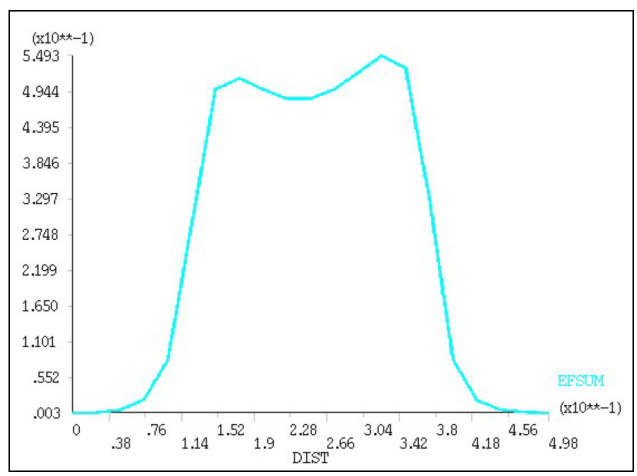

Figure 5: Electric Field along beam axis

3.2 Thermal Analysis

For the thermal analysis, thermal surface effect elements are mapped onto the high frequency solid elements at the internal cavity wall. A macro converts the currents induced by the surface magnetic field determined in the high frequency analysis into heat flux, which can then be applied as a load in further thermal analyses. The maximum heat flux is 54.64W/cm^2 for an input power of 100kW, this occurs where the HOM dampers and input couplers join the cavity body. The cavity body is then meshed using thermal solids. The cooling arrangement of the cavity, figure 6, is very complex to minimise thermal expansion of the cavity, particularly in the sensitive nose cone area.

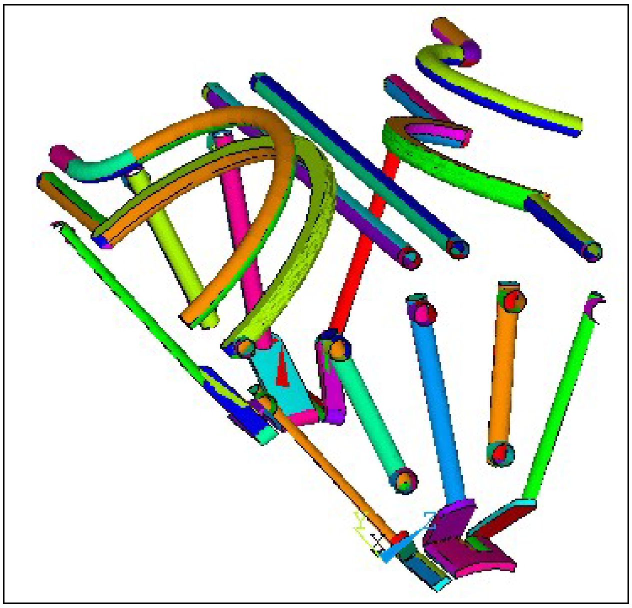

Figure 6: Cooling Arrangement

Although heat transfer coefficients of 18000W/m^{2}K are theoretically possible a more conservative 10000W/m^{2}K with a bulk temperature of 30°C was used to simulate water cooling of the cavity. The plot below, figure 7, shows the temperature of the cavity for the given boundary conditions. A maximum temperature rise of 42.44°C is indicated at the hot spot.

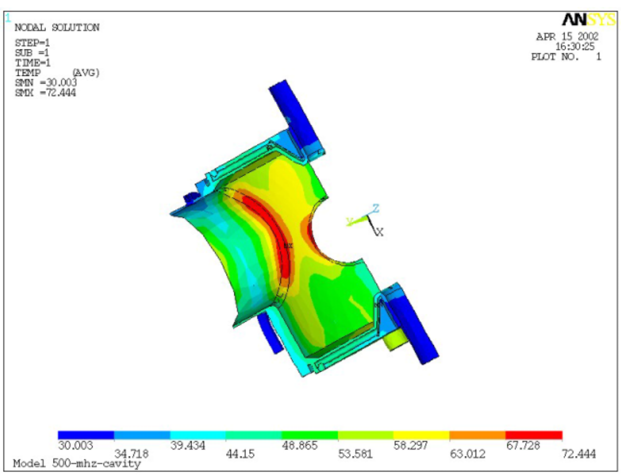

Figure 7: Temperature rise

3.3 Structural Analysis

The change from thermal to structural analysis is easily achieved in ANSYS as the element switch is automatic. The temperatures obtained from the previous analysis are now applied as a load to determine thermal stresses and displacement. The maximum thermal displacement is approximately 0.5mm, however the most critical area is the nose cone, which only moves 0.1mm into the cavity. Figure 8 shows the displacement in the nose cone area.

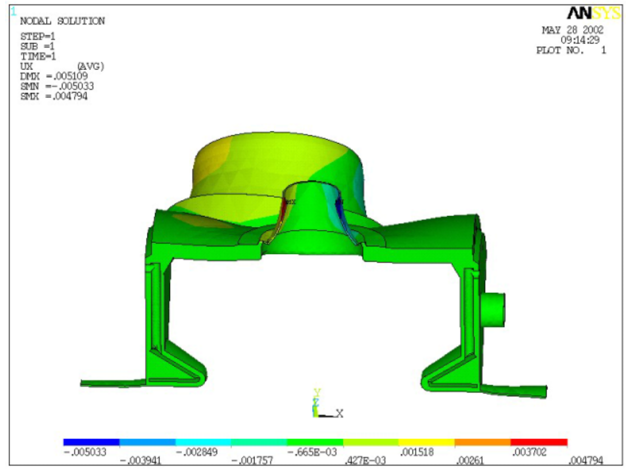

Figure 8: Thermal displacement of nose cones

Analysis shows that stresses and displacement due to vacuum loading are very small in the region of 12MPa and 0.02mm respectively. Von Mises stress due to thermal effects is only 3MPa. The total value of 15MPa is well within the proof stress of OFHC Copper of 124MPa.

4 CONCLUSIONS AND FURTHER WORK

The use of computer aided design tools has been effectively used to finalise the mechanical design of this RF cavity.

Discussions with prospective manufacturers are underway to determine ways of reducing the complexity of manufacture without compromising the performance of the cavity.

A final analysis should be undertaken when all manufacturing modifications have been made.

5 ACKNOWLEDGEMENTS

The authors would like to thank Neal Hartman of LBNL, USA for his invaluable assistance at the start of this project in the use of ANSYS to determine RF heating.

6 REFERENCES

[1] E. Weihreter, S. Küchler, Y.C. Tsai, K.R. Chu, Proc. of 6th EPAC, Stockholm, Sweden, 22-26. June 1998, vol. 2, p. 2065

[2] F. Marhauser, E. Weihreter, C.C. Yang, these proceedings

[3] N. Hartman et al, 'Electromagnetic, Thermal, and Structural Analysis of RF Cavities Using ANSYS', PAC2001 proceedings, p. 912