A RIDGED CIRCULAR WAVEGUIDE FERRITE LOAD FOR CAVITY HOM DAMPING*

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Abstract

The layout of an optimised homogenous circular ridged waveguide with ‘in vacuum’ ferrite tiles is presented to further improve the HOM damping characteristic of a normal conduction 500 MHz cavity, which has been developed for the use in SR sources. Low power reflectrometry measurements demonstrate good matching of the prototype load, and high power tests of the ferrite absorber elements indicate that the waveguide load is well suited for the cavity HOM power levels present in state of the art 3rd generation SR sources.

INTRODUCTION

In an attempt to provide a normal conducting 500 MHz HOM damped cavity for 3rd generation SR sources a prototype cavity has been designed [1,2] and tested [3,4] using three tapered circular double ridged waveguides as HOM couplers, with circular waveguide to coaxial transitions (CWCTs) and coaxial vacuum windows to dump the HOM energy in external coaxial rf loads. With this concept maximum longitudinal and transverse HOM impedances below 5 kΩ and 200 kΩ/m have been obtained respectively. However, with the use of homogenous waveguides (no tapering), the coupling of the cavity HOMs to the waveguide can be further improved giving a significant reduction of the HOM impedances down to 1.7 kΩ for the longitudinal (see Fig. 1) and 60 kΩ/m for the transverse case.

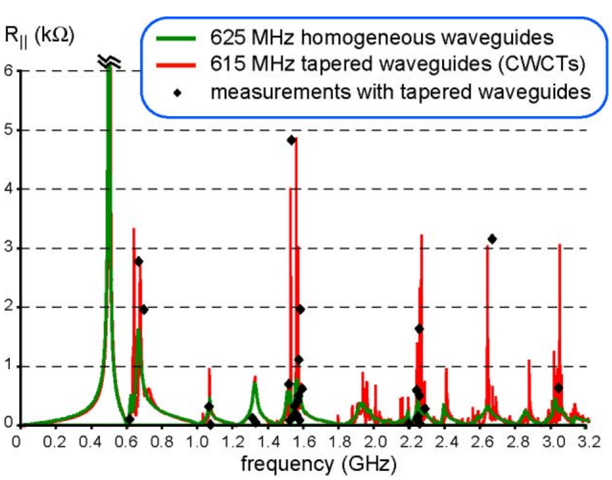

Figure 1: Longitudinal and transverse HOM impedance for an optimised HOM damped cavity with tapered and homogenous waveguide dampers.

*Work supported by BMBF and the Land Berlin…
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From an engineering point of view homogenous waveguides are simpler to manufacture than tapered structures. However, as the coaxial transition and the rf window at the end of the waveguide would become very bulky the rf load must then be integrated in the waveguide. In the following the design of an adequate HOM waveguide damper is described with ‘in vacuum’ ferrite absorber elements. The waveguide is fully compatible with the body of the HOM damped cavity as described in [8].

WAVEGUIDE AND ABSORBER LAYOUT

To absorb rf energy in a waveguide ferrites are well suited as they have complex permeability as well as complex permittivity and thus couple to the magnetic and to the electric field. Several ferrite materials are commercially available now that have proofed to satisfy accelerator requirements (e.g. TT2-111R / Transtech Inc., CMD10 / Ceramic Magnetics Inc., C48 / Countis Industries) such as UHV compatibility and amenability to bonding to a metallic substrate. Thorough measurements of complex μ and complex ε of such materials are given in [7]. We have selected C48, a NiZn ferrite, as much experience has been gathered with this material in the last 10 years by the Cornell group [6]. Figure 2 shows the layout of a homogenous ridged circular damping waveguide (cutoff frequency 625 MHz) made of OFHC copper with two dismountable wedge shaped ferrite absorber elements.

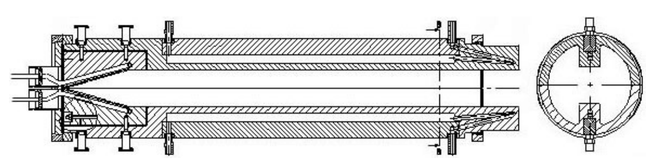

Figure 2: Homogenous ridged circular waveguide with two ferrite loaded absorber elements on the left hand side.

The geometry of the absorber elements and the thickness of the ferrite layer have been optimised numerically with the Microwave Studio code [5] to obtain good rf matching for HOM frequencies up to about 3 GHz (the TM_{01} cutoff frequency of a typical 3rd generation vacuum chamber cross-section) as well as a reasonably homogenous distribution of the absorbed rf power over the ferrite surface to maximise the power capability of the load. Excellent matching down to the level of 10% reflection has been achieved in the frequency range between 1.2 and 3.2 GHz whereas at lower frequencies between 0.8 to 1.2 GHz the maximum reflection is 37% which is still tolerable. As shown in Fig.

3 measurements of the reflection factor S11 for a low power prototype are in reasonable agreement with the simulations.

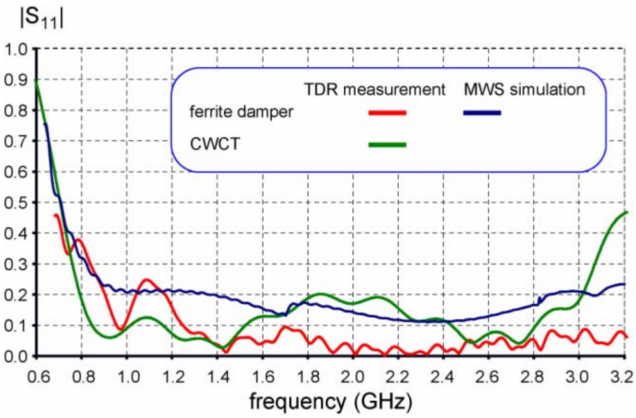

Figure 3: Simulation of S11 and time domain reflectrometry measurement for the waveguide absorber.

ENGINEERING CHALLENGES

The technical challenge in manufacturing the absorber elements is the bonding of the ferrites on a cooled metallic substrate with high thermal conductance, as the heat generated in the ferrite by the HOM fields must be removed efficiently. To our knowledge brazing and soldering are the only technologies to satisfy the constraints put on thermal conductance and UHV conditions. However, there is an inherent problem related with the difference in the linear thermal expansion coefficient between ferrites and metals (e.g. Δl/l = 8. 10-6/°C for C48, Δl/l = 16.8 10-6/°C for copper) which introduces thermal stresses in the ferrite layer during bonding and during rf operation.

At Cornell this problem was solved by introducing between the ferrite tiles and the copper substrate a plate made of Elkonite, a sintered tungsten /copper composite material with a thermal expansion coefficient adjustable via the copper content. We have favoured a simpler solution by soldering the ferrite tiles directly on the copper substrate, after annealing at 850 °C in a vacuum furnace to remove internal stresses and obtain a very low mechanical yield point. The prize to be paid is that the "soft" copper must not be work hardened in even the slightest fashion during assembly and operation. Otherwise, the induced mechanical stresses will fracture the ferrite the first time it is heated. Therefore careful design of the mechanical connection between the absorber element and the waveguide is mandatory. Figure 4 shows a simulation of the stress distribution in the absorber element introduced by an assumed axial force of 10^3 N exerted by the screws to mount the element in the waveguide, indicating that the region of the ferrite tiles is not affected by the induced stress.

To reduce the peak thermal stress during operation (and bonding) relatively small ferrite tiles (19.6 x 16.6 mm) have been used and all corners and edges on the upper surface were carefully rounded.

To minimize the thermal stress during bonding of the ferrites it is clear that the process temperature should be as low as possible, which favours soldering at low temperatures, but high enough to make sure that the operating temperature is always below the melting point of the solder material.

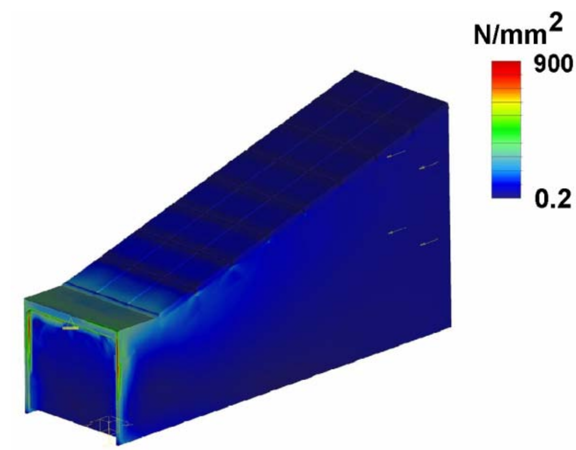

Figure 4: Stress distribution in the absorber element assuming an axial force of 10^3 N exerted by the screws. Maximum stress in the ferrite region is below 80 N/mm^2 in contrast to 800 N/mm^2 at the boundary to the waveguide

We made soldering tests using Au(80%)Sn(20%), an eutectic alloy with a 280°C liquidus, and Sn(90%)Ag(10%) a non-eutectic alloy with a 295°C liquidus and a 221°C solidus. For cost and simplicity reasons a Sn(90%)Ag(10%) foil with 0.1 mm thickness was used finally for soldering the prototype absorber elements at a temperature of 370°C under vacuum. For good adhesion between the solder and the ferrite the tiles have been sputtered before soldering with a 40 nm layer of Ti followed by a graded 300 nm layer of Ti and Cu using two sputter guns and a final 500 nm layer of Cu.

POWER TESTS

The total HOM power to be absorbed in the damping elements of a HOM damped cavity depends on the residual HOM impedance spectrum of the cavity and on the single bunch current, the bunch frequency and, most sensitively, on the bunch length of the storage ring under consideration. Conservative estimates have shown [9] that for many state of the art 3rd generation rings as ALBA/Spain , ALS/USA, BESSY II/Germany, ELET-TRA/Italy, SLS/Switzerland operating with 500 MHz rf systems the total HOM power absorbed per cavity will not exceed 1.2 kW. Assuming that additional 1.2 kW of power will be absorbed from the fundamental mode evanescent field this translates into a maximum power density of 4.8 W/cm^2 for the present absorber elements.

To check the quality of the ferrite bonding in an early phase of fabrication and to minimize the probability of ferrite cracking during operation all absorber elements must be tested at full power prior to the assembly in the waveguide. For this purpose a simple test set-up has been developed using commercial infrared radiators to generate power densities up to 10 W/cm^2. No cracks have been observed in the ferrite this up to this power density level. The IR radiators will be upgraded to generate power densities up to 20 W/cm^2 in the future.

Figure 5 shows the setup with an absorber element and a thermally isolated water-cooled shield to avoid IR radiation being absorbed by the copper surfaces of the absorber element. The power density transferred through the ferrite surface can then be determined by measuring the temperature increase in the cooling water of the absorber element. Concerning the generation of thermal stresses in the ferrite tiles this test can be assumed to be conservative as IR radiation is absorbed in a rather small surface layer in contrast to the HOM rf power which is absorbed in the bulk.

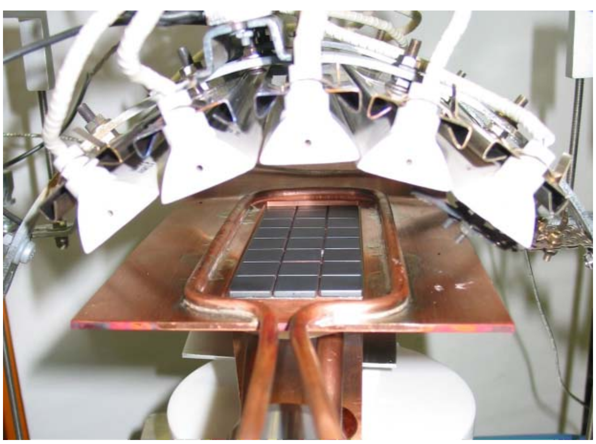

Figure 5: IR radiation setup for ferrite power tests.

Removing the IR radiator array shortly after exposure, IR images of the ferrite surface can be taken (see Fig. 6), which help to identify regions with poor thermal contact between the ferrite tile and the copper substrate.

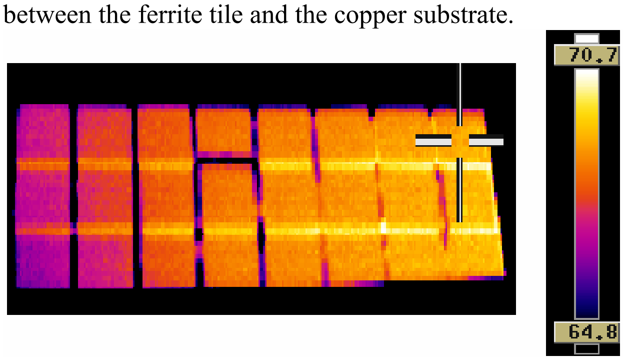

Figure 6: Surface temperature distribution on the ferrite tiles (in °C) from a IR camera image.

In addition to the IR test the prototype absorber elements have also been subject to an rf power test at 1.3 GHz under normal atmospheric conditions. RF power is coupled into the absorbing waveguide using a matched transition to a 7/8 “ coaxial line. With the present set-up the ferrite elements can be qualified up to a power of 700 W, corresponding to a power surface density of 2.1 W/cm^2. Modifications of the set-up to allow higher rf-power densities are under way.

CONCLUSIONS

A homogenous ridged circular prototype waveguide load with low reflection has been build and tested thermally with an absorbed power density of 10 W/cm^2 on the ferrite surface. The load has the potential to further reduce the maximum longitudinal and transverse HOM impedance of the BESSY HOM damped cavity down to the level of 1.5 kΩ and 30 kΩ/m respectively.

ACKNOWLEDGEMENTS

The authors would like to thank J. Borninkhof and D. Schüler for their help in setting up the equipment for the thermal power measurements and taking the IR camera pictures. We also want to thank FMB in performing the soldering tests, and ACCEL for manufacturing the first absorber element prototype.

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