BEAM PIPE HOM ABSORBER FOR 750 MHZ SRF CAVITIES *

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Abstract

Superconducting RF (SRF) systems typically contain unwanted frequencies or higher order modes (HOM). For storage ring and linac applications, these higher modes must be damped by absorbing them in ferrite and other lossy ceramic materials. Typically, these absorbers are brazed to substrates that are strategically located, often in the drift tubes adjacent to the SRF cavity. These HOM loads must have broadband microwave loss characteristics and be robust both thermally and mechanically, but the ferrites and their attachments are weak under tensile and thermal stresses and tend to crack. Based on existing work on HOM loads for high current storage rings and for an ERL injector cryomodule, a HOM absorber with improved materials and design will be developed for high-gradient 750 MHz superconducting cavity systems for storage ring and linac radiation sources. This work will build on novel construction techniques to maintain the ferrite in mechanical compression without brazing. The inside diameter requirements for a load for a 750 MHz superconducting cavity system depends on cavity models beyond the scope of this work; however, all elements of this study apply to the eventual final design. Attachment techniques to the metal substrates will include process techniques for fully compressed ferrite rings. Prototype structures will be fabricated and tested for mechanical strength under thermal cycling conditions. Furthermore, during beam operations, ferrites which see the beam can charge up, resulting in high-current instabilities. Consequently, coatings will be studied to determine how to ensure the adhesion of thin glassy films made with resistive materials.

INTRODUCTION

We received a Phase I grant to study process methods for constructing beampipe HOM loads using ferrite materials that would ultimately be used for 750 MHz cavity designs. Reliable beam pipe HOM loads must meet six critical pre-requisites, they must:

1. have an RF design and materials that damp the HOMs at cryogenic temperatures,
2. have a good mechanical design to remove the heat due to the absorbed RF, and
3. to withstand the temperature stresses,
4. have low outgassing rates for UHV compatibility,
5. have material strength such that there is no dust,
6. have some DC conductivity to prevent the buildup of charge.

The items related to the material requirements have been studied quite extensively by our collaborators at Cornell, and several materials have been found that meet the above requirements [1]. More recently that list has been reduced as further studies have indicated the degree to which these materials would lose their conductivity and be prone to charging at cryogenic temperatures [2].

Mechanical designs of HOM loads have ranged from various methods for attaching the HOM loads materials to the ID and/or OD of cylinders, to the sintering of the lossy material inside a cylinder for an "in situ" construction process.

All of these processes have worked to some degree, but their performance under the load stress has more often than not ended in failure. These failures usually involve the bond between the lossy material and the metal support structure, and/or the fracture of the lossy material.

The fracture of the lossy material is usually due to the low tensile strength of the material.

TECHNICAL APPROACH

The processes developed under this SBIR Phase I grant established the principles one would eventually use in the construction of a 750 MHz load. In addition these processes can be used to construct a beam pipe HOM load for any reasonable diameter beam pipe. Our general approach was to work at small diameters, perfect the process, and then work at large diameters. The small diameter in this case was a load with an ID of about 760 mm for the 1.3 GHz cavity in Cornell's ERL.

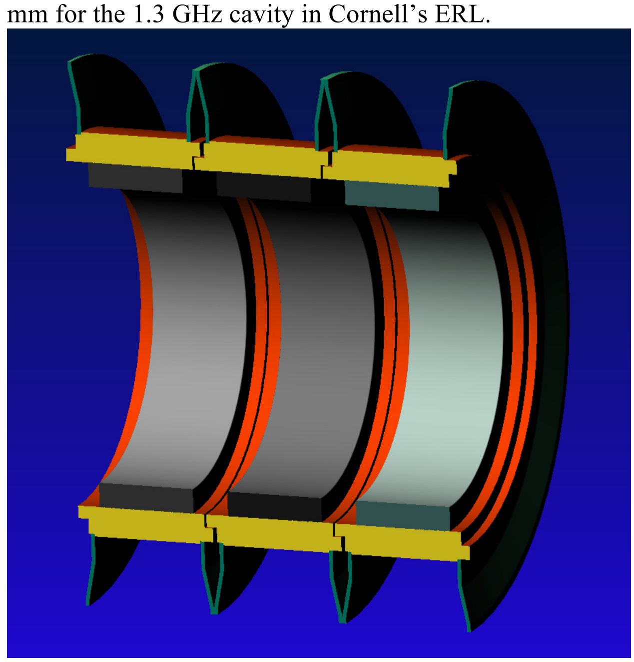

Figure 1: Conceptual drawing of Beam Pipe HOM loads

Material Considerations

The fundamental mechanical strength of ferrites, similar to ceramics, adheres to the fact that in

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compression the materials are about ten to twenty times stronger than when they are in tension. This fact was what led to compression windows, and in this paper we describe the HOM load construction process for compressing toroids made from ferrite materials. The manufacturer of the ferrite material we used to evaluate our processes indicated the compressive strength was in the range of 300-600 MPa. This is quite a large range, but gave us some flexibility in our experimental design.

The fundamental problem with working with copper is the issue of yield strength. Work hardened copper becomes soft after it is brazed into a sub assembly. In our experiments we found the hardness to change by a factor of about three. Copper when it was machined measured 86 HRF (Hardness Rockwell F-scale) and after brazing measured 33-34 HRF. This is roughly equivalent to a reduction of tensile strength by about a factor of three. The tensile strength of copper also increases about 20% going from room temperature to 76°K.

Assembly Process

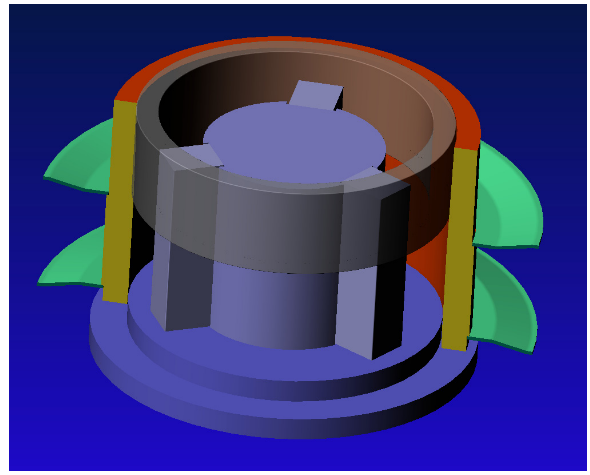
A one inch long cylinder of ferrite was decided on as a reasonable mechanical challenge. The manufacturer of the ferrite material also considered this to be a reasonable dimension for the initial set of experiments in the Phase I program.

The assembly process was based upon taking advantage of the differential expansion of the ferrite and copper. We used two different processes: a) the copper and ferrite were both raised to an elevated temperature such that the copper ID expanded to being greater than the ferrite OD, and b) the copper was raised to a moderate temperature and the ferrite cooled in LN at the beginning of a room temperature assembly process. The mechanical design of the copper compression ring assembly included a means for assuring the ring of ferrite would be guided into the copper to form the interference fit. Any tilt of the ferrite relative to the copper would have created an ellipsoid and the insertion process would undoubtedly end in failure.

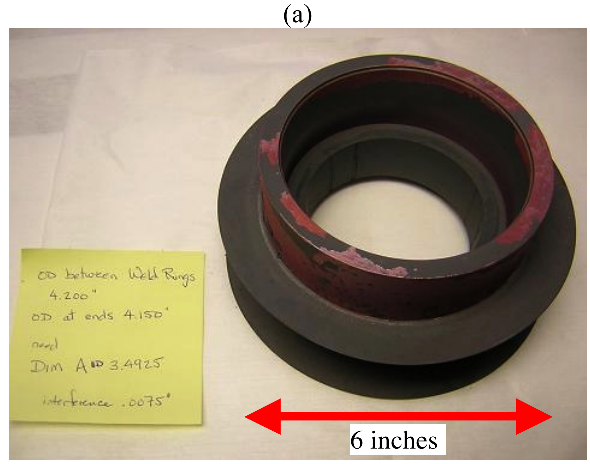
The linear taper at the top of the assembly drawing was used to guide the insertion of the ferrite cylinder and is later removed in a machining process. The linear taper at the bottom of the copper cylinder was to minimize edge stresses on the ferrite as the copper shrank down to form the interference fit at room temperature and during further cool down to operating temperatures.

After the insertion process, the assembly was machined to remove the sleeve taper, and the ends prepared such that several assemblies could be joined together to form a multi pack of ferrites as shown in Figure 1.

Figure 2 shows the results of an assembly done in an imperfect inert atmosphere. The oxidation of the copper is clearly visible and this step in the process will be avoided by improved control of the atmosphere. What we demonstrated at this step was the ability to properly orient the ferrite using the fixture we designed and heating to 500°C. The difference in thermal expansion of the ferrite and copper provided sufficient room for the ferrite to drop into place.



(a)



(b)

Figure 2: Ferrite ID is 3" with a nominal .030 wall. (a) Pictoral representation of the use of the assembly fixture, (b) results of a hot insertion.

Figure 3: Room temperature assembly process.

The room temperature assembly process included cooling the ferrite toroid to -200°C, and heating the copper to 100°C, then using a machine shop milling machine to align the ferrite with an insertion tool as shown in Figure 3. The guiding end of the assembly provided the necessary centering to make a smooth insertion.

Results of the Assembly Process

Table 1: Results of the assembly process for a designed interference fit at room temperature.

Run #	Type of Run	Interference fit on diameters	Results
1	Hot	.010"	failed
2	Hot	.005"	failed
3	Hot	.010"	success
4	Hot	.0075"	success
5	Hot	.005"	success
6	Room Temp	0.005"	success
7	Room Temp	0.005"	success
8	Room Temp	.0075"	failed

As shown in Table I, the first two hot runs were failures. We adjusted the way we used the fixture and the next three runs were successful at all interference fits we had designed for. The only problem with the hot run was the inadequate control of the atmosphere which created unwanted oxidation as shown in Figure 2.

The room temperature runs were a success until we tried too large of an interference fit. As shown in the table, the .0075 interference fit resulted in failure as the ferrite stuck half way through the insertion process.

Glass Coating Process

Figure 4: Glass coated ferrite in the final sub assembly module

Run #5 was made with a ferrite we coated with glass powder and melted in air at 800°C. The glass was designed to adhere to kovar by the manufacturer Elan Technologies [3]. It survive our assembly process, as the adhesion of the glass to the ferrite proved excellent. In the Phase II work we will continue with the experiments to include lossy materials such as nichrome powder in the glass mixture. The goal of this coating is to create the necessary losses to prevent the ferrites from charging up during beam operation and still allow the RF fields from the HOMs to penetrate through to the ferrite.

LOSS CALCULATIONS

Table 2: The data for the material characteristics used for the calculation of Loss (last column) in a 3 inch long cylinder of ferrite with a 3 in ID and a .25 in thick wall . The values for ε and μ are described in reference [1]. A final HOM load design will likely be constructed with several sub-assemblies using different ferrite materials, similar to what is shown in Figure 1.

Material	Freq, GHz	ε Re	ε Im	μ Re	μ Im	Loss, db
TT2-111R	10	11	0.25	0.4	1	2.6
TT2-111R	15	11.1	0.06	0.4	0.4	5.6
TT2-111R	20	11	1	0.6	0.1	4.3
TT2-111R	25	11	0.01	0.8	0.002	0.9
TT2-111R	30	12.77	0.27	0.80	0.004	0.9
HexMz	10	19	0.9	3	0.5	4.3
HexMz	15	18	0.9	1	1	6.9
HexMz	20	18	0.9	0.4	0.9	1.9
HexMz	25	18	0.9	0.5	0.7	1.7
HexMz	30	18.32	0.98	0.53	0.176	1.9
137ZR10	15	18	2.3	1	0.08	8.1
137ZR10	20	21	5	0.9	0.008	2.8
137ZR10	25	22	6	0.9	0.03	1.7
137ZR10	30	17.5	3.81	0.98	0.007	2.6

750 MHz DESIGN

The ultimate design of the 750 MHz HOM load will depend on the final design of the 750 MHz cavity, the location of the load relative to the cavity, and the inside diameter of the beam pipe where the HOM load resides.

CONCLUSION

During this Phase I effort, we have developed a process for making HOM loads which solves the problem of unwanted stresses on the load material due to the mismatched interface between the load material and the heat sink. This process includes a means for coating the load material to reduce charging effects. The size of the load can be easily scaled to larger diameters and lower frequency SRF cavities.

REFERENCES

[1] V. Shemelin, et. al., "Characterization of ferrites at low temperature and high frequency", Nuclear Instruments and Methods in Physics Research A 557 (2006) 268–271.

[2] E. Chojnacki, et. al., "DC Conductivity of RF Absorbing Materials", Presented at the 14th International Conference on RF Superconductivity, Berlin (SRF 2009).

[3] Elan Technologies, PO Box 779, Midway, GA 31320, http://www.elantechnology.com/