Design and Fabrication of a Ferrite-lined HOM Load for CESR-B*

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Abstract

The beam tubes on the CESR-B cavity have been designed so that all of the higher order modes (HOM's) will propagate out of the cavity. To damp these modes to Q values of ~100, we have proposed the use of HOM loads that are an integral part of the beam tube, though located outside the cryostat. The absorbing medium is ferrite tiles which are bonded to the inside of a 304 series stainless steel water-cooled jacket.[1] The bonding agent is an alloy which melts at ~220°C. This alloy provides good thermal, as well as electrical, conductivity. Calculations indicate that these loads will provide the necessary damping and measurements using full-size models have verified this. It is anticipated that each HOM load for CESR-B will have to absorb 10-20 kW of beam induced power. High power tests of a scale model of the CESR-B load have been performed. The full-size load awaits final construction to be followed by testing.

I. INTRODUCTION

CESR-B is the culmination of a proposed series of upgrades to the Cornell Electron Storage Ring. Each cavity in this asymmetric collider will have an HOM load located just outside the cryostat on either end of the cavity. The large beam tubes of the cavity function as the HOM couplers (for more on the cavity design see [1]). In the low energy ring of CESR-B each load must absorb 14-24 kW (13-23 W/cm^2) of HOM power. The Q's of the HOM's with high R/Q's must be less than ~100.

Each HOM load is a composite structure consisting of RF absorbing tiles bonded to a water cooled 304 SS shell. The end view of a load is shown in Figure 1. The back surface of the tiles is ground to a radius 0.005" (0.13 mm) smaller than the inner radius of the shell; the inside surface of the tiles is planar. The tiles are 0.125" thick at the thickest point, ~0.063" (1.6 mm) at the thinnest. A helical winding forces the cooling water to flow around the jacket.

A lossy ferrite will be used as the RF absorbing material. The chosen ferrite must: 1) suitably damp the HOM's; 2) be amenable to bonding to a metallic substrate; 3) not break during fabrication or under RF load; 4) be UHV compatible; 5) be dust free; 6) have some DC conductivity to prevent the buildup of charge due to stray particles. Items 4, 5 and 6 are required because the loads are on the beamline. We have identified three potential materials, described in Table I.

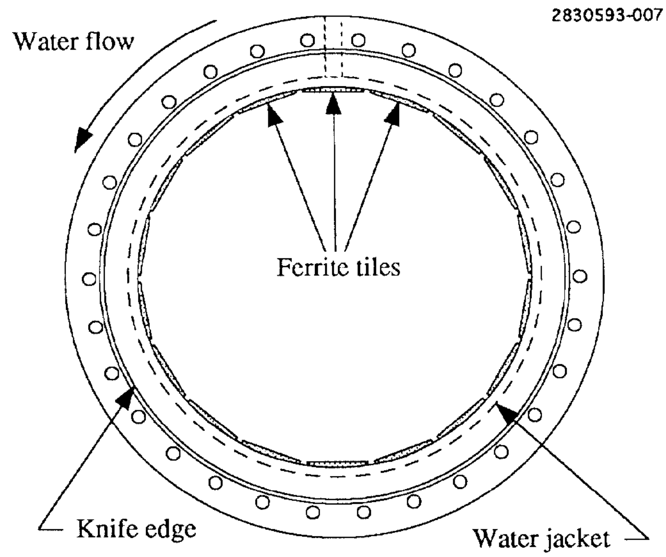

Figure 1. End view of the HOM load. The tiles are radiused on the outside surface only.

Table I
Potential RF Absorbing Ferrites for Use in CESR-B

Ferrite	DC Resistivity (Ω-cm)	Tensile Strength (ksi)
Ferrite-50[2]	10-100	~ 4.3†
TT2-111R[2]	4 - 100,000	59 ± 5
CMD-10[3]	1000	13 ± 4

† The presence of microcracks throughout sintered Ferrite-50 pieces makes this number very unreliable.

II. HOM DAMPING CAPABILITY

The effectiveness of HOM damping by the loads may be either measured or calculated. Because the properties of the ferrites are frequency dependent, damping measurements must be made on full-scale models in order to be relevant. The damped Q's of the monopole modes may be calculated using SEAFISH [2]. Lossy materials are accomodated in SEAFISH

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1 This process was developed by Reasearch & PVD Materials Inc., Ridgefield, NJ 201-943-1650

2 Product of Trans-Tech Inc., Adamstown, MD 301-695-9400
3 Product of Ceramic Magnetics Inc., Fairfield, NJ 201-227-4222

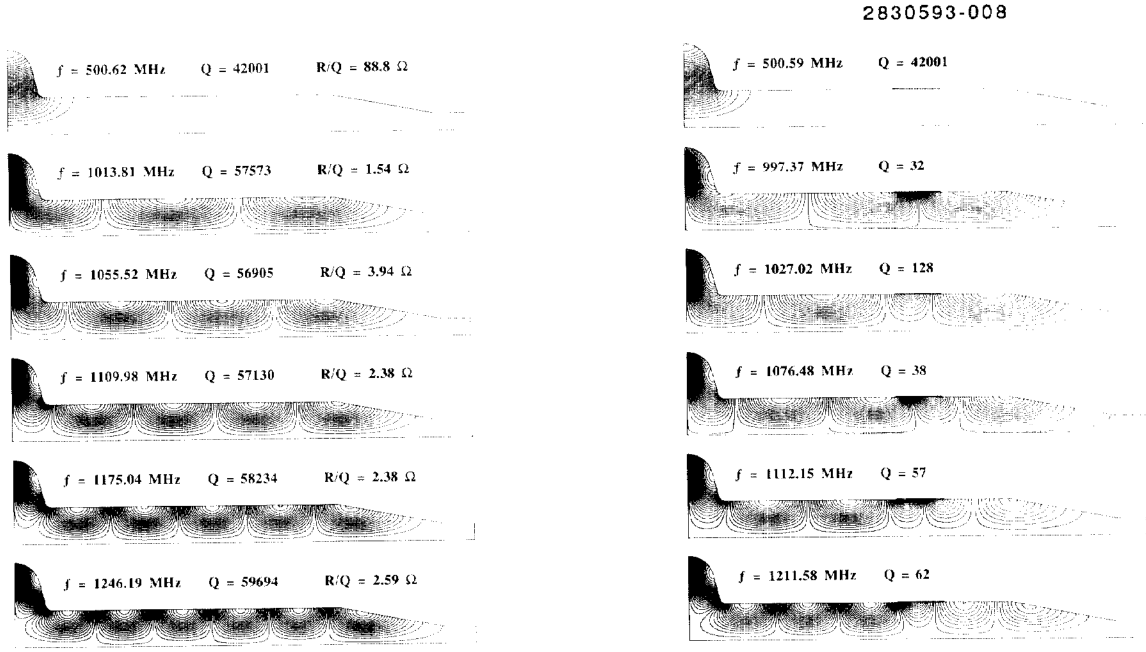

Figure 2. Calculated field patterns of the undamped and damped monopole HOM's. These modes have the highest R/Q's. The RF absorbing material was TT2-111R. The undamped modes were calculated using SUPERFISH, the damped modes using SEAFISH.

through the use of a complex ε and μ. It is, therefore, necessary to know ε and μ as a function of frequency for each ferrite. These parameters have been measured for several ferrites and are reported in another work [3]. Examples of the field patterns of undamped and damped modes are shown in Figure 2.

A comparison of measurements using a full-scale copper cavity and SEAFISH calculations is given in Figure 3. TT2-111R was the RF absorber in both cases. The measured Q's for the undamped higher order modes are lower than the calculated values because of joint losses. The agreement for the damped Q's is quite good. The results of damping on the dipole and quadrupole modes is given in another work [4].

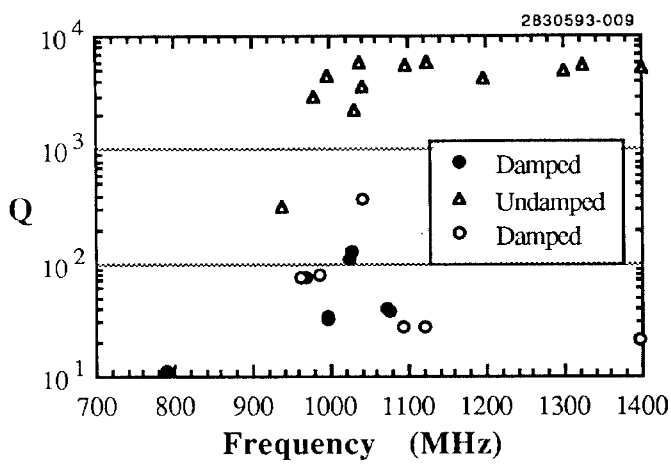

Figure 3. A comparison of measured (open symbols) and calculated (filled symbols) Q's for the monopole HOM's. The RF absorber was TT2-111R.

III. BONDING

Copper-silver based brazing alloys have limited usefulness for this application. The vacuum brazing ensures that the ferrite will be well-outgassed, but it may cause severe oxygen loss in the ferrite [5]. A through-transmission ultrasonic image of a piece of TT2–111R brazed to 410 SS is shown in Figure 4. Any break in the ultrasound path appears as a dark region in the image. A subsequent SEM examination of this sample in cross-section showed that some regions of the ferrite were not wet by the braze alloy. In other regions the wetting was good, but the ferrite cracked a grain away from the joint. It is presumed that this cracking was caused by the stresses produced when the composite was cooled to room temperature after brazing.

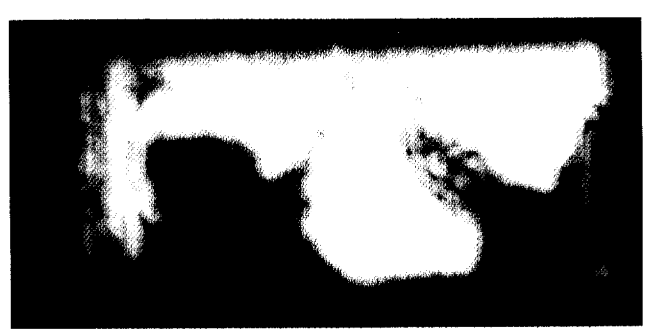

Figure 4. Through transmission ultrasonic image of TT2-111R brazed to 410 SS. The bright areas indicate a good bond. The sample dimensions are ~0.5" x 1.0" (~13 x 25 mm).

Tiles of Ferrite-50, TT2-111R and MN67 (another ferrite from Ceramic Magnetics) have been succesfully bonded to 304 SS using a low temperature soldering process.[1] An ultrasonic image of TT2-111R soldered to 304 SS is shown in Figure 5. In this process, the ferrite is metallized and then "tinned" with the solder without the use of flux. The stainless steel substrate is plated with ~0.0005" (~13 μm) of electroless nickel. To prevent oxidation problems and to further avoid the use of flux, tin is plated to a thickness of ~0.0001" (~2.5 μm) on top of the nickel. The pieces are then clamped together and heated to ~250°C. The low temperature required by this process has an advantage in that it does not affect the electromagnetic properties of the ferrite. It also makes the fixturing required for fabrication relatively simple. The disadvantage is that it limits the temperature one may use for vacuum outgassing.

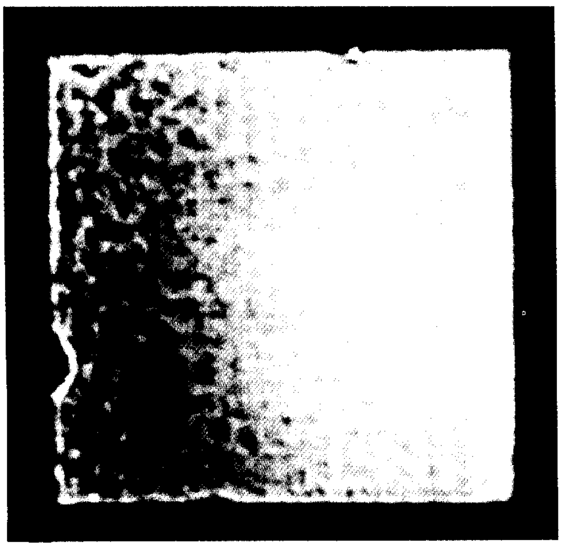

Figure 5. Through-transmission ultrasonic image of TT2-111R soldered to 304 SS. The contrast was increased in this image to vizualize the mottled intensity caused by thickness variations in the solder joint. The sample dimensions are ~1" x 1" (~25 x 25 mm).

IV. POWER HANDLING CAPABILITY

A scale model of the load was tested under high RF power. The load consisted of eight 0.6" x 2.0" (~15 x 51 mm) tiles of TT2-111R ferrite soldered to a water cooled 304 SS jacket. This load was used as the outer conductor of a 1.625" rigid coaxial line. RF power up to 800 watts was supplied by a 2450 MHz magnetron.

With this apparatus a power density of ~10 W/cm^2 on the ferrite surface could be achieved. The ferrite tiles suffered no ill effects, i.e. they did not crack or fall off. The power absorption was roughly linear, implying that ε and μ are not field dependent, at least up to these fields.

Cooling water at an input temperature of 30°C will flow through the full-size load at a rate of ~10 gpm. Under these conditions, the ferrite temperature is expected to rise to ~80°C when the absorbed HOM power is ~20 kW.

V. UHV COMPATIBILITY

We have opted to pre-bake the tiles at a high temperature before bonding them to the load shell in order to drive off the major vacuum contaminants. This is done after all of the grinding and cleaning operations. The bake cycle that has been recommended [6] for TT2-111R is as follows: ramp at 100°C/hr to 900°C; hold for two hours; ramp to room temperature at 100°C/hr. The firing must be done in air in order to prevent dissociation of the ferrite. We have followed this procedure and have found no significant change in the ε and μ of a sample. Following this firing, the tiles will be handled in a clean, dry manner when soldered to the load shell. The fully assembled load will receive a low temperature vacuum bake if necessary.

It should be noted that the TT2-111R ferrite has been used in the ACOL Ring at CERN with good results [7]. Several square meters have been operating in a vacuum of 10^{-11} torr. The tiles were baked at 250°C.

VI. SUMMARY

This approach to HOM damping appears to supply the damping required for stable operation of superconducting cavities in CESR-B. We have identified at least one complete fabrication path. Crucial to the success of load fabrication was the development of the low temperature soldering process. RF testing has been successfully completed up to a power density of ~10 W/cm^2, approximately half that expected in CESR-B. A full scale load is being completed and will be tested this summer.

V. REFERENCES

[1] H. Padamsee, et al., "Accelerating Cavity Development for the Cornell B-Factory, CESR-B", *Conference Record of the 1991 Particle Accelerator Conference*, Vol. 2, pp. 786-788, San Francisco, CA, May 1991

[2] SEAFISH is a complex version of SUPERFISH. SEAFISH was written by Mark de Jong, AECL Research, Chalk River Laboratories, Chalk River, Ontario, Canada K0J 1J0. SUPERFISH was written by R.F. Holsinger and is maintained by AT-6 Division, M.S. H829, Los Alamos National Laboratory, Los Alamos, NM 87545.

[3] W. Hartung, D. Moffat, T. Hays, *Measurements of the Electromagnetic Properties of Some Microwave-Absorbing Materials*, Internal Report SRF-930113/01, Laboratory of Nuclear Studies, Cornell University.

[4] V. Veshcherevich, et al., *Higher Order Modes Damping in CESR-B Cavity*, Internal Report SRF-920701-04, Laboratory of Nuclear Studies, Cornell University.

[5] Mark deJong, AECL Research, Chalk River, private communication.

[6] Lou Domingues, Trans-Tech, private communication.

[7] Fritz Caspers, CERN, private communication.