Use of Ferrite-50† to Strongly Damp Higher Order Modes*

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Abstract

A new higher order mode damping concept has been proposed for use with the superconducting RF cavities for the Cornell B-factory, CESR-B. All higher order modes are brought out of the cavity via the beam tubes which have a large diameter and special shape. Because of their propagation, these modes can be damped by a 15 cm long beam tube section of Ferrite-50 such that the Q's of all the modes are below 200, with most being below 100. The microwave losses of Ferrite-50 have been found to be $\geq 10^4$ times higher than copper at ~1 GHz, and to decrease by a factor of 10 at 10 GHz. The tolerance of Ferrite-50 to high power has been tested up to 10 watts/cm^2 (RMS). Its vacuum properties appear promising and a 200°C bake is permissible without a loss of its microwave absorptive properties. Techniques by which to fabricate a 24 cm diameter beam tube section are being explored.

I. INTRODUCTION

The Cornell B-factory design calls for the use of superconducting RF cavities. The primary reason for this is to provide the highest possible accelerating gradient and keep the overall machine impedance as low as possible (the design of the cavities for CESR-B is discussed in detail in another paper presented at this conference [1]). Beam power deposited in higher order modes (HOM's) in superconducting cavities is a potential problem because of the high Q_o's of these modes. In order to prevent deleterious effects on the beam it is necessary to aggresively damp these modes. Instead of traditional coupler(s), appropriately placed to damp these modes, we have opted to use an absorbing material in the beam tube wall as a load. This radically new design calls for many challenges to be overcome.

Our design places the following demands on the material to be used:

- RF resistivity ≈ 10^4 x copper
- use in a vacuum $\leq 10^{-9}$ torr
- electrically and thermally conducting
- broadbanded load able to handle the dissipation of ~ 10W/cm^2

We have identified Ferrite-50† as a candidate material for this use. This ferrite has a μ at 1 kHz >150 and a nominal DC resistivity of ~25 Ω-cm. In order to evaluate its suitability for our purposes we need to determine the following properties:

- complex ε_r and μ_r as a function of frequency[1]
- mode damping capability
- bondability
- vacuum compatibility
- power handling capability

II. ε_r AND μ_r MEASUREMENT AND MODE DAMPING

We have used a coaxial test line connected to an HP 8720A network analyzer to measure the real and imaginary parts of ε_r and μ_r from .2 to 20 GHz. The procedures and equations necessary to determine ε_r and μ_r from the S-parameters are given in [3,4]. To verify that our apparatus was yielding accurate results, a 6.5 mm piece of teflon was measured. The measured values of ε' and μ' were quite close to the accepted values over the frequency range .5-10 GHz. The measurements of ε'' and μ'' deviated from their correct values by a fair amount. This resulted, in part, because this technique does not measure low-loss materials accurately. It also showed that our apparatus was in need of refinement. While improvements were being made, we measured a 3.6 mm piece of Ferrite-50. Our results are shown in Figures 1 and 2.

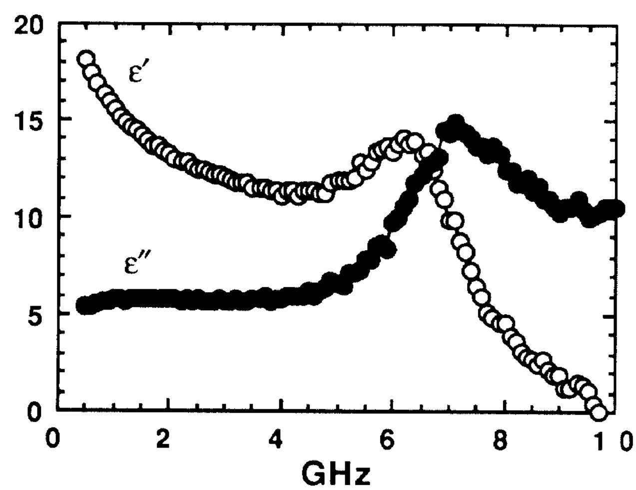

Figure 1. Measured values of ε_r for Ferrite-50.

Knowledge of ε_r and μ_r as a function of frequency allows one to calculate parameters such as skin depth, loss tangent, impedance, etc. Figure 3 shows the frequency dependence of the real part of the impedance of Ferrite-50 calculated using our

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†Ferrite-50 is the product of Trans-Tech, Inc., Adamstown, MD
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[1] The most common definitions of complex ε and μ are [2]:
$\varepsilon = \varepsilon_o \varepsilon_r = \varepsilon_o (\varepsilon' - j\varepsilon'')$ $\mu = \mu_o \mu_r = \mu_o (\mu' - j\mu'')$

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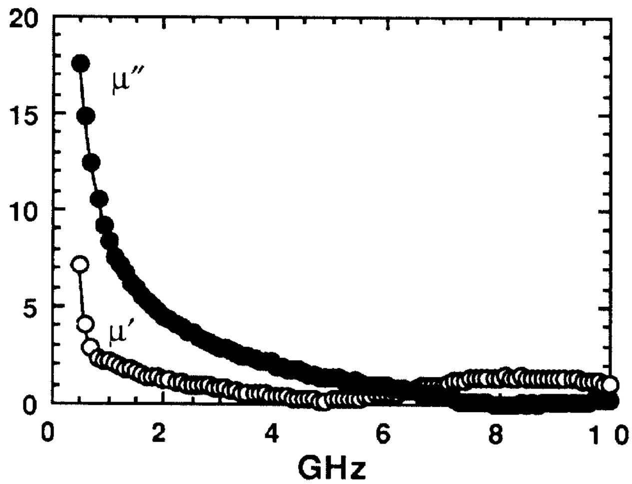

Figure 2. Measured values of μ_r for Ferrite-50.

measured values of ε_r and μ_r. The calculated skin depth of this ferrite at 1 GHz is 5.4 mm.

There is now a computer program based on SUPERFISH [5], called SEAFISH [6], which allows one to input the complex values of ε_r and μ_r. With these parameters, SEAFISH can calculate the resonant frequencies and field patterns of monopole modes for cavities with absorbing materials. Thus, one is able to calculate the frequency shift and drop in Q caused by loading a cavity. The agreement between SEAFISH and experiment for small ferrite cylinders in a cavity is good.

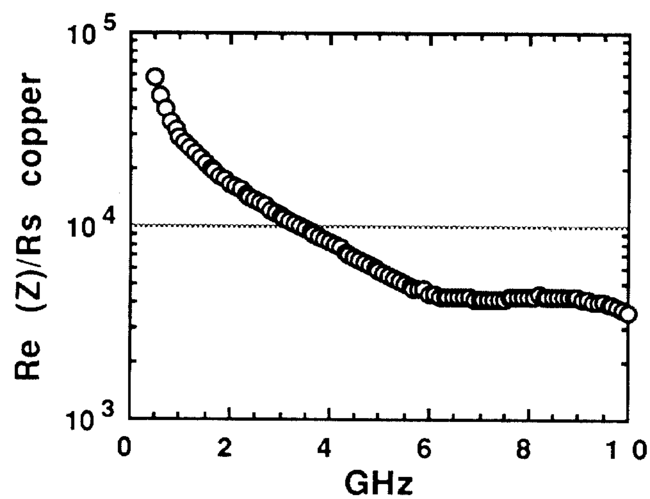

Figure 3. Frequency dependence of the real part of the impedance of Ferrite-50 divided by the surface resistivity of copper.

An S-band model of the B-factory cavity and ferrite loads was tested to verify the mode damping capability of the load. It was found that the Q's of the HOM's were lowered to ~100. More details can be found in [1].

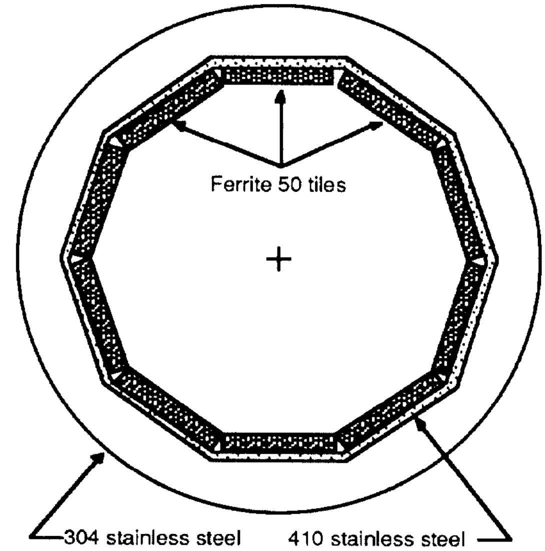

Figure 4. Ferrite beam tube load concept.

III. Bondability and Vacuum Compatibility

It will be impractical to make the full-size B-factory load, 24 cm ID x 15 cm long, from one piece of Ferrite-50. Thus we must design a shell that will be vacuum and water tight to which pieces of Ferrite-50 may be bonded on the inside. The thermal expansion coefficient of the shell material must be close to that of Ferrite-50 so that the ferrite pieces do not break or pop off. The bonding agent must be electrically and thermally conducting and must not degrade the vacuum.

Our present design for a load is shown in Figure 4. A Ferrite-50 tile(s) will be bonded to each side of the polygon. The number of sides of the polygon will depend on factors such as:

- bond quality as a function of bond area
- thermal differentials within a ferrite tile
- fabrication limitations on the ferrite dimensions
- deflection of the shell due to atmospheric loading

After some trial and error, we discovered a shell/bonding agent combination that worked well. The shell must be made of titanium, a titanium alloy, or a 400-series stainless steel. A bonding agent that satisfies our requirements is PYRO-DUCT 597[2]. PYRO-DUCT consists of an aqueous-based inorganic binder which is loaded with silver flakes. When cured, i.e. when the water is driven off, the result is a conducting ceramic which can used at temperatures as high as ~900°C. Both the metal substrate and ferrite pieces must be sand-blasted to permit a good bond.

A sample piece of Ferrite-50 bonded to 410 stainless steel was tested for vacuum compatibility. The sample and system were baked at 325°C for several hours. The vacuum of the system after this was limited by the pump to $\sim 3 \times 10^{-9}$ torr.

[2] PYRO-DUCT 597 is the product of Aremco, Inc., Ossining, NY

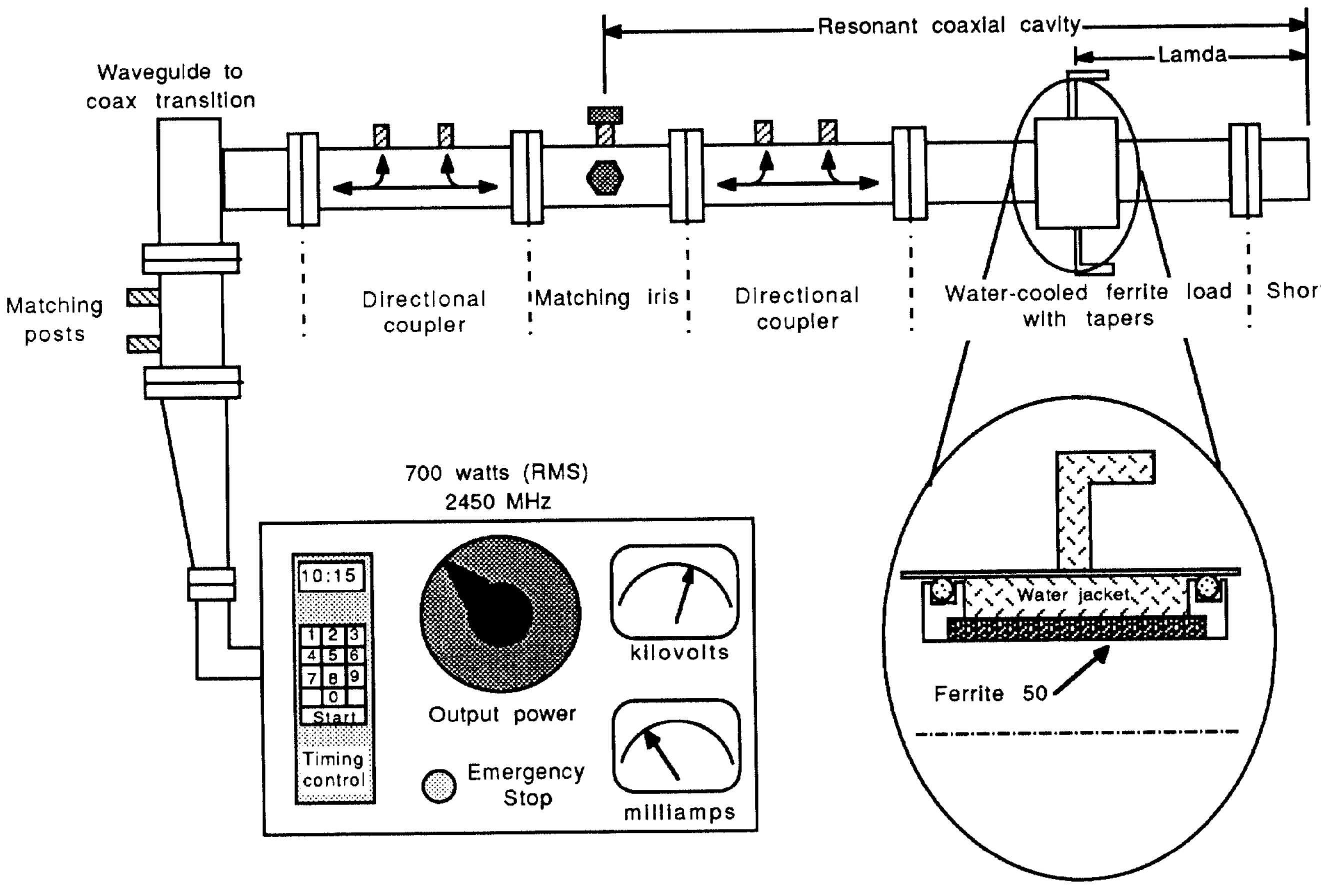

Figure 5. High power load test apparatus.

An outgassing rate of ~2×10^{-10} torr-ℓ/sec was determined by turning off the pump for 2.5 hours and measuring the increase in pressure.

IV. Power Handling Capability

The beam tube load must damp the higher order modes and absorb the anticipated power without breaking. The HOM spectrum consists of discrete modes, each with a different power level. It is not possible to simulate this spectrum at the anticipated power levels. As an alternative means of testing the load, we placed a Ferrite-50 tube at a magnetic field maximum in a resonant cavity made from 1-5/8" coax. The dimensions of the load were 45 mm ID x 52 mm OD x 30 mm. The resonant frequency of the cavity is 2450 MHz. The power source for the apparatus, shown in Figure 5, is the magnetron from a kitchen microwave oven.

For this test, the load was core-drilled from a solid block of Ferrite-50 and glued into flanges. Thus, the ferrite also served as the inner wall of the water jacket. At a power density of 10.7 W/cm^2 the ferrite tube began to leak water.

V. Summary

Ferrite-50 appears to have the intrinsic properties necessary for use as a beam tube HOM load. Further work needs to be done in the area of measurement of ε_r and μ_r. An S-band, tiled load is being fabricated and will be tested up to ~20 W/cm^2. The full-scale load is undergoing the first round of design considerations. SEAFISH calculations of mode damping in the B-factory geometry are continuing.

VI. References

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