FERRITE-LINED HOM ABSORBER FOR THE E-COOL ERL*

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Abstract
An R&D Energy Recovery Linac (ERL) intended as step towards electron-cooling of RHIC-II is being constructed at this laboratory. The center piece of the project is the experimental 5-cell 703.75 MHz superconducting "ECX" cavity. Successful operation will depend on effective HOM suppression, and it is planned to achieve HOM damping exclusively with room temperature ferrite absorbers. A ferrite-lined pillbox test model with dimensions reflecting the operational unit was assembled and attached to the 5-cell copper cavity. The cavity resonances of the lowest dipole and monopole modes and their damping due to the ferrite were determined. The effective ferrite properties in a form portable to other structures were obtained from network analyzer measurements of the ferrite absorber models and their interpretation with the simulation code Microwave Studio

INTRODUCTION

The constant quest for higher luminosities at the Relativistic Heavy Ion Collider is supported by an intensive experimental R&D program to develop electron-cooling of the ion beams. Electron cooling of RHIC at collisions requires electron beam energy up to about 54 MeV together with an average current reaching ~100 mA. The accelerator chosen to generate this electron beam is an Energy Recovery Linac (ERL). The "Electron-Cooling Xperiment (ECX)" for RHIC is being constructed at this laboratory based on a superconducting 703.75 MHz 5-cell cavity capable of 20 MeV and a superconducting 2 MV electron gun. [1]. Reducing higher order modes (HOM) in the superconducting accelerator cavity is one of several challenges and, following the techniques developed at Cornell [2,3], will be addressed exclusively by means of ferrite absorbers. The cavity design [4] intentionally provided enlarged 24 cm beam tube apertures to allow propagation of HOM towards the absorbers located at room temperature.

In contrast to low-loss RF cavities, the addition of ferrite limits the use of many open (free) simulation programs, and even in the commercial programs presents a nearly insurmountable challenge. The availability of a 5-cell copper cavity and attaching one stitched-together ferrite absorber provided the opportunity to assess the damping of the dominant lower-frequency monopole and dipole modes in the ERL. Transforming the prototype absorber into a ferrite-lined pill box provided the opportunity to compare experimental data with simulation results. A large quantity of experimental data was collected over a period of about two years and preliminary results have been reported elsewhere [5]. Computer simulation programs were evaluated pointing to the primary use of CST Microwave Studio [6]. Portable absorber properties, that is, parameters which describe the damping globally without the need of considering the details of the tiled structure are here presented in the form of an equivalent permeability and permittivity for a cylindrical absorber.

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CU CAVITY WITH HOM ABSORBER

The ECX 5-cell cavity with the prototype HOM absorber is shown in Fig. 1. S21 scattering coefficient measurements were performed to determine the frequencies and quality factors of the cavity HOM's. The cavity is excited by an input probe centered on the shorting disk on the left side in the picture. The output signal is taken either with a probe on the shorting disk on the right end or at the cavity side with the pick-up (PU) probe designed for operation of the Nb cavity. The PU probe is sensitive to monopole as well as dipole modes whereas the axially located probes strongly favour monopole modes. The beam tube has a ~24 cm diameter suppressing propagation of the TM010/n modes and limiting propagation of the lowest hybrid dipole mode to the coaxial end probe.

The S21 transmission coefficient from input to the PU probe is shown in Fig. 2, both for the cavity with the ferrite absorber and for the state where the absorber is

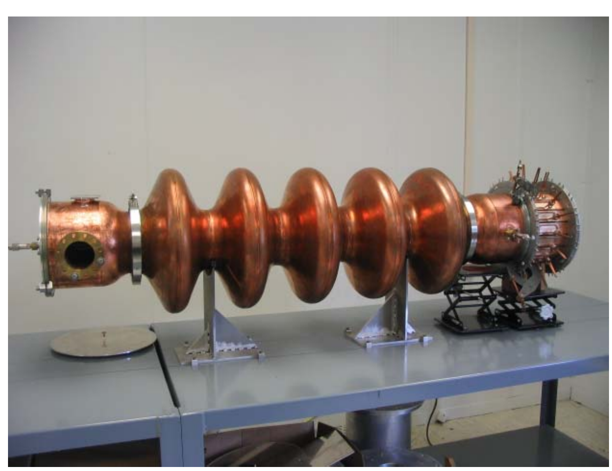

Figure 1: Cu cavity with HOM absorber

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replaced by a beam tube of equal length in order to maintain the electrical length and node positions of the standing waves. The output signal at the cavity end, yellow, shows 1) clearly the suppression by the beam tube below cut off, 2) the strong damping by the absorber, black, and 3) the weak signal on axis of dipole modes, red.

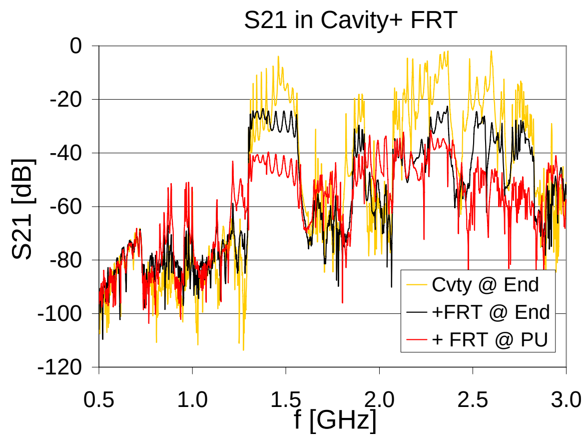

Figure 2: Transmission scattering coefficient

The lowest non-trapped order monopole modes are best measured by the on-axis end probes. The first two monopole TM02 pass bands, with forward and backward waves, are shown in Fig. 3. Eigenfrequencies and R/Q values for the shorted Cu cavity from simulations, and measured Q_{FRT} results and shunt impedance with the absorber added are given in Table 1. Contact losses limit Q in the Cu cavity whereas the Q_{FRT} and R is given by the ferrite losses.

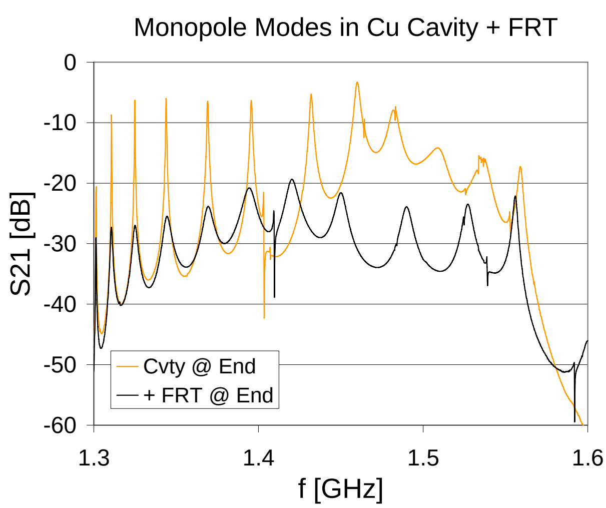

Figure 3. Monopole modes w/wo ferrite absorber

Studying the absorber damping of the transverse HOM's is best done by means of the S21 signal to the PU probe. The dominant dipole modes in the low-frequency range from 800 to 900 MHz are shown in Fig. 4. The excitation of the resonances was adjusted to separate the redundancy by their polarization in order to obtain accurate quality factors.

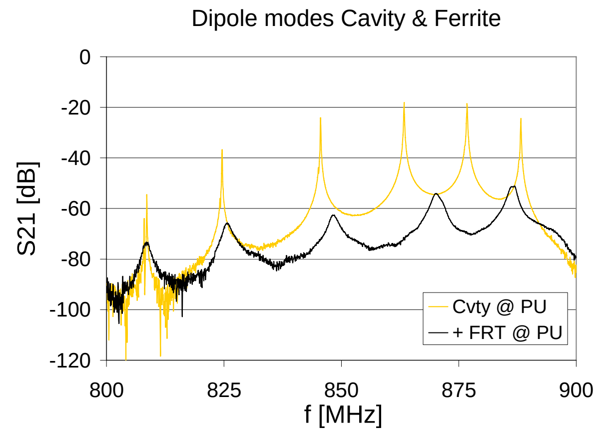

Figure 4: Dipole modes w/wo ferrite absorber

Table 1: Monopole modes in Cu Cavity

$f_{Cu\ [GHz]}$	f_{Frt} [GHz]	R/Q[kΩ]	Q_{FRT}	R [MΩ]
1.301	1.302	1.32	3891	5.1
1.309	1.312	3.49	902	3.1
1.321	1.327	6.63	381	2.5
1.338	1.348	1.96	237	0.46
1.361	1.377	1.81	148	0.27
1.389		2.84		
1.419		13.1		
1.456	1.448	1.73	166	0.29
1.496	1.491	1.46	164	.24
1.532	1.529	36.4	200	7.3
1.559	1.557	22.3	496	11.1

HOM FERRITE ABSORBER MODELS

The HOM absorber for the ECX superconducting 5-cell cavity is a cylindrical spool with ferrite tiles attached to the wall, similar to a test model shown in Fig. 5. The model was assembled with available surplus tiles in the shape of a ferrite-lined resonant pillbox. The operational unit has 18 bronze plate sections in the 25 cm diameter spool, each attached with two ferrite tiles of 2 × 1.5 × 0.125 in. dimensions. Transforming the model into a resonant cavity by shorting endplates with small axial probes allows scattering coefficient measurements.

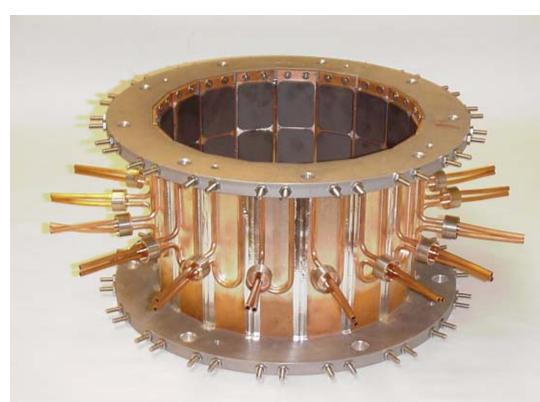

Figure 5: Absorber model with ferrite tiles

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Analyzing the experimental S21 transmission coefficient by means of the CST Microwave Studio simulation program or by analytical methods provides the opportunity to extract the ferrite parameters. The resonances of the prototype, 18.5 cm long, are overlapping, and a "very short (VS)" pillbox was assembled in which the TM010 resonance can be clearly identified.

TM010 Resonance at ~800 MHz

The empty VS pillbox has a radius of 12.03 cm and is 6.5 cm long. The ferrite tiles are 5.08 cm long leaving a gap, and due to the lack of material the VS cavity has two tiles missing. The JDM eigenmode solver of the MWS simulation program was used to find permeability values, (while keeping $\varepsilon \approx 13$ constant) which reflect the resonance at 800 MHz with $Q \approx 3.4$. Selecting sufficiently detailed mesh size, close to 400k, at the expense of running time, about two hours for the VS cavity, is important. With the fully detailed model, one finds $\mu \approx 4.5(1\text{-j}2.75)$. In order to make absorber parameters portable to other structures the computer model was simplified into two solid half-cylinders leading to $\mu \approx 11(1\text{-j}1.05)$. The working assumption is that the absorber properties in an operational structure can be obtained with a ferrite cylinder with these values.

Broadband Study of the Pillbox S21 Data Curves

Complex microwave permeability and permittivity data of the C48 ferrite used in the ERL absorber are available from a CLS report [7] covering the frequency range of interest here. The values were obtained at frequencies from 915 to 2800 MHz, based on measurements of small pellets, 3.5 mm in diameter and 3.175 mm thick. Other materials values were studied at Cornell [8]. Although relevant, their data is not directly applicable to the prediction of the HOM ferrite absorber with its tiled structure, and the study of an actual unit is required.

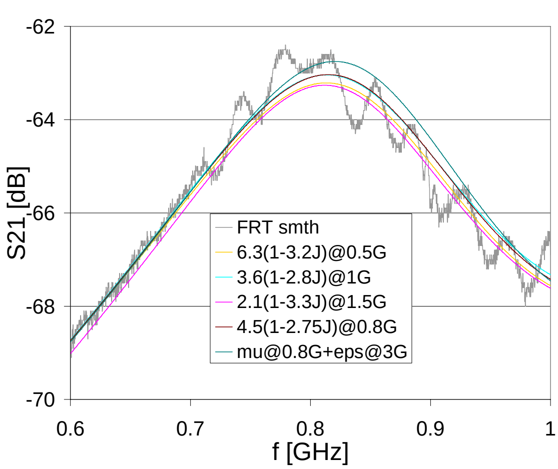

Figure 6: Matching of the S21 with different mu-values

In the fully tiled pillbox model, S21 measurements can be simulated using the MWS frequency domain solver with the free parameters of permeability given by its real part, (mup) and the $\tan\delta$ in a first order Debye model, defined at a specific frequency. Keeping the computer run time to a few hours, the frequency range is limited to the TM010 resonance. The loss contributions from the imaginary permittivity are small compared to the ferrite losses and exploratory simulations were done mostly with $\varepsilon = 13$. The simulation results for the 0.5-1 GHz resonance range are shown in Fig. 6 and the best match is obtained with μ(0.8GHz)= 4.5(1-j2.6) and with ε(3GHz)= 13(1-j0.05) from the CLS results. The permeability from this study is compared with CLS data in Fig. 7 and sufficient agreement is found in the frequency range covering the low dipole and monopole HOM's. The "best match" is used for the VS pillbox broadband study shown in Fig. 8.

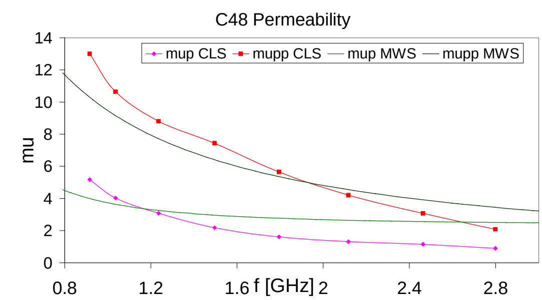

Figure 7: C48 Permeability from CLS and this study

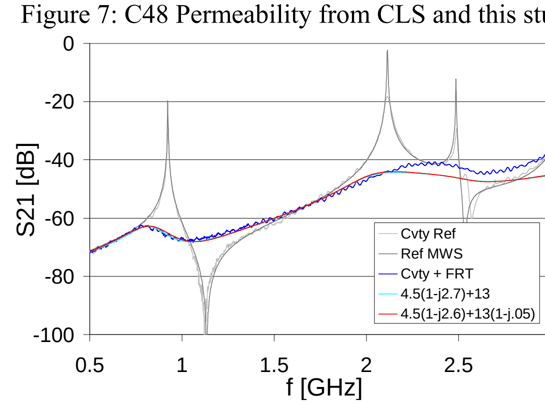

Figure 8: Simulation of pillbox cavity w/wo ferrite

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