HIGHER ORDER MODE DAMPING IN A PILL BOX CAVITY

F. Voelker, G. Lambertson, and R. Rimmer
Lawrence BerkeleyLaboratory
University of California
Berkeley, CA

ABSTRACT

We have substantially damped the higher order modes (HOM's) in a pill box cavity with attached beam pipe, while reducing the Q of the principal mode by less that 10%. This was accomplished by cutting slots in the cavity end wall at a radius at which the magnetic field of the lowest frequency HOM's is large. The slots couple energy from the cavity into waveguides which are below cut off for the principal mode, but which propagate energy at the HOM frequencies. Three slots 120 degrees apart couple HOM energy to three waveguides. We are concerned primarily with accelerating and deflecting modes: i.e. the TM_{mnp} modes of order m=0 and m=1. For the strongest damping, only three m=0 and m=1 modes were detectable. These were the principal TM_{010} mode, the TM_{011} longitudinal mode, and the TM_{110} deflecting mode. In addition the HOM Q's and the reduction of Q for the principal mode were determined by computer calculation. The principal mode Q for an actual rf cavity could not be measured because the bolted joints used in the construction of the cavity were not sufficiently good to support Q's above 6000. The measured Q of the first longitudinal mode was 31 and of the first transverse mode 37. Our maximum damping was limited by how well we could terminated the waveguides, and indeed, the computer calculations for the TM_{011} and TM_{110} modes give values in the range we measured.

I. INTRODUCTION

A large number of modes can be excited in an rf cavity by a bunched beam. Energy at frequencies below the cut off of the beam pipe will be trapped in the cavity, and interact with successive beam bunches. The voltage induced in the cavity at these higher order mode (HOM) frequencies is proportional to the shunt impedance of the mode. Shunt impedance is the product of a geometrical factor (R/Q) and the Q of the cavity; reducing the Q by damping the mode reduces the voltage excited at that frequency.

We are presenting a method to damp the HOM's without excessive damping of the principal mode. This has been demonstrated in a pill box cavity with three slots coupled to waveguides that carry HOM energy to terminating loads.

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HOM Damping

Imagine a typical rf cavity as a globe with the beam passing through the poles. The magnetic field of the principal mode at the wall is a maximum at the equator, and falls off toward a pole. On the other hand, most of the HOM's have zero H field at the equator, and the H field on the wall is a maximum at some distance away from the equator. The HOM's have broad maximums, and it is feasible to find a position where a slot couples strongly to most of them. The coupling is strongly dependent on the length of the slot, and less on height of the slot. A narrow aspect slot couples adequately, and it perturbs the fundamental mode less than a square aperture. Care must be taken not to place the slots on a zero of one of the HOM's.

The width of the waveguides is greater than the length of the slot, and was chosen to propagate the lowest troublesome HOM, but not the fundamental mode. The evanescent fields of the fundamental mode will reach a short distance into the waveguides, and the terminating loads must be far enough away in the guide to not damp the principal mode. The slots cause additional loss at the fundamental frequency because the wall currents are concentrated at the edges of the slots. Nevertheless, it is possible to have adequate coupling for the HOM's and still lower the fundamental Q less than 10 percent.

Experimental Setup

A pill box cavity with a 38.3 cm diameter and a 25 cm height was available from another mode damping experiment, and it was modified by adding 16.5 cm (inside diameter) beam pipes to each side. See figure 1. The beam pipes were terminated in 20.3 cm long crossed-wedges of 1 cm thick Eccosorb AN-73 material. Three 2.54 cm x 19 cm rectangular waveguides are attached to one end wall at a 14 cm radius and spaced at 120 degree intervals. The waveguides are coupled to the cavity through 2.54 cm x 15.24 cm rectangular slots, and are terminated by lossy elements at the far end. In an r.f. accelerator cavity the TM_{011} longitudinal mode is excited very strongly because it has a large R/Q. Because it is usually lower than the beam pipe cut-off frequency, it is trapped, and also has a high Q. We targeted our slot geometry to couple strongly to this mode, and the damping-waveguide cut-off frequency was chosen to be well below its frequency.

To sense beam coupling to the longitudinal modes, we need an antenna that couples to the E_z fields on the axis of the cavity. On the other hand, we don't want to perturb the fields on the axis with a metal coaxial line. Our solution

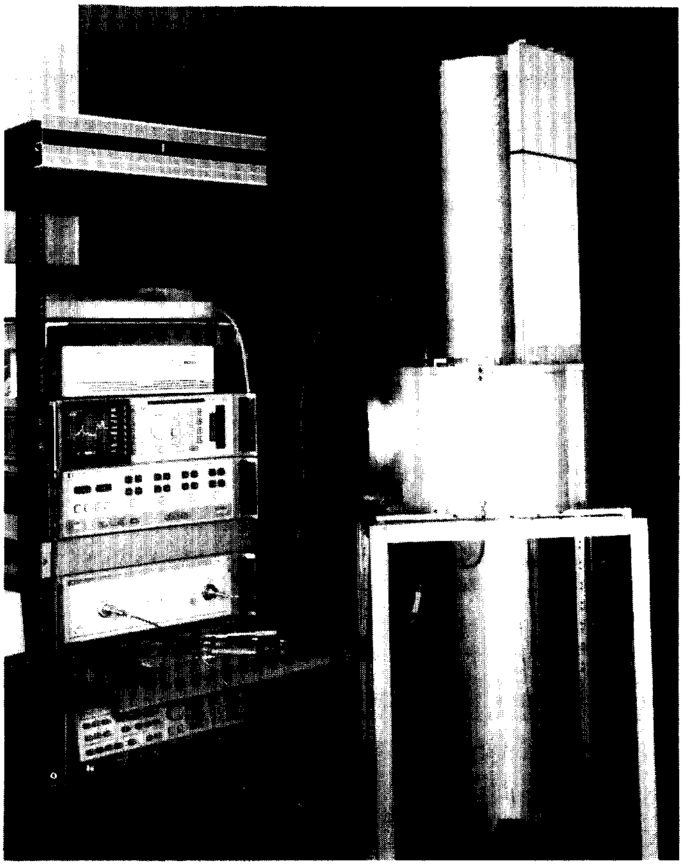

Fig. 1. Pillbox Cavity with One Damping Waveguide (CBB 905-3942)

was to use four 5 mm long electric-probes in the end walls as close to the beam pipe as mechanically feasible. These were spaced 90 degrees apart. Making them alike reduces coupling to modes with m=1, 2, or 3. The signals from these four probes are combined and become one port of the cavity. A similar electric-probe was placed on the opposite end wall and becomes the other port.

The probes are purposefully very short to simplify the Q measurements. The signals from the each pair of adjacent probes were combined in separate 180 degree hybrids. The sum signals from these hybrids are combined in another 180 degree hybrid, and for longitudinal modes the sum output is used as the port to the cavity. To measure transverse modes, i.e. m=1 modes, the difference signal is used as the cavity port. For both cases S_{21} was measured using an HP 8510B Network Analyzer. With the dampers in use, the signals for some modes were very weak, and the readings were enhanced by averaging 128 readings and smoothing the data slightly. We later lengthened the fifth probe to 9 mm to improve the signal-to-noise on some of the readings.

Measured Results

We started our measurements by covering the slots with metal tape to enable us to identify the basic cavity modes, and to allow us to determine the undamped Q's. Modes up to 2 GHz were identified by comparing with calculated frequencies from URMEL code. We also saw some quadrupole and sextupole modes, because the probes were not exactly symmetrical. These should not couple to the beam.

Our initial goal was to damp the HOM's sufficiently to reduce the Q's to less than 100. Our first waveguide terminations consisted of four 18 cm long wedges of Eccosorb material across the 2.54 cm dimension of each guide.

The damping greatly reduced the amplitude of most modes, and it was necessary to average the signals from the weakest signals to reduce the noise background. Even so, many modes disappeared into the noise background completely.

Waveguide Terminations

Preliminary measurements were made with a single waveguide, and a variable length slot. We observed that as the slot length was increased, the TM_{011} mode became smaller in amplitude to a point where it split into two frequencies. Further damping resulted in a greater separation in frequency, but no further reduction in Q.

For the final measurements using three slots, most of the HOM Q's were below 100, but the TM_{011} mode was split in two parts, one with a Q of 50.5 and the other a Q of 105. After some experimentation, we found that the mode splitting was caused by reflection from the waveguide termination. Reflections between the slot and the termination cause the waveguides to act like resonant cavities over-coupled to the main cavity.

The wedges were removed, and terminations made of Eccosorb NZ-51 (.5 cm x 3 cm x 6 cm) tiles inserted into the corner of each waveguide. The character of the split mode was observed as the number of tiles was increased. As tiles were added, the split mode coalesced and a final Q of 31 was reached. With these improvised terminations, the first tiles reached into the evanescent field of the principal mode and lowered its Q. However a longer waveguide with ferrite loading could be designed to give a sufficiently good match and without increasing the principal mode loss.

Calculated Values:

Using the MAFIA code together with a computational method developed by Kroll [1], the shunt impedance and Q of the pillbox cavity was calculated with three damping waveguides. Figure 2 shows the three dimensional model used to calculate these parameters. The cut-off frequency of the damping waveguides is 787 MHz, and the TM_{010} mode at 841 MHz is well damped. There is a TE_{111} mode in the cavity at 708 MHz that is not damped. We expected the symmetry of the probes to reject it, but it was quite visible as an undamped mode. For a typical accelerating rf cavity shape this mode occurs at higher frequency with respect to the fundamental, and it would also to be well damped even though we expect TE modes to couple only weakly to the beam.

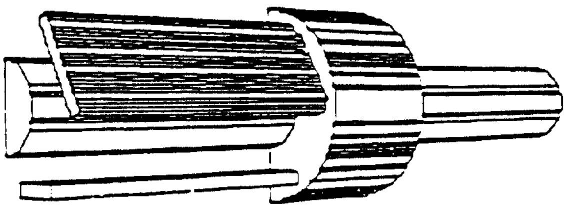

Fig. 2. Three Dimensional Model Used for MAFIA Calculations

The table below summarizes the results of both the calculations and the measurements. The frequencies of the damped modes were perturbed very little by the dampers, and there was no difficulty in identifying them.
Calculated Q values indicated that the principal mode was perturbed a minimal amount; the Q was reduced by only 8 percent. The first longitudinal mode (TM011) and the first transverse mode (TM111) were reduced to Q's of less than 40, and agreed closely with the calculated values. None of the other longitudinal or transverse modes were strong enough to see, but there was one quadrupole mode with a Q of 152. (We don't expect the beam to couple to quadrupole modes.)

	Calculated			Measured	
mode	**freq**	**Q**	**ΔQ**	**freq**	**Q**
TM010	611	33400	-8%	609.5	649*
TM011	840	15-35		836.2	31
TE111	708	39300	-7%	704.2	667*
TM110	907	56		898.8	37
TM111	1021	31		**	**
TE211	957	55		**	**
TM211	–	–	–	1366	152

* Waveguide load sees evanescent field.
** Not visible.

REFERENCES

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