TOWARDS STRONGLY HOM-DAMPED MULTI-CELL RF CAVITIES*

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Abstract

This paper discusses the prospects for very strong HOM damping in multi-cell RF cavities. There has been much progress in recent years towards "HOM-free" single-cell cavities. Many examples are now operating in high current storage rings around the world. There have also been successes in broad-band damping of multi-cell structures to levels appropriate for linear colliders and low average current applications. We describe the use of modern simulation tools to explore the potential for applying these techniques to multicell structures. Such cavities would be useful for high-current, high-power applications such as high luminosity collider storage rings, damping rings, energy recovered linacs and injector systems. These methods may be applicable in to both room temperature and superconducting cavities.

INTRODUCTION

Strong HOM damping in accelerator RF cavities has become increasingly important. Storage rings for light sources and colliders now routinely operate with strongly HOM damped single-cell cavities. Linear colliders are proposed that rely upon large numbers of multi-cell cavities with moderate HOM damping. Next generation light sources based on energy recovering linacs (ERL's) require a combination of high-gradient multi-cell structures and strong HOM damping. We study some of the factors that influence the ultimate performance of multi-cell structures using numerical simulations.

SIMULATION METHOD

We used the time domain module in MAFIA with a simulated bunch to excite the cavity either on or off axis [1]. By recording the wake potential behind the bunch and taking a Fourier transform we were able to calculate the broad-band impedance spectrum. We used the waveguide boundary condition to terminate the beam pipes and any damping apertures. We have not attempted to model the small coaxial DESY type couplers with this method.

BROAD-BAND DAMPING METHODS

The simplest method of HOM damping is to enlarge the beam pipe on one or both sides of the cavity so all harmful HOMs may propagate away, figs. 1a, 1e, [2]. A modification of this is the fluted beam pipe fig. 1b, used by Cornell [3]. Waveguide dampers in the beam pipe just outside the cavity, fig. 1c, have been used in CEBAF [4].

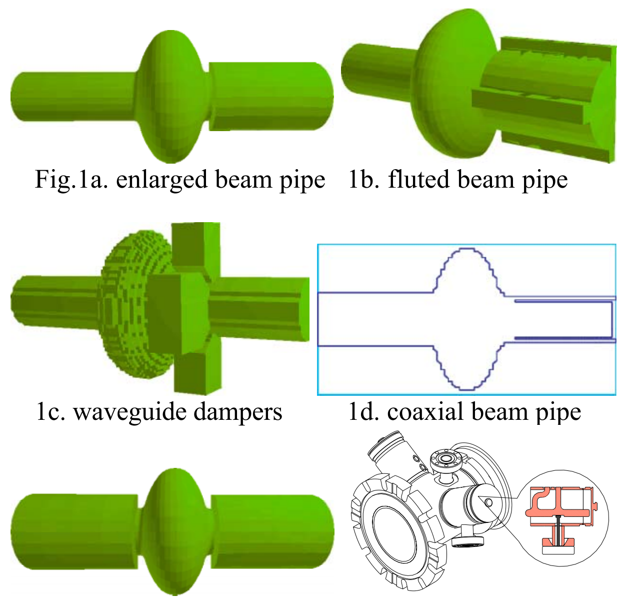

Fig.1a. enlarged beam pipe 1b. fluted beam pipe

1c. waveguide dampers 1d. coaxial beam pipe

1e. 2 enlarged beam pipes 1f. multiple coaxial loops

A coaxial insert in the beam pipe, fig. 1d, with a choke to reject the fundamental mode, has been proposed for low-order mode damping in deflecting cavities [5]. Coaxial HOM couplers fig. 1f, are already widely used and can give strong coupling if placed appropriately. Normal conducting cavities use openings directly into the accelerating cells for strong HOM damping but this is not normally used for SCRF cavities and is not studied here.

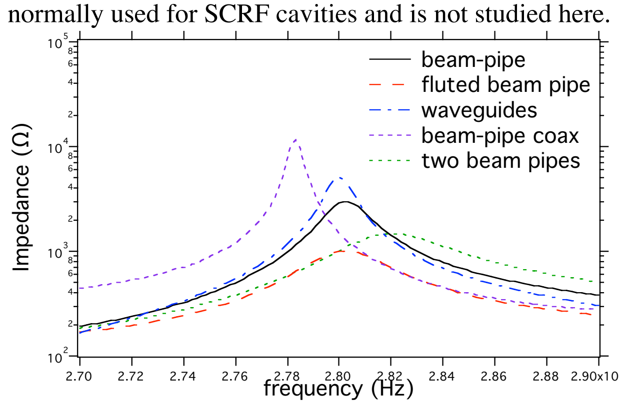

Figure 2. TM_{011} mode with various damping schemes.

We applied the beam pipe, waveguide and beam-pipe-coaxial damping methods to a MAFIA model of a single-cell 1.5 GHz cavity. Figure 2 shows the calculated spectra and table 1 lists the resulting loaded Q's and impedance for the strongest monopole HOM (TM_{011}). The beam-pipe damping on one or both sides or with flutes is very effective. The waveguides also give very good damping and the beam-pipe coaxial load is not far behind. Table 2 lists the results for the first two dipole HOMs (TE_{111}, TM_{110}). Strong damping is also evident in all cases.

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Table 1. TM_{011} mode for various damping methods

	freq MHz	Q	R* (Ω)	R/Q (Ω)
b-pipe	2803	252	3001	11.9
flutes	2803	137	1010	7.3
wguide	2800	353	5040	14.3
bp-coax	2783	725	11879	16.4
2xbp	2822	121	1481	12.2

*$R=V^2/2P$

Table 2. Dipole modes for various damping methods

	TE_{111} f,MHz	TE_{111} Q	TE_{111} R*, (Ω)	TM_{110} f, MHz	TM_{110} Q	TM_{110} R* (Ω)
b-pipe	1853	83	246	2028	130	1567
flutes	1857	79	239	2029	130	1479
w-guide	1867	553	1594	2027	1131	14419
coax	1924	341	1496	2065	502	5150
2xbp	1830	37	192	2018	53	735

*R calculated at 25mm offset in the cavity

MULTI-CELL STRUCTURES

To study the dependence of damping on the number of cells we calculated the monopole and dipole spectra with from one to seven cells per cavity, with open beam pipes on both ends. Figure 3 shows the impedance spectra for the TM_{011} passband. Tables 3 and 4 list the values for the strongest peak in each passband. Figures 4 and 5 show how the Q and impedance vary with number of cells. The strength of the highest mode in each passband increases with number of cells slightly faster than linearly. The TM_{011} and TE_{111} mode Q's rise with number of cells, the TM_{110} Q's are higher for even numbers of cells than odd numbers, however the impedance climbs monotonically.

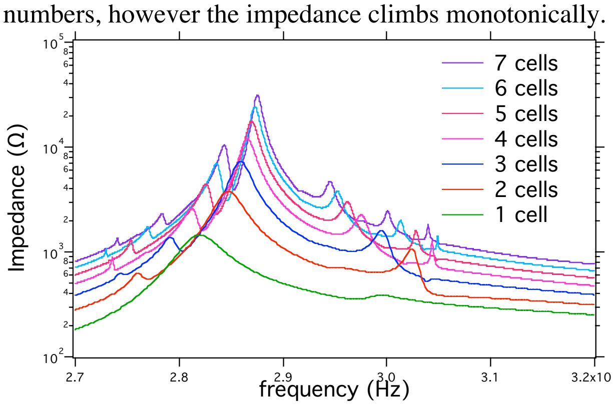

Figure 3. TM_{011} passband mode vs # cells

These results suggest that shorter structures might give better overall HOM performance than long ones, however the overhead in length from each HOM load or set of loads may decrease the average “real-estate”gradient. This might be offset by sharing HOM loads and power couplers between adjacent cavities in “superstructure” assemblies [6]. The maximum number of cells at a given frequency may also be influenced by infrastructure constraints, or limits on window or HOM load power.

Table 3. Strongest TM_{011} passband mode vs # cells

#cells	freq MHz	Q	R* (Ω)	R/Q (Ω)
1	2822	121	1481	12.2
2	2848	167	3856	23.0
3	2860	219	7369	33.7
4	2866	295	12140	41.1
5	2870	362	17795	49.1
6	2873	455	24360	53.5
7	2876	527	31463	59.7

*$R=V^2/2P$

Table 4. Strongest TE_{111}/TM_{110} passband modes vs # cells

#cells	TE_{111} f,MHz	TE_{111} Q	TE_{111} R*, (Ω)	TM_{110} f, MHz	TM_{110} Q	TM_{110} R* (Ω)
1	1830	37	192	2018	53	735
2	1907	46	569	2101	2641	10103
3	1940	45	1193	2093	2023	14362
4	1867	94	1844	2101	4058	29270
5	1892	121	3232	2097	3233	40923
6	1910	139	4859	2102	5029	46740
7	1922	135	6088	2099	4177	72101

*R calculated at 25mm offset in the cavity

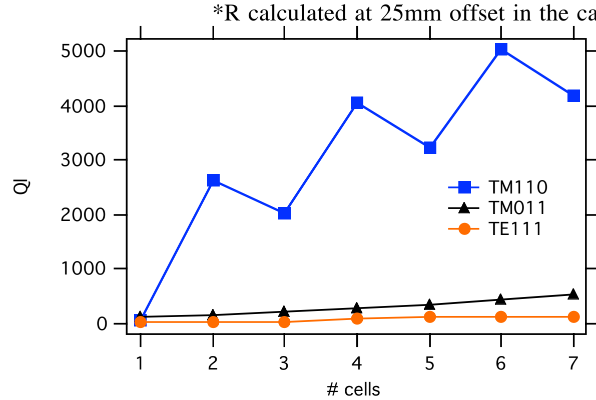

Figure 4. Loaded Q vs # cells, beam-pipe damping.

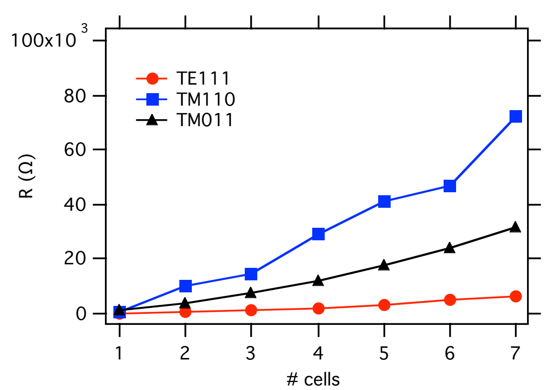

Figure 5. R vs # cells (R at 25mm for dipole modes).

To study the effect of cell shape and coupling strength we compared seven-cell cavities with the original Cornell (OC), high gradient (HG) and low loss (LL) cell shapes [7]. Figure 6 shows the monopole spectrum, while tables 6 and 7 list the peak values for the three passbands. The

TM_{011} mode response is similar for the OC and HG shapes, while the LL peak is lower in frequency but similar in amplitude (within about a factor of three). The dipole passbands show three distinct spectra and about a factor of two spread in amplitude for the TE_{111} mode and about a factor of four in the TM_{110} mode. There does not appear to be any correlation between HOM strength and cell-to-cell coupling in these results. In an operating accelerator the exact mode spectrum could make orders of magnitude difference in BBU threshold and HOM power, so cell profile may be important in this regard.

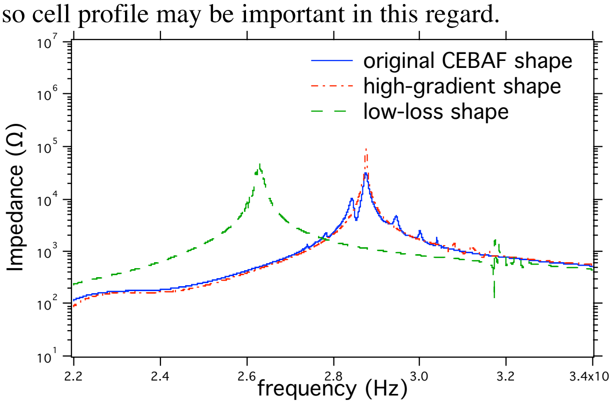

Figure 6. TM_{011} band, OC, HG, LL shapes, 7-cells.

Table 5. TM_{011} mode data for multi-cell cavities.

	#cells	Freq,MHz	Q	R† (Ω)	R/Q (Ω)
OC	7	2876	527	31463	59.7
HG	7	2876	1348	90380	67.0
LL	7	2629	985	53556	54.4
OC*	5	2871	707	35453	50.1
DESY**	4	910	600		

*waveguide damped. **500 MHz cavity, meas. Q. †$R=V^2/2P$

Table 6. TE_{111}/TM_{110} mode data for multi-cell cavities.

	# cells	TE_{111} f,MHz	TE_{111} Q	TE_{111} R†, (Ω)	TM_{110} f, MHz	TM_{110} Q	TM_{110} R† (Ω)
OC	7	1922	135	6088	2099	4177	72101
HG	7	2014	185	11359	2156	5694	146409
LL	7	2021	490	14107	2209	2071	39510
OC*	5	1894	956	22949	2103	3274	47064
DESY	4	650	4000		716	6000	

*waveguide damped. †R calculated at 25mm offset in cavity.

EXAMPLES

Figure 7 shows a five cell structure with waveguide damping. The highest peaks in each passband are listed in tables 5 & 6 (row 4). The TM_{011} peak is about a factor of two stronger for the waveguide damped cavity than for the beam pipe loaded one (table 3 row 5). For the TE_{111} mode (table 4 row 5), the factor is about eight but for the strongest dipole (TM_{110}) mode they are about the same The waveguide dampers take up very little beam line space compared to the beam pipe loads and can transport HOM power to room temperature loads if required.

Included in tables 5 & 6 are data for a four-cell 500 MHz DESY cavity damped by three coaxial HOM couplers [8]. The TM_{011} Q is very similar to the waveguide loaded cavity while the TE_{111} Q is a factor of four higher and the TM_{110} is only up about a factor of two. All of these examples are in the range suitable for next generation high current ERL's

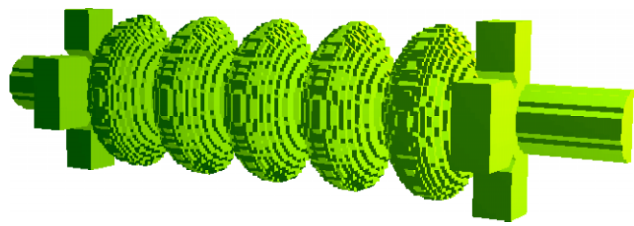

Figure 7. Waveguide damped 5-cell structure.

Other factors such as distortion due to tuning and field tilt might contribute to higher Q's. Having dampers at both ends of the cavity should help. Having symmetrically arranged couplers so that no transverse kick is imparted to the passing beam is also desirable.

CONCLUSIONS

We have shown that strong broad-band HOM coupling techniques used on single-cell cavities can plausibly be applied to multi-cell cavities. None of the schemes described here have been optimized but all show promise. The ultimate limit may be the rate at which energy can propagate through the cavity. To go significantly further we may want to look at more open structures. We would like to thank Jacek Sekutowicz for useful discussions on this topic.

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