A FOUR-CELL PERIODICALLY HOM-DAMPED RF CAVITY FOR HIGH CURRENT ACCELERATORS *

G. Wu†, R. Rimmer, H. Wang, Jefferson Lab, Newport News, VA 23606, USA
J. Sekutowicz, DESY, Notkestrasse 85, 22607 Hamburg, Germany
Sun An, Oak Ridge National Lab, Oak Ridge, TN 37830, USA

Abstract

A periodically Higher Order Mode (HOM) damped RF cavity is a weakly coupled multi-cell RF cavity with HOM couplers periodically mounted between the cells. It was studied as an alternative RF structure between single-cell and superstructure cavities in high current application requiring strong damping of HOMs. The acceleration mode in this design is the lowest frequency mode (zero mode) in the pass band, in contrast to the traditional "π" acceleration mode in multicell superconducting cavities. The acceleration mode of the four-cell cavity has been studied, along with the monopole and dipole HOMs. The frequency response through HOM ports has been simulated in HFSS™ with waveguide couplers, which shows almost constant Q_{ext} for several important HOMs, even with different number of cells. A 4x1 zero-mode cavity was studied with MAFIA time domain analysis. To understand the tuning challenge for this weakly-coupled cavity, ANSYS® and SUPERFISH codes were used to simulate the cavity frequency sensitivity and field flatness change, which will influence the design of the tuner structure. This paper presents the computer simulation of this novel accelerating structure that may be used for variety of accelerator applications.

INTRODUCTION

High current linacs require heavily HOM-damped RF cavities. In other words, the high-current accelerating structure should only confine the accelerating mode or at most the only modes within the first pass band. One such RF structure is a HOM well-damped single cell cavity, which is used in storage rings [1, 2]. To get higher voltage gain within the same machine length, one would use multi-cell cavities [3], or a superstructure cavity [4]. The multi-cell structure inevitably traps some HOMs. One would naturally think that something in between should provide a trade off between effective accelerating voltage per unit length and the good HOM damping.

One solution could be packing individually HOM damped single cell cavities in a chain to form a periodical structure, which we call the Zero Mode cavity. The other would be packing single cell cavity back to back, which is essentially a superstructure of two-cell cavities. The latter has been proposed and studied earlier [5]. This note investigates the former case, the Zero Mode cavity.

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†Electronic mail: genfa@jlab.org

ZERO MODE CAVITY

An enlarged beam pipe connects individual cells. Cell-to-cell coupling is expected to be quite weak. Since the high current RF cavity would mostly run in energy recovering mode, the weak coupling is thought to be less detrimental in terms of energy re-filling. The beam test of a 2x7 superstructure indicated that the energy flow between weakly coupled subunits was not a problem at least for TESLA's beam current [6].

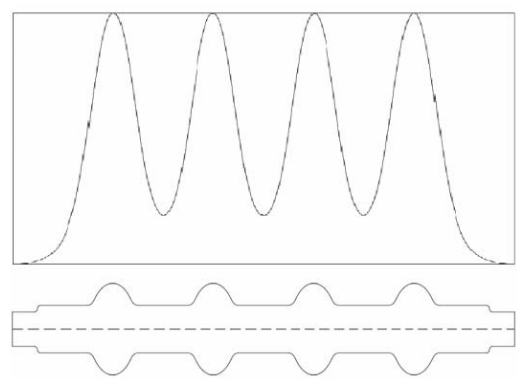


Figure 1: The four cell Zero Mode cavity and its on-axis electric field for acceleration mode.

A four-cell Zero Mode cavity is shown in Figure 1. Due to the non-zero field in the interconnecting beam pipe, lower R/Q is expected for the accelerating mode. The RF parameters are also listed in Table 1. From the E_p/E_{acc} ratio, a peak surface field 50 MV/m would be needed for a 10 MV/m accelerating gradient. The frequencies of the first pass band modes are plotted in Figure 2.

Table 1: RF parameters of Zero Mode cavity

Accelerating mode [MHz]	0	1498.703
Mode 2 [MHz]	π/4	1499.048
Mode 3 [MHz]	2π/4	1500.110
Mode 4 [MHz]	3π/4	1501.167
Cell number		1x4
Cell to cell coupling		7.91E-04
R/Q [Ohm] of accelerating mode		239
Geometric factor		277
Epk/Eacc		5.07
Bpk/Eacc [mT/(MV/m)]		8.42

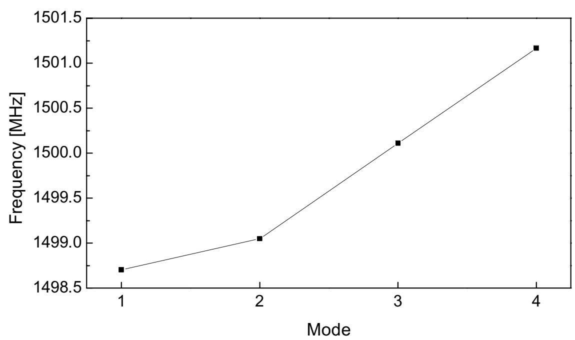


Figure 2: Frequencies of first pass band computed by Superfish.

HOM DAMPING

The interconnecting beam pipe allows the placement of HOM couplers between cells. Since this HOM damping scheme is considered very promising, shunt impedance minimization of HOMs may allow further cavity shape optimization to improve fundamental mode R/Q and Ep/Eacc ratio. For this configuration, the frequency and R/Q of the monopole and dipole modes have been calculated by MAFIA 2D as summarized in Table 3 and 4; those modes with very small R/Q values were not listed.

Table 3: Dipole modes

Mode	Frequency (MHz)	R/Q (Ω)	R/Q (Ω/cm^2)
1	1.582527	9.59	1.53
2	1.596888	1.70	0.27
6	1.868148	13.21	2.11
7	1.913363	15.63	2.50
9	2.161911	1.23	0.20
11	2.192195	29.18	4.67
12	2.193530	1.24	0.199
13	2.196425	0.80	0.13
14	2.455769	0.82	0.13
15	2.505229	3.85	0.62
16	2.575615	3.05	0.49
18	2.701776	0.91	0.15
20	2.987272	1.97	0.32
21	3.068014	1.13	0.18
22	3.129850	7.92	1.27
23	3.159913	2.65	0.42
24	3.385317	0.65	0.10
25	3.389713	11.33	1.81
26	3.403304	7.35	1.18
31	3.525925	1.77	0.28
36	3.659088	1.34	0.21
39	3.884062	1.28	0.21
40	3.886888	2.44	0.39

Table 4: Monopole modes

Mode	Frequency (MHz)	R/Q (Ω)
5	2.448852	2.56
6	2.459498	1.07
10	2.669108	1.47
11	2.709442	2.40
17	3.036354	5.24
19	3.211969	11.97
20	3.376769	2.70
21	3.378105	16.91
22	3.380678	6.10
23	3.548321	9.36
24	3.829342	24.92
25	3.844619	5.67
27	3.921957	23.34

The investigation assessed the effectiveness of rectangular waveguide couplers as HOM dampers, as a function of the number of cells in the structure. The configuration for a four-cell cavity is illustrated in Figure 3. The waveguide HOM transmission S-parameter was calculated for cavities with two, three, four cells. The result is shown in Figure 4. The S-parameter peaks for several modes are rather insensitive to the number of cells.

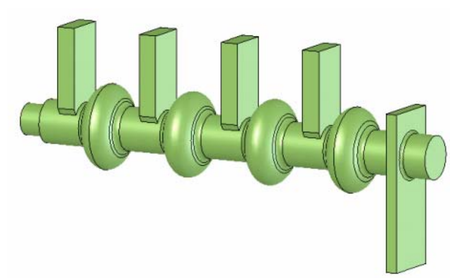


Figure 3: The model of zero mode cavity with periodic damping by waveguide HOM couplers.

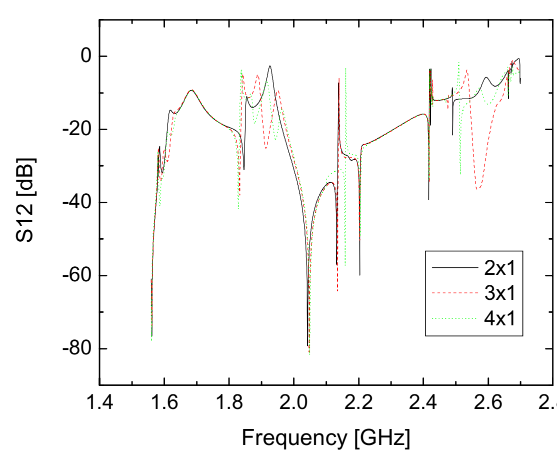


Figure 4: The transmission S-parameter computed for 2-cell, 3-cell, and 4-cell cavities.

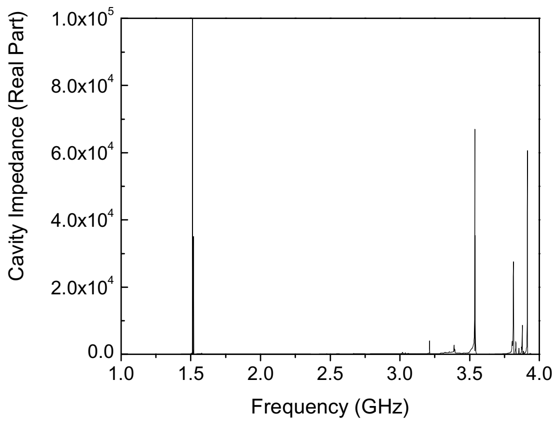


Figure 5: The cavity beam impedance showing several TM modes.

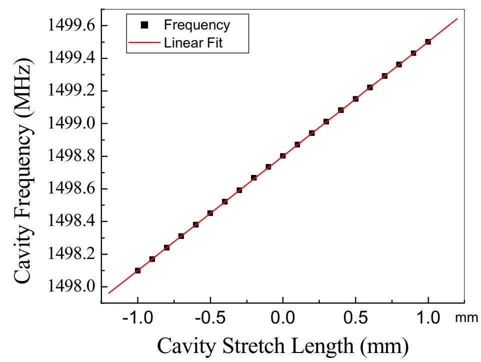
MAFIA time domain analysis [7] was used to calculate the actual Qext of monopole modes of the cavity shown in Figure 3. Since the dipole modes have quite small R/Q, effort should be focused on monopole HOMs as for superstructures [5]. Cavity impedance is plotted in Figure 5 showing several TM modes. The simulated Qext of monopoles were below 307 except two beam pipe modes in Table 4: mode 23 with 7100 and mode 27 with 2600. Beam pipes were electrically terminated in the simulation.

TUNING SENSITIVITY

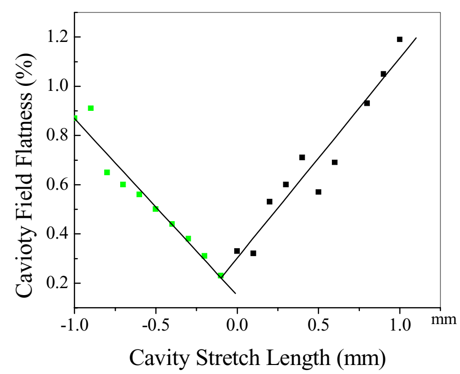
Due to the weak cell-to-cell coupling, cavity field flatness may be difficult to maintain when cold. Four-cell cavity tuning sensitivity and field flatness was simulated using the same procedure that has been used for SNS type cavities [8]. When the ideal cavity geometry was assumed, the frequency change and the field flatness due to cavity stretching have remarkably similar responses to the regular π-mode multi-cell cavity [8] as shown in Figure 6. The frequency sensitivity is 700 KHz/mm. The field flatness sensitivity is 1.1%/MHz. Imperfect cavity geometry may require four individual cold tuners to help maintain field flatness, or a single cold tuner with pre-configured stress memory, which requires some development to implement.

SUMMARY

It is concluded that the damping effect is independent of the cavity cell number for this zero mode cavities. This evaluation of simple waveguide HOM couplers suggests that the structure eases the design effort for HOM damping. The cold tuner remains a costly component. Some further studies, especially cold tests, are needed to find whether a single tuner is sufficient and whether an economic solution for a cold tuner is achievable. Some optimization effort is also needed to increase the fundamental mode R/Q for the four-cell cavity.



(a)



(b)

Figure 6: The tuning frequency response (a), and the field flatness degradation (b).

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