DESIGN CONSIDERATIONS FOR A SECOND GENERATION HOM-DAMPED RF CAVITY*

R. A. Rimmer†, D. Li, LBNL, 1 Cyclotron Road, Berkeley, CA 94720, USA

Abstract

The first generation of strongly HOM-damped RF cavities are now being operated with beam in accelerators with good success. We briefly review these designs and consider some factors in the design of a second generation HOM damped copper RF cavity suitable for use in high current storage rings such as linear collider damping rings, light sources and high luminosity colliders. We consider the problem of broad-band coupling to the higher-order modes (HOMs) and describe how straightforward modifications to the traditional cavity shape can lead to significant simplification of the mechanical design and reduction in cost. We also consider the problem of broad-band HOM damping in a multi-cell cavity.

1 INTRODUCTION

The development of machines with high average current in many bunches has focused attention on the need to reduce the impedance of the higher order modes (HOMs) of the RF cavities. At low to moderate current the HOMs may be detuned to safe frequencies, often by adjustment of the cavity temperature, or the beam motion may be controlled by feedback systems of modest power. At high current the HOM impedances must be reduced at source to keep the beam stable or allow containment by feedback systems of reasonable power. Several machines are currently operating or being commissioned to operate in this regime where broad-band damping of a large number of HOMs is required, including the PEP-II and KEK-B meson factories [1], the DAPHNE Φ factory and CESR-B. Many proposed fourth generation light sources, upgrades to third generation light sources, linear collider damping rings and other high intensity machines will also fall into this regime.

2 OVERVIEW OF CURRENT DESIGNS

All of the "factory" type machines mentioned above employ single-cell type cavities with strong broad-band HOM damping, although they employ a variety of technical solutions to achieve similar results. PEP-II and DAPHNE use room temperature copper cavities with the addition of rectangular HOM damping waveguides and broad-band loads. The PEP-II cavities typically operate at about 850 kV and 103 kW of wall dissipation [2]. The HOM openings are limited in size and strategically placed to maximize coupling to the worst HOMs. Figure 1 shows the calculated longitudinal impedance spectrum of the PEP-II cavity, which agrees well with measurements and beam-signal observations. The three HOM loads are designed to dissipate up to 10 kW each and the window is designed to transmit up to 500 kW. The PEP-II high-energy ring has operated at its design value of 750 mA [2] while the low energy rings has achieved 1.2 A of its 2 A goal in a short time [3].

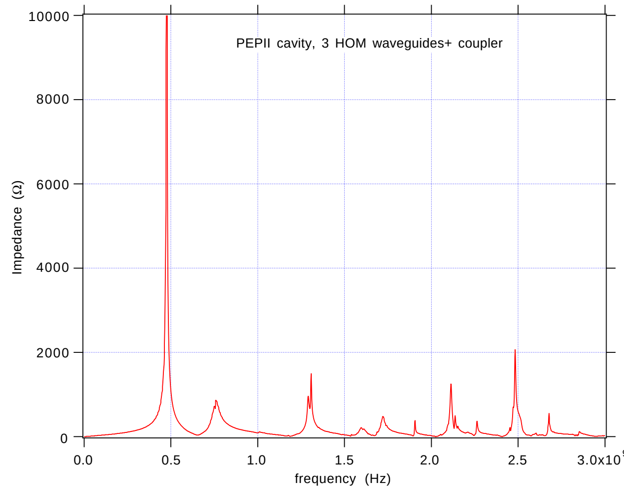

Figure 1. Calculated longitudinal impedance spectrum of PEP-II cavity (MAFIA T3 simulation).

The DAPHNE cavity [3] is a bell-shaped design with a lower shunt impedance, reflecting the modest voltage requirements and priority of low transverse impedance. It uses wide-band ridged-waveguide to coaxial transitions, coaxial feedthroughs and external loads. Two sizes of couplers cover the range of frequencies in the cavity and tapers. The feedthroughs and loads can comfortably handle the approximately 1 kW per load of beam-induced power.

CESR-B uses a single-cell superconducting cavity design with large beam pipes to propagate the HOMs to external loads [4]. The inherently low R/Q of this shape and the strong coupling to the loads results in very small residual impedances, while the shunt impedance for the fundamental mode is very high [5].

KEK-B has developed a similar superconducting design for the high energy ring, but will also employ room temperature cavities which have a combination of waveguide and beam-pipe dampers and an external energy storage cavity to reduce detuning for beam loading compensation. The KEK-B rings are currently being commissioned [6].

Future machines such as the linear collider damping rings will require HOM damped cavities that are as good or better than these existing designs.

*This work was supported by the U.S. Department of Energy under contracts DE-AC03-76SF00098.

† Email: RARimmer@lbl.gov

3 DESIGN IMPROVEMENTS

3.1 Cavity profiles

The PEP-II cavity uses the traditional re-entrant "nosecone" type profile that has been shown to give the highest shunt impedance for copper cavities. Most cavities of this type have a toroidal profile for the body of the cavity which means that the transition blend or fillet of all ports entering the body is a complex surface that must be made by a process such as multi-axis milling. For the PEP-II cavity with its many equatorial ports, see figure 2, this was a significant expense.

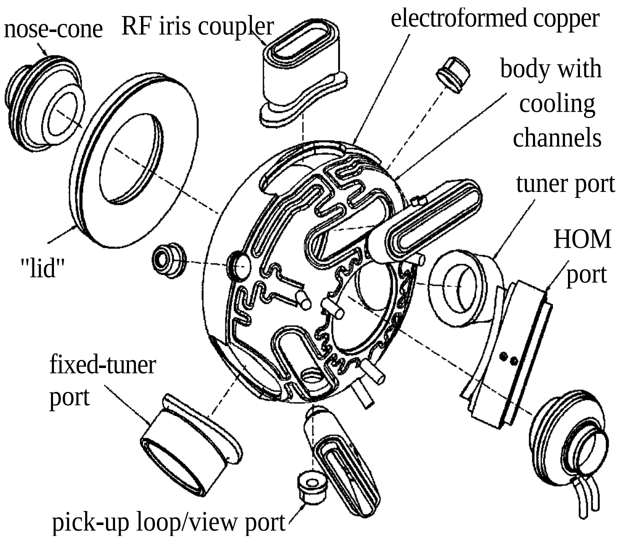

Figure 2. Assembly of PEP-II cavity showing body cooling channels on one half (exposed), equatorial and HOM port inserts, nose-cones and "lid" section.

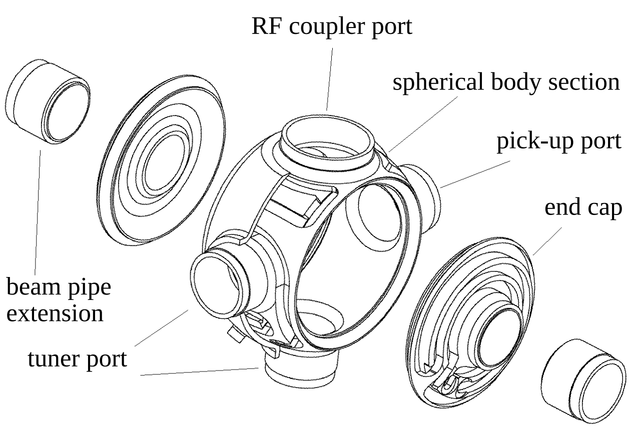

Figure 3 Assembly view of ALS Landau cavity

For the ALS 1.5 GHz Landau cavities which were recently designed by LBNL [7] and built by LLNL [8], a different shape was used, see figure 3, in which the center part of the cavity was spherical. This allowed all of the port blends to be turned on a lathe. The ports were actually integral to the body and the center section was all machined from a single piece of copper. This greatly simplified the fabrication process and reduced cost and technical risk compared to the PEP-II design. A similar fabrication scheme is being considered for the NLC damping ring cavities, see figure 4.

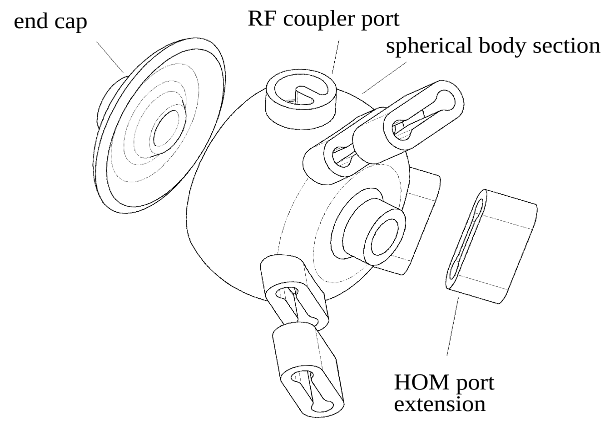

Figure 4. Possible NLC damping ring cavity assembly

3.2 HOM waveguides

For the PEP-II cavity simple rectangular waveguides were used, see figure 5a. The width of the waveguide was considered too great to enter the cavity directly so a smaller racetrack shaped iris was used between the cavity and the waveguide. This required additional parts and machining operations. The HOM waveguide opening causes a strong current concentration at the ends of the slot which results in the highest power density and stresses in the cavity and requires a carefully optimized cooling channel layout [9].

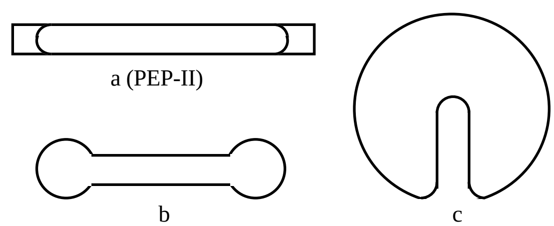

Figure 5. HOM waveguide cross sections with the same cut-off frequency, a: PEP-II rectangular guide, b: compact ridged guide, c: circular ridged guide

The peak power density is strongly dependent on the radius at the end of the slot and the radius of the fillet between the waveguide and the cavity wall. Figure 5b shows a more compact ridged guide cross section with the same cut-off frequency, which does not require an iris. This shape is being evaluated for the NLC damping ring RF cavity. Figure 5c shows a circular ridged waveguide that could be used on the mid-plane of the cavity as a HOM damping aperture or main coupler. The single sided ridge breaks the symmetry of the aperture which may be useful in coupling to HOMs that have no magnetic field on the mid-plane (the PEP-II cavity used an offset slot to gain useful extra damping of some modes). The circular section lends itself to the use of circular flanges which may improve reliability over the rectangular type used for PEP-II. With wire EDM techniques it is straightforward to make smooth transitions between these various profiles or to a broad-band load or coaxial feedthrough. A plunge-EDM technique is being evaluated to cut the port profiles and blend radii into the cavity body, which may simplify the manufacturing.

4 MULTI-CELL CAVITIES

Multi-cell cavities have the advantage that they offer very high shunt impedance but unfortunately they also have a large number of potentially harmful HOMs, some of which may not be well damped by couplers at the ends of the cavities. Adding damping waveguides to each cell would solve this problem but would lead to an ungainly structure. The problem may lie in the cell to cell coupling schemes often used for these structures. Beam iris coupling, figure 6a, is poor at transmitting many HOMs along the structure. Magnetic coupling via pairs of kidney-shaped slots between cells, figure 6b, is commonly employed in linacs and multi-cell cavities, but in this case some or all of the dipole modes will not be propagated through long structures. The simple expedient of using three equally spaced slots between cells, see figure 6c, will allow the dipole modes to propagate through the structure without introducing any dipole or quadrupole components into the accelerating mode. This coupling method is currently being investigated for short multi-cell structures, and appears promising. Figure 7 shows a preliminary calculation of the longitudinal impedance spectrum of a 3-cell HOM-damped structure, there are more HOMs visible than the single cell but even without optimization the total impedance does not appear to be worse than three single cells of the same profile and no modes appear to be completely trapped in the structure. The size of the coupling slots determines the frequency difference between the various versions of the fundamental mode (0, π, $\pi/2$ etc.), which may allow them to be tuned to safe frequencies. The impedance of modes other than the accelerating mode will also be reduced by the transit-time factor.

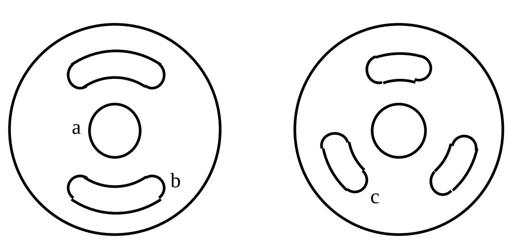

Figure 6. Coupling slot configurations. a: beam iris, b: dual kidney slots, c: triple kidney slots

5 CONCLUSIONS

HOM damped structures have been proven to be effective in reducing instabilities in high current storage rings. Changing the cavity body shape from toroidal to partly spherical may allow simpler fabrication with no penalty in shunt impedance. Modified HOM damping apertures may eliminate the iris feature, simplifying the design, and may use larger radii at the ends of the slots to reduce the RF surface current concentration, lowering the temperature and reducing stresses. HOM damping in multi-cell cavities may be practical and effective and will be studied further.

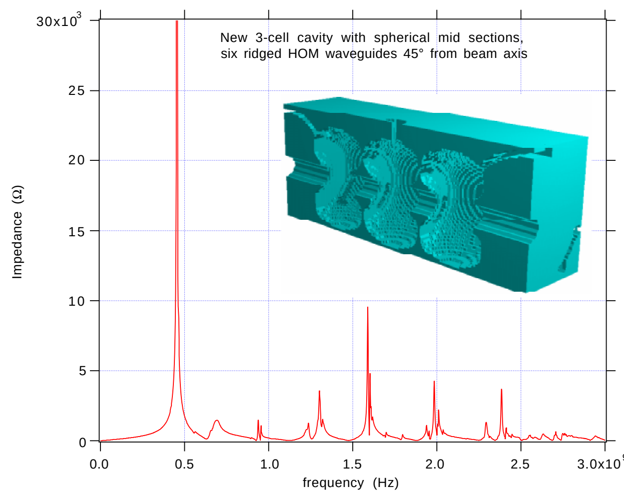

Figure 7. Calculated impedance spectrum of 3-cell cavity with 3 HOM waveguides at each end and three kidney slots between cells (MAFIA T3 simulation).

REFERENCES

[1] John T. Seeman, "Commissioning Results of B-Factories", these proceedings.

[2] R. A. Rimmer et. al., "Commissioning of the PEP-II High-Power RF Systems", EPAC 98, Stockholm, Sweden., June 1998, pp 1805-7, SLAC-PUB-7852.

[3] A. Gallo et. al. "Operational Experience with the DAFNE Radio-frequency Systems", these proceedings.

[4] S. Belomestnykh et. al. "Commissioning of the Superconducting RF Cavities for the CESR Luminosity Upgrade", these proceedings.

[5] H. Padamsee et. al. "RF Superconductivity for Accelerators", Ch. 20, pp 440-446, Wiley, 1998.

[6] K. Akai et. al. "Commissioning of the KEKB RF System", these proceedings.

[7] R. A. Rimmer et. al., "A Third-Harmonic RF cavity for the Advanced Light Source", EPAC 98, Stockholm, Sweden, pp 1808-10.

[8] R.M. Franks et. al., "Mechanical Design and Fabrication Processes for the ALS Third-Harmonic Cavities", these proceedings.

[9] R. Rimmer, et. al., "High-power RF Cavity R&D for the PEP-II B Factory", Proc. EPAC 94, June 27-July 1 1994, London, pp 2101-3, LBL-34960, PEP-II EE note 3-94.