SUPERCONDUCTING MULTI-CELL DEFLECTING CAVITY FOR SHORT-PULSE X-RAY GENERATION AT THE ADVANCED PHOTON SOURCE*

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Abstract

A superconducting multi-cell cavity for the production of short x-ray pulses at the Advanced Photon Source (APS) has been explored as an alternative to a single-cell cavity design in order to improve the packing factor and potentially reduce the number of high-power rf systems and low-level rf controls required. The cavity will operate at 2815 MHz in the APS storage ring and will require heavy damping of parasitic modes to maintain stable beam operation. Novel on-cell dampers, attached directly to the cavity body, have been utilized by taking advantage of the magnetic field null on the equatorial plane in order to enhance damping. Design issues and simulation results will be discussed.

INTRODUCTION

Deflecting cavities have been proposed at the APS for the generation of short x-ray pulses to produce pulse lengths on the order of picoseconds [1-4]. This will be implemented with a set of cavities utilizing a vertical dipole mode to produce a 4-MV kick to deflect the electron beam. Another set of cavities will be arranged in a nearby sector to return the beam to its nominal orbit such that the beam kick will be localized and will not affect other users of the APS. As a result, the deflecting cavities will operate seamlessly with normal operation of the storage ring. In addition to an exacting control system to ensure the beam deflection is precisely reversed, heavy damping will be required of higher-order as well as lower-order modes. For typical cavity geometries, the beam stability thresholds for monopole and dipole modes correspond to external Q values on the order of hundreds.

Single-cell cavities permit the heaviest damping of the parasitic modes [5], but their packing factor is poor. In addition, their overall cost may be substantially greater assuming each cavity requires dedicated power and controls systems. Multi-cell cavities, on the other hand, require fewer cavities and ancillary systems, but the issue of damping parasitic modes becomes more critical. It becomes especially difficult to selectively damp the modes in the passband of the operating mode for heavily damped applications. These modes are typically close in frequency to the operating mode and possess similar field configurations.

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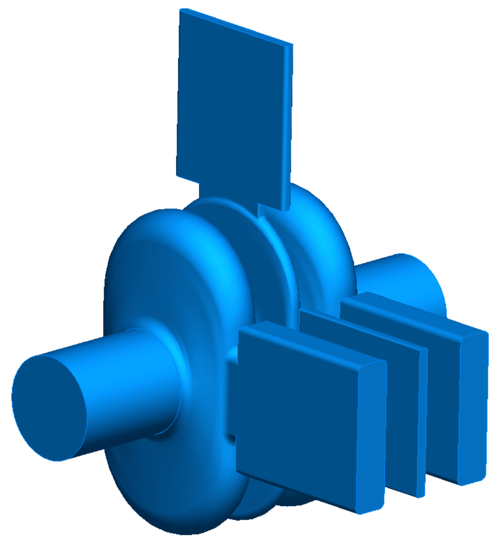


Figure 1: Geometry of a 3-cell cavity with horizontal cavity-mounted dampers on each cell. A vertical damper is located on the central cell to damp vertical dipole modes.

Additional flexibility in damping has been proposed for the deflecting mode cavities by locating dampers along the horizontal plane of the cavity, as shown in Fig. 1, where a magnetic null exists. If the size and location of the coupling iris is carefully selected, magnetic field enhancement due to the damper will be limited below existing peak values elsewhere in the cavity and, as a result, would not limit the operating gradient of the cavity.

CAVITY DESIGN

As compared with the single-cell cavity, a 3-cell cavity operating in the $\pi/2$ mode offers a greater deflecting voltage while achieving heavy damping requirements. The $\pi/2$ mode was chosen due to the simplicity of damping parasitic modes. In principle, the center cell contains little field due to the operating mode, while other dipole modes, notably the 0 and π modes in the same passband, have substantial field levels. A damper placed along the vertical plane in the center cell shown in Fig. 1 selectively damps the 0 and π modes while minimally affecting the operating mode.

In order to achieve the level of damping required at the APS, on-cell damping was utilized where waveguide damper coupling irises were attached directly to the body

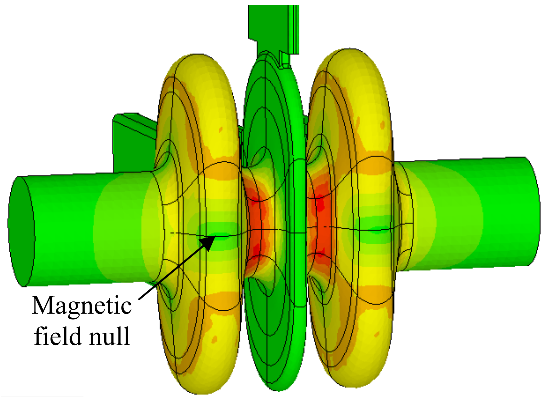


Figure 2: Magnetic field magnitude due to the π/2 mode on the 3-cell cavity where the red and green colors represent the maximum and minimum field levels, respectively.

of the cavity. Typically, on-cell damping is forbidden for high-gradient superconducting accelerating cavities due to the adverse enhancement of the magnetic field. However, the modal pattern of the dipole mode consists of nulls along the horizontal plane of the cavity, as shown in Fig. 2. Also due to the π/2 phase advance between cavity cells, the body of the center cell has low field levels. At these locations, dampers were situated to couple strongly to the monopole modes and other parasitic modes. Table 1 lists the external Q factor for the first passband of the monopole and vertical dipole modes using this damping configuration. Experimental verification of the on-cell damper concept is currently being performed at JLAB.

The beam is primarily deflected by the magnetic field in the end cells and by the electric field at the irises in the center cell, as shown in Fig. 3. However, it was necessary to adjust the cell lengths not only to maximize the shunt impedance (by extending the end cells and compressing the center cell) but also to ensure sufficient damping of the parasitic modes. The damping effectiveness improved as the length of the center cell increased, but detrimental damping of the π/2 mode also increased. As a result, the final dimensions were determined based on a compromise between beam stability requirements, operating mode damping, and shunt impedance.

The cavity length is approximately 110 mm with a 8-mm center cell, 18-mm cavity irises, and symmetric end cells. As compared with a single-cell cavity, the peak magnetic field in the cavity increased due to the presence of irises between cells. The cavity iris was enlarged to reduce the magnetic field with considerations made to the slope of the cavity walls in preventing parallel multipacting surfaces. Overall, the figure of merit representing the ratio of the peak magnetic field to the deflecting gradient was reduced by greater than 35% compared with the single-cell cavity.

The R/Q and the shunt impedance for various cavity modes is also shown in Table 1. The transverse impedance for the dipole modes is defined as follows:

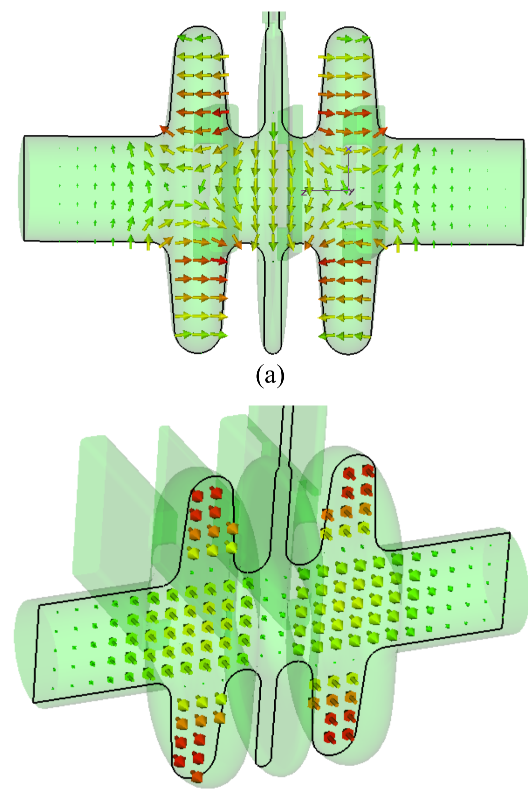
Table 1: The rf parameters of the first passband for the monopole and vertical dipole modes. The Type headings M and D_V correspond to monopole and vertical dipole modes, respectively. R_s is defined for monopole modes from the circuit definition of the shunt impedance, and R_T is defined as in Eq. (1) for dipole modes. For the sake of comparison, the APS stability threshold impedance limits can be seen in Fig. 4.

Type	Phase Advance	Freq (GHz)	$R_{S(T)}/Q$	Q_{ext}	$R_{S(T)}$ (10 cavities)
M	0	2.45	0.06	248.0	1.40E+02
M	π / 2	2.47	55.1	257.0	1.42E+05
M	π	2.6	12.4	5.9	7.28E+02
D_V	π	2.76	39.2	142.3	1.61E+06
D_V	π / 2	2.82	59.7	----	-----
D_V	0	2.87	5.05	745.0	1.13E+06

$$\frac{R_T}{Q} = \frac{V^2\big|_{r=r_0}}{\omega U (kr_0)^2}, \quad R_T = \frac{R_T}{Q} * Q_{ext} * \frac{k}{2}; \qquad (1)$$

where k is the wave number, and r_0 is the off-axis radius along which the voltage V is calculated.

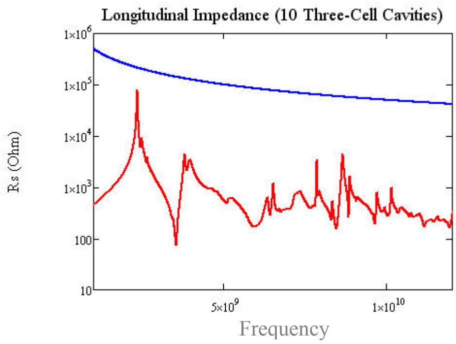
Due to the reduced size of the center cell, issues



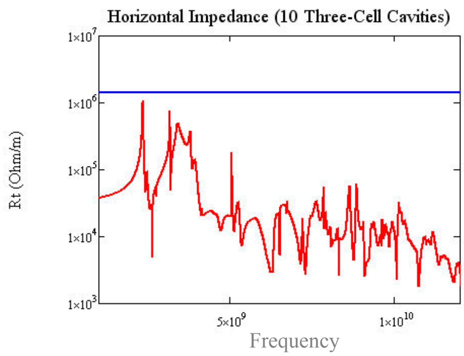
(a)

(b)

Figure 3: Field pattern for the π/2 dipole mode: (a) electric field and (b) magnetic field.



(a)



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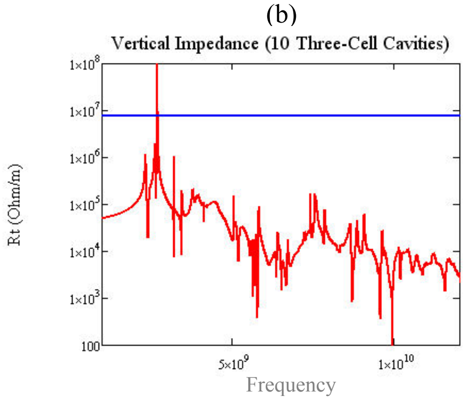

(c)

Figure 4: Impedance calculated by GdFidl for ten 3-cell cavities with matched port terminations: (a) longitudinal, (b) horizontal, and (c) vertical. The red plot represents the beam impedance and the blue line defines the APS stability limit.

regarding cavity manufacture and cavity processing will be undertaken. A vacuum-compatible copper prototype cavity is currently being constructed with a waveguide input coupler for low-power characterization and eventual insertion into the APS storage ring for passive cavity studies to evaluate beam stability, cavity performance, and damping effectiveness.

CAVITY IMPEDANCE

The broadband impedance of ten 3-cell cavities was calculated using the time-domain beam dynamics solver Gdfidl, as shown in Fig. 4. Port terminations were used at each waveguide port and on the beampipes. Long-range wake potentials were calculated for 250 meters for the longitudinal and horizontal impedance and for 500 meters for the vertical impedance.

The 3-cell cavity is shown to be stable across a large bandwidth where the APS limit is based on 200-mA beam current. The vertical dipole mode impedance for the 0 and π modes in the passband of the operating mode were shown to be heavily damped by the damping waveguide on the center cell of the cavity.

The cavity loss factor, calculated by integration of the bunch profile with the short-range wakefield, was 0.81 V/pC. For the worst-case 24-bunch nominal bunch pattern at the APS, the peak parasitic mode power loss to the damper loads was determined to be 1.2 kW due to broadband impedance for 100-mA beam current and 5.0 kW for 200-mA current.

CONCLUSION

A superconducting multi-cell deflecting cavity that achieves heavy damping of parasitic modes has been analyzed and is suitable for a third-generation storage ring. The 3-cell cavity operates in the π/2 mode in order to isolate the modal fields of the operating mode from the center damping cell.

Due to a magnetic null on the cavity equatorial plane, on-cell dampers have been utilized on each cell of the cavity in order to achieve sufficient damping of the strongly coupled cavity monopole modes. Due to low field levels in the center damping cell, an on-cell damper will also be utilized in the vertical plane to selectively damp the vertical dipole modes.

The 3-cell cavity has been shown to reduce the cavity impedance to stable levels while improving the cavity packing factor. The maximum gradient for a given peak magnetic field has been improved by over 35% as compared with a single-cell deflecting cavity.

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