HIGHER ORDER MODES DAMPING AND MULTIPACTING ANALYSIS FOR THE SPX DEFLECTING CAVITY FOR THE APS UPGRADE*

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Abstract

A single-cell superconducting deflecting cavity operating at 2.815 GHz has been proposed and designed for the Short Pulse X-ray (SPX) project for the Advanced Photon Source (APS) upgrade. Each deflecting cavity is equipped with one fundamental power coupler (FPC), one lower order mode (LOM) coupler, and two higher order mode (HOM) couplers to achieve the stringent damping requirements for the unwanted modes. Using the electromagnetic simulation suite ACE3P, HOM damping was calculated for the cavity including the full engineering design waveguide configurations and rf windows. Trapped modes in the bellows located in the beampipes connecting the cavities in a two-cavity cryomodule were analyzed. Multipacting activities in the cavity and damping waveguides were simulated under the condition of field asymmetry due to a realistic cavity imperfection to assess possible problems during high power processing.

INTRODUCTION

The Advanced Photon Source (APS) can provide photon pulses of several tens to hundreds of picoseconds. There are growing requests from users to use shorter pulse X-rays (SPX) for the analysis of short time-scale physical processes. It has been proposed at APS [1,2] to utilize a pair of superconducting deflecting cavity modules to generate ~1ps X-ray pulses at one of the straight sections, without disrupting the regular X-ray pulse usage for other users. In the proposed scheme, the first set of cavities add a correlation between bunch longitudinal position and transverse momentum. X-Rays produced by this bunch will also have this correlation, and can be put through transverse slits to produce a much shorter X-Ray pulse. The second set of cavities are located a multiple of 180 degrees of phase advance to unchirp the beam, removing the effects of the first cavity set. A cryomodule of four such cavities on each side of the undulator will be needed to produce the required 2-MV deflecting voltage [3].

A two-cavity prototype cryomodule, Fig. 1, is currently under construction and to be tested before the full installation of the four-cavity cryomodules for the APS upgrade. Because of the added complicity of the multi-cavity system, understanding of potential trapped modes and multipacting issues in such a multi-cavity system is essential to validate the design concept. In addition to the planned test, detailed numerical analysis of the HOM damping and multipacting were carried out on the two-cavity prototype module. In this paper, we present the simulation results of HOM damping and multipacting analysis under realistic imperfection conditions.

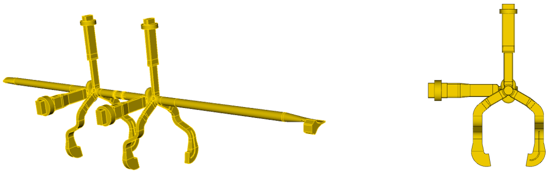

Figure 1: SPX two-cavity deflecting module, and the layout of the FPC and HOM/LOM damping couplers

TWO CAVITY PROTOTYPE MODULE

The layout of the two-cavity module, including the couplers, bellows, and extended beam pipes, is shown in Fig. 1. The cavity has a flattened oval shape and operates in the TM110 mode at 2.815 GHz, which has a strong magnetic field on the beam axis that produces transverse deflection. The RF power is fed from a fundamental power coupler (FPC) waveguide, the vertical waveguide in Fig. 1, which forms one of the legs of a ”Y”-end-group off-cell. The other two legs of the “Y”-end-group, the curved waveguide underneath the cavities, are for damping the higher-order modes. The cavity also supports a TM01 mode, which is at a lower frequency than the operating mode. An on-cell lower order mode (LOM) coupler, horizontal waveguide in Fig. 1, is directly attached to the cell at the cavity equator which offers a more compact geometry with enhanced LOM and HOM damping. Beampipe bellows are in between the two cavities for alignment flexibility.

We have used the parallel finite element EM code suite ACE3P [4] developed at SLAC to analyze the trapped mode damping and multipacting in the two-cavity cryomodule. Fig. 2 shows the finite element mesh around

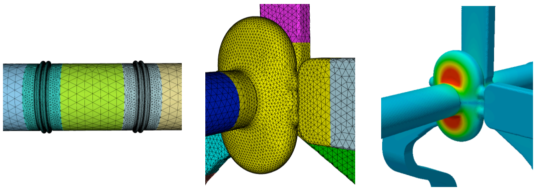

Figure 2: Finite-element mesh around the cavity and beam pipe bellows and the field profile of the operating mode.

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*Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357

the cavity and the bellows used by the ACE3P code. The electric field profile of the operating mode, which produces a vertical deflection, is also shown in Fig. 2.

TRAPPED MODES AND HOM DAMPING IN THE TWO-CAVITY MODULE

HOM Damping and Impedance

The HOMs up to 4.6 GHz were calculated using the Omega3P parallel eigensolver. The FPC, the LOM/HOM, and the beampipe ports are modelled with absorbing boundary conditions to evaluate the external Q_{ext}. Due to the geometry asymmetry, most of the HOMs are not centred at the geometric axis of the cavity. Because of this centre offset, a beam passing through the cavity centre will see multipole field components [5]. For example, a mode with a clear dipole mode pattern will have a finite monopole component when the centre is off the cavity axis. After the eigenmode calculations with Omega3P, the multipole components of each mode were calculated with respect to the beam centroid using a postprocessing tool. The impedances associate with the multipole field components of each mode were then calculated and are plotted in Fig. 3. The RF quantities plotted in Fig.3 are defined as the following, with "v" the voltage of the respective multipole component.

$$\left(\frac{R}{Q}\right)_T = \frac{|V_z(r_0)|^2}{\omega U\left(r_0\omega/c\right)^2} \qquad Z_T = \frac{\omega}{c}\left(\frac{R}{Q}\right)_T Q_{ext}$$

$$\left(\frac{R}{Q}\right)_L = \frac{|V_z(r_0)|^2}{\omega U} \qquad Z_L = \left(\frac{R}{Q}\right)_L Q_{ext}$$

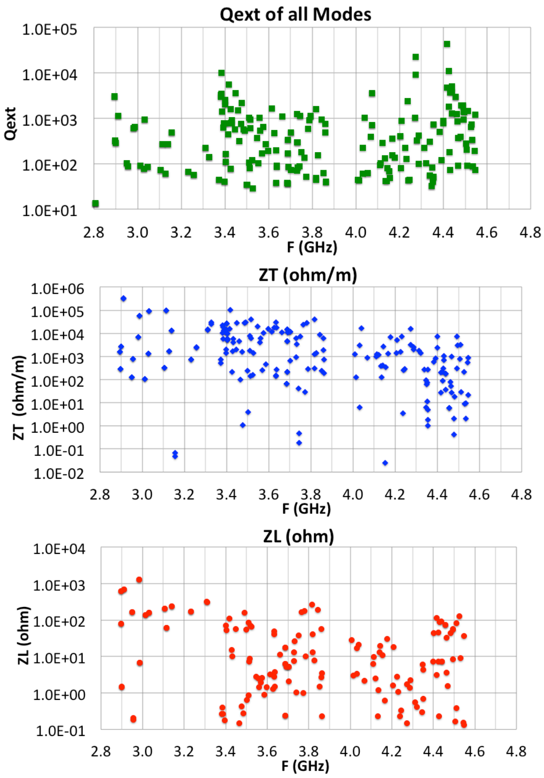


Figure 3: Q_{ext} and impedances of the HOMs in the two-cavity system.

Simulation results have shown that all the modes are well damped. There are no significant trapped modes found in the two-cavity system. Both transverse and longitudinal impedances met the requirements for beam stability [6].

HOMs in the Beam Pipe Bellows Region

There are a few modes above the beam pipe TM010 cutoff frequency of 4.41GHz that have longitudinal impedances of about 100 ohms. Two of these longitudinal modes are shown in Fig. 4. Both have relatively strong magnetic fields in the bellows region. These are the type of modes of concern in a multi-cavity module as they could produce RF heating to the bellows. Simulation results have showed that the two-cavity prototype module design can provide essential damping via the LOM and HOM couplers to these modes thus minimizes the beam coupling to the modes. As a result, the RF heating by these coupled modes does not seem to be of concern.

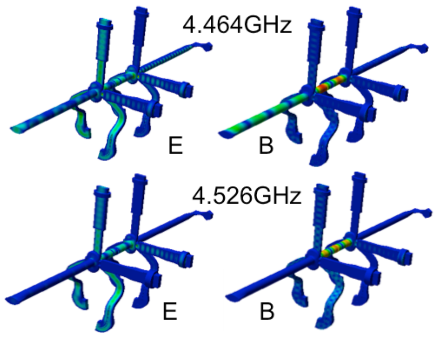


Figure 4: Monopole modes that have strong magnetic fields in the bellows region.

MULTIPACTING DUE TO FIELD ASYMMETRY

The rectangular LOM coupler has a TE10 mode cutoff frequency lower than the deflecting mode frequency. The rejection of the LOM coupler to the deflecting mode relies solely on the field symmetry. In an ideal case, the deflecting dipole mode can only couple to the TE20 mode of the LOM coupler which is cutoff at the operating dipole mode frequency. The asymmetric "Y"-end-group causes only a slight field asymmetry in the cavity which in turn induce negligible power leakage through the LOM coupler. However, the first horizontal test of a prototype cavity showed sharp heating at the LOM strongly correlated with a strong Q-switch and a significant power leakage through the LOM coupler [7]. This pointed to a field asymmetry caused by a shape imperfection and possible multipacting related to such a field that limited the cavity performance. Track3P multipacting simulation code was used to analyse multipacting resonances under a field asymmetry modeled with a simple "dent imperfection" on the cavity wall. The amount of "dent" induces an RF leakage that is comparable to the measurement. Fig. 5 shows the field leaking via the LOM coupler (horizontal) with the induced field asymmetry by a "dent". The multipacting map obtained for the "ideal" and "imperfect" cavities are shown in Fig. 6 for comparison.

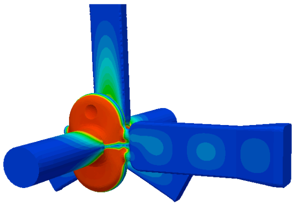
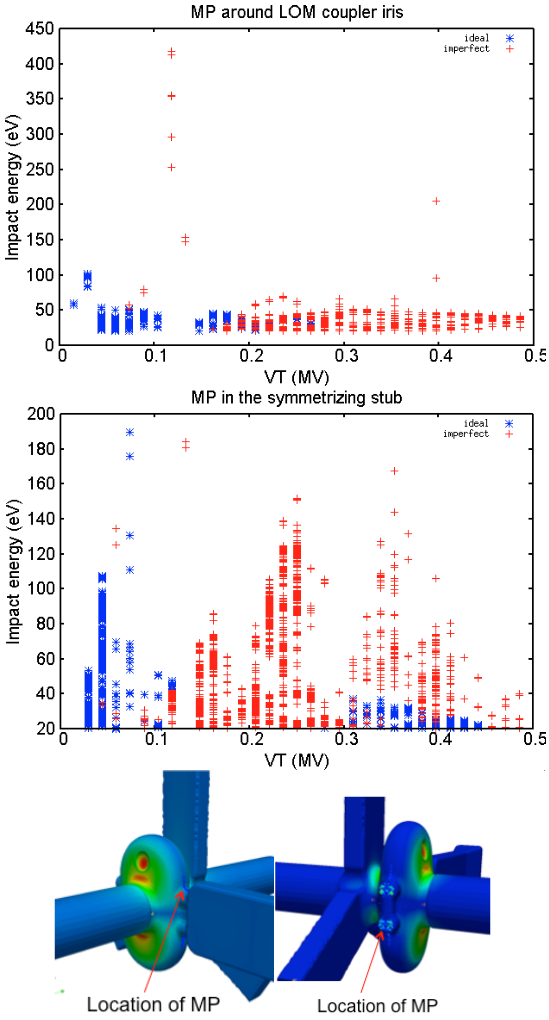


Figure 5: Power leakage through the LOM coupler in an imperfect geometry with a "dent", comparable to the leakage measured in the prototype cavity.



LOM iris Symmetrizing stub

Figure 6: Effect of a field asymmetry on multipacting.

The multipacting band in the LOM coupling iris region is shifted to a higher field level in the case with the field asymmetry. The impact energies of the resonant trajectories in this band are mostly lower than 50 eV. The SEY for niobium at these energies are relatively low, and the multipacting bands in both "ideal" and "imperfect" cases are considered not strong barriers.

An enhanced multipacting band around 0.24 MV deflecting voltage was found in the symmetrizing dog-bone in the case with the field asymmetry. The energies of the resonant trajectories in this band are as high as 140 eV. The SEY of these trajectories is much higher than the ones around the LOM iris. Significant multipacting is possible in this region when a field asymmetry exists. This multipacting band was observed in the RF testing of the prototype cavity that has a imperfection asymmetry [6]. The multipacting band was eliminated in the RF test by tuning the LOM coupler to minimize the leakage and subsequently the field asymmetry, which agrees with the analogy of an ideal cavity.

SUMMARY

HOMs and trapped modes were calculated for the two-cavity prototype cryomodule using the parallel code Omega3P. No dangerous trapped modes were found in the two-cavity system. All modes were well damped. Both the transverse and logitudinal impedances are below the instability threshold. A few monopole modes above 4.41 GHz were found to have strong fields in the bellows region. These modes are well damped by the LOM/HOM couplers and are low in impedances. HOM heating of the bellows does not seem to be a significant issue. Multipacting in the cavity due to imperfection and asymmetry was analyzed using Track3P. An enhanced multipacting band in the symmetrizing stub was found when there is a finite RF power leakage through the LOM coupler due to a shape imperfection, which can be eliminated by tuning the LOM coupler. The simulation results are in good agreement with the RF test of a prototype cavity.

ACKNOWLEDGEMENT

The work used the resources of NERSC at LBNL which is supported by the Office of Science of the U.S. DOE under Contract No. DE-AC03-76SF00098.

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