RF SIMULATIONS FOR AN LCLS-II 3RD HARMONIC CAVITY CYROMODULE*

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Abstract

The FNAL designed 3.9 GHz third harmonic cavity for XFEL will be used in LCLS-II for linearizing the longitudinal beam profile. The 3.9 GHz SRF cavity is scaled down from the 1.3 GHz TESLA cavity shape, but has a disproportionately large beampipe radius for better higher-order mode (HOM) damping. The HOM and fundamental power (FPC) couplers will generate asymmetric field in the beam region, and thereby dilute the beam emittance. Meanwhile, due to the large beampipe, all but a few of the HOMs are above the beampipe cutoff. Thus the HOM damping analyses need to be performed in a full cryomodule, rather than in an individual cavity. The HOM damping in a 4-cavity cryomodule was investigated to determine possible trapped modes using the parallel electromagnetic code suite ACE3P developed at SLAC. The RF kicks induced by the HOM and FPC couplers in the 3.9 GHz cavity were evaluated. A possible cavity-to-cavity arrangement is proposed which could provide effective cancellation of these RF kicks. In this paper we present and discuss the RF simulation results in the 3.9 GHz third harmonic cavity cryomodule.

INTRODUCTION

LCLS-II is a major upgrade add-on to the Linac Coherent Light Source (LCLS) at SLAC, by which its capabilities as a world-class discovery machine will be greatly advanced by the installation of a 4 GeV superconducting RF (SRF) linac and other instruments in the beamline [1]. The 3.9 GHz third harmonic cavity designed at Fermi National Accelerator Laboratory for the European XFEL will be used in the LCLS-II linac for linearizing the longitudinal beam profile. Two 3.9 GHz 8-cavity cryomodules will be installed between the 1.3 GHz linac segments L1 and L2.

The 3.9 GHz SRF cavity, shown in Figure 1, is scaled down from the 1.3 GHz TESLA cavity shape, but with a disproportionately large beampipe radius [2]. Strong multipacting was found in the curved leg region of the original loop-type HOM coupler design. Therefore, a new HOM coupler design with a probe plus a fundamental mode filter was adopted, illustrated in Figure 2 [3].

The HOM and FPC couplers in the LCLS-II 3.9 GHz linearizer cavities will induce field asymmetry, which will then kick the beam transversely and degrade the beam performance. The RF kicks produced by the HOM and FPC couplers in the original 3.9 GHz cavity design for XFEL have been evaluated [4, 5]. In this paper we will evaluate the RF kicks generated by the current HOM and FPC couplers in the 3.9 GHz cavity with an RF input coupling Q_{ext} of 1.3×10^7 for the FPC.

The HOMs have been studied experimentally and numerically for beam diagnostics in the 3.9 GHz modules [6, 7]. However, the RF simulations have been focused on finding the modes with higher R/Q in a cryomodule without damping information. In this paper, the HOM damping in a cryomodule is investigated to determine possible trapped modes in a 4-cavity cryomodule.

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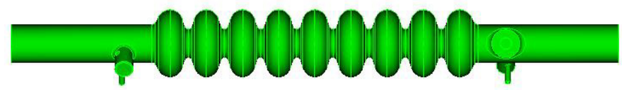

Figure 1: 3.9 GHz third harmonic cavity.

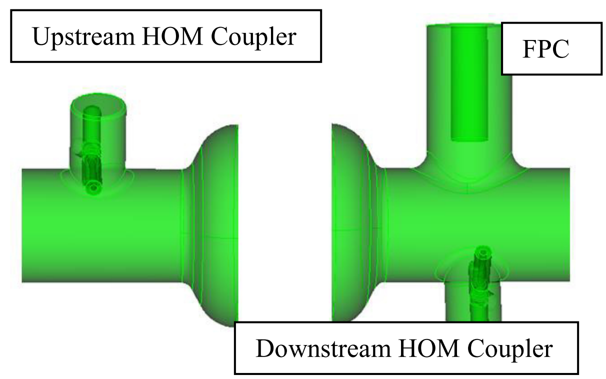

Figure 2: The upstream (left) and downstream (right) HOM/FPC couplers.

RF KICKS

RF field and kick simulations require high numerical solution accuracy to resolve the transverse components on the beam axis, which are usually about 2 or 3 orders of magnitude smaller than the accelerating field. The calculations were performed using the parallel electromagnetic code suite ACE3P, developed at SLAC. ACE3P is based on the high-order finite-element method, so that geometries of complex structures can be represented with high fidelity through use of conformal grids and high solution accuracies can be obtained using high-order basis functions in finite elements [8].

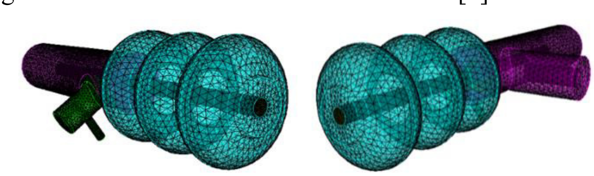

Figure 3: Upstream (left) and downstream (right) HOM/FPC coupler RF kick simulation models. Different colors represent different mesh qualities.

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The field asymmetry induced by the HOM and FPC couplers will spread through the neighbouring 2 to 3 cells due to the large iris aperture. Therefore, each end group plus its neighbouring three cells are used for the RF kick simulations, as shown in Figure 3. In addition, denser meshes are generated in the cavity central region, and third-order finite element base functions are used to solve the RF fields in the beam region with proper accuracy.

The longitudinal and transverse field components of the accelerating field calculated by the ACE3P eigensolver Omega3P are plotted in Figures 4 and 5 at a field gradient of 10 MV/m. Here the FPC coupler is in the horizontal plane (x-plane).

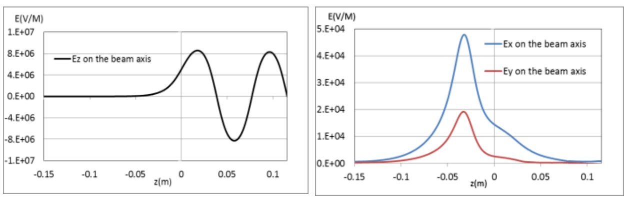

Figure 4: The accelerating field longitudinal (left) and transverse (right) components on the beam axis in the upstream HOM endgroup and its neighbouring 3 cells.

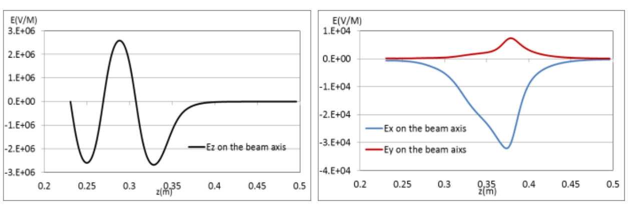

Figure 5: The accelerating field longitudinal (left) and transverse (right) components on the beam axis in the downstream HOM/FPC endgroup and its neighbouring 3 cells.

The transverse RF kicks are shown in Figure 6, where

$$\Delta(\gamma\vec{\beta}) = \frac{e}{m_0 c^2}\int_{z1}^{z2}(\vec{E} + c\vec{\beta}\times\vec{B})\bullet d\vec{z}$$

There is a small portion of traveling wave at the downstream end where the FPC is located, but it's mainly the standing wave fields that contribute to the RF kicks.

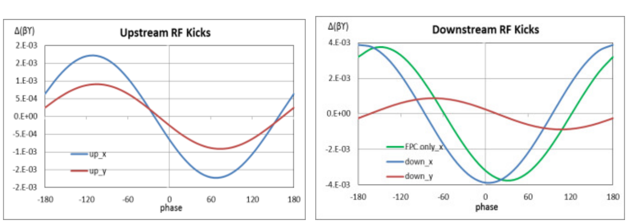

Figure 6: The upstream (left) and downstream (right) transverse RF kicks.

Table 1: Transverse RF kicks in the 3.9 GHz cavity with the one probe HOM design

	1e6*Vx/Vz (abs(Vx/Vz))	1e6*Vy/Vz (abs(Vy/Vz))
Upstream	-96.2+238.0i **(257)**	-37.3+139.1i **(144)**
Downstream	-593.4+62.4i **(597)**	21.6+136.6i **(138)**

The transverse RF kicks in the 3.9 GHz cavity with the current HOM coupler design are listed in Table 1. The current HOM coupler design gives RF kick amplitudes similar to those from the original design in [5]. The large RF kick at x-direction comes from the FPC. Without changing the input coupling of 1.3×10^7, we propose to move the FPC 15 mm away from the cavity end cell so that the antenna tip will be flush with the beampipe wall, which minimizes the field asymmetry. The FPC RF kick with this new configuration is smaller by a factor of 5 than the one in the current design, as shown in Figure 7. The total RF kick in x-direction is reduced by half.

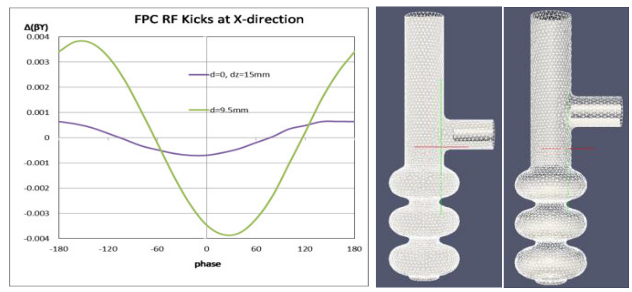

Figure 7: The FPC RF kicks in the current and proposed designs. d is the distance between the antenna tip and the beampipe wall.

Furthermore, another option is to rotate the adjacent cavity 180 degrees around the beam axis. The total RF kick can thereby be reduced by two orders of magnitude due to the cancellation of the contributions from the two cavities, as shown in Figure 8.

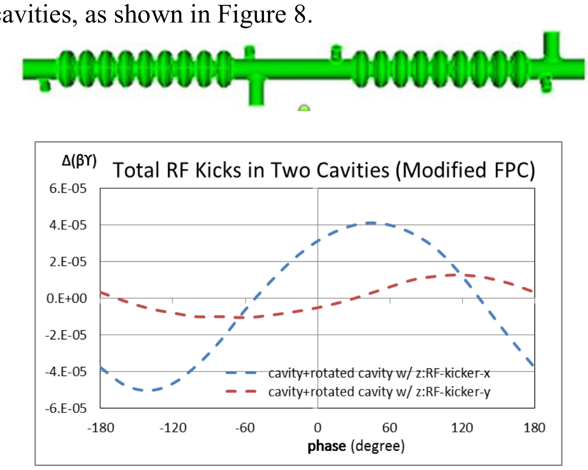

Figure 8: Cavity and rotated cavity arrangement (up) and the two cavities RF kicks (down).

HOM DAMPING

The dipole mode cutoff frequency is 4.4 GHz at a 20 mm beampipe radius in the 3.9 GHz cavity, and thus most of the HOMs will propagate into adjacent cavities. The f_{rms} for the 6 mm bunch length at the LCLS-II 3rd harmonic cryomodules is 11.25 GHz. The HOM parameters up to 10 GHz in a 4-cavity chain had been examined without investigating the HOM damping in references [6, 7].

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The HOM damping in a 4-cavity chain was calculated using Omega3P to determine possible trapped modes in the cryomodule. The beampipe spacing between two cavities is three times the wavelength. The HOM damping requirement is $Q_{ext} < 1\times10^7$ for LCLS-II.

It was found that for modes of the first two dipole bands Q_{ext}'s were all below 10^7, which satisfies the LCLS-II requirement. However, in the 3rd dipole band there are high Q_{ext} modes around 7.3 GHz, as shown in Figure 9. Among of them, the significant trapped mode's Q_{ext} is 3.25×10^7 assuming the FPC not coupling to this mode due to its narrow filter bandwidth. Its field pattern is shown in Figure 10, which shows coupling of the cavity dipole mode to a beampipe quadruple mode. The mode is twisted in the beampipes between cavities due to the complex 3D end-group geometry.

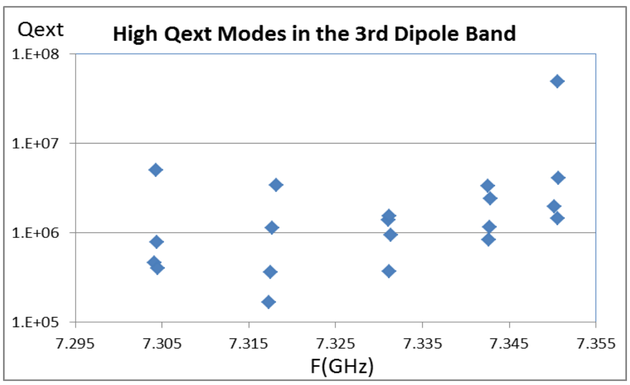

Figure 9: The high Q_{ext} modes damping in the 3rd dipole band in a 3.9 GHz 4-cavity chain.

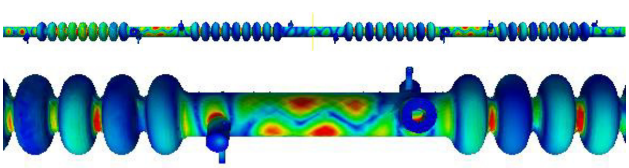

Figure 10: The first trapped mode around 7.35 GHz in a 3.9 GHz 4-cavity chain (top) and beampipe (bottom).

This mode will be re-examined in a 3.9 GHz 8-cavity cryomodule to see if it will cause any harm to the LCLS-II beam. The HOM damping above the 3rd dipole band is under investigation.

CONCLUSION

Calculations of RF kicks and HOM damping in the FNAL designed 3.9 GHz third harmonic cavity cryomodule have been performed using the SLAC developed parallel electromagnetic code suite ACE3P. The current probe-type HOM coupler gives similar RF kicks to the original loop-type HOM coupler, but the FPC coupler was found to give a larger RF kick than the value presented in ref [5]. Further cross checking is needed. In this paper, we proposed to move the FPC further away from the cavity end cell by 15 mm, and extend the antenna intrusion to the beampipe radius. Without changing the input coupling, the FPC RF kicks will then be reduced to one-fifth of the current value. Furthermore, by alternating the FPC coupler orientation between cavities, the total RF kick can be reduced by two orders of magnitude. In a 3.9 GHz cavity cryomobule, there is one third dipole band mode in the cavities that couples to the quadruple mode in the beampipe, and has Q_{ext} higher than the 1×10^7 limit. Possible other high Q_{ext} modes at higher frequencies are being investigated. The RF kicks and HOM damping results will be used for the beam dynamics analysis.

ACKNOWLEDGMENT

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