LCLS-II Technical Note

Optimizing of HOM Coupler Feedthrough Parameters in the 1.3 GHz LCLS-II Structure

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1 ABSTRACT

This paper reports the simulation results of monopole High Order Modes (HOM) spectrum in the 1.3 GHz structure for the LCLS-II linac. Based on these results we define optimum parameters of the HOM feedthrough in order to minimize RF losses on the antenna tip and to preserve monopole HOMs damping efficiency simultaneously.

2 INTRODUCTION

A continuous operation regime of the 1.3 GHz LCSL-II accelerating structure at the nominal gradient of 16 MV/m sets an extra caution on possible overheating of HOM couplers feedthroughs [1]. The HOM feedthrough coupling antenna is made of a solid Niobium, which doesn't produce significant amount of RF losses till its temperature is kept below critical and the niobium surface is in a superconducting state. Nevertheless, a radiation of HOMs and an operating mode leaking through the notch filter can cause RF heating of the feedthrough internal parts and then a heating of the antenna itself by a thermal conductivity. This effect may initiate a thermal runaway process when increasing the antenna temperature leads to larger RF losses and generate an additional antenna heating by itself. Eventually it will produce a sharp temperature rise and end up by a cavity quench. In order to avoid such a scenario, one has to minimize the antenna RF heating by using smaller antenna tip and increasing the gap between the antenna and the f-part of HOM coupler. At the same time we should not compromise the coupler capability to damp the cavity HOM spectrum. Bellow we compare ILC and XFEL design of the HOM feedthrough and analyze various antenna positions for finding optimum parameters.

3 MONOPOLE HOMS SPECTRUM.

The detailed study of resonant HOM excitation in the LCLS-II accelerating structure is performed in [2]. For the nominal parameters of LCLS-II linac the most dangerous are monopole HOMs with high shunt impedances which may result additional radiation of RF power to the HOM coupler port. Based on it we limited our investigation by the monopole HOMs only. Originally the spectrum of monopole modes in the 2D model of the TESLA 9-cell cavity is presented in [3] for first three TM-monopole passbands. Recently the detailed study of a thermal quench initiated by the overheating of the HOM antenna is published in [4] for various designs of the HOM feedthrough and trapped monopole HOMs below the beam pipe cut-off frequency of 2.942 GHz for the TM_{01} mode.

Table 1 Parameters of monopole HOMs

Mode #	Frequency, [GHz]	R/Q [Ω]	Q_{ext}
2-8	2.452	136	8.5e4
2-9	2.458	157	1.7e5
4-1	3.3976	0.025	1.0e4
4-2	3.4073	0.36	4.5e3
5-6	3.8528	4.9	1.0e4
5-7	3.8560	1.6	3.5e4
5-8	3.8578	42	1.4e5
6-1	3.9253	0.05	1.8e4
6-2	3.9453	0.12	5.0e3
7-7	4.7051	0.66	2.2e3
7-8	4.7209	5.8	4.5e4
8-5	4.8829	0.4	1.0e5
8-8	4.8926	0.5	3.8e4

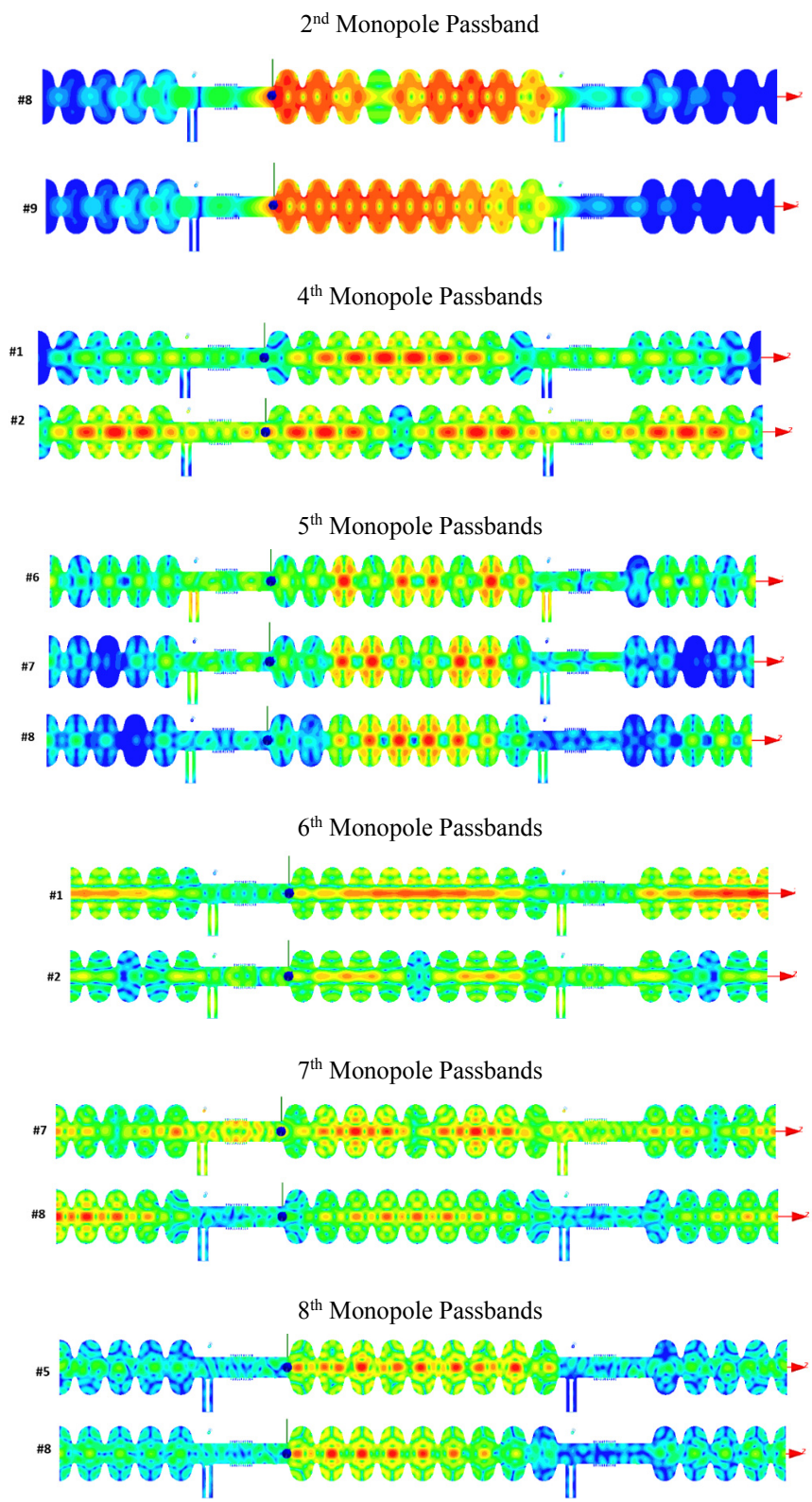

Figure 1: Electric field maps of trapped monopole modes in the 1.3 GHz LCLS-II structure.

We extend the search of trapped monopole modes beyond the beam pipe cut-off frequency. For this purpose we simulate the chain of three cavities where HOMs in the first and last cavities are slightly detuned from the middle cavity in order to approximate the actual spread of the HOM spectrum due to mechanical

tolerances. The cavity 3D model is based on actual mechanical drawings including HOM coupler feedthroughs. The results of electromagnetic calculations of monopole HOMs up to the 5 GHz frequency are illustrated in Figure 1 for modes with highest R/Q values in each passband. One can note that despite the frequencies of second monopole passband in the 1.3 GHz cavity is below the cutoff limit, the RF field is propagating through the beam pipe. The reason is a transformation of monopole TM_{01} mode in the cavity to the dipole TE_{11} mode in the beam pipe due to asymmetries introduced by HOM couplers. The coupled TE_{11} mode can freely propagate in the interconnecting beam pipe since its frequency is above the cut off limit of 2.252 GHz. The TE_{11} signal reaches to neighbor cavities and reflects back forming a standing wave pattern, which has a strong influence on a coupling with the HOM ports. Thus, the chain of at least three cavities is required for accurate simulation of monopole HOMs damping even for the passbands bellow the cutoff limit of the TM_{01} mode.

The calculated parameters of monopole HOMs are presented in the Table. 1 for the cavity with XFEL HOM feedthroughs installed. The cavity to fundamental power coupler coupling is set to 4e7 according to the LCLS-II specification. There are only three dangerous HOMs, modes #8 and #9 in the 2nd passband and mode #8 in the 5th passband, which have a combination of both high R/Q and Q_{ext} values. The rest of monopole HOMs are either heavily damped by HOM couplers or have a low R/Q and, therefore they will not introduce any problems for the nominal parameters of the LCLS-II linac [2]. Finally we decide to watch for the parameters of these three modes only for further HOM feedthrough optimizations. Since the 1.3 GHz cavity has different end cells, the RF field distribution is non-symmetric and tends to be loaded mostly on upstream or downstream side of the cavity. In addition, due a linear polarization of the dipole TE_{11} mode in the beam pipe, the mode can be coupled only with one out of two HOM couplers. Therefore as a conservative approach on cane assume that most of HOM power is radiated to a single HOM coupler.

4 OPTIMIZING OF THE HOM COUPLER FEEDTHROUGH PARAMETERS

Geometry of the HOM feedthrough is illustrated in Figure 2, where two parameters, size of the antenna tip and the gap between the antenna and the f-part have a most influence on monopole HOM damping and RF loss on the antenna tip. The ILC feedthrough has a tip of 11 mm diameter while modified XFEL feedthrough has a reduced tip size of 7.8 mm. The gap distance can be varied between fractions of millimeter to few millimeters.

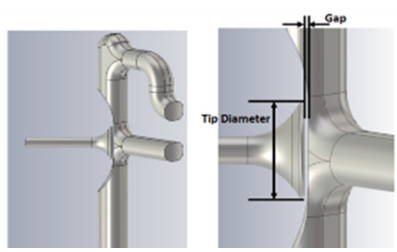

Figure 2 Geometry of the HOM feedthrough.

A distribution of surface magnetic field is shown in Figure 3 for the XFEL coupler antenna and different gap sizes. One can see that a larger gap moves antenna out of a resonant volume and, thus, significantly reduces the surface magnetic field and associated heat load.

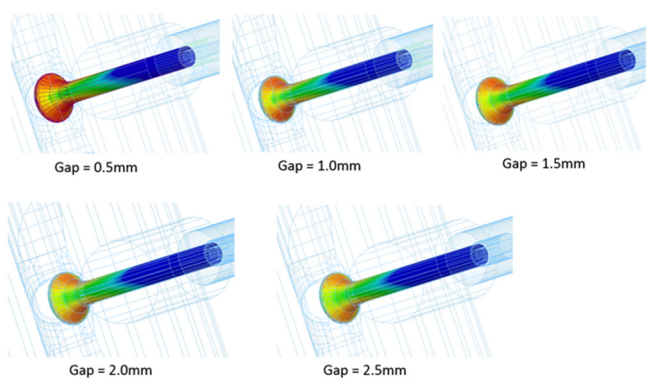

Figure 3 Surface magnetic field on the XFEL HOM feedthrough antenna tip for various gap sizes between the antenna and the coupler f-part.

Performances of ILC and XFEL HOM feedthroughs to damp monopole HOMs are compared in Figure 4. In spite a smaller size of the antenna tip the XFEL feedthrough demonstrates better coupling with the 2nd monopole passband. The reason for such a behavior is explained by the internal structure of the feedthrough. Because of a step in outer diameters of the coaxial line and the ceramic window, the antenna tip forms a low-Q resonator which affects on the monopole HOMs coupling. As a result, smaller antenna produces better coupling. The idea is illustrated in Figure 5 which shows electrical fields in the feedthrough cross section for ILC (left) and XFEL (right) HOM couplers. The dependence of damping 5th monopole band on the antenna geometries is very weak for the gap size below 1 mm and for larger gaps the performance of the ILC design is slightly better than the XFEL.

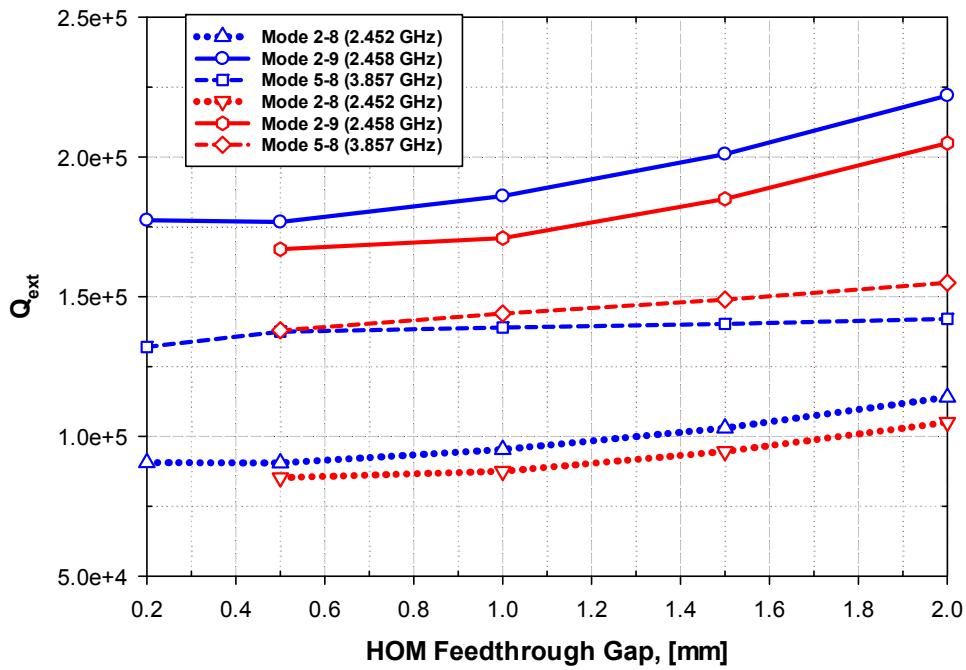

Figure 4 Monopole HOMs damping in the 2nd and 5th passbands by the ILC (blue) and XFEL (red) HOM couplers.

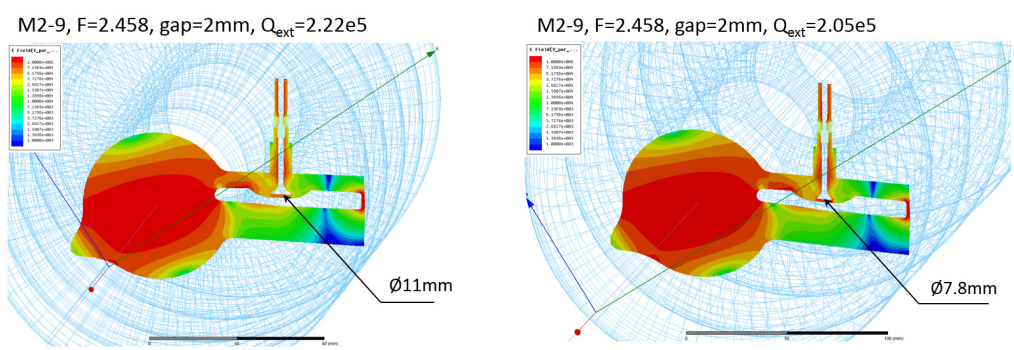

Figure 5 Map of electric field distribution in the ILC (left) and XFEL (right) HOM couplers.

Finally we quantitatively estimate the impact of gap size on reducing the heat load generated in the feedthrough and on damping of three most dangerous monopole HOMs in the XFEL coupler. We normalize the parameters of HOM feedthrough, antenna G-factor and HOMs external quality factors, on the parameters taken for the nominal gap size of 0.5 mm. The result is illustrated in Figure 6 where normalized Q-values are on the left side and normalized G- factors are on the right side of the plot. Evidently the antenna G-factor grows rapidly than the quality factors of associated monopole HOMs. For example, for the gap of 1.5 mm one can expect about 25% less RF losses while there is only 10% growing of the HOM quality factors.

Recent simulations of a multipactor phenomena in the gap between coupler f-part and the feedthrough antenna tip shows the advantage of larger gaps above 1.5 mm for avoiding resonant conditions and, thus, suppressing a multipactor [5]. Finally, we conclude that the optimum gap size for the XFEL HOM coupler feedthrough is within the 1.5 mm to 2.0 mm range.

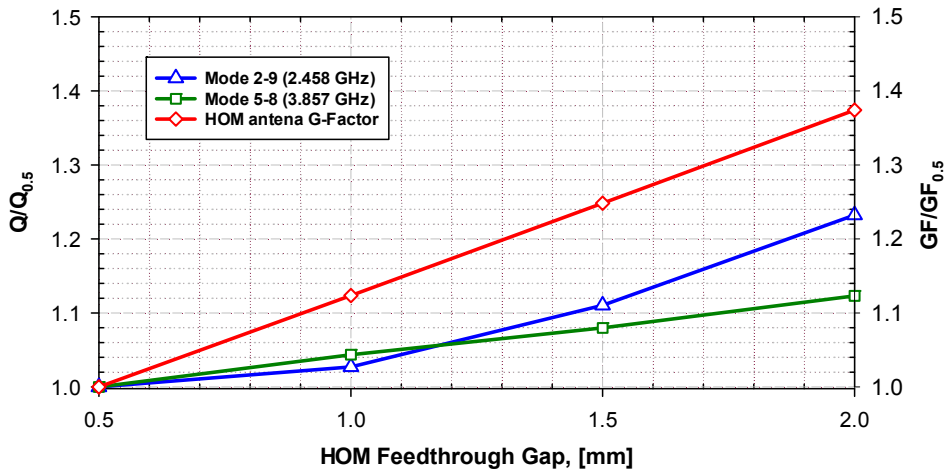

Figure 16 Normalized Q_{ext} and G-factors for different sizes of the HOM feedthrough gap.

5 CONCLUSIONS

We performed simulations of monopole HOM spectrum in the 1.3 GHz structure for LCLS-II linac with actual geometries of HOM feedthroughs. Local RF losses on the antenna tip were estimated for various sizes of the gap between the antenna and the HOM coupler f-part. Finally we conclude that the gap size can be safely increased up to 2.0 mm in order to minimize associated heat load in the HOM feedthrough and to suppress a multipactor phenomenon simultaneously.

6 REFERENCES

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