HOM ABSORBER STUDY BY PHOTON DIFFRACTION MODEL

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Abstract

Photon diffraction model (PDM) is one of the most promising candidates to study High Order Mode (HOM) power absorption on absorbing materials for high current SRF cavities. Because at very high frequency (>10GHz), the wavelengths of HOMs are much smaller compared with accelerators dimension, the phase of those HOM will be negligible. Meanwhile, Finite Element Method (FEM) cannot lend a high resolution on evaluation the HOM field patterns due to limited meshing capability. This PDM model utilizes Monte Carlo simulation to trace the ray diffusive reflection in a cavity. This method can directly estimate the power absorption on the cavity and absorber wall. This method will help design the HOM damper setup for eRHIC HOM damper. In this report, we evaluate HOM absorption on the cavity wall with different absorber setup and give a possible solution for power damping scheme for high frequency HOMs.

INTRODUCTION

Photon diffraction model (PDM) is one of the most promising candidates to study High Order Mode (HOM) power absorption on absorbing materials for high current SRF cavities. [1] Because at very high frequency (>10GHz), the wavelengths of HOMs are much smaller compared with accelerators dimension, the phase of those HOM will be negligible. Meanwhile, Finite Element Method (FEM) cannot lend a high resolution on evaluation the HOM field patterns due to limited meshing capability. This PDM model utilizes Monte Carlo simulation to trace the ray diffusive reflection in a cavity. This method can directly estimate the power absorption on the cavity and other HOM damping components. These two methods should agree well within certain frequency range and two methods would have different reliable governing range respectively. Figure 1 has illustrated such a scheme for both methods.

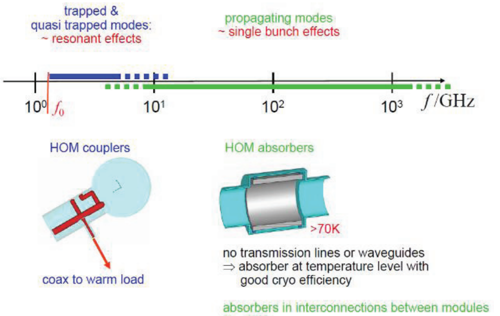

Figure 1: The schematic plot for photon diffraction and FEM methods on HOM damping components design for different frequency ranges consideration.

For relative low frequency HOM modes, their wavelengths are comparable to the cavity and HOM couplers dimension. For high frequency HOM mode, their wavelength is comparable to the surface roughness, the reflection is not specular reflection but diffusive reflection. In this case, FEM results cannot be trustworthy. Field distribution of high frequency HOM mode may not comply with Maxwell equations statistically, because interference and diffraction play dominates on these diffusive surfaces. Thus, the Fresnel diffraction integration law are appropriate to determine the field distribution (intensity) for those high frequency HOM. Meanwhile, the electromagnetic energy loss is understood as surface interface diffraction and reflection coefficients. On the other hand, the electromagnetic energy can also quantumized as photon particles. Photons are particles with weak phase information. Thus, the field patterns are reflected by the density of the photon numbers. At the same time, the photon number loss is reflected as photon rebounded and surface absorption. Intuitively, the three mechanisms are different exploration and explanations on the same matter. In this paper, we present a comprehensive method to understand the HOM field distributions, estimate the HOM power damping and design the HOM coupler and absorbers.

The absorptions and reflection indexes of SRF cavity surfaces and absorbing materials are given to estimate quality factors at different frequency too [2]. For superconducting surfaces, the reflection coefficient r can be calculated from surface resistant by equation 1 and 2.

$$1-|r|^2 = \left|\frac{Z_{met}-Z_0}{Z_{met}+Z_0}\right|^2 \tag{1}$$

$$Z_{met} = \frac{E_{\parallel}}{H_{\parallel}} \approx \sqrt{\frac{j\omega\mu_0}{\sigma_s}} = (1+j)\sqrt{\frac{\omega\mu_0}{2\sigma}} = (1+j)R_S \tag{2}$$

Where Rs is the surface resistant and Zmet is the surface impedance, and Z0 is characteristic impedance of the vacuum. Replace Zmet to equation 3, the reflection coefficient furtherly yields:

$$R_s = 0.25\times Z_0\times(1-|r|^2) \tag{3}$$

Where $Z_0 = \frac{1}{\varepsilon_0 c} = 377\Omega$ the characteristic impedance of the vacuum and r is the reflectivity index. The sticking coefficient is $1-|r|^2$. By integrating the energy inside the cavity and power absorbed by the surfaces, one can estimate the quality factor of this mode, for the fundamental mode, the quality factor is 1010 when we presume the surface resistant Rs is 10-9Ω.

HOM GENERATION FROM RAY TRACING SCHEME

The high frequency electromagnetic wave has small wavelength; the phase grid cannot extend too far with a reasonable decay of amplitude. It is more appropriate to resemble as a photon. Thus, this portion of energy has little phase information but only amplitude. Those particles can be either fully absorbed by some surfaces or kept rebouncing inside of the cavity vacuum. When a photon interacts with any surface, the probability of being absorbed is determined by a static reflection coefficient. Moreover, reflection is diffusive and the reflection angle should be a random angle determined by Monte Carlo simulation. This scheme is the same as particles inside a vacuum component. Molflow software is a Monte Carlo simulation code that can simulate the particle distribution inside of a vacuum component with multiple damping pump. The software will track the particle trajectory and density on each defined surface, in order to obtain the local pressure. We can record the particle numbers on different surfaces and floating in vacuum to estimate our external Qe for high frequency HOM at a steady state.

In Molflow software [3], sticking coefficients are assigned to each surface of SRF cavity, absorber and waveguides. These sticking coefficients are similar as the reflection coefficient of electromagnetic wave. They reflect to the surface photon absorption rate. If the sticking coefficient is 0.6, it suggests that 60% of total incident photons will be absorbed by this surface and 40% of total incident photons will be rebounce back to the vacuum with a diffusive angle. For metallic surfaces, the sticking coefficient has an empirical relation with surface resistant by DESY.

In this study, we will add the absorber materials at the end of the beam pipe and at ends of various HOM couplers. From previous measurements, we choose the sticking coefficient equals to 0.4 and 1e-7 for absorber materials and Niobium surface, respectively, for the modes whose frequency is greater than 4 GHz. By using BCS equation, Niobium surface resistance would be ~1μΩ at 5GHz.

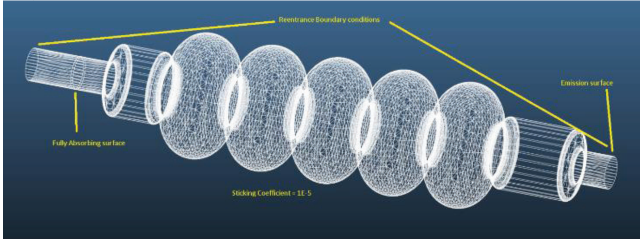

Figure 2: The detail setup up for a Monte Carlo simulation by using photon diffraction model.

The detailed simulation setup is shown in figure 2. The cavity is connected to the beam pipe absorber on each ends. The beam pipe openings are assigned as re-entrance boundary conditions, which means that a photon exits from one ports and will re-emit back with the same locations and angles. The simulated cavity is in a closed system and photons cannot leave the system. Figure 3 records a snapshot of photon tracking inside of the cavity. Absorption and reflection on each surface will be recorded and post-process will integrate the total energy of HOM damped on each component. In this Monte carlo simulation, the photon absorption number within a given time is plotted along the cavity longitude direction in Figure 3. The ratio between photon numbers on the absorber and cavity walls define the coupling coefficient β. One can obtain Qe from this β. The total absolute number in figure 3 alone is meaningless.

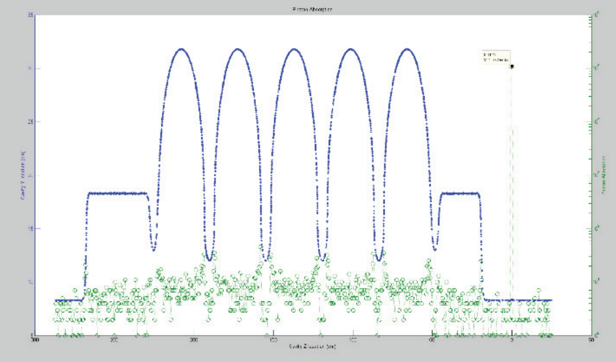

Figure 3: The photon absorption number is plotted along z axis. The green dots are absorbed photon number and blue is the cavity profile envelop.

DAMPING SCHEMES COMPARISON

There are different setups for the HOM damping for low frequency HOMs (<5GHz). One needs to estimate the HOM damping capability for high frequency HOMs. As mentioned earlier, the high frequency (>5GHz) HOM power generation is 2KW/cavity. The designed quality factor for fundamental mode of 650MHz is 3×1010 at accelerating gradient of 20MV/m. In this case, the cavity dynamic loss of fundamental modes is around 10W. In a good HOM design, we would like to maximize the coupling coefficient β to minimize the SRF surface loss. We are comparing various HOM damping cases: beam pipe absorbers, coaxial HOM couplers, Waveguide couplers and tapered waveguide couplers.

Cylindrical beam pipe absorbers can be placed at a location adjacent the SRF cavity, and they can take high frequency HOM power efficiently because the high sticking coefficients. One can use one or two solitary absorbers to damping both low and high frequency HOM power. In this study, we estimate their high frequency HOM power damping capability. The setup is shown in figure 4 and the materials properties are used as mentioned in the previous section. In figure 4, the longitude length of the absorber is 40cm and the radius is

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20cm while the cavity length is 1.68m and beam pipe radius is around 5.3cm. The area ratio between the absorber and cavity is 1/40. The absorbed photon number is plotted along the longitude direction in figure 4. After integration, the absorbers take 99.99% of total absorbed photon number while the SRF cavity takes the rest of 0.01% of the high frequency HOM energy. Based on the fact that the total high frequency HOM power is around 2KW, the high frequency (>5GHz) power goes to the SRF cavity surface and contribute the 2K cryogenics loss.

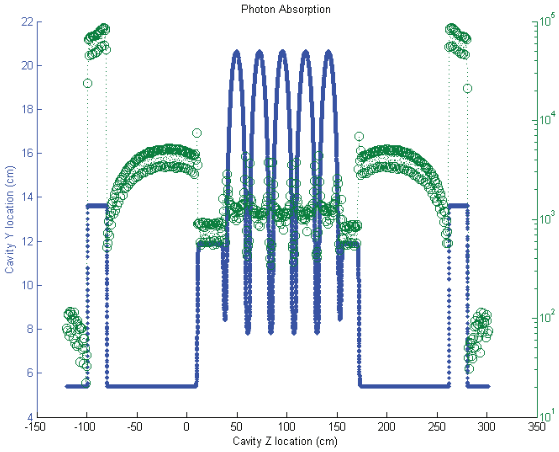

Figure 4: Monte Carlo setup and result for a combination of a cavity and a 40cm long beam pipe absorber.

In this paper, we can to compare the high frequency HOM absorption between three cases with different HOM couplers: A coaxial HOM coupler, a waveguide coupler and ridged waveguide couplers. Three cases all include additional beam pipe absorber with the same size. The competition between HOM couplers and absorber will be given for different cases. The setups for different cases are plotted in figure 5. In figure 5, absorbing boundary conditions are put at the end of the HOM couplers (in red) to absorb the energy already taken from the cavities.

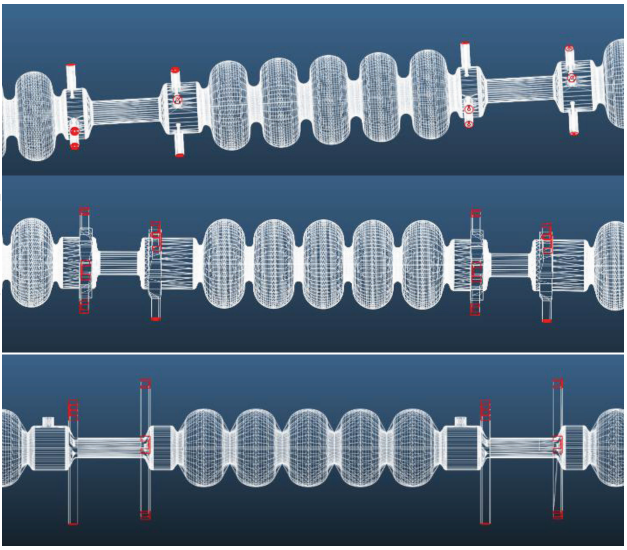

Figure 5: Three setups of the HOM damping scheme in a cryomodule.

The photon diffraction absorption is integrated by different RF components, and their absorption fraction of total absorbed photon numbers are given in Table 1.

Table 1: The percentages of high frequency HOM power on different components in a cyromodule.

	Coaxial	Double Ridge	Waveguide	Bare Cavity
SRF wall	0.012000%	0.008600%	0.007100%	0.068000%
Absorber+ Couplers	99.988000%	99.991400%	99.992900%	99.932000%
Couplers	53.034825%	56.823840%	65.611214%	0.000000%
Absorber	46.953175%	43.167560%	34.381686%	99.932000%

This result suggests that the HOM couplers also have a good capacity to take out high frequency HOM power. This capacity can help reduce the HOM power damped on the beam pipe absorber. The HOM pipe absorbers are connected directly on the cavity. Reducing the HOM damped power can help reduce the static loss of the cyromodule and reduce the cyromodule physical length.

CASCADING CAVITIES IN LINAC

Based on the consideration above, we may want to use a bigger piece of absorber to damp high frequency HOM generated by multiple cavities. We would like to estimate how many cavities we can put into a cryomodule. In this study, we show a cryomodule with 4 cavities and 2 pieces of beam pipe absorbers with 20cm long. We will increase the cavity number between these two beam pipe absorbers and estimate HOM power absorption by using Monte Carlo photon diffraction simulation. The absorbed photon fraction on absorbers and cavities walls are given in Table 2.

Table 2: The percentages of high frequency HOM power on SRF surface and absorbers in a cyromodule.

# of Cavities	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000	9.0000
Length(m)	7.8500	9.6800	11.5000	13.3200	15.1400	16.9600	18.7700
Nb	0.0379%	0.1166%	0.1722%	0.2480%	0.2820%	0.3082%	0.3358%
SIC	95.0580%	93.0902%	82.4140%	87.2299%	87.0519%	86.6935%	87.1799%
Transition	4.9041%	6.7932%	17.4138%	12.5221%	12.6661%	12.9983%	12.4843%

CONCLUSION

A photon diffraction model has been presented which may be used to calculate the steady state photon density in different cavity setups. At intermediate frequency range, this photon diffraction model agrees well with the FEM simulation to characterize the field intensity. With this model, the high frequency HOM power deposition on RF components can be directly estimated. SRF cavity dynamic loss on superconducting surface can be obtained. Damping on beam pipe absorbers and HOM couplers are also obtained for further design the cooling system.

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