ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB222

IMPEDANCE EVALUATION OF MASKS IN HEPS STORAGE RING*

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Abstract

Masks are commonly used in light sources to protect sensitive elements from synchrotron radiations. In the ultra-low emittance rings, small aperture vacuum chambers are adopted in order to reach the very high gradient in the quadrupoles, while many masks are required due to the high radiation power density. Therefore, the impedance of the masks becomes one of the dominant contributors to the impedance budget. In this paper, the impedance is evaluated among different mask designs. Meanwhile, the impedance cross talk between adjacent masks is discussed.

INTRODUCTION

The High Energy Photon Source (HEPS) [1] is designed with beam energy of 6 GeV and natural emittance of less than 100 pm. The synchrotron radiation from the bending magnets or insertion devices can cause serious damages on the sensitive components, such as the RF shielding of the flanges or bellows. Therefore, masks are installed in local areas to protect these components and avoid possible damages.

The beam pipe of HEPS has a radius of 11 mm. There are more than 500 masks located around the storage ring. The masks have typical intrusion height of 3 mm, and tapering ratio of 1/3 and 1/7 at the upstream and downstream direction, respectively. Since the radiation is restricted in a narrow cone tangential to the beam orbit, only horizontal obstructions on the outer side of the vacuum chamber are required. However, in order to keep the symmetry of the vacuum chamber, cylindrically symmetric masks or horizontal masks with two mirror symmetric jaws are normally adopted.

In this paper, three different designs of mask are considered, which includes cylindrically symmetric mask, horizontal mask with two mirror symmetric jaws, and horizontal mask with one jaw. The schematic views of the different designs are shown in Fig. 1. The structures are modeled with CST [2]. The impedances of different mask designs are investigated and compared. The detuning and transverse monopole impedance contributions due to the asymmetry of the mask are calculated. The impedance cross talk between adjacent masks is also studied considering different design scenarios. The influences of these impedances on the beam are out of scope of this study.

* Work supported by NSFC (11775239, 11805217 and 11922512), Youth Innovation Promotion Association CAS, NKPSTRD (2016YFA0402001), and High Energy Photon Source (HEPS) project, a major national science and technology infrastructure in China.
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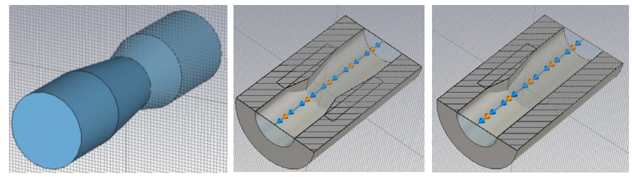

Model1 Model2 Model3

Figure 1: Schematic view of the geometry for different mask designs. (Model1: cylindrically symmetric mask, Model2: horizontal mask with two mirror symmetric jaws, Model3: horizontal mask with one jaw).

IMPEDANCE DEFINITIONS

The impedance can be expanded into a power series in the moments of the source particle [3]. The longitudinal impedance is defined as the Fourier transform of the wakefields excited by the monopole moment of the beam, while the transverse impedance is normally defined as the Fourier transform of the wakefield generated by the dipole moment of the beam. In the above definition, the transverse wake is proportional to the transverse offset of the source particle while the offset of the test particle is chosen to be zero. This definition is sufficient for a device with cylindrically symmetric and centered beam. However, for a device without axial or mirror symmetric we need to use the general definition of transverse wake and impedance [4-7].

By expanding the wake function into a power series in the offsets of both the source and test particles, the general transverse wake can be written as [6]

$$W_y^{gen} = A_y + W_y^{driv} y_0 + W_y^{det} y, \qquad (1)$$

where A_y is the monopole transverse wakefield generated by a beam pipe without mirror symmetric in the transverse plane, W_y^{driv} is the driving wake generated by the source particle with transverse displacement of y_0 and seen by a test particle at axis, W_y^{det} is the detuning wake generated by the source particle at axis and seen by a test particle with transverse displacement of y. The same concept holds for the generalized impedances, which are the Fourier transform of the wakes. The above expression applies to the horizontal plane as well.

So that for a device with cylindrically symmetric, there is only driving wake in the transverse plane, and for a device without cylindrically symmetric, both driving and detuning wake need to be considered. In addition, for a device without mirror symmetric or when the beam passes off axis in a symmetric geometry, the constant monopole transverse wake should be included.

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IMPEDANCE COMPARISON AMONG DIFFERENT MASK DESIGNS

To simulate the longitudinal impedance and transverse monopole impedance, both the source particle and the wake integration path have to be placed on the axis. To simulate the driving impedance, only the source particle needs to be displaced, while for the detuning impedance, only the wake integration path needs to be displaced. In addition, for a device without mirror symmetric, the driving and detuning impedances should be normalized by subtracting the transverse monopole impedance [6].

The comparison of the longitudinal impedance for different mask designs is shown in Fig. 2. We can see that the impedance for the cylindrically symmetric mask is more broadband in a wide frequency range, while the impedance shows clear resonances for the case with constriction only occurs in the horizontal plane.

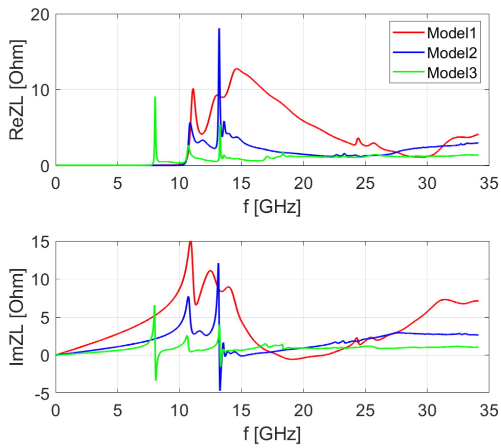

Figure 2: Comparison of the real and imaginary part of the longitudinal impedance for different mask designs.

With fundamental RF frequency of 166.6 MHz in HEPS, the rms bunch length varies from 4.4 mm to 52 mm, depends on the setting of the harmonic RF cavity as well as bunch stretching due to the impedance. The loss factor and longitudinal effective broadband impedance are evaluated with different rms bunch lengths, as shown in Fig. 3. The cylindrically symmetric mask shows higher loss factor at short bunch lengths, while with longer bunches, the loss factors for all the different design scenarios become negligible. The longitudinal effective impedance of the horizontal mask is less than half of that for the cylindrically symmetric mask. With only outer side jaw, the longitudinal effective impedance will be further reduced to half of that with both jaws.

The comparison of the driving term of the transverse impedances for different mask designs is shown in Fig. 4. The horizontal mask with either one jaw or two jaws show much lower vertical impedance, meanwhile, an extra resonance rises at around 8 GHz in the horizontal plane.

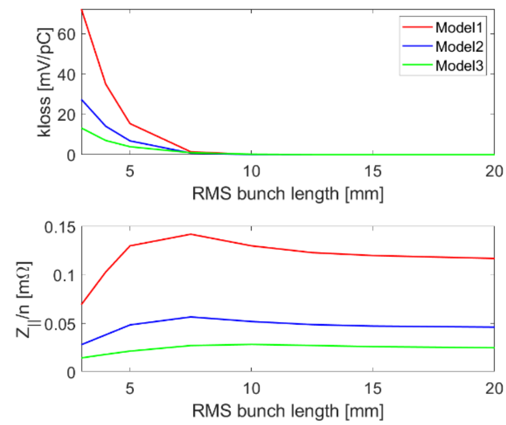

Figure 3: Comparison of the loss factor and longitudinal effective broadband impedance versus rms bunch length for different mask designs.

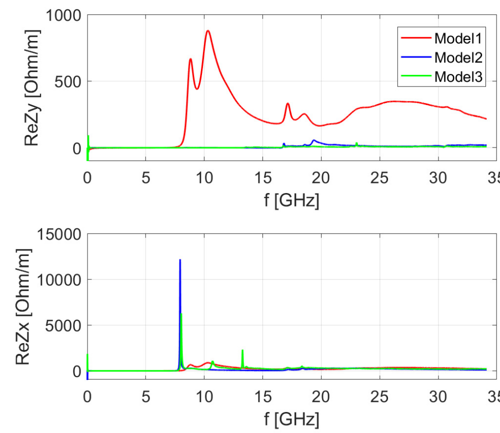

Figure 4: Comparison of the driving term of the vertical and horizontal impedance for different mask designs.

The transverse kick factors are compared between different mask designs and shown in Fig. 5. With the horizontal mask designs, the vertical kick factor is reduced by an order of magnitude, while the horizontal kick factor is reduced to approximately half of the symmetric design. In addition, considering the two horizontal mask designs, the horizontal kick factor is higher for the case with double jaws. For the horizontal masks, the detuning and horizontal monopole impedances are calculated, as shown in Figs. 6 and 7, respectively.

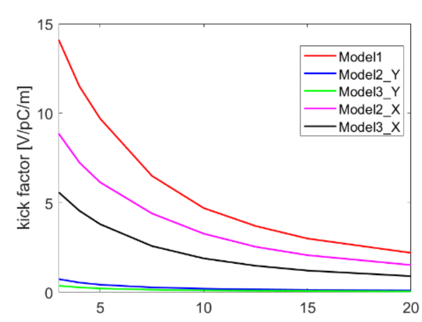

Figure 5: Comparison of the transverse kick factor versus rms bunch length for different mask designs.

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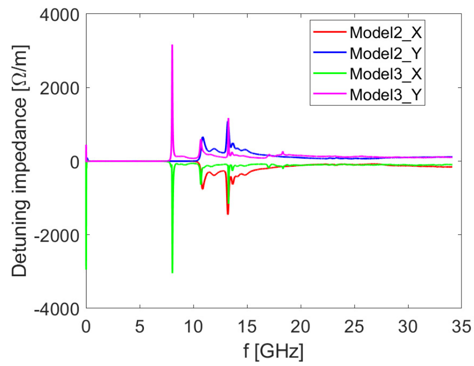

Figure 6: Real part of the horizontal and vertical detuning impedances for the horizontal masks with one jaw and two jaws.

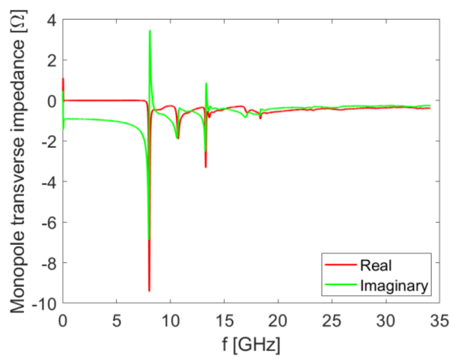

Figure 7: Horizontal monopole impedance for the horizontal mask with one jaw.

IMPEDANCE CROSS TALK BETWEEN ADJACENT MASKS

For cylindrically symmetric masks close to each other, the wake fields generated during the beam passage can cross talk with each other, and in certain situations induce extra resonances. Therefore, evaluation of this effect can be important to reach more accurate impedance model. The shortest longitudinal distance between adjacent masks in HEPS is around 500 mm, with intrusion height of 3 mm. The two masks are modelled in one structure and the impedances are compared with that simulated with two separate masks, as shown in Fig. 8. We can see that multiple of extra resonances are raised up in both transverse and longitudinal plane when the two adjacent masks modelled together. The peak values of both longitudinal and transverse impedances are increased by a factor around 20.

Similar studies are performed for two horizontal masks with two mirror symmetric jaws. Compared to the masks modelled separately, more impedance peaks emerges as well, and the peak value of the impedance is increased by a factor of 4, as illustrated in Fig. 9. The impedance cross talk between adjacent masks has been significantly mitigated with the horizontal mask design.

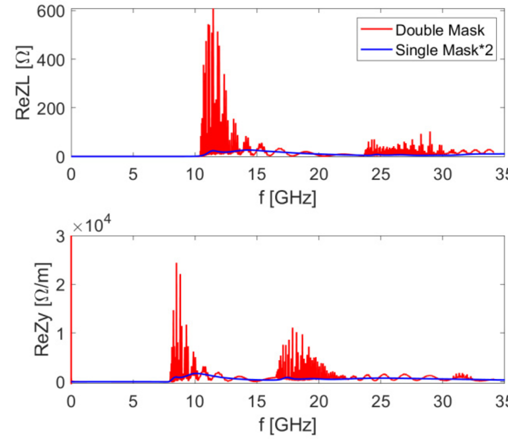

Figure 8: Real part of the longitudinal and transverse impedance with two cylindrically symmetric masks modelled separately or in one model.

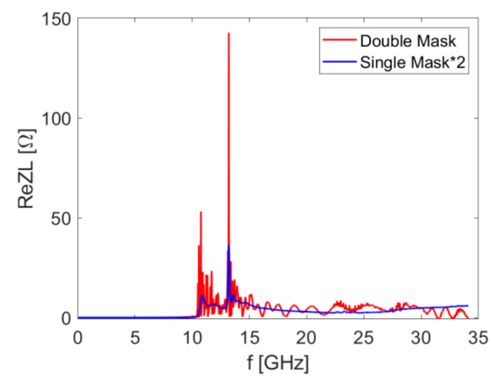

Figure 9: Real part of the longitudinal impedance with two horizontal masks modelled separately or in one model.

SUMMARY

The impedance of different mask designs has been evaluated for HEPS. The cylindrically symmetric mask shows highest broadband effective impedances, while the horizontal masks generate narrow resonances in the horizontal plane, which can induce coupled bunch instabilities due to the large quantity of the masks. Meanwhile, the detuning impedances and the transverse monopole impedance should be included when applying horizontal mask designs. Considering the large broadband impedance tolerance due to the long bunch, as well as to eliminate any higher order impedances or resonances, the cylindrically symmetric masks were chosen to be the basic design. The impedance cross talk between two adjacent masks induces extra resonances, which is still acceptable since the wake cross talk only exist in limited number of masks.

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