NUMERICAL ESTIMATIONS OF WAKEFIELDS AND IMPEDANCES FOR DIAMOND COLLIMATORS

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Abstract

The storage ring of the Diamond Light Source uses two collimators in the injection straight, one in the horizontal and another in the vertical plane, to protect the Insertion Devices (IDs) from the injection and the Touschek losses. These collimators in the form of metallic intrusions into the beam pipe, may produce considerable wakefields and contribute to the overall machine impedance. We have estimated the wakefields and impedances of these collimators using computer codes MAFIA and ABCI. This paper presents the results of our simulation studies.

INTRODUCTION

The Diamond storage ring will be equipped with a pair of copper collimators which are designed to protect the IDs from 3 GeV electrons lost during injection or Touschek scattering events. A very efficient collimation is achieved with a pair of 30 mm copper rods located in the injection straight with a nominal half aperture gap of 17.5 mm in the horizontal plane and 5.3 mm in vertical plane [1]. In order to prevent any abrupt variation in the vacuum chamber profile, the collimators have been provided with tapered sections at both ends as shown schematically in Fig. 1. Due to tight space constraints in the injection straight the taper angle is quite limited especially in the horizontal plane. The geometry of the collimators is shown in Fig. 1 with tan(α) = 0.5 and 0.2 for horizontal (HC) and vertical collimators (VC) respectively. The ratio a/b for horizontal and vertical collimators are 0.44 and 0.46 respectively.

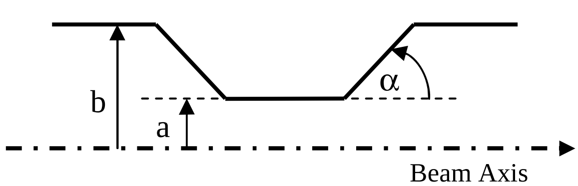

Fig. 1: Geometry of the collimators.

Given their proximity to the beam axis and the relatively large tapering angle, a careful analysis of the impedance generated by these collimators has been performed. The code MAFIA [2] was used to compute the longitudinal wake potentials generated by the full 3D structure of the collimators. A series of preliminary tests were performed with ABCI [3] and MAFIA on a simplified collimator geometry with cylindrical symmetry, to estimate the effect of the beam tube lengths outside the collimator on the wake potentials.

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WAKE POTENTIAL COMPUTATION ASSUMING CYLINDIRCAL SYMMETRY

The Diamond storage ring collimators are structures which protrude into the beam tube. Therefore the geometry of these collimators is not suitable for indirect method of wake field integration [4]. We therefore resorted to the use of the direct method of wake field integration. The direct method can generate unphysical wakes due to the numerical noise propagated from the outer beam tubes. Furthermore very long outer beam tubes have to be simulated to reach convergence in the wake potential computation. Particular care was taken in assessing the impact of these two effects in order to obtain reliable estimates of the wake potential generated in the structure by comparing the results with those from ABCI.

2D Simulations

In order to establish the effect of the outer beam tube length while keeping a reasonable simulation time, the collimator structure is simulated in 2D assuming cylindrical symmetry. In these simulations, the length of the beam tube is increased until convergence in the computation of the wake field integrals is reached. As an indicator of the convergence we report in Fig. 2 the minimum (W_{min}) and maximum (W_{max}) values of wake potential normalized to their values $|W_{min\text{-}sat}|$ and $|W_{max\text{-}sat}|$ respectively at the end of a 1.7 m outer tube length. Figure 3 shows the comparison of the wake potential for the vertical collimator computed with MAFIA in 2D and with ABCI, assuming cylindrical symmetry. The MAFIA direct method result (in blue) agrees very well with that from ABCI using Napoly contour [5] (in pink) for a beam tube length of 1.7 m. These simulations are performed with a mesh size of 0.25 mm and bunch length (σ_z) of 3 mm.

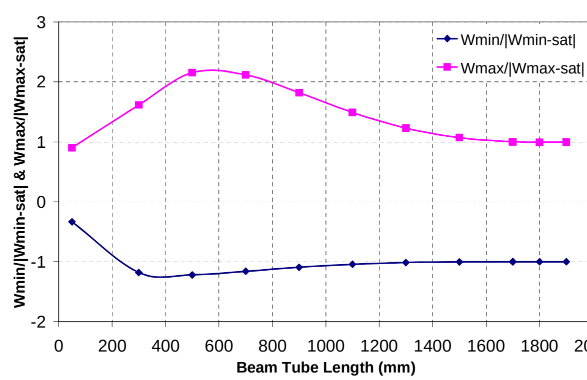


Fig. 2: Normalized values of the wake potential minima and maxima as a function of beam tube length.

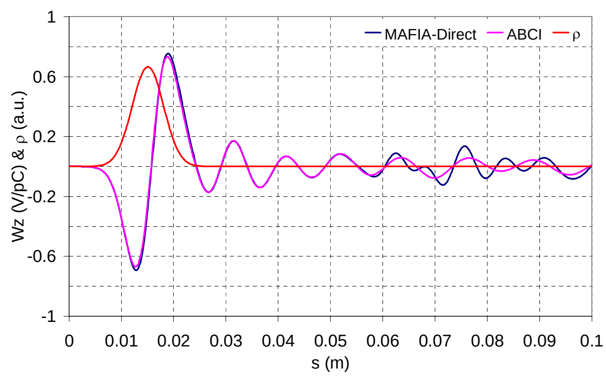


Fig. 3: Wake potential for the vertical collimator; blue – MAFIA-direct integration; pink – ABCI Napoly contour. The bunch charge density is shown in red.

3D Simulations

As mentioned above, the computation of wake field integrals in 3D with MAFIA for collimator like structures suffers from the unphysical wake observed before the passage of the bunch arising from the numerical noise due to the beam tube. This unphysical wake (shown by thick red arrow in Fig. 4) can be removed by subtracting the wake due to the beam tube alone calculated in a separate run. Since MAFIA does not produce any result for a smooth beam tube, a very small perturbation (protrusion of one mesh unit in thickness) is added to the beam tube at the location of the collimator. The net wake potential for the collimator is obtained by subtracting this 'tube alone' wake from that of the full structure and is shown in Fig. 4.

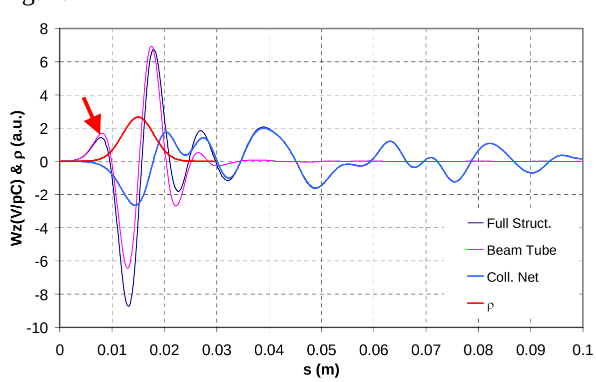


Fig. 4: The net wake potential for the horizontal collimator assuming cylindrical symmetry (light blue) is obtained by subtracting the wake potential of the beam tube (pink) from that of the total structure (dark blue).

The estimated bunch length in the storage ring is ~ 3 mm and the maximum relevant frequency will be $f_{crit} = c/2\pi\sigma_z = 16$ GHz. The real and imaginary parts of longitudinal impedance computed with MAFIA and ABCI are shown in Fig. 5 and Fig. 6 respectively. In general the form of the impedance function seems to be same from both the codes but the difference in amplitudes may be attributed partly to the slight difference in the wake potential values computed by two different techniques and partly to the different data windowing techniques used in MAFIA and ABCI to reduce the spectral leakage in the Fourier transform.

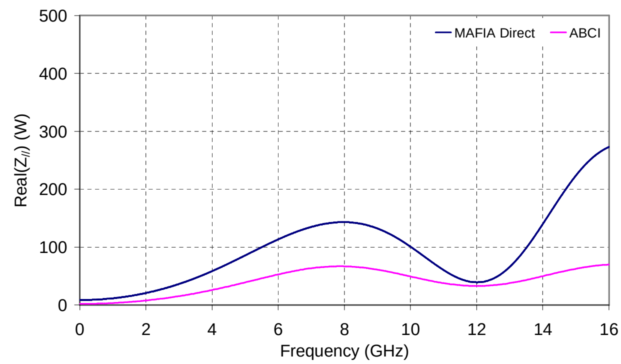


Fig. 5: Real part of longitudinal impedance for horizontal collimator for the wake potential depicted in Fig. 4; dark blue – MAFIA-direct, pink – ABCI.

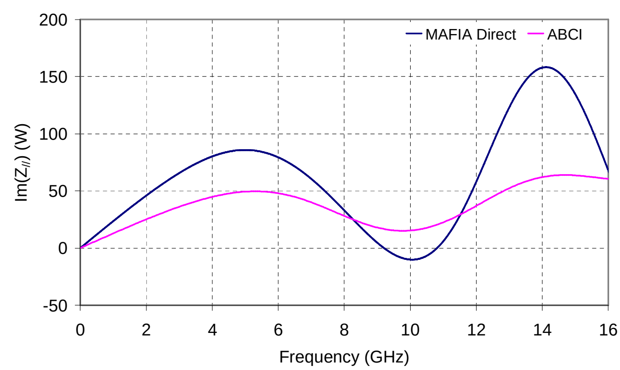
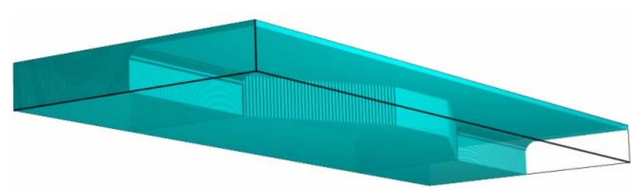
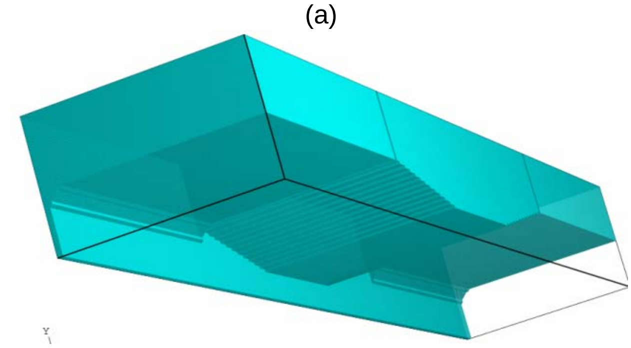


Fig. 6: Imaginary part of longitudinal impedance for horizontal collimator for the wake potential depicted in Fig. 4; dark blue – MAFIA-direct, pink – ABCI.

SIMULATION OF THE REAL COLLIMATORS



(a)



(b)

Fig. 7: MAFIA models (quarter of the structure) of (a) horizontal and (b) vertical collimators.

The results of 2D and 3D simulations assuming cylindrical symmetry confirm sufficiently converged estimates of the wake potentials for 1.7 m long beam tubes on the exit side of the collimator. Using the same beam tube lengths, the real geometry of the collimator (which is not cylindrically symmetric) is simulated. Figure 7 shows MAFIA models for the two collimators. To reduce the computation time and the memory requirements, only a quarter of the geometries are simulated as the collimators have mirror symmetries in vertical and horizontal planes. Figure 8 shows the longitudinal wake potential computed with MAFIA for the real geometry of the horizontal collimator while the real and imaginary parts of the longitudinal impedance are shown in Fig. 9. The wake potential for the vertical collimator is shown in Fig. 10, and the real and imaginary parts of longitudinal impedance in Fig. 11.

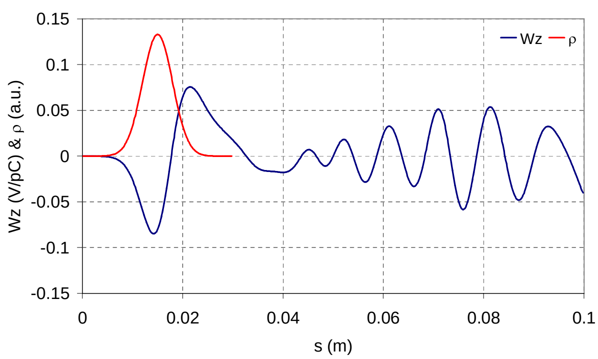


Fig. 8: Longitudinal wake potential of horizontal collimator. The current density is shown in red.

Table 1 lists loss factors calculated for cylindrically symmetric structures using MAFIA and ABCI in the first two columns. The last two columns give loss factors for real collimators computed from MAFIA results. The wake potential and impedance of the vertical collimator is observed to be higher than that of the horizontal collimator though the taper in vertical collimator is much slower. This is due to the fact that the vertical collimator approaches much closer to the beam axis. The loss factor for the vertical collimator is correspondingly higher.

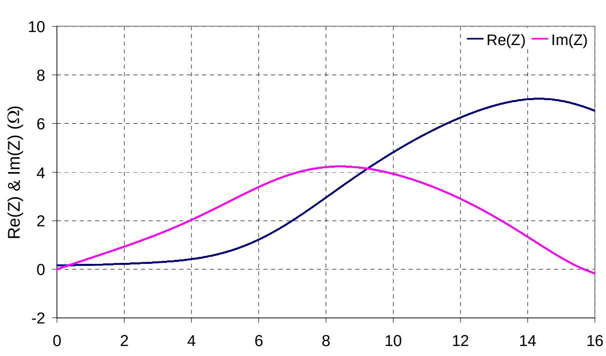


Fig. 9: Real and Imaginary parts of longitudinal impedance for the horizontal collimator.

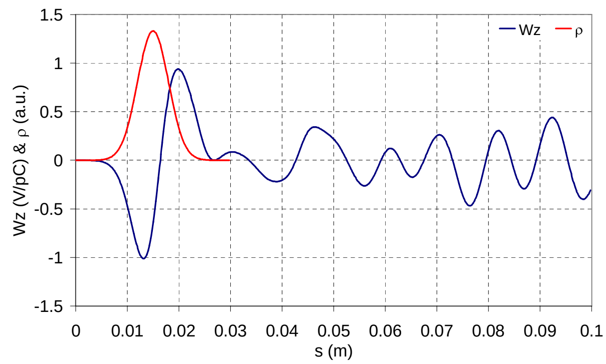


Fig. 10: Longitudinal wake potential of the vertical collimator.

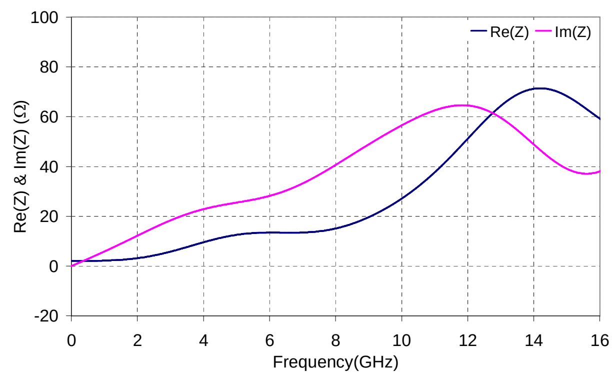


Fig. 11: Real and imaginary parts of longitudinal impedance for the vertical collimator.

Table 1: Longitudinal loss factors $k_{||}$ (V/pC) for σ_z=3 mm

	Cyl. Symmetric		Real Structures	
	HC	VC	HC	VC
MAFIA	1.35	0.0786	0.04	0.26
ABCI	1.26	0.075	–	–

CONCLUSION

The geometric longitudinal impedance of the Diamond storage ring collimators has been estimated with MAFIA 3D simulations. These simulations are part of a campaign to provide realistic estimates of the impedance of the most significant impedance contributors in the storage ring vacuum chamber and to assess their effect on beam dynamics.

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