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STUDIES OF THE SHORT-RANGE WAKEFIELDS FOR THE ELECTRON STORAGE RING IN THE ELECTRON ION COLLIDER*

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Abstract

We investigate the short range wakefields for the electron storage ring in the Electron Ion Collider and show, for a few considered vacuum components, how the results from ECHO3D compare with that obtained from GdfidL and CST.

INTRODUCTION

During the estimates of impedance budget for the Electron Storage Ring (ESR) of Electron-Ion Collider (EIC), various codes, including GdfidL [1], CST [2] and ECHO3D [3], have been used to calculate the short-range wake-fields due to the vacuum components [4].

ECHO3D calculates in time domain the electromagnetic field induced by an electron bunch passing through an arbitrary 3D structure [5]. The latest version, V1.3, is thread parallelized. The code allows the structure to consist of multiple materials with different permeabilities and permitivities, but the volume and wall conductivities are not implemented at the moment. The code requires a STL file created by an external software as input to describe the geometry of the structure. It then creates the mesh, solve the 3D electromagnetic field, and calculates the wake potential using the indirect integration method. The code is typically used in Windows platform and recently a MacOS version has been made available. For our studies, ECHO3D is installed on a personal computer and hence the available RAM is currently limiting the minimal mesh size to be applied for the simulation.

In this work, we concentrate on the short-range wake fields as calculated by ECHO3D and how it compares with the results obtained from other codes. Such cross-checking helps us to set up simulation properly, to identify some bugs in the simulation codes, as well as to check consistency in the 3D model. In the following sections, we will present our findings during these cross-checking for various vacuum components considered for the ESR of the EIC.

COLLIMATOR

The collimator design of the high energy ring in SKEKB [6] has been considered as a preliminary design for the ESR of EIC. Figure 1 shows the schematics of the ramp collimator. The ramp length, L was initially 3 cm and then increased to 40 cm to reduce the longitudinal wake potential induced by the collimator. As shown in Fig. 2 (left), reasonable agreements have been reached among the three codes for ramp length of 30 cm. For the ramp length of 40 cm, there is about 20% difference between results from ECHO3D and CST. The discrepancy is likely caused by the shallow tapering, which requires extremely fine mesh to obtain accurate results. By increasing the ramp length, the loss factor reduces from 240 mV/pC to 6 mV/pC.

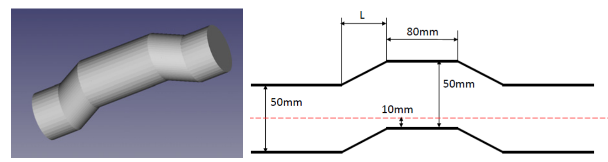

Figure 1: Schematics of the collimator model used for cross-checking ECHO3D, GdfidL and CST. The ramp length, L, has been increased from 3 cm to 40 cm to reduce the longitudinal wake field.

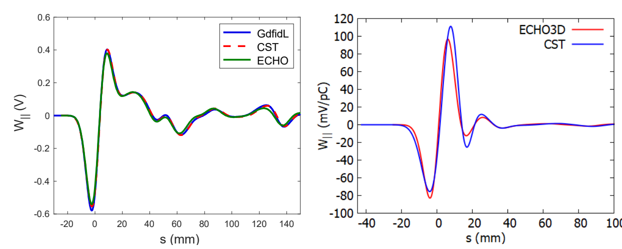

Figure 2: Longitudinal wake potential due to collimator with ramp length of 3 cm (left) and that with ramp length of 40 cm (right). The RMS bunch length is 5 mm and bunch charge is 1 pC.

FLANGE ABSORBER

As a rough estimate, the wakefield of the NSLS-II flange absorbers has been used for the impedance budget of the ESR in EIC. The schematic of the design is shown in Fig. 3.

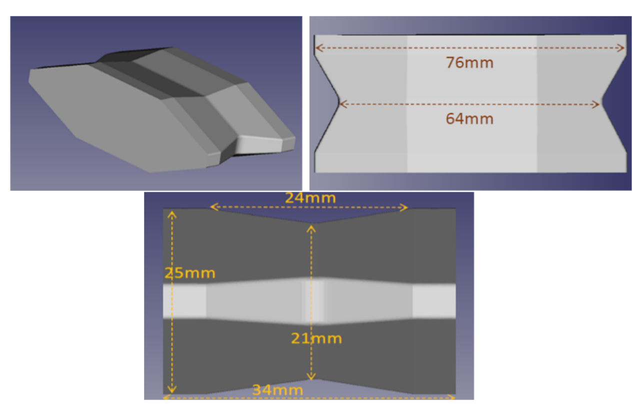

Figure 3: Schematics of the NSLS-II type flange absorber.

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As shown in Fig. 4, the longitudinal wake potential calculated by ECHO3D agrees well with that calculated by GdfidL.

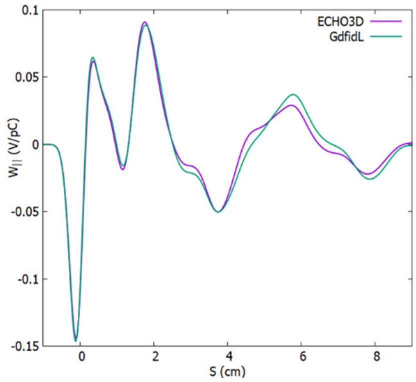

Figure 4: Longitudinal wake potential due to flange absorber as calculated by ECHO3D and GdfidL with RMS bunch length of 2 mm.

However, there is significant discrepancy for the transverse wake potential as calculated by the two codes. Figure 5 (left) suggests that the vertical wake potential of the dipole mode calculated by ECHO3D is a factor of two lower than that calculated by GdfidL. To search for the sources of the discrepancy, we did convergence study for ECHO3D simulation and as shown in Fig. 5 (right), the results converge well with mesh size smaller than 0.2 mm.

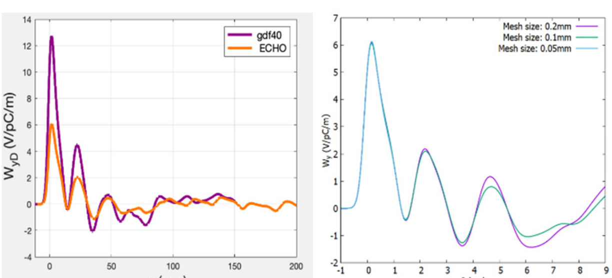

Figure 5: Dipole wake potential in vertical plane due to flange absorber as calculated by ECHO3D and GdfidL with RMS bunch length of 2 mm. (a) comparison of results from GdfidL (magenta) and that from ECHO3D (orange); (b) ECHO3D results with different mesh sizes.

As the horizontal dimension of the flange absorber is a factor of three larger than the vertical dimension, the wakefield generated by it should be close to that of a rectangular absorber as illustrated in Fig. 6.

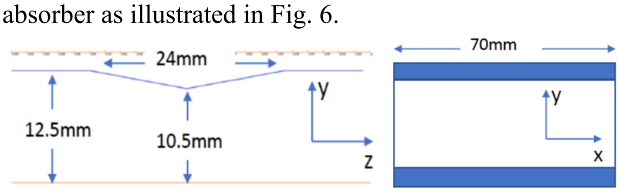

Figure 6: Schematics of a test flange absorber with rectangular cross section for cross-checking the vertical dipole wake potential with ECHO2D.

As a cross checking, we calculated the vertical dipole wake for the rectangular absorber with ECHO2D and as shown in Fig. 7, the results are indeed similar to that of the octagonal flange absorber. The cross-checking indicates that the vertical wake potential calculated by ECHO3D should be trustworthy. We suspect that the discrepancy is caused by the relatively coarse mesh size of the GdfidL simulation and further studies are needed to confirm the sources of the discrepancy.

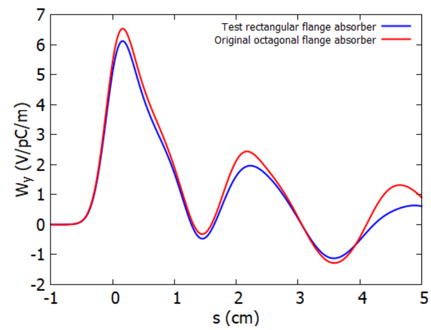

Figure 7: Comparison of the vertical dipole wake potential due to the NSLS-II type octagonal flange absorber (red) and that due to the rectangular test absorber as illustrated in Fig. 6 (blue). The wake from octagonal absorber is calculated with ECHO3D and that from the rectangular absorber is calculated with ECHO2D.

BELLOWS

The initial design of the ESR bellows followed that of the NSLS-II. Figure 8 shows the schematics of the design.

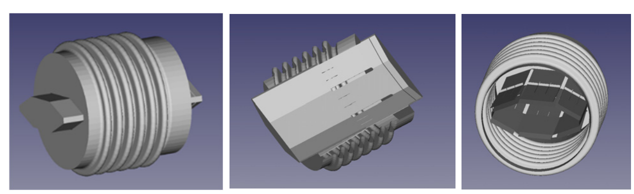

Figure 8: Schematics of NSLS-II type bellow.

The longitudinal wake potential as calculated by ECHO3D agrees well with GdfidL as shown in Fig. 9 (left). However, there were discrepancies in vertical dipole wake caused by numerical errors in ECHO3D simulation. The error was due to the approach used for the calculation, i.e. subtracting results of two independent simulation, one with transverse offset and the other without offset. After taking the image charge approach, the dipole vertical wake potential is directly obtained from a single simulation by setting up proper boundary conditions, which leads to much less numerical noise and the result agrees well with that from GdfidL simulation as shown in Fig. 9 (right).

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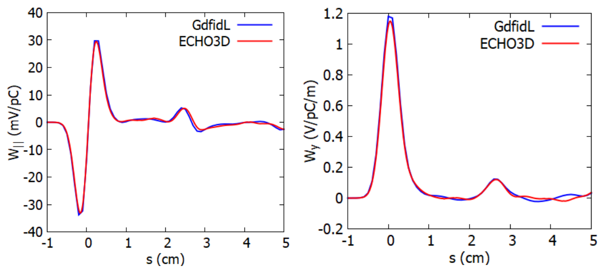

Figure 9: Comparison of longitudinal and vertical dipole mode wake potential induced by NSLS-II type bellows as calculated by ECHO3D and GdfidL. The RMS bunch length is 2 mm.

The bellows design has been recently updated to what shown in Fig. 10 (left) and the longitudinal wake potential has been calculated with ECHO3D, GdfidL and CST. As shown in Fig. 10 (right), the results from ECHO3D and that from GdfidL agree reasonably well. However, the longitudinal wake potential calculated by CST is about a factor of two higher than that from the other two codes. The sources of the discrepancy is still under investigation.

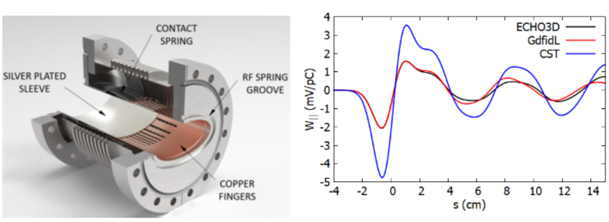

Figure 10: Comparison of longitudinal wake potential as calculated by ECHO3D, GdfidL and CST. (left) Design of ESR bellows; (right) longitudinal wake potentials calculated for RMS bunch length of 8 mm.

IR CHAMBER

The schematics of the vacuum chamber design for the interaction region is shown in Fig. 11 (left). Although the overall contribution of the impedance of the IR chamber is small, accurate calculations of the longitudinal wake potential and the loss factor are important for estimating the beam-induced heating. Significant discrepancy was found during the initial stage of the calculation. As shown in Fig. 11 (right), results from ECHO3D show that the longitudinal wake is dominantly resistive, in contrary to the reactive wake obtained from GdfidL simulation. Fourier analysis of the resistive wake calculated by ECHO3D reveals that the real part of the impedance is 2 Ω at zero frequency, which can only happen for unequal size of beam pipe at the entrance and exit of the IR chamber. Indeed, we found that the model has 60 mm of ID at the entrance and 62 mm at the exit. The expected real part of the impedance at zero frequency can be calculated as

$$\mathrm{Re}\left(Z_{||}\right) = Z_0 \ln\left(b_2 / b_1\right) / \left(2\pi\right) \approx 1.96\Omega$$

which agrees with the simulated value. Further investigation of GdfidL simulation discovered a bug in the code and after fixing the bug, GdfidL reproduced the results from ECHO3D. To minimize the heating due to longitudinal wake, the updated design of the IR chamber has equal diameters of the vacuum chamber at the entrance and exit [7]. Figure 12 shows the longitudinal wake potential as calculated by GdfidL and that calculated by ECHO3D. The discrepancy between the two codes is likely caused by the relatively large mesh size compared to the thickness of the electron beam pipe, 1mm. Due to the length of the structure, it is impractical to reduce the step size further in ECHO3D simulation since it runs in a personal computer with limited RAM. Further improvement of the results requires a cluster version of ECHO3D.

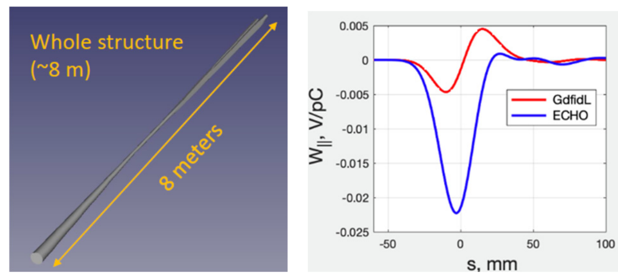

Figure 11: The schematics of the IR chamber design for ESR (left) and the longitudinal wake potential calculated for the original IR chamber with unequal size of the vacuum chamber at the entrance and exit (right).

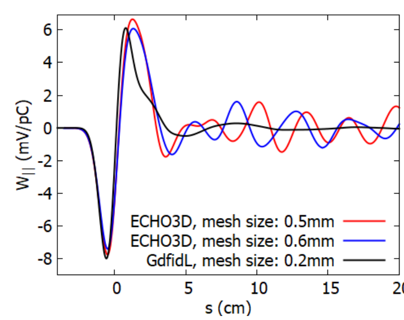

Figure 12: Comparison of longitudinal wake potential as calculated by GdfidL and ECHO3D, for the updated IR chamber with equal diameters of vacuum chamber.

SUMMARY

A relatively new code, ECHO3D, has been used to calculate the short-range wakefields for various vacuum components in the ESR of EIC. While cross-checking the results from ECHO3D with that from GdfidL and CST, we found some discrepancies, which either caused by coarse mesh, numerical error associated with subtracting two large numbers and bugs in the simulation codes. It appears that ECHO3D converges faster than other codes, especially for the structures with shallow tapering, such as the SKEKB type collimator with a 40 cm ramp length,

However, there are limitations in the current version of ECHO3D such as not supporting port boundary condition and lacking a cluster version. We look forward for the updated version to be released.

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