First numerical wakefield studies of new in-vacuum cryogenic and APPLE II undulators for BESSY II

M. Huck, J. Bahrdt, A. Meseck

HZB Helmholtz Zentrum Berlin

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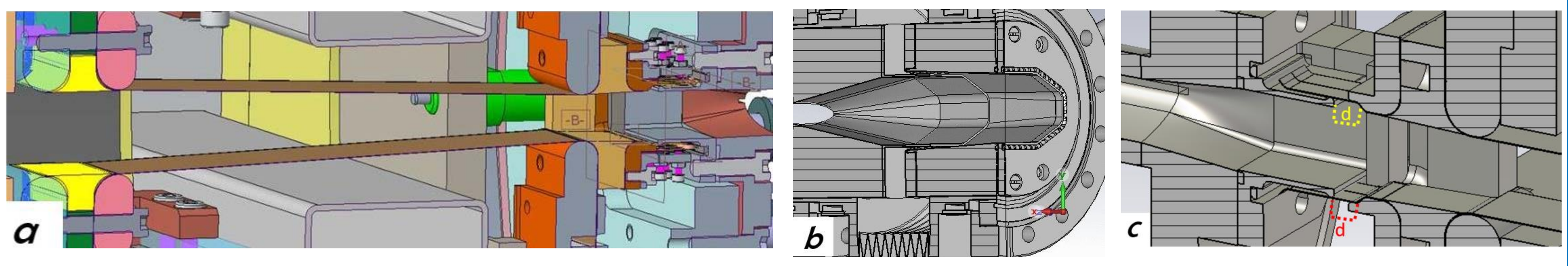
Abstract

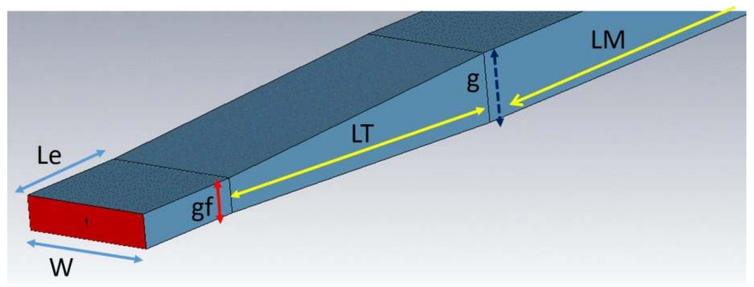
While the new in-vacuum cryogenic undulator is in its last commissioning stages, a worldwide new in-vacuum APPLE II undulator is being designed and constructed for BESSY II storage ring. Besides the challenging mechanical design of these small-gap and small-period undulators, challenges arise due to interaction with the electron beam. Therefore, detailed studies of this interaction is required to minimize the adverse effects on beam dynamics and the device itself. For this purpose, the wakefield effects have been computed numerically for critical parts of these devices i.e. the RF-shields, flexible tapers and taper sections. A brief overview of preliminary simulation results and discussions are presented in this paper.

CPMU17 structure and simulation

Standard RF-shields made of a 50 µm Copper layer coated on a 50 µm thick Nickel foil screens the discontinuities of the magnets. The Nickel side is attracted by magnetic forces whereas the Copper side faces the electron beam. A taper made of Copper-Beryllium alloy connects the magnet part to the flexible taper mechanics (taper section). One end of the taper has a fixed height of g_f=11 mm and the other end has a height equal to the magnetic gap. Down- and upstream the ID and, there are transition bellows with cross section varying from elliptical to octagonal form. The magnet-shield-length and -width amounts to LM=1517.13 mm and w=46 mm, respectively, and the taper is LT=119.37 mm long.



Since the dipolar and vertical impedance is normally stronger than the quadrupolar and horizontal one, we present here only the vertical-dipolar impedance spectra.



Preliminary Results

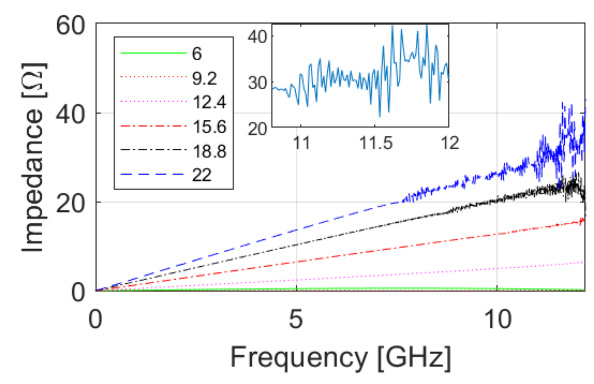
Z_z (v) by ID-gap variation

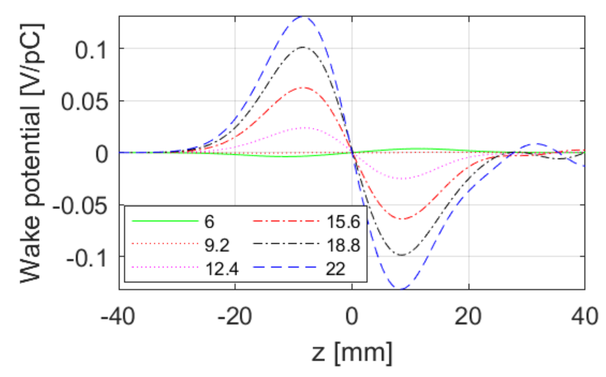
single-bunch of rms length of σ_b=8.4 mm (28 ps), and 8x10^{-9}C (10 mA) charge, which are the beam parameters in our measurements. 140 cell per wavelength, dz = 0.08 mm mesh size in z plane at taper, 0.17 mm in other planes, and **422 million** mesh cells.

The largest impedances 43 Ω occurs at gap of 22 mm, where the taper is steepest, and the structure has a cavity form. The minimum impedance is, as expected, at g=11 mm, where the taper is flat.

spikes appear at frequencies above 8 GHz at ~65 MHz steps, by increasing the mesh numbers these spikes get less pronounced

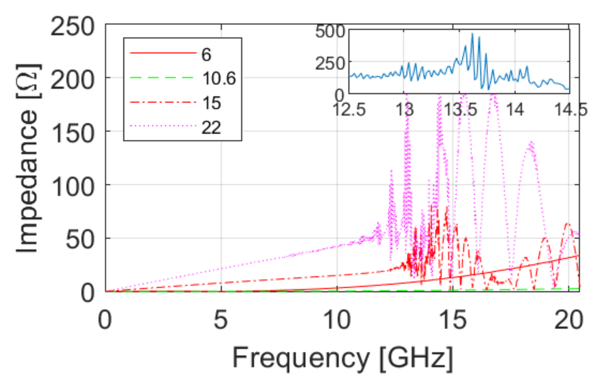
The small bump at the wake potential could be sign of numerical dispersion affecting the results in terms of loss factor and it can be resolved by using more mesh cells.





Z_z (v) by ID-gap variation for a shorter bunch

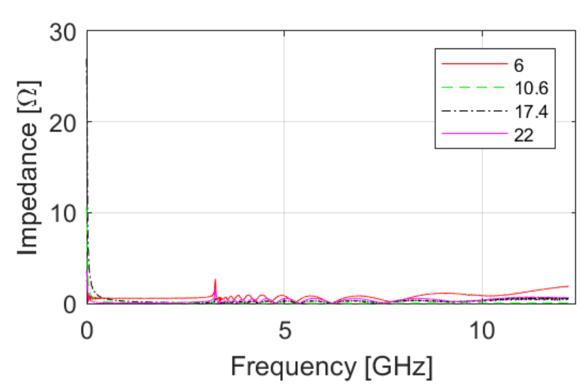
Bunch length 5 mm = 16 ps . 0.3 mA (0.24 nC) bunch current (low alpha mode at BESSY II).
largest impedances 475 Ω occurs at gap of 20 mm
10 time larger than the longer bunch.
spikes appear at frequencies above 8 GHz.
For this short bunch, much finer mesh cells should be used for more accurate results.



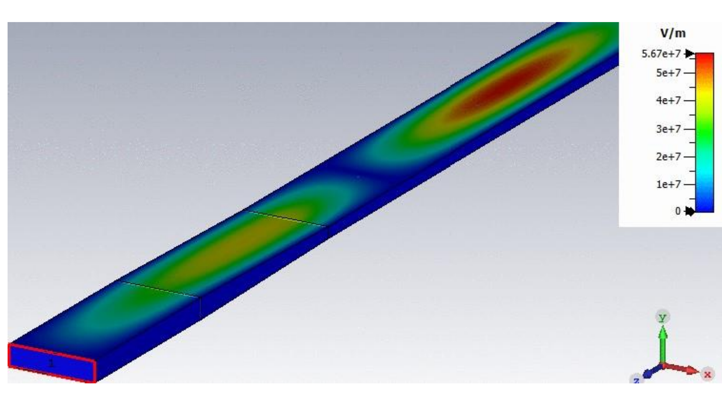
Z_y (v) by ID-gap variation

Dipolar impedance: source beam was located at y_b= 0.2 mm, and the test beam at the center of ID.
Quadrupolar impedance: the location of the source and test beams was flipped.

Spectrum has a peak of Z_y(v)= 3.4 Ω at v= 3.3 GHz (at gap of 6 mm) corresponding to mode 4, derived by eigenmode solver



Electric field distribution of eigenmode 4 for downstream half of ID for the half downstream of ID (symmetric with upstream)

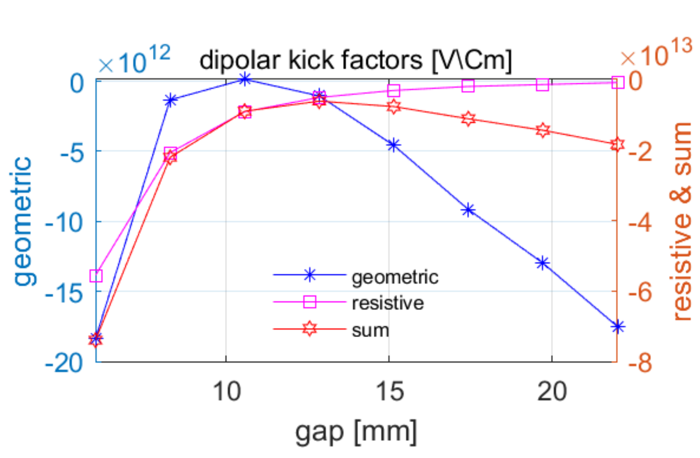


Kick factors by ID-gap variation

Vertical dipolar kick factors of "geometric"- (RF shields + tapers), and resistive-impedances, and their total sum.
The maximum total kick factor amounts to ~ -8x10^{13} V/Cm.

The contribution of the taper section is almost equal for all gaps amounting to ≈ 1.5 × 10^{14} V/Cm.
For comparison, the kick factor arising from each bellow, under the same simulation condition, was 1.9x10^{14} V/Cm.

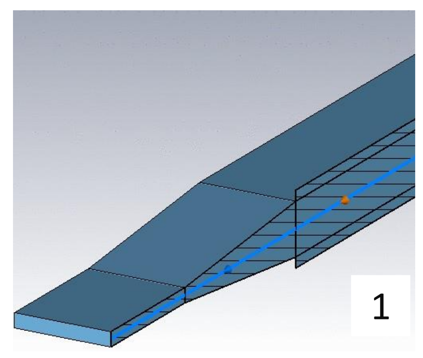
Resistive-wall impedance should be calculated again considering anomalous skin depth effects of the thin Copper shields at cryogenic temperature



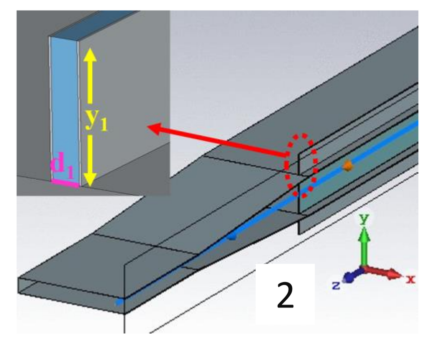
IVUE32 structure and simulation

IVUE32 consists of 4 magnet rows, with horizontal separation of ~ 0.8 mm. Each magnet row is covered with an individual foil which is canted at the slit close to the beam axis. The rows are movable independently in longitudinal direction (for the polarization adjustment), and RF shields follow the same motion pattern. But, the taper foils is made of one piece. The magnetic length is 2664 mm, foil width 75 mm, and taper length 150 mm. The material properties of foils will be similar to those of CPMU17.

2 variants of CST model:
1: structure is made of vacuum and the background is PEC. in this paper the results of this variant are presented.



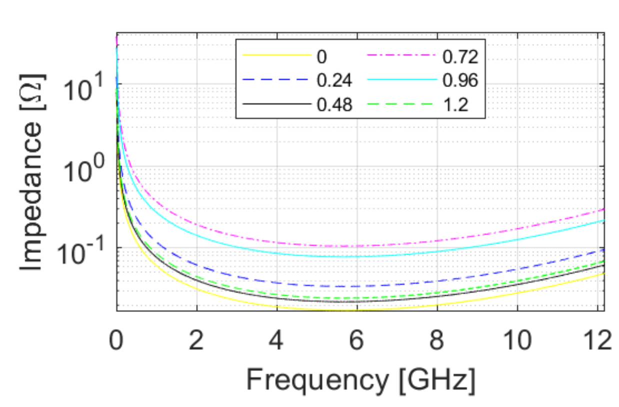
2: the background is vacuum, RF shields and tapers are PEC. side walls only at the end sections or along entire ID.



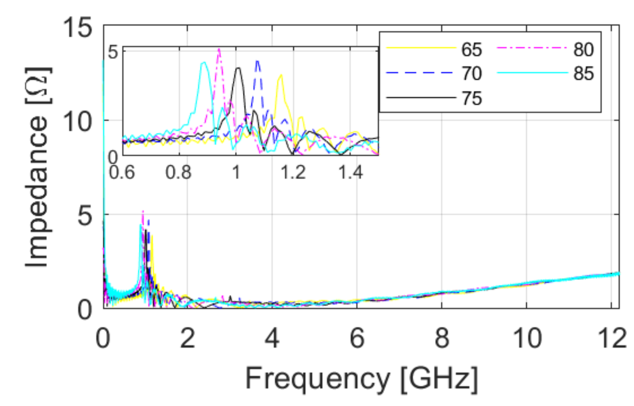
- Simulation were done by sweep over slit width and height d_1, y_1 , and foil width w, at gap of 7 mm.
- d_1=0.8, y_1=3 mm, and w =75 mm are used for the rest of the simulations.

Preliminary Results

Z_x by slit width variation, log. Scale



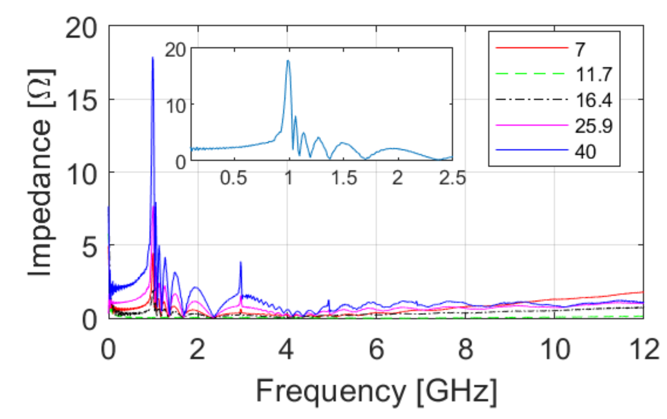
Z_y by foils width variation at a gap of 7 mm



The results shows that, except for minor variation, the impedances in 3 planes do not respond significantly to changes in the parameters d_1, y_1, and w.

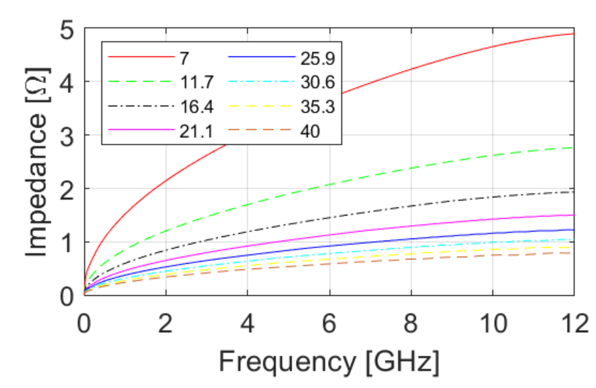
Z_y (v) by ID-gap variation

The maximum of Z_y=18.6 is at 1 GHz is at gap of 40 mm, and is larger than the Z_y maximum in CPMU17 by factor of ~7.
Resonances occur at about 1, 3 and 5 GHz.



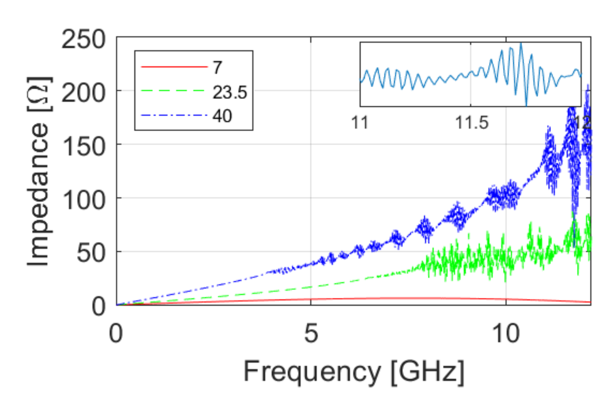
Z_R (v) by ID-gap variation

To simulate the resistive impedance, two parallel Copper plates with a length equal to LM have been used. As expected Z_R (v) and kick factor were decreasing by increasing the gap, and Z_R (v) increases with the frequency.



Z_z (v) by ID-gap variation

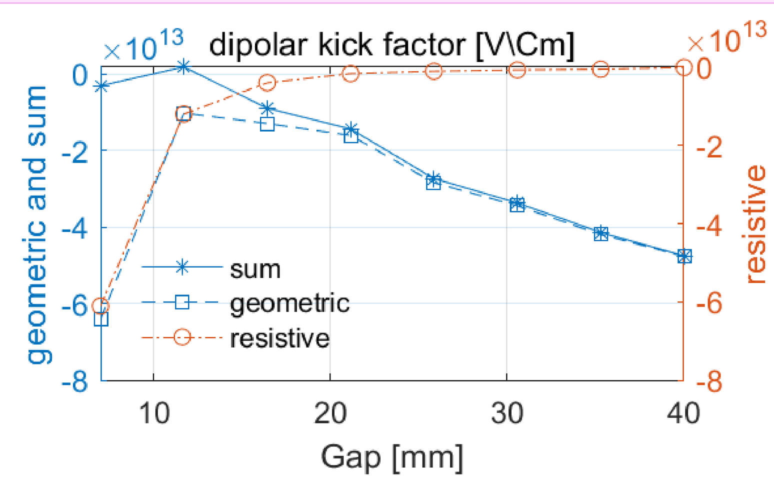
Resonant peaks are observed at longitudinal spectra, especially at larger gaps due to cavity-like form. By increasing the gap, this pattern is more emphasized and its start point in the spectrum shifts toward the lower frequencies above ~5 GHZ. The exact origin and description of these patterns needs further studies, and more mesh numbers.
For this simulation, the 2nd variant of IUVE32 CST model with Pec walls has been used.



For the two CST models mentioned above the preliminary simulations results are to some extent different. The exact interpretation of these differences will be investigated further, while using smaller mesh cells.

Kick factors by ID-gap variation

The magnitude of the resistive kick factors are comparable to the geometrical dipolar ones.
Contribution of the taper section have not been added here.



Remarks

- Simulations are not yet converged due to relatively low mesh cell numbers.
- Empirical accuracy condition for physically valid results is not satisfied: mesh size ΔZ : $\Delta Z^2 < \frac{a\,\varphi\,\sigma_b}{100}$, φ=*taper angle*, a=*chmaber height* .
- For this condition to be satisfied, mesh cells about **several billions**, simulation time for above several weeks, and MPI simulation setup with **several cluster nodes** are required.

Conclusion & Outlook

- The impedance spectra, and vertical kick factors have been calculated for simplified models, and the **preliminary** results have been presented.
- These simulations should be repeated with much higher mesh numbers for a more reliable and converged results.
- Simulations can be done in future, by assuming the vacuum tank and the magnet girders together as a round ridge waveguide.