Impedance Analysis of Insertion Devices

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- **NSLS-II/BNL:**

- **SLAC:**
  M. Ferreira, A. Novokhatski

- **DIAMOND:**
  V. Smaluk, R. Bartolini, R. Fielder, G. Rehm

- **EM Field Software Developers:**
  W. Bruns (GdfidL), I. Zagorodnov (ECHO)
Outline

- Axially Symmetric Tapered Structure
- Rectangular Tapered Structure
- DIAMOND IVU (ID16)
- NSLS-II SRX IVU21
- Adaptive Gap Undulator
NSLS-II Computer Cluster Resources

- Available Resources for Impedance Simulations:
  - 42 nodes with 8 Cores per node and 1334GB Total Memory (RAM)
  - Two Racks with Intel Xeon Processors E5430 & E5530 (2.66GHz and 2.4GHz)
  - Upgraded every year during Sep. 2006 to 2011
Axially Symmetric Tapered Structures

- Geom. Parameters: $d=9.2\text{mm}$, $L=108\text{mm}$
- Bunch Length: $\sigma_s=7\text{mm}$
- Radius $b$ is varied from 2.5mm to 15mm

Axially Symmetric Tapered Collimator

$\text{Vertical Dipole Wakepotential}$

- GdfidL $W_{yD}$ does converge to ECHO $W_{yD}$ by decreasing the stepsize
- $W_{yD}$ does not depend on separation length “g” between two tapers.

Axially Symmetric Cavity Structure

CST Simulations – Courtesy by R. Fielder

Zoomed In Long-Range Tail of the Vertical Dipole Wakepotential

Vertical Dipole Wakepotential

Vertical Dipole Wakepotential
Kick Factor as a Function of Radius “b”

- In inductive regime for a slow axially symmetric taper $\theta \ll 1$ (G. Stupakov)

$$k_{yD} = \frac{Z_0 c \theta}{2\pi^{3/2} \sigma_s} \left( \frac{1}{b} - \frac{1}{d} \right)$$

- Quadrupole wakepotential is $W_{yQ} = 0$ for axially symmetric structures
- $W_{yD}$ simulated by GdfidL for a 50um stepsize
- GdfidL Version: single.mpich2-gd1-2013-11-28i
Rectangular Tapered Collimator

- Geom. Parameters:
  \[ b_{\text{max}} = 9.2\text{mm} \]
  \[ w = 42\text{mm} \]
  \[ L = 108\text{mm} \]
  \[ g = 500\text{mm} \]

- Bunch Length: \( \sigma_s = 7\text{mm} \)

- Half-aperture \( b_{\text{min}} \) is varied from 2.5mm to 15mm

- \( w_y \) for a driving bunch with transverse coordinate \( y_d \) acting on a following bunch with coordinate \( y_f \)

\[
w_y(s, y_d, y_f) \approx y_d w_{y,D}(s) - y_f w_{y,Q}(s)
\]

Small Aperture: \( b_{\text{min}} = 2.5\text{mm} \)

Vertical Dipole Wakepotential

- \( L \gg 2w \gg b_{\text{min}} \)

Quadrupole Wakepotential

Dipole Kick Factor

Small Aperture: $b_{\text{min}} = 2.5 \text{mm}$

Vertical Dipole Kick Factor as a function of Width “$w$”

- Results for width dependence are shown for 50um stepsize to speed up calculations.

The Dipole Kick Factor becomes independent on width “$w$” for $2w \gg L$

- In inductive regime for a case of a slow rectangular taper, $\theta \ll 1$ (G. Stupakov)

$$k_{yD} = \frac{Z_0 c}{2\sqrt{\pi} \sigma_s} \frac{w \theta}{4 b_{\text{min}}^2} \left( 1 - \frac{b_{\text{min}}^2}{b_{\text{max}}^2} \right)$$

Width: $w = 42 \text{mm}$

Vert. Dipole Kick Factor as a Function of Aperture $b_{\text{min}}$

- A Partial Fit

$$k_{yD} \approx 0.017 \times \frac{Z_0 c}{2\sqrt{\pi} \sigma_s} \frac{\theta}{4 b_{\text{min}}^2} \left( 1 - \frac{b_{\text{min}}^2}{b_{\text{max}}^2} \right)$$

G. Stupakov’s Equation does not show width saturation and valid in the regime when $L \gg 2w \gg b_{\text{min}}$
Quadrupole Kick Factor as a Function of Gap

- In inductive regime for a case of a slow rectangular taper, $\theta \ll 1$ (G. Stupakov)

- Quadrupole Kick Factor ($w \gg b_{\text{min}}$)

\[ k_Q = \frac{Z_0 c}{2\sqrt{\pi} \sigma_s} \frac{\theta}{2\pi b_{\text{min}}} \left(1 - \frac{b_{\text{min}}}{b_{\text{max}}}\right) \]

- Quadrupole kick factor $k_Q$ does not depend on width “w” for $w \gg b_{\text{min}}$

- The numerical results converge to G. Stupakov’s Equation in the limit of small enough stepsize.
**DIAMOND In-Vacuum Undulator (ID16)**

- **Orbit bump method**
  \[
  \Delta y' = \frac{\Delta q}{E/e} k_{\perp} y_0
  \]

  Orbit deviation:
  \[
  \Delta y(s) = \frac{\Delta q}{E/e} k_{\perp} y_0 \frac{\sqrt{\beta(s)\beta(s_0)}}{2 \sin \pi \nu} \cos\left(\frac{\mu(s) - \mu(s_0)}{\pi \nu}\right)
  \]

  \(\Delta q\) – bunch charge variation; \(y_0\) – bump amplitude

- **Beam kick**: 
  \[
  \Delta y' = \frac{\Delta q}{E/e} k_{\perp} y_0
  \]

- **Orbit deviation due to a local bump in DIAMOND.**

- **Kick Factor as a Function of Gap**

- **STL-file is under development**

3D Rendering Model of the DIAMOND IVU (ID16) without Vacuum Vessel.

![3D Rendering Model of the DIAMOND IVU (ID16) without Vacuum Vessel.](image)

3D GdfidL Model

Geometric Dimensions of Tapered Transition

**Gap, mm**

<table>
<thead>
<tr>
<th>Gap</th>
<th>(\Delta q)</th>
<th>(y_0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.1 nC</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>

**Orbit deviation**

**Courtesy by V. Smaluk & R. Bartolini**

**Gap, mm**

**Logarithmic Scale**

**Linear Scale**

**k_yT (geom&rw)**

**k_yT (Meas.)**
NSLS-II In-Vacuum Undulator (SRX, IVU21)

- STL-file of SRX IVU21 has been created for numerical simulations.

Entrance to Tap. Transition

3D Plot of SRX IVU21 in the GdfidL code. Applying STL-file.

Courtesy by C. Hetzel
NSLS-II Adaptive Gap Undulator

LDRD Leading by O. Chubar - “Adaptive Gap Undulators”

Table 1: Loss Factors, Power Losses and Kick Factors for $\sigma_s = 4.5\text{mm}$

<table>
<thead>
<tr>
<th>Loss Type</th>
<th>Geom. Loss Factor $k_{\text{geom}}$, mV/pC</th>
<th>RW Loss Factor $k_{\text{RW}}$, mV/pC</th>
<th>Power loss @300mA $P_{\text{loss}}$, W</th>
<th>Kick Factor $k_{\perp}(\sigma_s)$, V/pC/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Gap, $b = 3.5\text{mm}$</td>
<td>0.89</td>
<td>108</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>Linear Gap Variation, $b_{uv} = 3.2\text{mm}$</td>
<td>0.84</td>
<td>118</td>
<td>26</td>
<td>19</td>
</tr>
<tr>
<td>Stepped Gap Variation, $b_{uv} = 3.2\text{mm}$</td>
<td>0.84</td>
<td>118</td>
<td>26</td>
<td>91</td>
</tr>
</tbody>
</table>

- Inductive regime (Yokoya)
  $$\kappa_{\perp} = \frac{Z_0 c}{2\pi^{3/2}} \frac{1}{\sigma_s} \frac{d-b}{L} \left(\frac{1}{b} - \frac{1}{d}\right), \quad \frac{d-b}{L} \frac{b}{\sigma_s} \ll 1$$

- Kick Factor $\kappa_{\perp}^{Yok} = 21$ V/pC/m for 7mm gap, $L=200\text{mm}$, $d=12.5\text{mm}$ and $\sigma_s = 4.5\text{mm}$.

- The taper length becomes significantly longer due to Linear Gap Variation. It compensates change in radius from 3.5mm to 2.6mm.
Summary

● The GdfidL code has been cross-checked against analytical results for rectangular and axially symmetric tapered structures and vs. numerical data obtained by the ECHO code and the CST code.
● The GdfidL code demonstrates reliable results with applied small enough stepsize.
● Vertical dipole kick factor for the rectangular tapered structure becomes independent on width for $2w >> L$
● The realistic DIAMOND IVU geometry is under analysis including all changes in the vacuum chamber before the IVU entrance.
● Impedance analysis of the final designed Insertion Devises for NSLS-II has began. The results are collected in the NSLS-II Accelerator Physics Database as a part of the Impedance Lattice.
● AGU offers increase of source brightness. Its impedance study is in progress.
RECENT ACTIVITIES IN
NSLS-II
NSLS-II Bellows With Thermocouples

Cell 8

RF Shielded Bellows in NSLS-II Tunnel

Courtesy by C. Hetzel
Commissioning of NSLS-II with PETRA-III 7-Cell Cavity

- **Longitudinal HOM’s**

  ![Brillouin Diagram](image)

  - Real Part of the Longitudinal Impedance
    - $E_{010}$
    - $E_{011}$

  - Real Part of the Transverse Impedance
    - $E_{110}$
    - $E_{111}$

- **Transverse HOM’s**

  ![Graph](image)

  - Frequency (f), MHz
  - Phase (ϕ), Deg.

  - $E_{111}$
  - $E_{110}$
  - $H_{110}$
• Impedance Lattice is updated with new available wakefields.
• It is important to connect each impedance element with the magnet lattice from Collective Effects Analysis and Impedance Measurements point of views.
• J. Choi works under design and contents of the Accelerator Physics Database where Impedance Lattice a part of it.
PASSIVE LANDAU CAVITY EFFECTS IN MAXIV SR WITH GAP IN THE Fillings

**Self-consistent simulations with OASIS code (G. Bassi)**

1) Uniform Fillings (nominal configuration): $\sigma_{\tau} = 200\text{ps}$

2) Gap in the Fillings:

- Instability with saturation after 300K turns
- Stable after 300K turns

**Storage Ring Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>$E = 3\text{GeV}$</td>
</tr>
<tr>
<td>Average Current</td>
<td>$I = 500\text{mA}$</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>$M = 132$</td>
</tr>
<tr>
<td>Harmonic number</td>
<td>$h = 176$</td>
</tr>
<tr>
<td>Circumference</td>
<td>$C = 528\text{m}$</td>
</tr>
<tr>
<td>Bunch length w/o HC</td>
<td>$\sigma_{\tau} = 40\text{ps}$</td>
</tr>
<tr>
<td>Energy Spread</td>
<td>$\sigma_{p} = 7.7\times10^{-4}$</td>
</tr>
<tr>
<td>Energy loss per turn</td>
<td>$U_{s} = 364\text{keV}$</td>
</tr>
<tr>
<td>Momentum compaction</td>
<td>$\eta = 3.07\times10^{-4}$</td>
</tr>
<tr>
<td>Long. radiation damping</td>
<td>$\tau_{\text{rad}} = 25\text{ms}$</td>
</tr>
</tbody>
</table>

**NC Cavity System:**

4 MAIN and 1 LANDAU (3rd harm.) cavity

<table>
<thead>
<tr>
<th>Per cavity parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF frequency</td>
<td>$f_{rf} = 99.93\text{MHz}$</td>
</tr>
<tr>
<td>RF voltage</td>
<td>$V = 0.255\text{MV}$</td>
</tr>
<tr>
<td>Beta coupling</td>
<td>$\beta = 1.9$</td>
</tr>
<tr>
<td>Shunt impedance</td>
<td>$R_{L} = 1.759\text{M}\Omega$</td>
</tr>
<tr>
<td>Quality factor</td>
<td>$Q_{L} = 20946$</td>
</tr>
<tr>
<td></td>
<td>$Q_{H} = 21600$</td>
</tr>
</tbody>
</table>

**300K turns**

**600K turns**

BROOKHAVEN SCIENCE ASSOCIATES

(case study, IPAC13 paper MOPB03)
Spectral Flux of AGU and Conventional Undulators - "Candidates" for Inelastic X-Ray Scattering Beamline

On-axis Single-Electron Spectral Flux per Unit Surface at 20 m Observation Distance

- scAGU(13.6±15.4)
  7x1 m, 482 per. (h3)
- SCU15, 5.9 m, 392 per. (h3)
- cAGU(15.4±17.6)
  7x1 m, 423 per. (h3)
- AGU(16.7±18.8)
  7x1 m, 394 per. (h3)
- AGU(19.6±22.5)
  7x1 m, 331 per. (h3)
- cIVU17, 5.2 m, 305 per. (h3)
- IVU22, 6 m, 272 per. (h5)
- IVU18, 5.3 m, 294 per. (h3)

Spectral Flux through 100 μrad (H) x 50 μrad (V) Aperture from Finite-Emittance Electron Beam

- scAGU(13.6±15.4)
  7x1 m, 482 per. (h3)
- SCU15, 5.9 m, 392 per. (h3)
- cAGU(15.4±17.6)
  7x1 m, 423 per. (h3)
- AGU(16.7±18.8)
  7x1 m, 394 per. (h3)
- cIVU17, 5.2 m, 305 per. (h3)
- IVU18, 5.3 m, 294 per. (h3)
- IVU22, 6 m, 272 per. (h5)

\( E_e = 3 \text{ GeV}, I_e = 0.5 \text{ A}; \) NSLS-II High-\( \beta \) (Long) Straight

Courtesy by O. Chubar