Resistive Effects in Ceramic Kicker Chamber. Roughness Effects in Undulator Chamber.

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Uni Hamburg

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Topics

- Impedance Structure Investigation for Ceramic Kicker Vacuum Chamber with metallic coats.
- Resistive and Geometrical Wakes.
- Influence of Surface Roughness in Undulator Chamber on the Beam.
Impedance Structure Investigation of Ceramic Kicker Vacuum Chamber with Metallic Coats.

Longitudinal Impedance. Monopole term.

\[ Z(k) = -\frac{jZ_0}{\pi kU} \]

\[ U = a^2 - 2 \frac{a_2 \varepsilon_3}{\chi_3 \varepsilon_0} \times \frac{\varepsilon_3 \chi_4 R_4(a_3)S_3'(a_2) - \varepsilon_4 \chi_3 R_3'(a_2)R_4'(a_3)}{\varepsilon_3 \chi_4 R_4(a_3)S_3(a_2) - \varepsilon_4 \chi_3 R_3(a_2)R_4'(a_3)} \]

\( R, R', S, S' \) - combination of Bessel functions.

Single layer cylindrical tube

\[ U = a^2 - 2 \frac{a \varepsilon}{\varepsilon_0 \chi} \frac{K_0(\chi b)I_1(\chi a) + I_0(\chi b)K_1(\chi a)}{K_0(\chi b)I_0(\chi a) - I_0(\chi b)K_0(\chi a)} \]
Metallic type layers

\[ \varepsilon_i = \varepsilon_0 - j \sigma_i / \omega \quad \chi_i = \sqrt{j \mu_0 \sigma_i \omega} \]

**Good approximation** - the smallness of each layer skin depth with respect to the layer inner radius \( \delta_i / a_i << 1 \)

\[
U = a^2 - 2 \frac{a \varepsilon_3}{\varepsilon_0 \chi_3} \times \frac{1 + \alpha \theta \chi_3 d_3 \theta \chi_4 d_4}{\theta \chi_3 d_3 + \alpha \theta \chi_4 d_4}
\]

\[ \left| a_2 \chi_3 \right| >> 1 \]

\[ \alpha \approx \left( \sigma_3 / \sigma_4 \right)^{1/2} \]

**Single layer tube** \( \alpha = 1 \)

\[
U = a^2 - 2 \frac{a \varepsilon}{\varepsilon_0 \chi} c \theta \chi d
\]

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Ceramic type layers with metallic coats

Good approximation:

\[
\begin{align*}
|a_2\chi_3| & \gg 1 & \text{Metallic layer} & \quad \varepsilon_3 = \varepsilon_0 - j \frac{\sigma}{ck} & \quad \chi_3 = \sqrt{j\varepsilon_0\mu_0\sigma k} \\
|a_3\chi_4| & \gg 1 & \text{Ceramic layer} & \quad \varepsilon_4 = \varepsilon_0 n^2 & \quad \chi_4 = jk\sqrt{n^2 - 1}
\end{align*}
\]

\[ U = a^2 + 2 \frac{a\varepsilon_3}{\varepsilon_0\chi_3} \times \frac{1 - j\alpha \text{th}(\chi_3d_3)\text{th}(kn'd_4)}{\text{th}(\chi_3d_3) - j\alpha \text{th}(kn'd_4)} \]

\[ U = a^2 + 2 \frac{a\varepsilon_3}{\varepsilon_0\chi_3} \text{cth}(\chi_3d_3) \quad \text{kn'}d_4 = \pi l \quad l \in N \]

\[ U = a^2 + 2 \frac{a\varepsilon_3}{\varepsilon_0\chi_3} \text{th}(\chi_3d_3) \quad \text{kn'}d_4 = \frac{\pi}{2} + \pi l \]

Actually for all the practical applications, the formula (*) is valid and well approximates the exact solution.

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Numerical Examples

Ceramic Kicker Vacuum chamber:
Ceramic with Titanium-Stabilized High Gradient Steel (TSHGS) coats

Vacuum Chamber Parameters
- Radius - 0.01 m
- Length - 0.9 m

TSHGS Parameters
- Thickness - 0.7 μm
- Resistance - R/L = 10 - 12 Ωm⁻¹
- \( \sigma \approx (2.0841 \pm 0.18946) \times 10^6 \text{Ω}^{-1}\text{m}^{-1} \)

Parameters from T. Wohlenberg
Longitudinal monopole impedance as function of dimensionless wave number \( \kappa = k \cdot s_0 \) for several cases of vacuum chamber material:

1. Ceramic with TSHGS coats.
2. TSHGS single layer tube with finite and infinite thickness.
3. Copper single layer tube.

\[ \kappa = k s_0 \]

**s_0 characteristic distance:** \( s_0 = \left( \frac{2ca^2 \varepsilon}{\sigma} \right)^{1/3} \approx 63.4 \mu m \)

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Resistive wall longitudinal wake potentials of Gaussian bunch with $\sigma_b = 20 \mu m$ for several cases of vacuum chamber material:

1. Ceramic with TSHGS coats.
2. TSHGS single layer tube with finite and infinite thickness.
3. Copper single layer tube.

$E = 17.5 \text{ GeV}$

<table>
<thead>
<tr>
<th></th>
<th>Ceramic+TSHGS</th>
<th>TSHGS</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss Factor[kV / nC]</td>
<td>-108.43</td>
<td>-108.4</td>
<td>-26.29</td>
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<tr>
<td>Energy Spread [%]</td>
<td>0.288</td>
<td>0.288</td>
<td>0.12</td>
</tr>
</tbody>
</table>

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Geometrical Wakes

Geometrical longitudinal wake potentials of Gaussian bunch \( \sigma_b = 20 \mu m \)

\[
E = 17.5 \text{GeV}
\]

<table>
<thead>
<tr>
<th></th>
<th>Entrance</th>
<th>Exit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss Factor[kV / nC]</td>
<td>0.36</td>
<td>-462.39</td>
<td>-462.1</td>
</tr>
<tr>
<td>Energy Spread [%]</td>
<td>(1.12 \times 10^{-3})</td>
<td>1.057</td>
<td>1.058</td>
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</tbody>
</table>

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Surface Roughness in Undulator Section

R.m.s. distortion \( \Delta \approx 0.568 \, \mu m \)

Measurement data from T. Wohlenberg

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\[ Z(\omega) = \frac{Z_s(\omega)}{2\pi R} \left[ 1 + i \frac{\omega R}{c} \frac{Z_s(\omega)}{Z_0} \right]^{-1} \]

Surface Impedance

\[ Z_s(\omega) = Z_s^\sigma(\omega) + Z_s^L(\omega) \]

where

Inductance define as

\[ L = \frac{Z_0}{2\pi ca} \int dk_x dk_z \tilde{R}(k_x, k_z) \frac{k_z^2}{\sqrt{k_x^2 + k_z^2}} \]

Where \( \tilde{R}(k_x, k_z) \) is spectral density defined as Fourier Transformation of Autocorrelation function:

\[ R(x, z) = \frac{1}{A(x, z)} \int \left[ \delta(\hat{x}, \hat{z}) \delta(\hat{x} - x, \hat{z} - z) \right] d\hat{x} d\hat{z} \]

G.V. Stupakov, SLAC-PUB-8208, 1999
M. Dohlus. TESLA 2001-26, 2001

\[ \sigma = 58 \times 10^6 \Omega^{-1} \text{m}^{-1} \]
\[ R = 4.4 \text{ mm} \]

\[ Z_s^\sigma(\omega) \approx \sqrt{\frac{i\omega\mu}{\sigma(\omega)}} \]
\[ Z_s^L(\omega) \approx i\omega L \]
Wake Potential of Corrugated pipe

Loss Factor \([\text{kV} / \text{nC}]\):
- Ideal: -50.698
- Corrugated: -52.703

Energy Spread \([\%]\):
- Ideal: 0.286
- Corrugated: 0.33
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AU</td>
<td>Gold</td>
</tr>
<tr>
<td>CU</td>
<td>Copper</td>
</tr>
<tr>
<td>ELP</td>
<td>Electro polish</td>
</tr>
<tr>
<td>UNB</td>
<td>Untreated (Unbehandelt)</td>
</tr>
<tr>
<td>GEB</td>
<td>Etched (Gebeizt)</td>
</tr>
</tbody>
</table>

### R.m.s. value of the roughness in \( \mu m \)

<table>
<thead>
<tr>
<th></th>
<th>AL_AU</th>
<th>AL_CU</th>
<th>AL_ELP</th>
<th>AL_UNB</th>
<th>AL_GEB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meas. 1</strong></td>
<td>0.568</td>
<td>0.371</td>
<td>0.395</td>
<td>0.567</td>
<td>2.835</td>
</tr>
<tr>
<td><strong>Meas. 2</strong></td>
<td>0.547</td>
<td>0.745</td>
<td>0.360</td>
<td>0.520</td>
<td>--------</td>
</tr>
<tr>
<td><strong>Meas. 3</strong></td>
<td>0.514</td>
<td>0.418</td>
<td>0.346</td>
<td>0.457</td>
<td>--------</td>
</tr>
</tbody>
</table>

### Arithmetical Mean Roughness \( Ra [\mu m] \)

<table>
<thead>
<tr>
<th></th>
<th>AL_AU</th>
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<th>AL_UNB</th>
<th>AL_GEB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meas. 1</strong></td>
<td>0.425</td>
<td>0.288</td>
<td>0.312</td>
<td>0.463</td>
<td>2.202</td>
</tr>
<tr>
<td><strong>Meas. 2</strong></td>
<td>0.430</td>
<td>0.362</td>
<td>0.285</td>
<td>0.418</td>
<td>--------</td>
</tr>
<tr>
<td><strong>Meas. 3</strong></td>
<td>0.410</td>
<td>0.333</td>
<td>0.274</td>
<td>0.356</td>
<td>--------</td>
</tr>
</tbody>
</table>
Summary

• Impedance Structure for Ceramic Kicker Vacuum Chamber was investigated. For Kicker was shown that Wake Potential for two layer tube can be estimated by single layer tube formula.
• Was analyzed the transition Wakes influence on the beam.
• Influence of surface corrugation in Undulator vacuum chamber on the beam was calculated.

Acknowledgements:

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