Coherent Synchrotron Radiation Shielding Experiment at ATF

Vladimir N Litvinenko

Team
AFT: Mikhail Fedurin, Vitaly Yakimenko
C-AD: Alexei Fedotov, Dmitry Kayran, Vladimir Litvinenko

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Content

• Experiment description
• Theory - longitudinal CSR wake
• Selected results
• Comparison with theory (qualitative)
• Conclusions
Experimental layout

RF Gun  S-band Linac  Chicane

Energy collimator

Tail 200keV  Head

Energy →

Aluminum plates with adjustable gap are installed in the second dipole

Energy spectrum after dipole with plates open and closed

Energy →

200keV

β (m)  vs  s (m)

β →  0.5  0.7  0.9  1.0

D (m) →  1.0  0.7  0.5  0.2

Tail  Head

Energy →

closed  open
Beam at AFT: we used chirp in the energy

Optical function of the transport line from linac exit to spectrometer beam profile monitor. Energy collimator is located at position of 12.5m and magnet with shielding plates is installed at 20m position.
Beam at AFT

\[ f(x, z, s) := \frac{(\text{Erf}((x + z/2)/s) + \text{Erf}(-(x - z/2)/s))}{2/z} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>57.6</td>
<td>MeV</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>112.72</td>
<td></td>
</tr>
<tr>
<td>( \beta )</td>
<td>0.99996064</td>
<td></td>
</tr>
<tr>
<td>Magnet Length</td>
<td>0.4</td>
<td>m</td>
</tr>
<tr>
<td>Angle</td>
<td>0.34906585</td>
<td>rad</td>
</tr>
<tr>
<td>Radius</td>
<td>1.14591559</td>
<td>m</td>
</tr>
<tr>
<td>Flat top</td>
<td>5.00E-04</td>
<td>m</td>
</tr>
<tr>
<td>Edge</td>
<td>1.00E-04</td>
<td>m</td>
</tr>
<tr>
<td>Peak current</td>
<td>70</td>
<td>A</td>
</tr>
<tr>
<td>Charge</td>
<td>1.40E-10</td>
<td>C</td>
</tr>
<tr>
<td>Ne</td>
<td>8.74E+08</td>
<td></td>
</tr>
</tbody>
</table>

\[
\frac{e\beta^2}{R_o^2} N_e L = 0.3838 \text{ eV}
\]

Measured autocorrelation of the electron beam is drawn with points. Autocorrelation of the flat-top 600micron long (FWHM) pulse with 50 microns rise/fall is shown in violet. Autocorrelation of the abovementioned flat top distribution with low frequency cut of the detection system taken into account is plotted in light brown.
Plates

- Remotely controlled two 40+ cm Al plates change vertical gap from 0 to 12 mm
- Previously used rough Al plates were replaced by polished plates
- Rough plates: ~30 \( \mu \)m width, ~30 \( \mu \)m spacing, 5-10 \( \mu \)m deep, very long grooves
- Mirror polished plates: ~1\( \mu \)m wide, ~10-30 \( \mu \)m spacing, <1\( \mu \)m deep, very long grooves
Deformations

\[ E = E_0 + \epsilon t + W(t) \]

\[ f(E) \Rightarrow \frac{f\left(E - W\left(\frac{E - E_0}{\epsilon}\right)\right)}{1 + \frac{W\left(\frac{E - E_0}{\epsilon}\right)}{\epsilon}} \]
Summary of experimental results

With closed gap the distribution is close to that from the HE slit – opening gap increases the distortions
Exact Theory

- Tricky part is the retarded time
- I use analytical parametric dependence
- It allowed to calculate exactly radiated field by any charge (real or reflected)
- Integration with real bunch distribution provides the resulting wake-field

\[
\begin{align*}
\vec{r}(t') &= R_o(\hat{x}\cos\theta + \hat{y}\sin\theta), \quad \rightarrow \quad \vec{r}_n(t') = R_o(\hat{x}\cos\theta_n + \hat{y}\sin\theta_n) + \hat{z}n h; \\
\vec{r}(t) &= R_o(\hat{x}\cos\theta + \hat{y}\sin\theta).
\end{align*}
\]

\[
\begin{align*}
\psi &= \frac{\theta(t) - \theta_n(t)}{2} \\
\Delta \theta &= 2\psi - \frac{\omega}{c}\sqrt{4\sin^2\psi + n^2h^2/R_o^2}
\end{align*}
\]

\[
E_{\text{rad}} = \frac{e\beta^2}{2R_o^2(1 - \beta \cdot \text{sign}\psi \cos\psi)} \left( \beta - \cos\psi \cdot \text{sign}\psi \right) \left\{ \hat{y} - \hat{x}\cos\psi \right\}
\]

\[
E_{\text{rad, - n}} = \frac{2e\beta^2}{R_o^2(\rho - \beta \sin 2\psi)^3} \left[ \hat{x}(\rho^2 \cos^2 2\psi - \rho\beta \sin 2\psi + 4 \sin^4 2\psi) \right] \left\{ \hat{x}(\rho^2 \cos^2 2\psi - \rho\beta \sin 2\psi + 4 \sin^4 2\psi) \right\}
\]

\[
\rho_n(\psi) = \sqrt{4\sin^2\psi + n^2h^2/R_o^2}
\]
Exact Theory - cont...

\[ W(\varphi) = N_n \sum_n \int E_n(\varphi-\theta) f(\theta) d\theta = \sum_n \int E_n(\theta) f(\varphi-\theta) d\theta; \]

\[ W(\varphi) = N_n \sum_n \int E_n(\theta)(\psi) f(\varphi-\theta(\psi)) \frac{d\theta}{d\psi} d\psi, \]

\[ \theta_n = 2\psi - \beta \sqrt{4 \sin^2 \psi + n^2 h^2 / R_o^2}; \]

\[ \frac{d\theta_n}{d\psi} = 2 \left( 1 - \beta \frac{\sin 2\psi}{\sqrt{4 \sin^2 \psi + n^2 h^2 / R_o^2}} \right) \]

\[ W(\varphi) = \frac{2e\beta^2}{R_o^2} N_e \sum_{n=-\infty}^{\infty} (-1)^n \int_{-\infty}^{\infty} \frac{-\rho_n(\psi) \sin 2\psi + 2 \sin^2 \psi \rho_n(\psi) \beta + 4 \cos \psi \sin^3 \psi}{(\rho_n(\psi) - \beta \sin 2\psi)^3} \frac{d\psi}{\rho_n(\psi)} \left( -2\psi + \beta \rho_n(\psi) \right) \left( 1 - \frac{\sin 2\psi}{\rho_n(\psi)} \right) d\psi \]
Wakefield - calculations

1 unit - 0.38 eV

* I used +/- 40 reflections, adding more does not change results
Wakefield - calculations
1mm - suppression by $\times 1000$

* I used +/- 40 reflections, adding more does not change results
Opening gap from 1 mm to 12 mm
Opening gap from 1 mm to 12 mm

Current distribution vs. De-convoluted wake

Energy/Time vs. Plates gap [mm]

1 mm, 2 mm, 4 mm, 6 mm, 8 mm, 12 mm
1 mm gap – kills CSR
both the energy loss and the energy spread

More details in:

Slides from IPAC’11
Conclusions

• Small gap vacuum chamber eliminates both average energy loss from CSR as well as RMS energy spread (in contrast to predictions in some papers and previous presentations on CSR!)
• New type of experiments with focus on the f(E) modification were performed at ATF and demonstrated excellent sensitivity to short-range wake-fields (better than 1 keV for 60 MeV beam)
• Exact analytical theory for the case of parallel plates is developed and is in good agreements with the measurement
• Detailed analysis is under way
• We’ll present poster and paper at PAC’11 with detail of the experiments, simulations and comparison
Long range wakes