Coherent Synchrotron Radiation Issues

Juhao Wu
T.O. Raubenheimer, G.V. Stupakov, M.C. Ross, and J.C. Frisch

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Recent studies indicate that Coherent Synchrotron Radiation could be a potential problem leading to an instability.

ATF Damping ring is a good test bed for the existing theory and also for further studies.

Existing experiments mostly study the CSR radiation, we need understand how the CSR radiation acting on the beam.

Extracted beam measurements at ATF allow unprecedented energy spread measurements.

We will study the effect on the beam NOT the light
• **Theory** [Stupakov-Heifets, PRST-AB, 5 (2002) 054402] indicates a potential instability due to the CSR impedance from dipoles;

• **Experimental observations** [Byrd, *et al.* , PRL 89 (2002) 224801; NSLS/BNL; BESSY-II]
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CSR Impedance

• **Free Space Impedance**
  
  – **Dipoles** (\(\alpha > 0\)) ([Murphy-Krinsky-Gluckstern, PA, 1997])
    
    \[
    Z_D(k) = -i A k^{1/3} / R^{2/3}
    \]
    \[
    A = 3^{-1/3} \Gamma(2/3)(\sqrt{3} i - 1)
    \]
  
  – **Wigglers** (\(\alpha < 0\)) ([Wu-Raubenheimer-Stupakov, PRST-AB, 2003])
    
    \[
    Z_W(k) = K^2 / \gamma^2 \left\{ \frac{\pi k}{4} - \frac{i k}{2} \log \left[ \frac{k}{k_{FEL}} \right] \right\}
    \]
    \[
    \text{for } \frac{k}{k_{FEL}} \in (0, 0.1]
    \]

• **Scaling**

  \[
  k^{1/3} \leftrightarrow \{ k \text{ and } k \log[k] \}
  \]

Dipole impedance dominates for long wavelength; ATF wiggler-off operation mode is good!
Threshold vs. wavelength

- We hope to get experimental verification!

Threshold determined by the longest wavelength
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ATF Damping Ring

Growth Rate vs. wavelength

- We hope to get experimental verification!

\[ \omega = \sqrt{i c^2 n_b r_e \eta k Z(k) / \gamma} \]

\[ \tau^{-1} \propto \text{Im}(\omega) \]
\[ \propto \text{Im}(\sqrt{\pm i k Z(k)}) \]

\[ Z(k) \propto k^\varepsilon \]
with \( \varepsilon > 0 \)
Shielding Cut-off

- **Cut-off** ([Stupakov-Kotelnikov, PRST-AB, 2003])

\[ k \approx \frac{2.12}{a} \sqrt{\frac{R}{a}} \]

- **ATF parameters give**

\[ \lambda \approx 1.6\,\text{mm} \implies f \approx 187\,\text{GHz} \]

- **High current operation mode, or local density fluctuations**

*Should we see something, and how?*
Shielding added as an ad hoc cutoff, but...
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**CSR Power**

- **Coherent enhancement**
  \[ P_{CSR}(\lambda) = [1 + (N - 1)f(\lambda)]P_{ISR}(\lambda) \]

- **Gaussian form factor**
  \[ f(\lambda, \sigma_z) = \exp[-(2\pi\sigma_z/\lambda)^2] \]

- **ATF parameters**
  \[ \lambda = 1.6 \text{ mm}, \quad \sigma_z = 5 \text{ mm} \]

\[
(1.0 \times 10^{10} - 1) \exp \left[-\left(\frac{2\pi 5}{1.6}\right)^2\right] = 3.67986 \times 10^{-158}
\]

**Smooth is not enough!**
An estimate

- **Density perturbation**
  \[ \hat{n}_1 e^{-i \omega s / c + ikz} \]

- **CSR-induced energy modulation**
  \[ \delta = \frac{A \hat{n}_1 r e c k^{1/3}}{\gamma R^{2/3} \omega(k)} e^{-i \omega s / c + ikz} \]

- **Saturation**
  \[ \delta \rightarrow \delta_0 \quad \Rightarrow \quad f(1.6\text{mm}) \approx 2.5\% \]

- **Estimated power**
  \[ P_{ISR} \approx 0.35 \text{nW/mrad}\theta/\text{mm} \]
  \[ P_{CSR} \approx 0.17 \text{W/mrad}\theta/\text{mm} \]

What will seed or initiate the modulation?
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Future Issues

• Theory is relatively simple and need consider other effects
  – Other wakefields (seeding the modulation?)
  – Extend Vlasov to Vlasov-Fokker-Plank
• Verify shielding effect
• Single mode CSR? ([Heifets-Stupakov, 2003])
• Understand the quasi-periodic CSR bursting ([Venturini-Warnock, PRL, 2002])

Need Experiments to verify the existing theoretical understanding and also stimulate further studies