Instability Considerations for Ring-Based Transient Production of Beam for an FEL

- We only care about single-bunch effects.
- We are concerned about transient rather than equilibrium effects
  - 1GeV x 1kA: rapid rotation in longitudinal phase space to produce high peak current.
  - Booster+photo-injector (BOOPI): accelerate the beam before QE, IBS, or some instability ruins it.
- The conditions of interest are
  - Low energy spread
  - Very short bunches for “short” times
  - Very small emittances
  - Very long synchrotron oscillations (1Gevx1kA)

Impedances for Dummies
Other Dismal Science

- Use the longitudinal broad-band impedance, consistent with a Q=1 resonator with resonance frequency $\omega_c = \frac{c}{b}$, where b is the beam pipe radius.
- People quote the slope of the impedance as $\omega \to 0$ as the "broad band impedance" $\left|\frac{Z}{n}\right|$, where $n = \frac{\omega}{\omega_0}$.
- The longitudinal microwave instability (LMI) is the most significant one, with a peak-current threshold of

$$I_p = \frac{2\pi\alpha E\sigma_\delta^2}{\left|\frac{Z}{n}\right|}$$

Overview of Problems for 1GeV x 1kA

- All instabilities get worse at lower energy.
  We can’t get anywhere near 1kA at 7GeV.
  LMI peak current threshold goes as σ_δ^2 for a total energy dependence of E^3.
- At 1GeV and 3.68nC with $\left|\frac{Z}{n}\right| = 1 \ Ohm$ the thresholds for LMI are
  10kV, 0.014%: 28mA (want 32A)
  10MV, 0.43%: 28A (want 1kA)
- Growth rate of LMI is typically << synchrotron period, according to ZAP manual.

Overview of Problems for BOOPI

- The beam travels 10^7 m to gain 1.5GeV, an average of 100 eV/m. This is pathetic compared to linacs at > 20 MeV/m.
- The beam must survive ~50ms with bunch length of ~1.5 ps and energy spread of 0.01%. For 1nC and 1.5ps, the peak current is 265A.
- For $\left|\frac{Z}{n}\right| = 1 \quad Ohm$, LMI threshold is 40mA peak at 450 MeV.
  LMI growth rate is probably much faster than 50ms.

Plan of Attack

- We need to do more than the standard computations of thresholds that are done for a storage ring design:
  - Determine impedance models
  - Compute thresholds and *growth rates*
  - Do tracking simulations
- Alternative:
  For the 1Gev x 1kA, “just do it.” It might cost less...
- Experimental impedance determination:
  Can we determine the impedance spectrum to high enough frequency with our present bunch lengths?
- Simulation-based impedance determination:
  Do you believe it? To high frequencies?

Experimental Determination of Longitudinal Impedance

- It's been done at various facilities (SPEAR, ESRF) to a better degree than we've done it.
- Some ideas (mostly from Wiedemann)
  - Measure bunch length vs current. Problem: Only gives the broad-band impedance. No frequency dependence.
  - Measure loss factor using two-bunch method for variable current and bunch length to get the resistive impedance vs ω. Problem: Requires precise measurement of time or phase between to bunches.
  - Measure incoherent synchrotron tune shift vs beam current and bunch length to get reactive impedance vs frequency. Problem: Requires measuring $2\nu_s$. [I'm not sure I've ever seen it.]