ILC Damping Rings Stability Study

(work in progress)

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timer

Setup

Our goal was to have a setup which allows a quick estimate of beam stability for various designs of the ILC DRs.

The current setup is based on a collection of Mathematica notebooks. The advantage of using Mathematica:

- Compact code
- Powerful symbolic and graphical capabilities
- Easy documentation of algorithms used in the code
- Transparent handling of the system of units and dimensional variables

We plan to have a tool that is similar to (and better than) the old ZAP computer program.

Setup

Mathematica notebooks:

- Formulate an impedance model for each ring (resistive wall, HOMs, a broadband impedance)
- Compute transverse mode coupling instability (Satoh-Chin model)
- Compute transverse and longitudinal multibunch instabilities

For microwave instability, we plan to use the Oide code (or its modification) including Haissinki equilibrium into analysis.

We also have available a Vlasov-Fokker-Planck solver (developed by R. Warnock) that allows to track nonlinear evolution of the single bunch longitudinal instability.

At this point we use input parameters from DRMegaTable (of 7/5/05) and A. Wolski's paper LBNL-57045-CBP Tech Note-331.

Impedance – resistive wall

We assume aluminum wall of round cross section. The longitudinal impedance and the wake are:

$$Z_{RW,long}(f) = L\frac{1-i}{cb}\sqrt{\frac{f}{\sigma}}$$

$$w_{RW,long}(z) = -L\frac{1}{2\pi b}\sqrt{\frac{c}{z^3\sigma}}$$

We arbitrarily assume $b = 2$ cm for all machines, except for BRU and MCH. For those rings we find b_{arc}, b_{wiggler}, and b_{straight} in A. Wolski's paper LBNL-57045-CBP Tech Note-331.

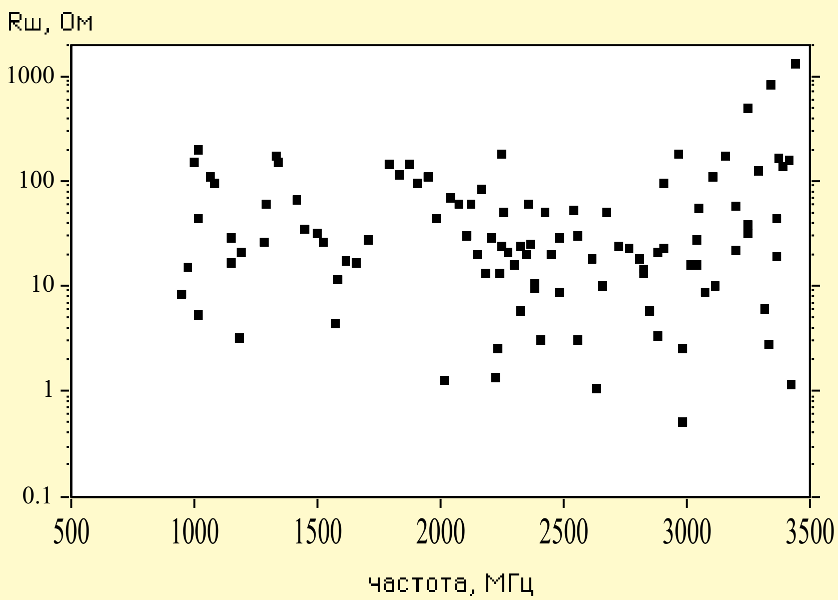
Note singularity of the wake function at $z = 0$, which should be properly treated in calculation of the microwave instability.

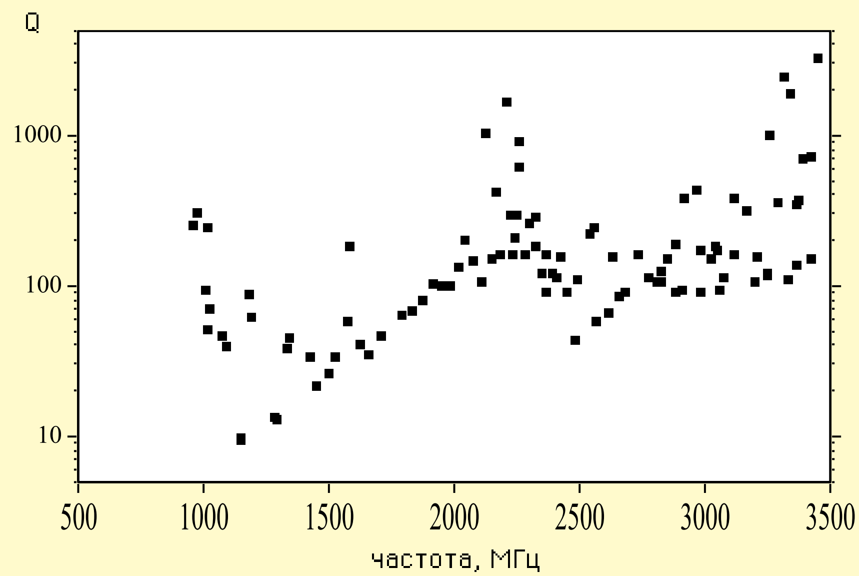
Impedance – HOMs

Impedance of an HOM mode

$$Z_{long,mode}(f) = \frac{R}{1 - iQ(f/f_0 - f_0/f)}$$

HOM modes at CESR SC cavity, $f_{\text{fund. mode}} = 500$ MHz, computed with CLANS (from S. Belomestnykh thesis, 1998).





Typical Q are from 100 to 1000.

Impedance – HOMs

The empirical value for the total loss factor of all HOMs is (from S. Belomestnykh, ”On the BB1 Cryomodule Loss Factor Calculations”, SRF 990714-08)

$$\kappa_{\mathrm{loss}} = 7.73\left(\frac{\sigma_z}{\mathrm{mm}}\right)^{-1.118}\frac{\mathrm{V}}{\mathrm{pC}}$$

We assume the voltage 2 MV per cavity (CESR - 1.8 MV; KEKB - 1.6/2.0 MV; LHC - 2.0 MV) and compute the number of cavities in the ring from the total voltage.

Broadband impedance in the ring

The broadband impedance describes a contribution from many small elements in the ring, such as BPMs, transitions, flanges, bellows, etc. It also has a resistive component in it. We use the model proposed by Heifets and Chao (SLAC-PUB-8398, 2000):

$$Z_{induc,long}(f) = -\frac{Z_0}{4\pi} \frac{i\omega\mathcal{L}/c}{(1 - i\omega T)^{3/2}}$$

where $\mathcal{L}$ is the inductance, and T is a parameter with the dimension of time. For $\omega \gg 1/T$, $Z_{induc,long} \propto \omega^{-3/2}$ which is the diffraction limit for a high frequency impedance.

For PEP-II $\mathcal{L} \approx 100$ nH. We assume that this impedance is distributed uniformly over the ring and get a value per cell: $100/146 = 0.68$ nH. We are trying to figure out the number of cells in each ring using the averaged beta functions. We do not rescale the value of $\mathcal{L}$ to account for various pipe radius (?).

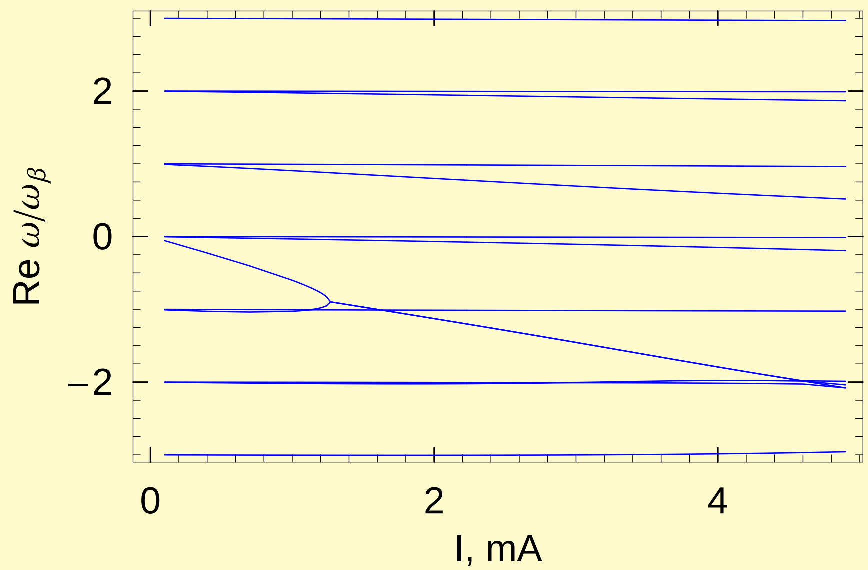
Mode Coupling

We satoh Satoh-Chin equations.

$$\alpha_h = -i\frac{Nc^3 r_e}{4\pi C\gamma\omega_\beta\omega_s\sigma_z}\beta_h(\lambda)\sum_{h'=0}^{\infty}\alpha_{h'}\int d\chi\, Z_\perp(\chi)F_{h'}\left(\chi-\chi_\xi\right)F_h\left(\chi-\chi_\xi\right)$$

where $\chi = \omega\sigma_z/c$, $\chi_\xi = \omega_\beta\xi\sigma_z/c\eta$, $\lambda = (\Omega-\omega_\beta)/\omega_s$,

$F_h(\omega) = \frac{\omega^h}{\sqrt{2^h h!}}e^{-\omega^2/2}$, $\beta_0 = \frac{1}{\lambda}$, $\beta_1 = \frac{2\lambda}{\lambda^2-1}$, $\beta_2 = \frac{2\lambda}{\lambda^2-4} + \frac{2}{\lambda}$, . . .



Result for the BRU ring for zero chromaticity

Coupled Bunch Instabilities

We use formulation in terms of wakes rather than impedances. Those series converge faster. We assume uniform distribution of bunches over the ring.

Longitudinal CBI:

$$\frac{\delta\omega}{\omega_s} = -\frac{N_{\text{part}} r_0 \eta c}{2\omega_s^2 \gamma T} \sum_{k=1}^{\infty} w'(k s_b) \left[e^{ik(2\pi l/M + \omega_s s_b/c)} - 1 \right]$$

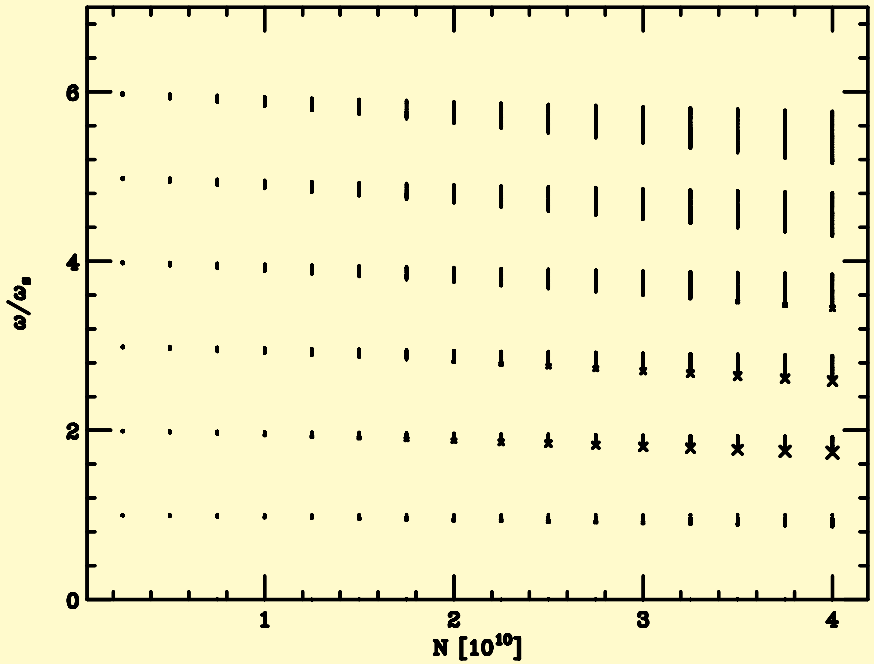
where $s_b = C/N_b$ is the distance between the bunches.

Transverse CBI:

$$\frac{\delta\omega}{\omega_s} = -\frac{\beta N_{\text{part}} r_0}{2\gamma T \omega_\beta} \sum_{k=1}^{\infty} w_\perp(k s_b) e^{ik(2\pi l/M + \omega_\beta s_b/c)}$$

Microwave Instability

The simplest approach is to compute the Keill-Schnell-Boussard creterion which gives Z/n. We plan to use the Oide code that solves eigenmode equations and finds the threshold of the instabilities.



Calculation of microwave instability threshold for PPA. The growth rate equals τ_l at $N_p = 1.75 \times 10^{10}$ with $\omega = 1.89 \times \omega_s$.

Discussion and Plans

- The existing model of impedance is incomplete—we need more input for vacuum pipe radii, cavities HOMs, etc.
- We need a better understanding of the multibunch instabilities in the situation when we do not have detailed information about HOMs
- More work is needed with the microwave instability
- We plan to add estimations of the CSR instability to the code