Integrated Storage Ring Design with Instability Thresholds: A Discussion

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Inspiration*

M. Bei, M. Borland, Y. Cai, P. Elleaume, R. Gerig, K. Harkay, L. Emery, A. Hutton, R. Hettel, R. Nagaoka, D. Robin, C. Steier, "Potential of an Ultimate Storage Ring for Future Light Sources," DOE BES Workshop on Physics of Future Light Sources (Sept 2009), Nucl. Instrum. Meth A, in press (2010).

Choice of lattice and machine parameters potentially result in low current thresholds for instabilities, especially single bunch

Would it be possible to integrate instability thresholds into optimization of storage ring designs?

What has been done so far? Include chromaticity (Borland, WG2); Parameter scaling (Borland, Plenary); ILC DR design (Emery); …

Brainstorm with the experts in WG2

* Thanks also to Yong-chul Chae and Ryutaro Nagaoka

Example #1: TMCI

Threshold estimated as current at which tune slope equals synchrotron tune*

$$I_{\mathrm{TMCI,th}} = \frac{2\pi \nu_s E/e}{\sum_i \beta_i \Im(Z_\perp)_{eff,i}}$$

Minimize beta functions at large $\Im(Z_\perp)_{eff}$

$$\nu_s = \sqrt{\frac{\alpha h V_{rf} \cos\varphi_s}{2\pi E/e}}$$

$\left(\frac{\alpha}{E/e}\right)$ too small can lead to small ν_s and low TMCI threshold

$$\Im(Z_\perp)_{\mathrm{eff}} = \frac{\sum Z_\perp(\omega) h_m(\omega - \omega_\xi)}{\sum h_m(\omega - \omega_\xi)}$$

Small bunch length results in wide spectral width, on same order as ω_ξ

$$\sigma_s = \sqrt{\frac{2\pi\alpha R C_q}{J_\varepsilon \rho_0} \frac{\gamma^2 E/e}{h\omega_0 V_{rf} \cos\varphi_s}}$$

$$\nu_s E/e \propto \sqrt{\alpha E/e} \propto \sigma_s$$

(*conservative; can operate well above threshold with positive chromaticity or feedback)

TMCI and double rf systems

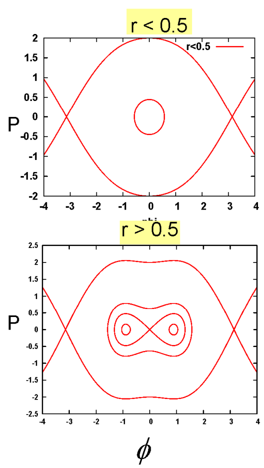
Harmonic cavity can be used to lengthen the bunch without increasing the energy spread (and exceed energy aperture). Longer bunches should increase the TMCI threshold, but smaller synchrotron tune tends to reduce it.

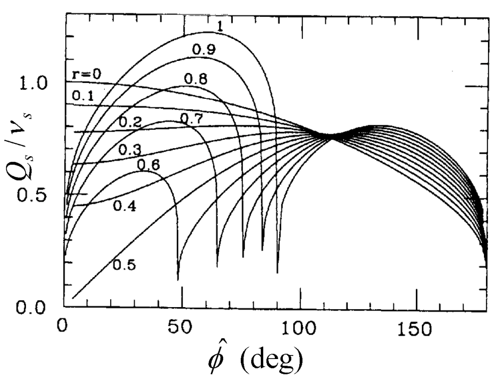
PETRA: higher threshold with double rf [S. Kramer, Argonne LS-96 (1988)]

LEP: higher threshold with single rf [Yong ho Chin, Proc. EPAC 1994, 1078]

Conclusion: B**unch lengthening has to win out over small ν_s (also Landau damping with σ_E/E)**

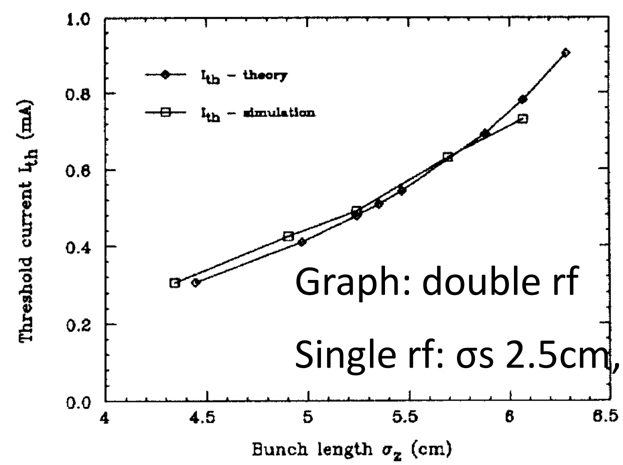
Synchrotron tune: graph





Synchrotron tune variation w.r.t. phase amplitude for a double RF system.

Shaoheng Wang (2004)



Graph: double rf

Single rf: σs 2.5cm, Ith 1.4 mA

Figure 5: The threshold current as a function of the bunch length.

Y. Chin, EPAC94

Example #2: Microwave instability

Longitudinal instability associated with energy spread growth above the threshold:

$$I_{\mu,\mathrm{th}} = \frac{3\omega_0^3 \sigma_{th}^3 V_{rf} \left|\cos\varphi_s\right|}{2\sqrt{2\pi}\,\Re(Z_L)_{eff} \big/ (f_{res}/f_0)}$$

σ_{th} is bunch length at instability threshold -- lengthens with potential well distortion and with harmonic cavity.

How important is energy spread blowup? Growth only about a factor of 2 in APS above the 5-7 mA threshold (up to 20 mA). Maybe more important in other rings? Operate below threshold (PEPX)?