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Collective Single-Beam Effects

- Job description excludes beam-beam effects and insertion design that affect beam parameters
- We shall look at collective effects in single beams
- Effects in large machines like LHC
  - Resistive-wall transverse growth rate dominated by smooth vacuum chamber over most of circumference
  - Remaining effects dominated by impedances of objects in small numbers, with resonances, occupying fraction of circumference → compute thresholds
  - coherent synchrotron tune shift
  - longitudinal microwave instability
  - transverse mode-coupling instability
- Evaluate effects and extend list this week

Resistive wall growth rate

$$\frac{1}{\tau_{RW}} = \frac{r_c}{e}\,\frac{I_b\,\beta_\perp\,\delta_s}{\gamma\,b^3}$$

(I_b: beam current; $\beta_\perp$: average β-fct; δ_s: skin depth; b: chamber radius)

$$\delta_s = \sqrt{\frac{\rho_w}{\mu_0 \pi f}}$$

ρ_w: wall resistivity

f: frequency of lowest mode < f_{rev}.

Coherent synchrotron tune shift

$$\mathrm{Im}\left(\frac{Z_\parallel}{n}\right)_{eff} = \frac{6}{\pi^3}\,\frac{h^3\,V_{RF}}{I_b}\left(\frac{2\pi\sigma_s}{C}\right)^5$$

(h: harmonic number; V_{RF}: RF voltage; σ_s: bunch length; C: circumference)

Longitudinal μ-wave

$$\left(\frac{Z_{\parallel}}{n}\right)_{eff} = \frac{12}{\pi^3}\,\frac{h\,V_{RF}}{I_b}\left(\frac{2\pi\sigma_s}{C}\right)^3$$

Transverse mode-coupling

synchrotron tune: Q_s; energy: E

$$\mathrm{Im}\,(Z_{\perp})_{eff} = \frac{8\,Q_s\,E}{\bar{\beta}_{\perp}\,I_b}\,\frac{2\pi\sigma_s}{C}$$

- Many thresholds have dependence on bunch length σ_s
- Will much damage occur when thresholds are exceeded for 10^3 turns?
- Where is feedback needed and useful?
- Where to find parameters needed for our calculations?

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Parameter Search for HEMC

- I like the following equation

$$\bar{L} = \frac{\tau_0}{e\mu_0} \frac{\dot{N}_\mu \xi \gamma B}{\beta_\perp} \frac{2\pi\rho}{c}$$

- Expresses average luminosity $\bar{L}$ over fill and decay cycle in terms of relevant physical parameters

- beam-beam tune shift ξ $\longrightarrow$ WG
- β-function at IP $\longrightarrow$ WG
- dipole field B
- energy γ
- muon storage rate $\dot{N}_\mu$

Approximations

- Round beams $\beta_x = \beta_y \quad \sigma_x = \sigma_y \quad \xi_x = \xi_y$
- Head-on collisions
- Repetition time $T_r \gg \gamma \tau_0$
  neglect $\exp(-2 T_r / \gamma \tau_0) \ll 1$
- Neglect "hourglass" effect

$$\beta_* \not< \sigma_s$$

Procedure

- Embedded in Mathematica notebook; could be done with other products
- Recycle much material from other circular machines
- Steps in procedure
  - Fix E, A bunch area, number of bunches $k=1$, $\bar{L}$, $T_r/\gamma\tau_\mu = 3$

Comment: Consider running HEMC with bunch trains of length $\leq$ beam delivery system, bunch spacing $>$ low-β insertion $\Rightarrow$ interesting extra constraint of well-separated parasitic collisions inside beam-delivery system.

  - Compute $\dot{N}_\mu$, N, ε_x, σ_x
- Can calculate ANY quantity in notebook for different input parameters within seconds.

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26/9/99

Questions to WG:

- Length of beam delivery system?
- Scaling of length with E and other parameters?
- How does a modern formula for minimum β agree with my old formula?

$$\beta_y \geq \frac{e Z_0}{8\pi^2} \frac{F_Q N \sigma}{B_Q Q' \xi} \left(\frac{2\hat{L}}{f k} \right)^{1/2}$$

quad fill factor

peak L

contribution of first quad to chromaticity, related to momentum bandwidth

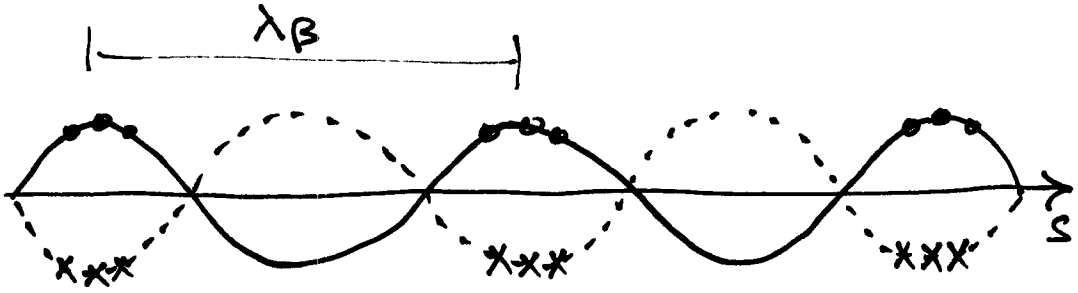
rev. frequency

bunches

- Derived for flat beams and doublets
- Interest in large k = number of bunches

Questions to WG (cont'd)

- Can injectors and beam delivery systems deliver and handle bi-periodic trains?



Calculation (cont'd)

- Inspect synchrotron radiation
  - Total power is MW
  - Power/m is ~100 W/m, not good for cryogenic system
  - Power density at impact is MW/m^2 or W/mm^3 higher than any number I find in my notebooks ~~except~~ except in Z_0-factory in SPS tunnel at $L = 10^{33}\ cm^{-2}s^{-1}$!

- Inspect RF system
  - Achieving $\sigma_s \ll \lambda_{RF}$

    implies $\sigma_\varepsilon \ll$ bucket height

    implies $\eta \ll 1/Q^2$

    implies arcs other than FODO

Conclusions

- Hopefully planted a few questions which the other working groups find interesting
- Started a menu for working group on collective effects
- Hope for contributions from many others
- Did not anticipate results of working group
- Hopefully have something substantial to say on Friday