Report Joint Groups 1 & 3

Round / Flat beams and Damping Dynamic

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Report by Chao, Talman, 9/20/00

Three questions:

1. Is synchrotron radiation helping or hurting?
2. Is high field better or low field?
3. Is round beam better or flat beam?

Question 1 ≅ Question 2 because high field ≅ more SR and low field ≅ less SR.

We have no (almost) definite answers to these questions, but we had 2 fun days discussing them.

Question 1 Is SR helping or hurting?

1.1 SR relaxes the demand on ε_{inj}. As long as the beam doesn't scrape, ε_{inj} will damp to ε_{eq}. SR obviously helps here.

[Remaining question: should we inject directly into $\varepsilon_{inj} = \varepsilon_{eq}$ and avoid the transients?]

S. Son
M. Harrison

1.2 SR relaxes the demand on emittance growth limit due to injection process. Magnet nonlinearities and injection errors tolerances can be relaxed accordingly.

[Remaining question: The above statement is not too convincing unless quantified.]

1.3 SR is a large heat load on cryosystem. The high field version gives 6 W/m. If absorbed at 80K, this means ~ ~~36~~ 15 MW wall plug power.

[Remaining question: e^- cloud is a tough problem. Must be avoided. Ask Group 2.]

R. Talman
B. Parker
P. Limon

1.4 ~~Remaining Question~~ If SR heat load is the only problem, ~~30~~ 15×2 MW limit seems soft. Beam energy can be increased! For example, if 20 ~~k~~W/m can be absorbed, what beam energy can be reached? In one effort by the working group — see Sec. 2.1 later — one way of optimization gives $E \simeq 50\ \text{TeV} \times \left(\frac{20}{6}\right) = 160\ \text{TeV}$!

Although 160 TeV maybe an exaggeration, the issue of the limiting E remains an ~~open~~ important question.

R. Talman

P. Limon

B. Parker

1.5 SR at $\gtrsim 100$ keV can be source of (a) radiactivation and (b) DC heat load to the magnet coils.

Beam-gas collisions have similar effects.

These effects need to be evaluated. SR >100 keV may be small effect but beam-gas maybe not.

P. Limon

1.6 SR allows the possibility of manipulating ε_x, ε_y to optimize $\mathcal{L}$. This is potentially very important advantage of SR. It needs to be fully explored.

Three examples:

Ex. 1 Adding combined-function wigglers in arcs

J. Murphy

$\Rightarrow$ can control the partition numbers J_x, J_ε.

$\Rightarrow$ maybe one can approach

$J_x \approx 3 \Rightarrow$ smaller ε_{x0} and therefore higher $\mathcal{L}$

$J_\varepsilon \approx 0 \Rightarrow$ no need of longitudinal heating to fight IBS

Ex 2. Controlling J_x, J_ε by f_{RF}

T. Sen

f_{RF} is an additional knob.

Estimate of the needed $\frac{\Delta f_{RF}}{f_{RF}} \approx 5 \times 10^{-7}$

and the corresponding $\langle \Delta x \rangle \approx 7$ mm $\leftarrow$ maybe a bit too large for comfort

Ex. 3 Adding wigglers in non-dispersive region

J. Murphy
R. Talman

$\Rightarrow$ increases radiation damping, i.e. shorter τ_d, while no/little quantum excitation

a low-field VLHC can do SR too!

R Talman says doesn't work.

1.7 Does shorter τ_d allow a higher head-on beam-beam limit ξ_{max} ?

~~Ex~~trapolating from (PETRA, CESR,) LEP, Tevatron, LHC (design), we find two possible answers.

S. Peggs
T. Sen

<u>Answer 1</u> SR doesn't help ξ_{max} for VLHC.

$$\xi_{max} \text{ (for 1) IP} = \begin{cases} 0.009 & \text{high field} \\ 0.009 & \text{low field} \end{cases}$$

to be compared with design $= \begin{cases} 0.004 & \text{high field} \\ & \text{low field} \end{cases}$

<u>Answer 2</u> SR does help ξ_{max} for VLHC

$$\xi_{max}/IP = \begin{cases} 0.009 & \text{high field} \\ & \text{low field} \end{cases}$$

The range of answer comes from uncertainty of extrapolation. SR either doesn't help ξ_{max} or it helps a little bit. This issue remains to be resolved.

Question 2. Is high field better or low field?

2.1 Overall, SR seems to hurt more than help.

For high field design,

Total SR power $P_{SR} = \frac{U_0}{T_0} \cdot N$

$$N \approx \mathcal{L} \cdot \sigma_{tot} \cdot \tau_{store}$$

S. Peggs

J. Johnson

R. Talman

$$\tau_{store} \approx \text{multiple } n_1 \text{ of } \tau_d$$

$$\approx \text{multiple } n_2 \text{ of } \tau_{fill}$$

$$\tau_d = \frac{T_0 E}{U_0}$$

$\Rightarrow$

$$P_{SR} \approx \mathcal{L} \sigma_{tot} n_1 E \propto E$$

Surprisingly simple scaling.

Lower E is better for P_{SR}.

Optimum occurs when E is such that $\tau_d \approx \tau_{fill}$

This imposes an optimization on τ_{fill}.

Question 3. Is round beam better or flat beam?

3.1

$$\mathcal{L} = \frac{N_B^2 f_c}{4\pi \sigma_x^{*2} \kappa}$$

$$\kappa = \frac{\beta_y^*}{\beta_x^*} = \frac{\varepsilon_y}{\varepsilon_x}$$

When N_B is limited (e.g. by SR heat load), the smaller κ, the better for $\mathcal{L}$.
Flat beam is better!

3.2 What happens if κ is "too small"?
There is a limit on how small κ is desirable.
When κ is too small,

- IBS $\propto \frac{1}{\kappa}$. $\kappa = 0.1 \Rightarrow \tau_{IBS} = 30\,hr$; $\kappa = 10^{-3} \Rightarrow \tau_{IBS} = 3\,hrs$

J. Wei — However, one can control IBS by heating the longitudinal phase space

- When σ_y^* is too small, one loses flexibility in choosing x- or y- crossings at IP

T. Sen

S. Peggs

- Long range beam-beam $\Delta\nu_y \propto \frac{1}{\kappa}$. This is potentially the strongest lower limit on κ.
[This needs more quantitative evaluation.]

S. Peggs

3.3 IR optics, two options:

S. Peggs

- triplet, round beam, $\kappa \approx 1$
- doublet, flat beam, $\kappa \ll 1$

No clear advantage of triplet option. unless inject round beam?

B Parker

3.4 It's crucial to fight for small κ. for high field

$$\Rightarrow \begin{cases} \text{higher } \mathcal{L} \\ \text{and/or lower } P_{SR} \text{ for given } \mathcal{L} \end{cases}$$

The ~~re~~-realization of the importance of small κ is one high light of this workshop.

One should design the lattice with κ in mind

3.5 How small can κ be?

κ is determined by $\frac{d\varepsilon_y}{dt} = -\frac{\varepsilon_y}{\tau_d} + \frac{\varepsilon_{y0}}{\tau_d} + \dot{\varepsilon}_{y\,noise}$

where $\dot{\varepsilon}_{y\,noise}$ comes from

S. Peggs

- e^- cloud
- IBS
- x-y linear and nonlinear coupling
- beam-beam nonlinearities
- noise, power supply ripple, tune jitter, ground motion, feedback noise, ...

Needs to study $\dot{\varepsilon}_{y\,noise}$ theory and expt. Design expts. at RHIC (for IBS) and Tevatron (for other noise effects)!

3.6 It's likely that $\frac{\varepsilon_{y0}}{\tau_d}$ is small $\ll \dot{\varepsilon}_{y\,noise}$.

Talman
S. Peggs
T. Sen

This means designing the lattice to minimize $\varepsilon_{equilibrium}$ is a wrong thing to emphasize.

Should design the lattice to minimize $\dot{\varepsilon}_{y\,noise}$

This might be the determining consideration for choosing L_{cell}.

3.7 IBS calculation needs to be done for flat beams!

J. Wei

For flat beams, IBS gives a steady-state (growing emittances) with

$$\kappa_\infty = \frac{1}{8}\left(\frac{\gamma_{transition}}{\gamma}\right)^2 \sim 10^{-6}$$

However, IBS is not a big effect, especially when longitudinal heating is applied.