Reflections on the bend-based CeC designs

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My consideration of the CSR [3, 4] actuality in physics of CeC designed as a multi-cell microwave amplifier (MWA) with use of electron bends (following a long inertial section) is based on an argument that, effective region (length) of collective Coulomb interaction in relativistic beams in longitudinal direction is about $\frac{\sigma_\perp}{\gamma}$, while MWI of CSR is actual for distances larger than R/γ^3, where $\sigma_\perp$is beam transverse size , R is bend radii and $\gamma \gg 1$ is Lorentz factor. Thus, In terms of the Furrier space harmonics (wave vectors k) effective area of Coulomb amplification is limited as follows:

$$\frac{\gamma^3}{R} < k \leq \frac{\gamma}{\sigma_\perp}.$$

From here one concludes that Coulomb interaction dominates in the collective dynamics only at sufficiently large bend radii, namely at:

$$R \gg \gamma^2\,\sigma_\perp\,;$$

otherwise, CeC MW dynamics i.e. amplification is driven by the CSR. Other aspect of CSR impacts is, of course, the related radiation noise which affects the electron beam itself.

For example, assume the following set of an MBEC design parameters:

$R = 2.7M;\quad \sigma_\perp \sim 0.3mm;\quad \gamma \approx 300 \longrightarrow \quad \gamma^2\,\sigma_\perp \approx 27\,M$.

Thus, in this area of parameters we have

- $R \ll \gamma^2\,\sigma_\perp$.

This inequality indicates with certainty that, in the shown set of parameters CSR dominates over the Coulomb interaction in the e-beam when passing through the chicanes.

- Strong bends are introduced in the proposed design with a purpose to facilitate maximally the electron longitudinal mobility $\frac{dv_z}{cd\gamma}$ in the chicane sections :

$$(l_C^{-1})_0 \sim \frac{k}{\gamma}\left|\frac{J}{J_A}\frac{dv_z}{cd\gamma}\right|^{\frac{1}{2}}$$

Here l_C is Coulomb "increment length", J is peak current, $J_A = 17\;KA$, and v_z is electron transport velocity as function of energy.

- **However,** ***strong CSR*** **exceeding in strength the Coulomb interaction inside the beam area arrives here [4]** ($(l^{-1})_{CSR}$ is inverse increment length of the CSR MWI [4]):

$$(l^{-1})_{CSR} \sim (l_C^{-1})_0 (\frac{\gamma^3}{kR})^{\frac{1}{3}} \; ; \quad k < \frac{\gamma^3}{R}.$$

- **Concerning the Landau damping due to energy spread, and smearing due to emittance**

Also very unfortunately, large increase of orbit curvature, dispersion at large beam size due to emittance (weak focusing) in chicanes leads to huge powering of two more unwanted dragons:

- **Super-fast** ***Landau damping*** **against MWI, - due to the existing energy spread:**

$$(l^{-1})_{LD} = k(\gamma \frac{dv_z}{cd\gamma}) \frac{\Delta\gamma}{\gamma}$$

- **Fast smearing of the MWI increment by the transverse horizontal emittance:**

$$(l^{-1})_{sm} \sim k \frac{\sigma_\varepsilon}{R} \sim \frac{\gamma}{R} \quad (!)$$

A few of the history

- ***Negative longitudinal mass (NMI) MWI*** was proposed in [2] and even earlier in first note of 1980 about the CeC idea. Obviously, its realization takes strong enough bends that normally delivers negative longitudinal mass. In my view, a multi-chicane CeC amplifier of D. Ratner is a full equivalent of the NMI idea.

References

[1] D. Ratner. Phys . Rev. Lett. 111 084802 (2013)

[2] Ya. S. Derbenev, UM HE 91-28 (1991) http://inspirehep.net/record/318036;

Also in: AIP Conf. Proc. 253, 103 (1992)

[3] Y.S. Derbenev et al. DESY Sept.19, 1995.

[4] G. Stupakov and S. Heifets. PRSTAB v.5 054402 (2002)

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1. A comment concerning a shortness of a bend

One has to compare length l_b of a bend with length l_k of forming CSR at wave length $2\pi/k$:

$$l_k \sim R\theta_k \sim R(\frac{1}{kR})^{\frac{1}{3}};$$

CSR is actual at $l_b > l_k$. Taking $k \sim \gamma / \sigma_\perp$, we obtain:

$$l_k \sim R(\frac{\sigma_\perp}{\gamma R})^{1/3}$$

For the above shown parameters we obtain: $l_k \sim 2cm$;

for $R = 1M$ we obtain $l_k \sim 1cm$.

{I guess, in both design there is $l_b > l_k$ - a condition for forming the CSR}.

Finally, at $l_b < l_k$, we meet either the undulator (FEL) or transition radiation, instead of the CSR.

Conclusion: ***Coulomb'amplifier requires*:** $R \gg \gamma^2 \sigma_\perp$

2. Comment about: *Beam in a wiggler*

Condition to cut CSR by wiggling: $\frac{1}{k_w} < R(\frac{1}{kR})^{\frac{1}{3}} \sim R(\frac{\sigma_\perp}{\gamma R})^{\frac{1}{3}}$; $here\ k_w \equiv \frac{2\pi}{\lambda_w}$

Then we get FEL process. For Coulomb interaction to dominate, the FEL radiation wave length should be longer than the Coulomb length $\frac{\sigma_\perp}{\gamma}$:

$$\frac{1}{\gamma^2 k_w} > \frac{\sigma_\perp}{\gamma}$$

Comparing two conditions results in: $R \gg \gamma^2 \sigma_\perp$.

- **Conclusion:**

Condition for Coulomb'amplifier in wiggler : $R \gg \gamma^2 \sigma_\perp$.