Coupled bunch instability growth rates for a general bunch fill pattern

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Outline

- Code *clinchor* from ANL.
- Normal mode analysis coded in *clinchor.*
- Comparison to ZAP:

  Transverse dipole CBM due to

  RF Cavities' HOMs for *e*-ring at 10 GeV.

ANL's *clinchor* :

*Calculation of **L**ongitudinal and transverse coupled bunch **IN**stability due to **C**avity **H**igher **O**rder mode **R**esonators*

- Calculates growth times τ_g of longitudinal and transverse Coupled Bunch Instabilities (CBI) in storage rings.
- Combines features found separately in e.g: *ZAP, BBI, PC-BBI.*

- Stability condition: **Growth time > Damping time ($\tau_g > \tau_d$)**

  Damping by e.g. Synchrotron radiation, ion cooling…

Beam Distribution

- *ZAP, BBI* : Symmetric bunch distribution:

$$\begin{cases} \dfrac{1}{\tau_g^{||}} = \dfrac{\alpha_c I_{total}}{4\pi \left({E_b}/{e} \right) \nu_s} \displaystyle\sum_p \omega_p Re[Z_z(\omega_p)] \\ \dfrac{1}{\tau_g^{\perp}} = \dfrac{\omega_0 I_{total}}{4\pi \left({E_b}/{e} \right)} \beta_{\perp} \displaystyle\sum_p Re[Z_t(\omega_p)] \end{cases}$$

- *clinchor*: Symmetric bunch pattern, bunch train , general pattern
  - Based on a <u>normal mode analysis of irregularly spaced bunches.</u>
  - Accepts bunches with different charge.

- Bunch form factor can be defined explicitly, gaussian otherwise.

Normal Mode Analysis of Irregularly Spaced Bunches

- Based on:

K. Thompson and R. Ruth, ``Transverse and Longitudinal Coupled Bunch Instabilities in Trains of Closely Spaced Bunches,'' in *Proceedings of the 1989 IEEE Particle Accelerator Conference*, p. 792, 1989.

- Motion of the bunch centroids only:

Coherent dipole modes of CB oscillations expected to be dominant.

- Single particle moving in a focusing lattice, x(s) is the transverse displacement from ideal orbit:

$$x''(s) + K(s)x(s) = 0$$

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- Eq. of motion for bunch *i:*

$$\ddot{x}_i(t) + \overbrace{2\zeta\dot{x}_i(t)}^{\text{Damping term}} + c^2K\big(\bar{s}_i(t)\big)x_i(t)$$

$$= \frac{Ne^2c^2}{E_0}\sum_{j=1}^{n}\sum_{q=0}^{\infty} W_t[\underbrace{L_{ij} + qT_0c}_{\substack{\text{Z, separation btw. exciting}\\ \text{and test bunch}}}, \underbrace{\bar{s}_i(t)}_{\text{Disturbance location}}]\ \overbrace{x_j(t - {}^{L_{ij}}/_{c} - qT_0)}^{\substack{\text{Interaction btw bunches is proportional to}\\ \text{particle (centroid) offset}}}$$

- W_t gives the interaction between bunches
    - Resistive wall
    - Resonant element, HOMs
    - …

- Normal mode solutions of the form

$$x_i(t) = a_i e^{-i\Omega t}$$

  a_i are constants and Ω is the coherent frequency of the mode.
- Eigenvalues of the characteristic equation.
- The imaginary part of Ω gives the growth rate of the coherent bunch mode

476 MHz PEP-II Cavities for JLEIC e-ring @10 GeV

- Input values in *clinchor* and ZAP

Parameter	Value	Unit
Energy	10	GeV
Circumference	2181.89	m
Betax/betay	11.954/13.145	m
h	3464	
Mom. Compaction factor	1.09e-3	
RF freq	476	MHz
Emittance x/y	22/4.4	$\times 10^{-9}\pi$-m
Bunches	866	
Current p/bunch	0.81	mA
RMS bunch length	1.4	cm
RMS mom. spread	9.28e-4	

Parameter	ZAP	clinchor
Beam pipe radius	3 cm	-
Broadband Impedance	2 Ohm	-
Wall material	Copper	-
Tune hor/ver.	52.7475 / 52.7685	

Impedance for PEP-II RF Cavities

Longitudinal modes

f [MHz]	Rs [Ohm]	Q
475	3.81e06	32469
758	810	18
1009	55	128
1283	1740	259
1295	2290	222
1595	730	300
1710	140	320
1820	70	543
1898	440	2588
2121	620	338
2160	6	119
2265	130	1975

Transverse modes

f [MHz]	Rs [Kohm/m]	Q
792	42.0	115
1063	38.0	27
1133	1.82	54
1202	12.2	871
1327	76.7	611
1420	126.9	1138
1542	0.89	92
1595	1.39	145
1676	64.5	783
1749	2.31	1317

"PEP-II RF cavity revisited", R. Rimmer et. al, (1999)   (Courtesy to Shaoheng Wang)

ZAP vs clinchor result comparison

- ZAP growth times calculated by R. Li
- deQ factor =1 is assumed

Growth time for transverse CBI in the JLEIC e-ring design (HOM from RF cavities)		
E [GeV]	10	
code	ZAP	Clinchor (x/y)
t_a=0 [ms]	64	156/142
t_a=1 [ms]	58	N.C.
t_damp [ms]	10.1	

- Broadband impedance and wall material difference?

Comments

- ANL's *clinchor* calculates CBI growth times of bunch centroid modes due to RF cavity HOMs .
- Takes a general bunch fill pattern:
    - Irregularly spaced bunches.
    - Different charge per bunches.

- <u>Crab Cavity Impedance estimation using a realistic bunch fill pattern.</u>