Summary of the Collective Effects/RF/Feedback Working Group

23rd Advanced ICFA Beam Dynamics Workshop on High Luminosity e+e- Colliders

V. Shiltsev and J. Rogers
Beam-beam interaction - observations

- M. Palmer (CESR)
- J. Seeman (PEP-II)
- Y. Funakoshi (KEKB)
- A. Valishev (VEPP-2M)
- R. Talman (Round beams/Möbius in CESR)
- J. Seeman, T. Sen (HERA-e high ξ result)
- E. Simonov (VEPP-4)

Beam-beam interaction - theory

- R. Talman
- B. Schmekel
- J. Rogers
- J. Seeman
- T. Sen
- V. Shiltsev
Beam-beam interaction- simulations
• Y. Cai
• J. Rogers
• A. Valishev

Beam-beam interaction- instrumentation
• V. Shiltsev
Other collective effects - observations

- T. Ieiri, J. Flanagan (KEKB)
- A. Temnykh (CESR)
- M. Boscolo (DAΦNE)
- J. Seeman (PEP-II)

Other collective effects - theory and simulations

- S. Heifets - ECI/CSR
- J. Flanagan - electron cloud simulation
What are the problems and operational difficulties common to several machines?

- Beam-beam effects (all machines)
- Electron cloud $\rightarrow$ “2.5 ± 0.5 stream instability” (B-factories only)
- Geometrical impedance (B-factories)
Luminosity instability: observation

Unstable fill

Good fill
Bunch-to-Bunch Differential Orbits

BBI Luminosity Monitor
- Shake a particular bunch (or bunches) at a fixed frequency
- Measure the BBI induced amplitude in the opposing bunch
- Provides much faster response than CLEO luminosity measurement

Adjust differential offset between e⁻ and e⁺ bunches at IP (VCROSING 7 Knob)
- Vary betatron phase advance in the vertical separator bump at the 2nd IP
- Optimize collisions for each car

Observations
- Car-to-car orbit differences at the 0.5σ level (σᵥ ≈ 4µm)
- Strong dependence on beam current
- Consistent with machine operators having to actively tune VCROSING 7 through the course of a run

Increasing time ⇔ decreasing current
## DAΦNE COUPLING IMPEDANCE

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Estimated</th>
<th>Measured</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z/n, \Omega$</td>
<td>2</td>
<td>0.6</td>
<td>$&lt; 0.6 \text{ e+}$</td>
<td>Additional 40 clearing electrodes in the e- ring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.9</td>
<td>$&lt; 0.9 \text{ e-}$</td>
<td></td>
</tr>
<tr>
<td>$Z_T, \text{k}\Omega/\text{m}$</td>
<td>Below TMCI</td>
<td>$\sim 90$</td>
<td></td>
<td>Betatron tune shift is a small fraction of synchrotron tune</td>
</tr>
<tr>
<td>$k_l, \text{V/pC}$</td>
<td></td>
<td>0.52</td>
<td></td>
<td>For the bunch length of 3 cm</td>
</tr>
<tr>
<td>$Z_{\text{HOM}}, \text{k}\Omega$</td>
<td>$&lt; 10$</td>
<td>$\sim 2$</td>
<td></td>
<td>From grow-damp feedback measurements</td>
</tr>
<tr>
<td>$Z_{T\text{HOM}}, \text{k}\Omega/\text{m}$</td>
<td>$\sim 1000$</td>
<td></td>
<td></td>
<td>HOM in the injection kicker. The instability is damped by the vertical feedback and due to beam-beam collisions.</td>
</tr>
</tbody>
</table>
Synchrobetatron beam-beam mode tunes vs. $\xi$.
Comparison of measured (circles) and calculated (lines) data.
### Impedance Measurements in KEKB (from T. Ieiri)

<table>
<thead>
<tr>
<th>parameter</th>
<th>HER</th>
<th>LER</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>Z/n</td>
<td>$ (measured)</td>
<td>0.076 Ω</td>
</tr>
<tr>
<td>$</td>
<td>Z/n</td>
<td>$ (design)</td>
<td>0.015 Ω</td>
</tr>
<tr>
<td>$Δv_x$ (measured)</td>
<td>-0.001/mA</td>
<td>-0.001 – 0.0015/mA</td>
<td></td>
</tr>
<tr>
<td>$Δv_y$ (measured)</td>
<td>-0.004/mA</td>
<td>-0.0014/mA</td>
<td>mask open</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-0.0034/mA</td>
</tr>
<tr>
<td>$Δv_y$ (design)</td>
<td></td>
<td></td>
<td>-0.0004/mA</td>
</tr>
<tr>
<td>$k$ (measured)</td>
<td>20 – 30 V/pC</td>
<td>20 – 30 V/pC</td>
<td>at $σ_i = 6 – 7$ mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>design $σ_z ≤ 4$ mm</td>
</tr>
</tbody>
</table>
Tune Shift in HER (Multi-bunch)

\[ \xi_x = 0.97 \quad \xi_y = 5.41 \]

**Horizontal**

- \[ y = 0.51704 + 2.5536e-05x \quad R = 0.98595 \]
- \[ y = 0.51761 + 2.6048e-05x \quad R = 0.99902 \]
- \[ y = 0.51676 + 2.8131e-05x \quad R = 0.99738 \]

**Vertical**

- \[ y = 0.60975 - 3.747e-05x \quad R = 0.99887 \]
- \[ y = 0.60911 - 3.6677e-05x \quad R = 0.99928 \]
- \[ y = 0.60966 - 3.8086e-05x \quad R = 0.99869 \]

-> Tune shift depends on the beam current.

-> Focusing in horizontal and defocusing in vertical.

-> A quadrupole field is induced by the beam.

ON MULTI-BUNCH TUNE SHIFT
in KEK-B HER
(similar effect observed in PEP-II - J. Seeman)

DEUTUNG WAKE IN NON-ROUND VACUUM CHAMBERS

\[ F_{x,y} = W \cdot (x_h, y_h) + 0 \cdot (x_t, y_t) \]

in round geometry
force on tail particle

in slat pipe

\[ F_{x,y} = W \cdot (x_h, y_h) + \left( -D \cdot X_{\text{tail}} + D \cdot Y_{\text{tail}} \right) \]

and \( D = W \)

\[ \rightarrow \text{for multi-bunch operation DEUTUNG force dominates} \]
\[ \rightarrow \text{HOR. TUNE SHIFT IS POSITIVE} \]
\[ \rightarrow \text{VERT. TUNE SHIFT IS NEGATIVE} \]
How much further can parameters be pushed to improve machine performance?

- Current $I$ needs proper understanding of e-cloud
- $\beta^*_y$ requires shorter $\sigma_z$ for minimizing geometrical impedance + CSR
- Beam-beam parameter $\xi_y$

$$L = 2.2 \times 10^{29} \gamma \text{cm}^{-2} \text{s}^{-1} \frac{\xi_y}{\beta_y} \frac{1+R}{2}$$

- Beam aspect ratio $R$

Dependence of on damping decrement:

- Chao (1980s)
  $$\tilde{\beta}_{y}^{\max} = \frac{1}{4\alpha_0} \sqrt{\frac{\tilde{\beta}_{y}}{\Lambda}}$$  damping decrement
  $$\lambda < 0.03 = \text{function of tune, distr., etc}$$

- Gao (1998)
  $$\tilde{\beta}_{y}^{\max} = \frac{H_0}{2\tilde{\beta}_{y}}$$  
  $H_0 = \frac{1}{6} \times 10^6$  
  ???

- Assman (2000)
  $$\tilde{\beta}_{y}^{\max} = \frac{4}{2\pi} \frac{\sqrt{\tilde{\beta}_{y}}}{2\tilde{\beta}_{y}}$$  
  $I$ is unknown randomness parameter

- Talman
  bad tunes
  $$\tilde{\beta}_{y}^{\max} \sim \frac{1}{T_0 R}$$
  good tunes (2nd order)
  $$\tilde{\beta}_{y}^{\max} \sim \left(\frac{S}{B_0}\right)^{1/2}$$
  great tunes
  $$\tilde{\beta}_{y}^{\max} \sim \left(\frac{5}{B_0}\right)^{1/3}$$
Coherent Synchrotron Radiation Effects:
* overtaking "tail-head" interaction

\[ \text{Overlapping length } \sim \frac{3}{10} \frac{\sqrt{\sigma_z R^2}}{R} \]

Longitudinal Force

\[ \Delta E_{\text{long}} \]

Transverse Force

\[ E_1(s) \sim \frac{\sigma(s)}{R} \]

\[ \downarrow \]

1. Emittance growth
2. Microbunching

* If bunches are short & intense

S. Heyfets: CRS will be a problem @ \(10^{36}\)
* \(\mu\)-bunching
* No CSR screening
  \[ \text{if } \sigma_z < 4 \text{ mm} \]
ECI: Electron Cloud Instability

STEP VARIABLE = TIME  STEPS = 512  DELAY = 5.000

31-DEC-00 08:51:12

STEP VARIABLE = TIME  STEPS = 512  DELAY = 5.000
LER beam size measured by using a SR interferometer

Solenoid OFF

Solenoid 2.5A

Solenoid 4.8A
Beam blow-up is a single-bunch effect

but e-cloud density builds up along bunch train

**Effect of chromaticity**

Vertical beam size (arbitrary unit)

Bunch
Tune Shift in LER

**Solenoids all on**

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<td>2/32//4 + one</td>
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**Solenoids all off**

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-> The tune depends on where a bunch is placed, which is affected by the electron cloud.

measured in April 2001

Observation (summary)

- Probe bunch tune shift versus bunch spacing
  (normalized to 10mA of leading bunch current)

  - Vertical tune shift
    \[ \Delta Q_e^y = 2.5 \cdot 10^{-3}, \Delta Q_e^- = -\Delta Q_e^+ \]

  - Horizontal tune shift
    \[ \Delta Q_e^x = 0.5 \cdot 10^{-3} = \frac{1}{5} \Delta Q_e^y \]
KEK LER:
Sol ON
Sol OFF

$\Delta Q_v = 0.006$

$\Delta Q_h = 0.0045$

CESR: Hor/vert asymmetry

$\Delta Q_v = (5-10) \Delta Q_h$

Explanation for KEK LER:

- e-cloud in dipole
- Hor size > vert

Explanation for CESR

$* \text{ or } \beta_v = 5 \beta_h$

and
THAT CONTRADICTS

e-cloud simulations
code results ($L, \xi, \sigma_{x,y}$) are in excellent agreement with PEP-11 observations.

* code is fast
Benchmarking the code with CESR at 5.3 GeV: Tune scan of luminosity using ODYSSEUS simulation:

Simulation conditions: perfectly linear lattice, no vertical radiation excitation. Beam allowed to find its own equilibrium vertical size due to the beam-beam effect. **Predicted luminosity is** $1.02 \times$ best observed CESR luminosity. 

*J. Rogers et al., Factories 2001*
Tevatron Electron Lens

- Operates in Tevatron, produces $\sigma Q \approx 0.01$ in 980 GeV p's

* e-lens for electron machines looks much simpler (less current, shorter, etc.)

* Flat e-beam is possible
\[ I_{\text{per beam}} = 21 \text{ mA} \]
\[ \overline{\Delta Q_{\pi}} = 0.098 \]

\[ \Delta Q = 0.103 \]
\[ \Delta Q = 0.092 \]

*Novosibirsk: VEPP-2000 round beams with proper optimized sextupole distribution → prospects for high \( Z \)*
What are the critical steps in improving machine performance?

- **Beam-beam interaction**
  Work at beam-beam models until they are really predictive. Round beam option: explore limiting $\xi$ (VEPP-2000, CESR-c, ...).

- **Two- (or three-) stream instabilities**
  Simulations and models need to predict effect with much better precision. Need to make sure all important physics (ions? bunch length effects?) is included. Vigorous experimental programs help!

- **Geometrical impedance**
  3-D modeling of all (possibly long or complicated and non-axisymmetric) structures (IR chambers, collimators, ...) is necessary to avoid surprises in impedance or loss factor. Investigate coherent synchrotron radiation effects.

- **Feedback for BBI**
  Long range BBI creates need for bunch-by-bunch correction of collision offset, tunes, (beam sizes...?). Hardware development: fast kickers, RFQs, electron lens,...?