Round Colliding Beams at VEPP-2000 with Extreme Tuneshifts

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**VEPP-2000 overview**

### Design parameters @ 1 GeV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>24.388 m</td>
</tr>
<tr>
<td>Beam energy</td>
<td>150 ÷ 1000 MeV</td>
</tr>
<tr>
<td>N of bunches</td>
<td>1×1</td>
</tr>
<tr>
<td>N of particles</td>
<td>1×10¹¹</td>
</tr>
<tr>
<td>Betatron tunes</td>
<td>4.14 / 2.14</td>
</tr>
<tr>
<td>Beta*</td>
<td>8.5 cm</td>
</tr>
<tr>
<td>BB parameter</td>
<td>0.1</td>
</tr>
<tr>
<td>Luminosity</td>
<td>1×10³² cm⁻²s⁻¹</td>
</tr>
</tbody>
</table>

- Round beams concept
- 13 T solenoids for FF
- 2.4 NC dipoles @ 1 GeV
- CBS for energy control

Operating with IC#VEPP-5 since 2016
The concept of Round Colliding Beams

Axial symmetry of counter beam force + X-Y symmetry of transfer matrix IP2IP

Additional integral of motion (angular momentum $M_z = x'y - xy'$)
Particle dynamics remains nonlinear, but becomes 1D

Lattice requirements:

- Head-on collisions!
- Small and equal $\beta$-functions at IP: $\beta_x = \beta_y$
- Equal beam emittances: $\varepsilon_x = \varepsilon_y$
- Equal fractional parts of betatron tunes: $\nu_x = \nu_y$

Round beam
$M_x = M_y$

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L.M. Barkov, et. al, Proc. HEACC’89, Tsukuba, Japan, p.1385.
V.V. Danilov et al., EPAC’96, Barcelona, p.1149.
Round beam due to coupling resonance? The simplest practical solution!

Both simulations and experimental tests showed insufficient dynamic aperture for regular work in circular modes options.

Below 600 MeV “short” FF solenoids are available.

Flat to Round/Mobius or Long to Short change needs polarity switch in solenoids, realignment and new orbit correction.
Machine tuning

1) Orbit correction & minimization of steerers currents using ORM techniques
2) Lattice correction via ORM SVD analysis ($\delta\beta < 5\%$)
3) Betatron coupling correction in arcs ($\delta\nu_{\text{min}} \sim 0.001$)
4) Working point fine tuning & small shift below coupling diagonal
5) Sextupoles fine tuning (chromaticity slightly undercompensated)

Specific luminosity & linear lattice correction

After correction

Before correction

Lifetrac by D. Shatilov, 2008
"Flip-flop" effect

E = 240 MeV, $I_{\text{beam}} \sim 5 \times 5$ mA

Pickup spectrum of the coherent oscillations

Coherent beam-beam $\pi$-mode interaction with machine nonlinear resonances?
Bunch lengthening & microwave inst

Single bunch length measurement with phi-dissector as a function of single beam current for different RF voltage @ 478 MeV.

Energy spread dependence, restored from beam transverse profile measurements.
Flip-flop suppression with long bunch

$U_{RF} = 35 \text{ kV}$

$I = 15 \text{ mA}$ corresponds to $\xi_{nom} \sim 0.1$

$E = 392.5 \text{ MeV}$

$U_{RF} = 17 \text{ kV}$
**BeamShaker**

Idea (Ivan Koop): kicked bunch oscillations decoheres very fast in the presence of counter beam’s strongly nonlinear field. Weak and fast kicks should effectively increase the emittance similarly to quantum excitation by wiggler.

At low energies emittance growth is available up to aperture restriction. That allow with the same beam-beam parameter (particles density) increase the beam current and luminosity.

Typical values:  
50-100 V, 300 ns, 50 µs  
\( T_{\text{rev}} = 81.4 \, \text{ns} \)

Experimentally: permanent excitation of “strong” beam size prevent it from shrinkage to natural value during injection cycle of “weak” beam, or whatsoever. Very effective suppression of flip-flop meta-stable states. In addition large emittance results in a lifetime enhancement.
Periodically excited oscillations gives the line spectrum.

@ 274 MeV:
\[ \sigma_x = 250 \, \mu m \] @ pickup
\[ \tau_{damp} = 130 \, \text{ms} = 1.6 \times 10^6 \, \text{turns} \]
Luminosity and beam-beam parameter

\[ \xi_{\text{nom}} = \frac{N^+ r_e \beta_{\text{nom}}^*}{4\pi \sigma_{\text{nom}}^*} \]  - normalized beam current

\[ \xi_{\text{lumi}} = \frac{N^+ r_e \beta_{\text{lumi}}^*}{4\pi \sigma_{\text{lumi}}^*} \]  - “beam-beam parameter”

\[ L = \frac{N^+ N^-}{4\pi \sigma^2} f_0 = \frac{N f_0 \gamma}{r_e} \frac{\xi_{\text{lumi}}}{\beta_{\text{nom}}^*} \]
Coherent beam-beam spectrum

\[ \Delta \nu = \arccos(\cos(\pi \nu_0) - \frac{-2 \pi \xi \sin(\pi \nu_0)}{\pi - \nu_0}) \]

\[ \nu_\sigma = 0.135, \quad \nu_\pi = 0.345 \]

\[ \Delta \nu = 0.21 \quad \rightarrow \quad \xi = 0.17/\text{IP} \]

Here the Yokoya factor \( Y = 1 \), due to fast kick method of eigen modes excitation and due to short period analysis (studied @ VEPP-2M; simulated for VEPP-2000 by D. Shatilov)
Data collection

CMD-3 luminosity, averaged over 10% of best runs

Below 500 MeV
Above 500 MeV

2017-2018 data

Highest luminosity achieved
$L_{\text{peak}} = 5 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
@ 550 MeV
Total luminosity integral

Lowest energy ever obtained in $e^+e^-$ colliders
Streak-camera observations

Streak-camera always observing electron bunch.
Beamshaker switched off.
Both currents above beam-beam threshold.
E = 392.5 MeV

1. Circulating e\(^-\), injecting e\(^+\). Turn #40.

2. Circulating e\(^-\), injecting e\(^+\). Turn #80.

3. Injecting e\(^-\), circulating e\(^+\), Turn #40.

Note: \( \nu_s = 0.002 >> T_s = 500 \) turns
Summary

- Round beams give a serious luminosity benefit.

- VEPP-2000 with new BINP injector and upgraded booster started data taking in all energy range of 200–1000 MeV with a luminosity increased in a factor of 2-5.

- Novel technique (“beamshaking”) for effective emittance control allow to suppress flip-flop effect and increase beams intensity at middle energies.

- Strong discrepancy between coherent and incoherent $\xi$ is observed: problem to be solved.

- First studies with streak-camera have shown fast longitudinal bunch tilts.

- Upcoming new run will be devoted to energy range above 500 MeV with intent to achieve the target luminosity.

Thank you!