On-axis Beam Accumulation Enabled by Phase Adjustment of a Double-frequency RF System for HEPS

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Topics

- Introduction to HEPS
- Different Injection schemes
- New scheme
- Comparison between different schemes
- Conclusion
High Energy Photon Source (HEPS)

Related studies on HEPS physics design, will be presented in WEPOW025, WEPOW026, HPMB019, THPMB017, THPMB018 in this conference.

Main parameters for HEPS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>circumference $C$ (m)</td>
<td>1295.616</td>
</tr>
<tr>
<td>beam energy $E_b$ (GeV)</td>
<td>6</td>
</tr>
<tr>
<td>beam current $I_0$ (mA)</td>
<td>200</td>
</tr>
<tr>
<td>natural emittance $\epsilon_0$ (pm)</td>
<td>59.4</td>
</tr>
<tr>
<td>betatron tunes $v_x/v_y$</td>
<td>116.155/41.172</td>
</tr>
<tr>
<td>momentum compaction $\alpha_c$</td>
<td>$3.74 \times 10^{-5}$</td>
</tr>
<tr>
<td>rms energy spread $\sigma_\varepsilon$</td>
<td>$7.97 \times 10^{-4}$</td>
</tr>
<tr>
<td>harmonic number $h_f/h_h$</td>
<td>720/2160</td>
</tr>
<tr>
<td>SR energy loss $U_0$ (MeV/turn) $^2$</td>
<td>1.995</td>
</tr>
<tr>
<td>damping times (ms) $\tau_x/\tau_y/\tau_s$</td>
<td>18.97/25.99/15.95</td>
</tr>
</tbody>
</table>

Optics function for one cell
HEPS lattice DA & MA
Different Injection schemes light source

• Transverse
  Orbit bump: need about 10~15mm DA, accumulation
  Nonlinear magnets: need 5mm DA at least, accumulation
  M. Borland, Swap-out: on-axis injection, 2~3mm DA, not accumulation

• Longitudinal
  Aiba(PSI), "Golf club", transverse kick, longitudinal accumulation
  Bocheng Jiang, double RF(250:500MHz), transverse kick, longitudinal accumulation
Our scheme

• fundamental (166.6 MHz) + 3rd harmonic cavities (500 MHz), (Other combination 100 & 300, or 216 & 650 MHz is feasible, need some balance between RF and Kicker)

• Multiple cavities of each frequency (avoid Voltage fast ramping especially for SC cavities)

• Individually knob the reference phase of each cavities to fully utilize the four independent knobs, and a better control of RF buckets in longitudinal phase space

• First figure out important modes and then ramp RF phases, to obtain a complete injection cycle.
The longitudinal dynamics with a double-RF system

• A particle’s longitudinal motion is described by the Hamiltonian

\[
H(\phi, \delta; t) = \frac{h_f \omega_0 \eta}{2} \delta^2 + \frac{\omega_0}{\pi E_b \beta^2} \left[ \sum_{i=1}^{N_f} V_f^i \cos(\phi + \phi_f^i) \frac{h_f}{h_h} \sum_{j=1}^{N_h} V_h^j \cos(\frac{h_h}{h_f} \ast \phi + \phi_h^j) + \phi U_0 \right]
\]

• Equivalent RF voltages and phases:

\[
V_f \cos(\phi + \phi_f) = \sum_{i=1}^{N_f} V_f^i \cos(\phi + \phi_f^i) \quad \text{Four independent knobs} \ (V_f, \phi_f, V_h, \phi_h)
\]

\[
V_h \cos(\frac{h_h}{h_f} \ast \phi + \phi_h) = \sum_{j=1}^{N_h} V_h^j \cos(\frac{h_h}{h_f} \ast \phi + \phi_h^j)
\]
Operation mode to injection mode
Injection mode to operation mode
Evolution of equivalent RF parameters
Evolution of circulating bunch parameters

Shortened bunch length leads to an emittance growth of about 10% assuming initial emittances are 60/10 pm, due to IBS.

The beam lifetime also drops but an injection cycle takes several damping time and will not lead to observable beam loss.
Aiba’s paper indicates to inject beam here, well beyond the MA of HEPS. Here is the region the lattice MA permits injection.
Longitudinal phase space w/ radiation damping

Aiba’s paper indicates to inject beam here, well beyond the MA of HEPS.

Here is the region the lattice MA permits injection. Our scheme is superior in maximum allowed kicker rise time & tolerance of phase and energy jitter when applied at HEPS.
Comparison of different scheme

- Swap out: more beam intensity from injector, beam energy waste
- Golf club: need very large MA
- Jiang’s scheme: center of circular beam vibrate by a large amplitude
- Our scheme: need additional active RF system, this is not so easy especially for the HOM issues of SC. 100/166MHz cavity.
Conclusion

• In order to overcome the shortage during injection for “old scheme” we propose a new scheme, it can avoid the beam/energy waste, the vibration of the center of circulation beam which is unlike for SR users, need not a very large MA. Of cause, it need a active 3\textsuperscript{rd} harmonic RF system which means more money.

• Thank you very much for your attention!
Injection simulation (backup)

• Error seeds generation:
  • quadrupole relative gradient error of 5e-4 rms
  • quadrupole, sextupole and octupole roll error of 0.1 mrad rms
  • horizontal and vertical misalignment error in sextupoles and octupoles of 25 micron rms

• Select machines with beta-beating between 3% and 8%, vertical emittance between 5 pm and 15 pm. No correction is applied.

• 100 selected machines are used in injection tracking.

• Physical aperture: 11 mm (Horizontal), 2.5 mm (vertical, pessimistic)