Diagnostics for Physics Applications at SPEAR3

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SPEAR Overview

- SPEAR storage ring
  - $3\,\mathrm{GeV}$ synchrotron light source
  - $200\,\mathrm{mA}$ operation; $500\,\mathrm{mA}$ operation to begin within the coming year
  - $234\,\mathrm{m}$ circumference
  - Beam sizes
    - $10\,\mathrm{nm-rad}$ emittance
    - $\sigma_y = 30\,\mu\mathrm{m}$
    - $\sigma_\tau = 17\,\mathrm{ps}$ (normal mode)
    - $\sigma_\tau = 3\,\mathrm{ps}$ (low α mode)
  - RF System
    - Copy of PEP-II RF system
    - $f_{RF} = 476.316\,\mathrm{MHz}$
    - $h = 372$
    - $h_{IF} = 13$

Single-Turn BPM System

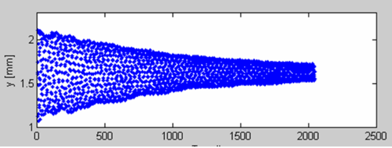
- Detect signal at $f_{RF} = 476.316\,\mathrm{MHz}$
- Mix down to $f_{IF} = 16.646\,\mathrm{MHz}$
    - Improves phase resolution by factor 372/13
    - Easier to synthesize desired analog band pass filters
- Digitize signal
- Perform "single turn FFT" on data
- Amplitude of complex signal gives transverse beam position
    - Betatron motion produces amplitude oscillations
- Phase of complex signal gives longitudinal beam position
    - Synchrotron motion produces phase oscillations
- Can trigger on injection to measure injected pulses

Optical Diagnostics

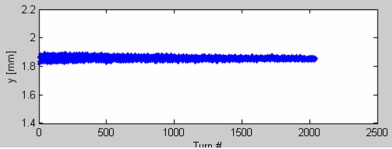
- Fast gated camera
  - Roper Pi-Max
  - Gating down to $2\,\mathrm{ns}$
  - Measures transverse distribution of single bunch
- Streak camera
  - Hamamatsu synchroscan
  - $3\,\mathrm{ps}$ resolution
  - Measures longitudinal distribution of single bunch
- Delay generator after injection trigger allows cameras to sample evolution of injected signal on successive injection cycles

Injection Coupling Studies

- Injection septum caused skew coupling that transferred horizontal injection kick into vertical plane
- Measured the strength of the coupling to specify design of multipole corrector
- Multipole corrector reduced coupling by an order of magnitude



Vertical oscillations before corrector installation



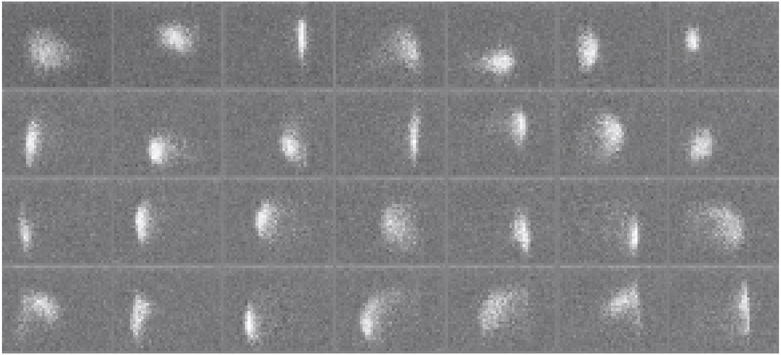
Vertical oscillation after corrector installation

- Phase space distribution of injected beam determined by
  - Lattice function in Booster
  - Lattice function in Booster to SPEAR transport line
- Phase space distribution in SPEAR determined by SPEAR lattice
- Phase space of injected beam determines “initial conditions” for SPEAR lattice
- Want these initial conditions to “match” to minimize quadrupolar oscillations of injected beam
  - Maximizes capture of injected beam
- Gated camera images sample sequence of stored bunches at increasing delays after injection
- Dipole (betatron) oscillation is expected

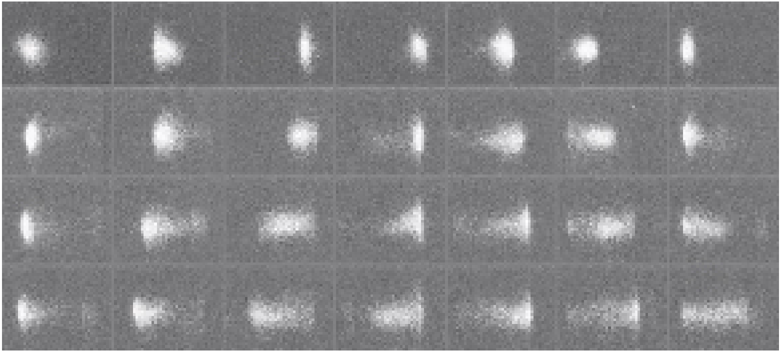
Injection Transverse Phase Space Matching

Mismatched Transverse Initial Conditions

- Quadrupole oscillation shows mismatch of injected beam phase space to ring lattice function

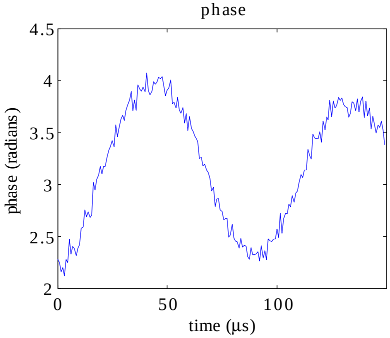


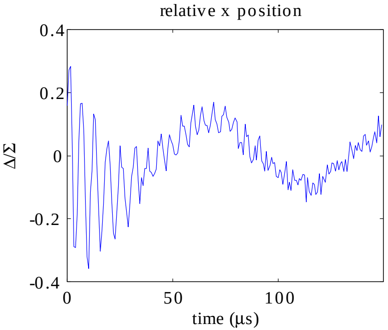
- Correcting injection lattice eliminates quadrupole oscillations



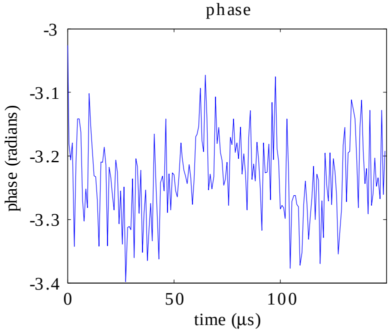
- Arrival time and energy are the conjugate longitudinal variables
  - $\tau(t) = \tau_0 \cos \omega_s t$
  - $E(t) = E_0 \sin \omega_s t$
- Injected beam of correct energy that arrives at the correct time has zero oscillation amplitude
- Mismatched beam oscillates at synchrotron frequency
  - Time mismatch generates cosine-like oscillation
  - Energy mismatch generates sine-like oscillation
- Energy oscillation is measurable as a transverse oscillation in dispersive regions
- Injected current (single bunch) is very low ($\approx 50\,\mu\mathrm{A} - 100\,\mu\mathrm{A}$)
  - Average over 16 injections to quadruple SNR to obtain desired resolution

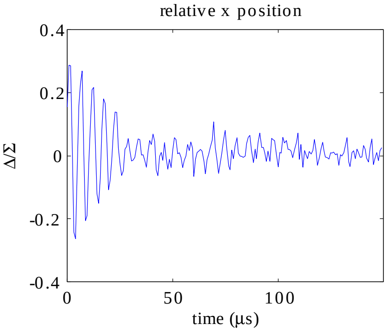
- Typical measurement of an injection phase error
  - Phase curve is cosine-like
  - Horizontal (dispersion) curve is sine-like
  - Fast horizontal motion is betatron oscillation from injection





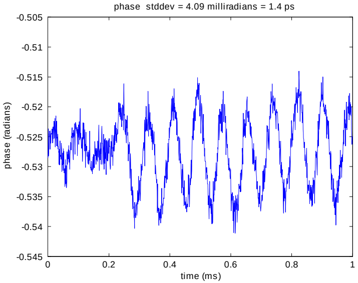
- Properly tuned injection minimizes synchrotron oscillations
- Horizontal betatron oscillation of injected beam still exists, as expected





Low Level RF Tuning

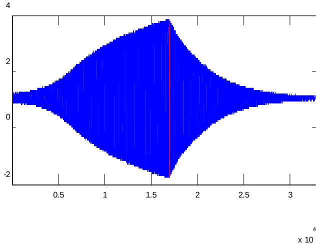
- SPEAR has a short bunch "low α" mode
  - $\approx 3\,\mathrm{ps}$ RMS bunch
  - Require RF induced oscillations to be significantly smaller
- Measure phase oscillations of stored beam
  - Major contribution comes from HVPS SCR switching transients
- Increase LLRF loop gain to reduce amplitude to acceptable level



Lattice Resonance Experiments I

Probe Resonance Effects as a Function of Oscillation Amplitude

- Resonantly drive beam vertically to desired amplitude
- Kick beam horizontally
- Distance from the resonance can be measured by the damping time
- Data here with slow damping shows beam near resonance



Lattice Resonance Experiments II

Probe Resonance Effects as a Function of Oscillation Amplitude

- Lattice now tuned away from resonance
- The right hand figure is an expanded version of the data seen on the left
- Tune shift with amplitude can be calculated along the decay