Vertical Instability Studies at the MLS

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Outline

1. Introduction
   - Metrology Light Source Parameters
   - Coupled-bunch Instabilities

2. Qualitative Overview
   - Feedback Operation
   - Qualitative Summary

3. Beam Studies
   - Single Bunch Calibration
   - Longitudinal Grow/Damp Measurements
   - Vertical Grow/Damp Measurements
Machine Parameters

- Small 500 MHz electron storage ring;
- Used by German national metrology institute;
- Very low energy injection, ramping;
- Too small for an ion clearing gap;
- Rich beam dynamics.

### Parameters

- **Injection energy**: 105 MeV
- **Operating energy**: 629 MeV
- **Circumference**: 48 m
- **Harmonic number**: 80
- **Beam current**: 200 mA
- **RF frequency**: 500 MHz
- **Tunes, X/Y**: 3.18/2.23
- **Natural emittance**: 110 nm rad
- **Damping time, ||/⊥**: 11/22 ms
MLS Beamlines
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Instabilities and Control

- Both transverse and longitudinal coupled-bunch instabilities are present in the MLS;
- Strong energy sensitivity;
- In the transverse plane the beam is very sensitive to the coupling;
- A full complement of bunch-by-bunch feedback systems is installed and commissioned.
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Coupled-bunch Instabilities

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Operating Approach

- Inject and ramp without feedback;
- Coupling knob dialed to 100% to reduce losses;
- At full energy, turn on the feedback systems (Z→X→Y);
- Reduce the coupling knob to 10%–25%;
- Beam spot shrinks, lifetime drops;
- Sometimes coupling reduction still leaves the beam blown up;
- Transient excitations can often facilitate the transition.
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Qualitative Observations

- With all feedback systems operating the beam is stable long-term;
- Destabilizing transients (feedback tuning, grow/damps) can lead to the loss of control;
- Unstable motion in both X and Y;
- Impossible to recapture, see both centroid motion and blow-up;
- Need to raise the coupling, turn off the feedback systems to re-stabilize;
- Sensitivity to gain balancing between horizontal and vertical planes.
- Very strong sensitivity to fill patterns.
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Single Bunch Calibration

Front-end Calibration: Transverse Plane

- Set up controlled orbit bumps in X and Y;
- Measure bunch signal displacement in ADC counts;
- At 2 mA per bunch ADC LSB corresponds to 26 and 10 $\mu$m in X and Y respectively;
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Set up controlled orbit bumps in X and Y;

Measure bunch signal displacement in ADC counts;

At 2 mA per bunch ADC LSB corresponds to 26 and 10 µm in X and Y respectively;
Single bunch at 0.23 mA excited with a swept-sine signal;

- Sweep span of 7 kHz around 1450 kHz;
- At the excitation amplitude of 0.05 FS tune is "pushed" by the swept excitation;
- Fit second-order beam response to the spectrum;
- Little tune shift at low amplitudes.
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Vertical Tune Measurement

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Single bunch calibration results:

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Longitudinal Growth Rates vs. Beam Current

- Fairly typical HOM-driven instabilities;
- Mode 43 open-loop eigenvalues vs. beam current;
- Threshold of 6 mA, zero current damping of 4.8 ms;
- Effective impedance of 39.2 kΩ at $nf_{rf} + 268.6$ MHz.
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Mode -1 growing and damping at low amplitude (9 µm peak);

Fast feedback damping;

Exponential fits look good;

Positive tune shift of 0.01;

Small tune shift increase in open loop, some reactive shift from the feedback.
A Grow/Damp Measurement (Small)

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A Grow/Damp Measurement (Medium)

- Mode -1 growing to 21 \( \mu m \) peak;
- Same initial frequency as before, large downward shift;
- Large tune shift starts at around 12 \( \mu m \) amplitude.

MLS:oct2711/195827: l0=106.3132mA, Dsang=1, ShifGain=4, Modes 60, At Fs: G1=30.1261, G2=0, Ph1= -103.8825, Ph2=0, Brkpt=21000, Calib= 48.25.
Vertical Grow/Damp Measurements

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A large spike in the transient;
- Low mode -1 amplitude in open-loop, large spikes in closed loop;
- Initial part of mode -1 transient looks normal;
- Mode -2 starts tune shifted above 1650 kHz - tune shift of 0.03.
In the study of vertical grow/damp measurements, the following observations were made:

- A large spike in the transient;
- Low mode -1 amplitude in open-loop, with large spikes in closed loop;
- Initial part of mode -1 transient looks normal;
- Mode -2 starts tune shifted above 1650 kHz, with a tune shift of 0.03.
A large spike in the transient;
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Vertical Grow/Damp Measurements

**Vertical Growth Rates vs. Beam Current**

- At 110 mA beam stabilized;
- Had to lower the knob to 20%;
- Too few data points for any conclusions...
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Two States: A Hypothesis

- It almost seems that feedback is mis-tuned when transverse motion cannot be suppressed;
- Reasonable (±60 degrees) feedback phase adjustments do not help;
- Are we picking up signals from both the beam and the ions?
- Phase shift between electron and ion oscillations would explain control difficulties;
- In transients, ion motion makes the difference between clean damping and loss of control/spikes in closed-loop.
It almost seems that feedback is mis-tuned when transverse motion cannot be suppressed;

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Ideas for Future Measurements

- Try DC clearing voltage at or near the feedback pickups;
- Use a second acquisition system to measure the signal between the bunches;
- Try transient measurements with large feedback phase shifts in the unstable/blown-up state.
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Summary

- We have observed very rich transverse dynamics;
- Dramatically different behavior from machines at higher energy (or operating with ion clearing gap);
- Can we mine the data for more information? What else should we measure?
- What is the best way to test the "mixed signals" model?
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