Keeping Nanometer Beams Colliding
Vibration Stabilization of the Final Doublet

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NLC MAC review
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• Vibration stabilization test system progress
• Motion sensor development
• Future plans
Major Contributors

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- Eric Doyle
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- Tom Himel
- Joe Frisch
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- Steve Smith
Effect of fast motion on the beam
= produce beam offset at IP

Rough scale of jitter tolerances:

- **Linac quads** (many of them!):
  - tolerance ~ 10nm
  - natural quietness, good girders.

- **Some quads in beam delivery**:
  - tolerance ~ 5-10 nm
  - natural quietness, maybe some active method

- **Final quads**: tolerance
  ~1/3 IP beam size ~ 1 nm
  - rely on active methods to keep beams colliding

- **Frequency of concern**: above
  significant beam-based feedback gain ~1Hz

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Inertial stabilization R&D at SLAC

one object, 6D, digital feedback

Schematic of the object to be stabilized

Digital feedback @ real time OS

Hardware and software are working and being improved
Calibration/Orthogonalization

- Excite each of 6 actuators with sine wave at 110 frequencies.
- Record amplitude and phase at each of 6 sensors.
- Result is 6x6 = 36 plots like these.
- Do 96 parameter (resonant freqs and Q’s, sensor freqs and Q’s, 2 6x6 coupling matrices) nonlinear least squares fit.
Check of calibration/orthogonalization

- Excite mode 3 (mostly vertical motion) with sine waves at 110 different frequencies.
- Plot the amplitude and phase of the mode 3 sensor combination (red “+”)
- Compare to model of harmonic oscillator and sensor (blue line)
- Note there are no peaks at other resonant frequencies so the calibration is good.

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Effect of beam-beam deflection feedback must be folded in to get beam/beam separation

- Solid curve is modeled suppression of beam-beam separation by beam-beam deflection feedback.
- Measurements at SLC corroborate it.
- Note trade-off between good low frequency rejection and high frequency amplification.
- Solid curve folded in when evaluating FD stabilization. Without this, low freq. motion is very large.
The signal to noise ratio determines how well a feedback can work.

The loop gain needs to be large where the signal is large and small where the sensor noise is large.

This plot is for a commercial geophone (HS1) which measures velocity.
Signal to Noise as a position

- Here the detector sensitivity (it falls off rapidly below 4.5 Hz) is taken into account and the velocity is integrated to get a position.
- Note that all these spectra factor in the effect of beam beam deflection feedback and the differential motion for 2 doublets.
- Note very poor S/N at low freqs.
Open Loop Transfer Function

HS1 Sensor

- Goal: Large gain where S/N > 1; small gain where S/N < 1
- Slope can’t be too steep where gain crosses zero to keep the phase from being too large and the loop from being unstable.
- This is an LQG controller designed to minimize the RMS motion. It uses a Kalman filter.
• RMS is the sqrt of the integral under a curve

• Note that major contribution for the closed loop case comes from near 1 Hz.

• Note feedback improves on the sprung mass motion by a factor of 6, but does not improve on the ground motion.
Position Signal to Noise for a Planned Capacitive Sensor

- Capacitive sensor measures position instead of velocity. Hence sensitivity falls off less rapidly at low freq.
- Capacitive sensor readout is very low noise and has no 1/f noise.
- S/N crossover freq down a factor of 50.
• RMS now down to 0.33 nm.
• Note there is a commercial capacitive sensor (the STS2 made by Streckeisen) which works still better than this.
• We are building our own which is smaller and non-magnetic.
Real Data from Test System

- Feedback was turned on after 10 seconds.
- RMS improved dramatically.
- Still doesn’t work as well as simulation. Investigating it.
Capacitive Sensor Development

- We are developing our own capacitive sensor that will be low noise, small, and non-magnetic. Unfortunately we have not found any commercial sensors that meet our requirements.
- Carlos Damien built a few mechanical prototypes to gain an understanding of the problems.
- Eric Doyle is now using ANSYS to refine the design.
- Electronics have been developed.
- Custom leaf springs have been purchased.
Capacitive Sensor Modeling

First Mode: Freq = 1.37
This is the desired vertical mode

Leaf spring. When unstressed, is bent over 90 degrees

Second Mode: Freq = 43.9
Bending of aluminum tube. Trying carbon fiber to increase this frequency

Mass and capacitive sensor

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Prototype with one mass and 6 degrees of freedom:
- System works and has been extensively used.
- DSP can read ADCs and write to DACs and do feedback calculations.
- DSP is slower and has less floating point precision than desired so we are planning to go to a much faster PowerPC CPU.
- Commercial geophones with 4.5 Hz resonant frequency are in use.
- Calibration/orthogonalization works spectacularly well.
- Have tested several feedback controllers including an optimal LQG controller.
- Starting investigations of robust controllers that are not as close to instability as the LQG controller.

- A lower resonant frequency (and hence more sensitive there), capacitive geophone is under design.

- Later stages will include 2 coupled masses and an extended mass.