Vibration Stabilization R+D

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Stabilization Projects

- Beam based feedback
  - Simulations (Not discussed here).
  - Nanometer BPM development

- Final Focus Vibration Feedback
  - Extended Object Tests – Algorithm development
  - Inertial sensor development
  - Interferometer (at UBC). (not covered here)

- Final Focus Intratrain Feedback - FONT
Nanometer Resolution Cavity BPM

- Use in NLC LINAC for beam diagnostics
  - Beam alignment / feedback in LINAC
  - May be able to measure bunch tilt
- Use with beam as an alignment tool
- Multi-Lab collaboration
  - Using BPMS developed at BINP
  - Tested on ATF extracted beamline at KEK
  - Electronics developed at SLAC
  - Precision mechanical mounts being developed at LLNL
BPMs Installed on Temporary X,Y, Theta-X, Theta-Y mounts at ATF
BPM Circuit Block Diagram

System mixes reference, and X or Y cavity signals down to a ~15MHz IF frequency. This signal is digitized, and fitted to extract I and Q components.
Fit to Typical Pulse

5 parameters fit:
DC offset
Decay Time
Amplitude
Frequency
Phase at T=0
Noise Result from Earlier Run

Error ~170nm (BIG)

**Improvements:**
- Better data analysis
- RF phase locks
- Better pre-amps
- Better beam stability?
LLNL Support Frame for BPMS

Uses Flexure mounts, driven by stepper motors

Provides 6 DOF control for each BPM

Rigid, high stability interconnection between BPMS

Expect installation at ATF in late 2003
Object Stabilization
Extended Object Stabilization

- Real final focus magnet doesn't look like a nearly cubical block!
- Will have internal degrees of freedom with resonant frequencies in the range of interest
- May have degenerate suspension frequencies
- We have constructed a mechanical mock-up of a final focus support system
  - Models magnet raft and support tube
Extended Object Status

• Mechanical construction complete
• Installing electrical connections to sensors and pushers
• Electronics and Software ready to begin commissioning
• Will initially test with commercial sensors, later convert to new low noise sensors.
Why Build Our Own Sensor?

• Block feedback limited by sensor noise
• Want $\sim 3 \times 10^{-9} \text{M/s}^2/\text{sqrt(Hz)}$ noise at $F > 0.1\text{Hz}$.
• Compact sensors for machinery vibration measurements (used for single block test) have noise $\sim 300X$ larger
• Geo Science seismometers have noise $< 10^{-9} \text{M/s}^2/\text{sqrt(Hz)}$, but are magnetically sensitive and physically large
• Could not find commercial sensors which met our requirements
Feedback Seismometers

- High suspension mechanical Q improves thermal noise - but results in large amplitude motion at resonance
- Below resonance sensitivity decreases as $w^2$ - leads to dynamic range problems
- Use feedback to keep suspended mass motionless relative to sensor housing. (Standard technique)
  - Can use feedback force as acceleration signal
  - Optionally use force and residual error as signal
Sensor Housing

Adjust motor

Cantilever

Suspension flexure spring (pre-bent to be flat under gravity load)

Electrostatic feedback pusher ~50V, 500um

Signal null at center

Cable delay 1 nanosecond

Signal combine

Mass

Signal split

I/Q

Signal null at center

DAC position feedback

Slow adjust flexure

DAC phase match feedback

ADC - get position and phase mismatch information

VCO ~20dBm
Sensor Parameters

- Suspended mass 40 grams
- Resonant frequency 1.46Hz
  - Next mode ~96Hz, ANSYS simulation
- Mechanical Q ~ 15-50 varies – not understood
- Theoretical Thermal Noise $2.5 \times 10^{-10} \text{M/s}^2/\text{sqrt(Hz)}$
  - 10X better than needed
- Theoretical electrical noise 2X smaller than mechanical thermal noise
Mechanical Design Issues

• BeCu spring (high tensile strength, non magnetic)
  – Pre-bent, operated at high stress to increase higher mode frequencies
  – Extensive creep measurements done at SLAC

• Thermal effects very large!!
  – $\sim 10^{-8} \text{C}^\circ$ corresponds to (0.1Hz) noise limit
  – Use multiple "thermal filters", Gold plating to reduce temperature variations. Operate in < 1 um vacuum.
  – Expected to be ultimate low frequency noise limit
Spring
Cantilever
Electrodes, Test Mass
RF IN
RF Out
Sensor Performance - Feedback Off

PRELIMINARY

Noise limit 100nm/sec^2/sqrt(Hz)

30X design

Feedback still off
Sensor Status - Feedback

- Feedback has been tested, but needs more actuator power (~X6) due to high level of 30Hz vibration in lab

- Will Increase drive voltage from 40V to 120V (needs new amplifier card).

- Use of feedback expected to improve sensor noise.
  - Operation at null RF power eliminates many noise sources – **but may not be limit!**
Sensor Status - Mechanical

- Sensor cantilever is Aluminum, and Mass is Tungsten. Forces from magnetic field gradients and variations will interfere with reading.
- Will replace cantilever with ceramic (better properties than Aluminum for this).
- Need material to replace mass:
  - Heavy Ceramic: HfO$_2$ (density=9.7)
  - Tungsten loaded epoxy (Will test soon)
Status - Data Acquisition

• DSP / VxWorks / Matlab system working!
  – 24 channels in and out, with programmable filters, gains.
  – Sensor feedback works (except actuator limit)
  – Single block feedback works (6 X 1d problem)

• For extended object “tilt sensitivity” may require full 8X8 DOF solution
  – Need to test speed of DSP
  – Faster DSP available, but $$
Sensor Status Overall

- Correlation with STS-2 suggest noise is ~30X design.
  - Still at least 10X better than old sensors
  - Hope feedback will improve noise
- Proceed with construction of 10 sensors for extended object feedback?
- Build a 2\textsuperscript{nd} generation prototype?

Cost / Risk vs. Schedule trade off
Feedback on Nanosecond Timescales

• Similar to TESLA scheme, try to close a feedback loop within a single train.

• For NLC, short train train length: 270ns requires fast electronics

• Concept test at NLCTA using 170ns beam (bunched at X-band)
  – Needs stronger kicker
  – Do not have beam / beam amplification: 100um kicks CAN test 1nm system!
Tube Kicker Amp

“Resonant button”
BPM for X-band beam
**FONT First Test Results**

BPM, BPM electronics, Non-linear normalizer, Power amplifier, Kicker: all functional

Feedback with ~70ns delay
FONT upgrades for 2003

• Install 2 additional BPMs to monitor beam independent from feedback. (Done)
• New normalization electronics (base on Log amplifiers) being tested
• New solid state kicker amplifier (higher power, faster)
• Pulse to pulse feedforward to remove repeatable beam motion
• General electronics speed increase
Vibration Stabilization Overall

- Nanometer BPMs
  - Some parts tested, full system under construction
  - Need to demonstrate nanometer noise

- Inertial stabilization
  - Progress on sensors, extended object
  - Still need to demonstrate full stabilized system
  - Need to improve sensor noise

- FONT
  - Basic concept demonstrated, Upgrades underway

Nanometers are Small!