VIBRATION STABILIZATION OF A MECHANICAL MODEL OF A X-BAND LINEAR COLLIDER FINAL FOCUS MAGNET*

Josef Frisch, Allison Chang, Valentin Decker, Eric Doyle, Leif Eriksson, Linda Hendrickson, Thomas Himel, Thomas Markiewicz, Richard Partridge, Andrei Seryi, SLAC, Stanford CA, USA

Abstract

The small beam sizes at the interaction point of a X-band linear collider require mechanical stabilization of the final focus magnets at the nanometer level. While passive systems provide adequate performance at many potential sites, active mechanical stabilization is useful if the natural or cultural ground vibration is higher than expected. A mechanical model of a room temperature linear collider final focus magnet has been constructed and actively stabilized with an accelerometer based system.

PROTOTYPE SYSTEM

One option for the warm linear collider is to use a permanent magnet final focus. The small beam sizes at the IP of the linear collider require nanometer scale stabilization of the final doublets. Passive stabilization, interferometer based stabilization, and inertial stabilization have been considered. This paper describes a prototype of the inertial stabilization system.

The prototype system is designed to have mechanical properties similar to an actual permanent magnet final doublet and support raft, but is constructed somewhat differently, figure 1. It is referred to as the "extended object" to distinguish it from an earlier prototype consisting of a simple suspended block. [1]

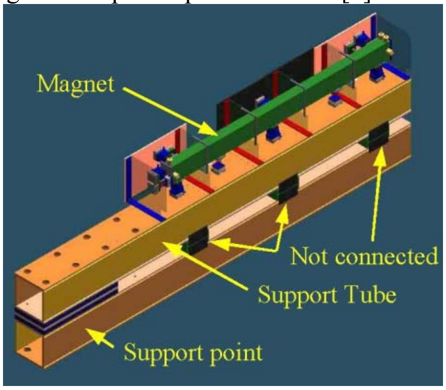

Figure 1: Vibration stabilization demonstration system.

Extended Object Mechanical Design

The extended object contains a simulated magnet support raft constructed of 4 thick-wall welded steel plates. It has the same dimensions, weight, and first two internal design mode frequencies as one of the designs for the NLC final doublet support raft.

Table 1: Simulated magnet properties

Length	3 Meters
Height	21 cm
Width	11.4 cm
Wall thickness	2.54 cm
Weight	240 Kg

The simulated magnet is supported on 6 spring mounts, designed to give the 6 rigid body degrees of freedom resonant frequencies of 2.5 to 6 Hz. This low support resonant frequency provides good attenuation of high frequency motions, which limits excitation of internal modes of the extended object and simplifies feedback.

The springs are mounted on a steel beam which has the same mass and resonant frequencies as the support tube which in an actual final focus would be cantilevered into the detector. Note that mounting the support tube rigidly to the detector risks coupling vibrations from the detector.

Table 2: Support tube properties

Length	3.35M (unsupported length)
Height / Width	40.6 cm
Wall thickness	1.6cm
Weight	1090 Kg

Figure 2: Photo of stabilization demonstration system.

Vibration Sensors

The position of the magnet mass is measured using 8 Geospace GS-1 1Hz magnetic coil seismometers [2]. These seismometer are not suitable for use in the magnetic field of a physics detector, however they have noise similar to the non-magnetic prototype seismometer being developed for the NLC [3]. These sensors are

---

* Work Supported by DOE Contract DE-AC03-76SF0515

specified from 1Hz to 75Hz, with an integrated noise of ~0.3 nanometers above 1Hz.

The 8 GS-1 sensors are used in a digital feedback loop to control the 6 rigid body modes, and 2 lowest bending modes of the extended object.

An Additional GS-1 sensor is mounted on the free end of the cantilevered support tube and is used in an analog feedback to damp the lowest resonance of the support tube.

Two Streckeisen STS-2, three-axis seismometers are used as an independent measurement of the motion of the extended object, and of the ground. These are very low noise sensors, with integrated noise <0.03nm above 1Hz, and <1nm integrated above 0.1Hz [4].

Feedback Actuators

The low stiffness suspension springs allow the use of low actuator forces to control the extended object position, ~0.025N for 100nm of motion.

Piezoelectric actuators are too stiff for this application, and would prevent the use of a low resonant frequency support system. Magnetic coil actuators are not suitable for use in the magnetic field of the physics detector, and so are not used in this prototype.

Electrostatic pushers - approximately 10x10cm plates, with a ~1 mm gap, and ~1KV high voltage are used for feedback. These provide sufficient force, and have very low stiffness, figure 3.

Figure 3: Close-up of sensors and electrostatic actuators.

Electronics

The eight GS-1 sensors signals are sent on differential cables to gain =100 instrumentation amplifiers (AD624 [5]), then to a set of programmable gain differential amplifiers (Frequency Devices PGA5-100 [6]), then to 500Hz, 4-pole low pass filters (Frequency devices D824), then digitized at 16 bits, at (typically) 1.5KHz (Pentek 6102 [7]). The digitized signals are read across the MIX (Pentek proprietary) bus into a TMS320C40 DSP (Pentek 4284 module). The DSP performs the feedback calculations. The output of the DSP is converted to analog at 16 bits, 1.5KHz (Pentek 6102), then amplified by 1KV, 100KHz bandwidth high voltage amplifiers to drive the pushers. Note that the DSP takes the square root of the required force to produce the drive voltage.

Feedback Algorithm-Extended *Object*

The actuators are operated over a range of frequencies (both swept sine, and random have been used), and all of the sensors are recorded. The data is fit to a model with 8 independent modes (6 rigid body, 2 lowest internal modes). From this a matrix to take sensor measurements to mode amplitudes and a matrix to take mode amplitudes to actuator strengths is created.

Orthoginalizing the problem into 8 independent mode feedbacks reduces the computational complexity. A variety of feedback algorithms for the individual modes, typical stat-space " optimal" control is used.

Note that this model of the system is only valid for relatively high frequencies. At very low frequencies (<~1Hz), the "tilt sensitivity" of the sensors becomes a problem. A horizontal sensor cannot distinguish a horizontal acceleration from a tilt (relative to gravity), thus a fixed angle tilt, appears as a fixed horizontal acceleration (2 time derivatives different). The effect is to convert the 8 independent modes now used into a fully coupled 8x8 system.

Work will begin to solve the fully coupled problem after a higher performance feedback processor (Power PC based) is installed.

Feedback Algorithm - Support Tube

In addition to the primary feedback on the cantilever, an analog feedback is used to damp the lowest order vertical resonance of the support tube. This feedback takes the signal from a GS-1 seismometer, which acts as a velocity sensor at 10Hz, and uses it to drive a second GS-1 seismometer acting as an inertial actuator.

Since force applied by the actuator is proportional to velocity, it acts as a damping term, to reduce the amplitude of the 10 Hz cantilever resonance.

In an actual NLC application (in the detector selonoid), the magnetic actuator could be replaced with a piezoelectric inertial actuator.

Performance Measurements

The GS-1 seismometers used for feedback have noise similar to the prototype NLC non-magnetic sensor. The STS-2 seismometers have very low noise, and are used as an independent measurement to quantify the performance of the system. The feedback algorithm does not use data from the STS-2s.

STABILIZATION EXPERIMENTS

The experiments were conducted in End Station B at SLAC. ESB is located near a large accelerator pumping station and cooling tower, and the site Helium liquefier, resuting in a large background vibration - approximately

40 nanometers integrated above 1Hz. This environment probably represents a worst credible case for the vibration to be expected in the experimental hall of a linear collider.

Note that the ground motion spectra in the ESB vary significantly with time, and therefore measurements taken at different times may not be consistent.

Vibration Spectra

Figure 4 shows overlaid vibration power spectra taken at different points and under different conditions.

- Ground Motion - from STS-2 seismometer
- Support tube motion from GS-1 seismometer.
- Extended object motion measured with STS-2 seismometer taken with digital feedback off
- Extended object motion with digital feedback on.

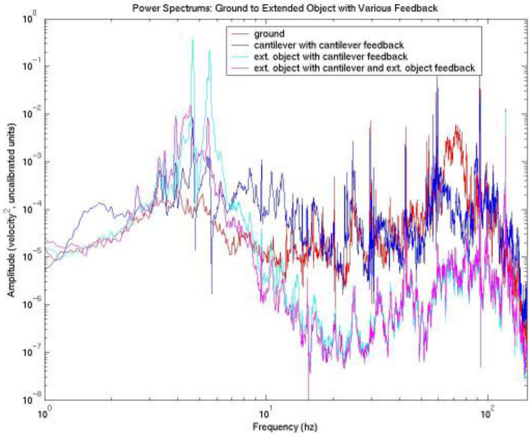

Figure 4: Vibration Spectra.

Since accelerometers cannot measure absolute position (or velocity), it is not possible to measure the "motion" of the magnet as a single number. The STS-2 sensors used provide a good indication of the motion down to approximately 0.1Hz.

Integrated Magnet and Beam Motions

Figure 5 shows the RMS integrated motion spectrum of the ground sensor, and of the magnet sensor with the feedback on and off. Note that the trace for "magnet attached to ground" is for reference. It is not practical to connect the final doublets rigidly to the ground in the accelerator due to the presence of the physics detector.

From Figures 4 and 5, it can be seen that the mechanical suspension of the magnet reduces high frequency motions (above the suspension frequency of ~5Hz), while increasing low frequency motion. The active feedback then reduces the low frequency motions introduced by the support resonance.

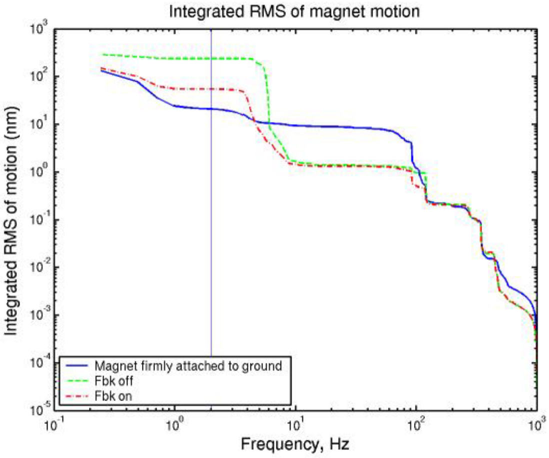

Figure 5:

The performance of the stabilization system is best evaluated by applying a simulated 120Hz beam-beam feedback to the measured magnet motion. Note that the factor of sqrt(2) is included to account for the (presumed) uncorrelated motions of the two magnets. The simulated beam-beam position from the measured magnet positions are shown in figure 6.

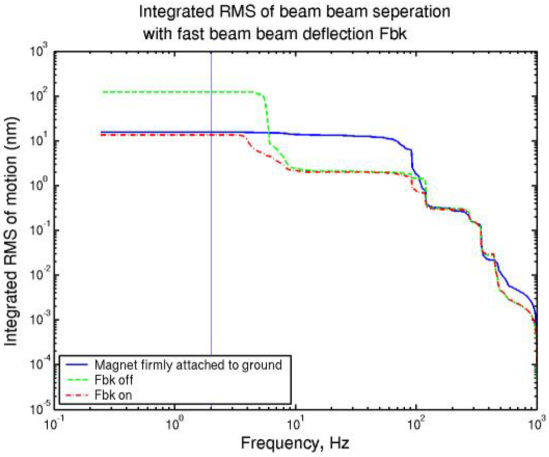

Figure 6: Beam - beam separation at IP from data.

REFERENCES

[1] Allison et al. "Active Vibration Suppression for the Next Linear Collider", SLAC-PUB-9149, August 2002

[2] http://www.geospacelp.com

[3] Frisch et al. "Development of a Non-Magnetic Inertial Sensor for Vibration Stabilization in a Linear Collider", LINAC04.

[4] "Zeroth-Order Design Report for the Next Linear Collider", Appendix C, SLAC-474, May 1996.

[5] http://www.analog.com

[6] http://www.freqdev.com

[7] http://www.pentek.com