Goal: Develop a mechanical stabilization system for the NLC final quadrupoles (and possibly additional magnets) based on inertial position sensors.
Inertial Vibration Stabilization Project - Steps

**Single Block Stabilization:** Construct a system to stabilize all 6 rigid body degrees of freedom of a test block.

- Develop a software simulator *(done)*
- Construct a multi-channel real time data acquisition and control system
- Gain experience with sensor and actuator technologies
- Compare simulation results with experiment in a simple system.

**Dual-Block Stabilization:** Construct a second identical block. Use a laser interferometer or capacitance distance measurement between the block to simulate the 120Hz beam data.

- Planning to skip the Dual Block step - save time.

**Extended object stabilization:** Construct an extended object (e.g. an Aluminum I-beam) with similar resonant frequencies to the real final focus magnet supports. Stabilize using inertial sensors.

- Expand number of system channels
- Develop algorithms to stabilize an object with internal and “hidden” modes.
Inertial Vibration Stabilization Project - Technologies

**Control Theory:** The control of MIMO (Multiple input, multiple output) linear systems is standard feedback theory. At this time the NLC group does not have any expertise in this area. We need to develop both theoretical understanding (Himel) and simulations (Frisch).

**Control System - hardware:** Modern DSP based control systems have sufficient bandwidth for this application. We are using a VME / DSP based system.

**Sensors:** High quality commercial seismometers have sensitivities of <1nm and <0.1Hz but are too bulky. Compact geophones have sensitivities of <1nm at 1Hz, but have resonances at a few hertz, which is within our desired feedback band. Piezoelectric accelerometers have sensitivities of 1nm at ~10Hz. We will initially use Piezoelectric accelerometers, then switch to compact geophones. In the future we will need to develop low noise accelerometers.

**Actuators:** Standard piezoelectric actuators are too stiff for this application. “Bending mode” actuators have resonance frequencies that are too low. We plan to use electrostatic capacitive pushers. The available force is marginal, and as a fall back we will use magnetic pushers - while developing high force electrostatic actuators.
Geophone Sensitivity

SHUNT DAMPING
A  OPEN  28%
B  2800Ω  60%
C  1820Ω  70%

Geo Space, LP
HOUSTON, TEXAS, U.S.A.

SEISMIC DETECTOR RESPONSE CURVE
OUTPUT VS FREQUENCY

TYPE: HI-1  DETECTOR: MODEL: IM31T
NATURAL UNDAMPED FREQUENCY: 8.50 Hz
D.C. RESISTANCE: 1250 Ω at 25°C
INSTRINSIC SENSITIVITY: 1.150 V/IN/SEC
OPEN CIRCUIT DAMPING: 28.0% OF CRITICAL

SHT 3 OF 3 S 90664 REV
Inertial Vibration Stabilization Project - Tasks

反馈滤波：低噪声紧凑型加速度器在4.5Hz内具有共振，属于我们的信号带。正在测试一个去共振算法（在模拟中）。

模拟：一个完全的3维时间域模拟程序已经被编写。该模拟允许输入任意的机械块、弹簧以及驱动器。该模拟包括地面运动。反馈代码已设计，可以直接用于DSP。

软件/仿真器正交化：测量信号以及驱动器需要正交化以针对机械块的模式。这在30dB的准确度上已经实现（一个早期的版本的仿真器（没有地面运动，且噪声有限制））。将转移到新的模拟器版本，目前正在进行中。

数据采集系统：一个6路输入，6路输出，X 10KHz的DSP基于数据采集系统正在开发。DSP接口到VxWorks基VME系统以及软件工具现在都在工作。接口到A-D / D-A卡需要完成。

单块系统结构：一个20x20x30cm的铝块已被设计。大部分部件已经被生产。这个块已经被测试，其最低的共振在5.9KHz。一个粗略的预估预测5KHz为第一模式。刚体模式是设计用于几Hz。

Simulation: A full 3-d time domain simulation has been written. The simulation allows for arbitrary input of mechanical blocks, springs, and actuators. The simulation includes ground motion. Feedback code is designed to directly ported to the DSP.

Software / simulator orthogonalization: The measured signals, and actuators need to be orthogonalized with respect to the mechanical modes of the block. This has been done to 30dB accuracy using an earlier version of the simulator (without ground motion, and with limited noise). Transfer to the new simulator version is underway.

Data Acquisition System: A 6 channel in, 6 channel out, X 10KHz, DSP based data acquisition system is being developed. The DSP interface to the VxWorks base VME system and software tools are now working. Interface to the A-D / D-A card is to be done.

Single block system construction: A 20x20x30 cm Aluminum block and support has been designed. Most parts have been fabricated. The block has been tested and the lowest resonance is 5.9KHz. (A crude calculation predicts 5KHz as the first mode). The rigid body modes are designed for a few Hz.
Orthogonalization Simulation Results
Single Block Mechanical Design
Inertial Vibration Stabilization Tasks - Continued

**Sensor testing:** The accelerometers have been tested, and found to have noise a factor of 20X their specification. On detailed reading of the specification, “electrical” not mechanical noise was specified. This noise level is sufficient for initial tests, but we will switch to the compact geophones as soon as the resonance correcting software is available.

**Sensor amplifiers:** The geophones require low noise amplifiers. Design (based on commercial instrumentation amps) is underway.

**Actuators:** High voltage amplifiers for the actuators have been ordered. Simple interface modules to adapt to the D-A card need to be constructed. We are considering including a capacitance distance measurement system with the high voltage drive.

**Single block system testing:** The block will be set up in the Cryo lab room 105 - initially using the accelerometers.

  - Setup data acquisition and control system
  - Transfer orthogonalization code - decompose system into normal modes.
  - Close 6 PID (or state space) feedback loops
  - Switch to using geophones when resonance correcting software is available.
Extended Object Simulator: The existing simulator can be used to model an extended object (entered as a set of rigid objects connected together). Mode orthogonalization and feedback software need to be tested in the simulator.

Extended Object Design: Need to construct an object with similar proportions and resonant frequencies to the NLC final quad support. We will probably use an Aluminum rectangular beam.

Sensor / actuator location: The number and locations of sensors and actuators needs to be determined from simulator results. It is assumed that compact geophones will be used for this test.

Data acquisition system expansion: The present system can control up to 8 sensors and actuators. It is easily expandable to ~24 sensors and actuators. In the (unlikely) event that more channels are required, additional development will be required.

System testing: System performance tests will be performed in the Cryo lab, and possibly also in a low noise environment (SLD Pit).
Additional Tasks:

**Develop non-magnetic geophones:** The electronics for a non-magnetic geophone have been tested. The mechanical design is fairly complex.

**Internal noise attenuation:** Most of the development work is focused on external ground motion and cultural noise. Some tests of the sensitivity to internal noise (cryo-fluid motion, cooling water, etc.) need to be conducted.

**Integration with interferometer and feed forward:** It is likely that the optimal plan for final focus stability will use a combination of technologies. A demonstration of the combined technology will be required.

**Real girder test:** It would be desirable to stabilize a real girder. A large effort is required to produce a girder for testing.
Schedule - single block system ready for testing: 4/1/01

Simulator orthogonalization code update to version 2 (Hendrickson)
Single block hardware (with accelerometers): (Eriksson / Tankersley)

Single Block Electronics: (Frisch)
   High voltage driver amplifiers due 3/15/01
   Low noise amplifiers being designed, needs assembly (shop)
   High voltage interface module being designed, needs assembly (shop)

Single block data acquisition hardware interface ready: (Hendrickson)
   Interface to A-D / D-A card.
   Transfer orthogonalization and feedback code.

FY01 January close: $33K M+S, Shops $5K, Labor $15K.
Estimated committed: $15K M+S, Shops $5K, Labor $5K
Estimate additional: $10K shops, $5K labor, $5K M+S.
Schedule - Single block system close loop. Complete: 6/30/01 (Snowmass)

Transfer orthogonalization code to DSP 5/1/01 (Hendrickson)
Orthogonalize system: 5/15/01 (Hendrickson)
Close accelerometer loop 6/1/01 (Hendrickson)
   This should demonstrate ground motion attenuation, but may not reach the required
   noise levels.

Resonance filtering software ready for testing 4/1/01 (Himmel)
Filtering scheme transferred to simulator 5/1/01. (Himmel)
Install Geophones 6/15/01 (Frisch, Eriksson, Tankersley)
Close geophone loop Optimistic:6/30/01 (Hendrickson)

Estimated costs:
M+S $5K Shops: $6K Labor $15K (Hendrickson)
Schedule - Dual Block System. Complete: 1/1/02 (Now Cancelled)

Design 2 block support 8/1/01 (Eriksson, Tankersley)
Decide on interferometer / capacitive sensor 8/1/01 (Frisch)
Simulator version 3 with dual block, dual data rate 8/1/01 (Frisch / Hendrickson)
Close simulator version 3 loop 9/1/01 (Frisch / Hendrickson)
New hardware (DAQ, sensors, etc.) delivered 10/1/01
2 block system machined 10/1/01
2 block system assembled 11/1/01 (Eriksson, Tankersley)
Transfer simulator code to DSP / block 12/1/01 (Hendrickson)
Close 2 block loop 1/1/02 (Hendrickson).

FY01 expenses
M+S $30K (capacitive sensor, New DAQ cards, HV Amplifiers)
Shops $10K
Labor $25K (Hendrickson, Tankersley)

FY02 Expenses
M+S $20K (stages, low noise amplifiers, etc.).
Shops $2K
Labor $15K
Schedule - Extended Object Tests. Complete 7/1/02

Design extended object: 8/1/01 (Frisch)
Write simulator for extended object 9/1/01 (Frisch)
Simulate control algorithm 10/1/01 (Hendrickson, Himmel, Frisch)
Design multi-channel control system 11/1/01
Multi-channel control system parts delivered 3/1/02
Multi-channel control system ready 4/1/02
Extended object mechanical design 11/1/01 (start 9/1/01) (Eriksson, Tankersley)
Extended object fabrication 2/1/02
System assembly 5/1/02 (Eriksson, Tankersley)
Algorithm testing 7/1/02 (Hendrickson)

Costs FY01 (after 7/1/01) M+S 10K (miscellaneous), Shops 5K, Labor $20K

Costs FY02 (up to 7/2/02)
M+S: DAQ system $20K, Amplifiers $20K, Sensors / pre-amps $25K, Mechanical components $5K, Miscellaneous 10K. Total $80K
Shops: $30K, Labor $70K (assumes additional 1/2 time person)

Estimated costs to end of FY02 M+S 5K, Shops 5K, Labor $20K
## Budgets

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<th>Type</th>
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Note: Original budget did not include software labor.