Precision Tilt Measurement for Torsion Balance Experiments

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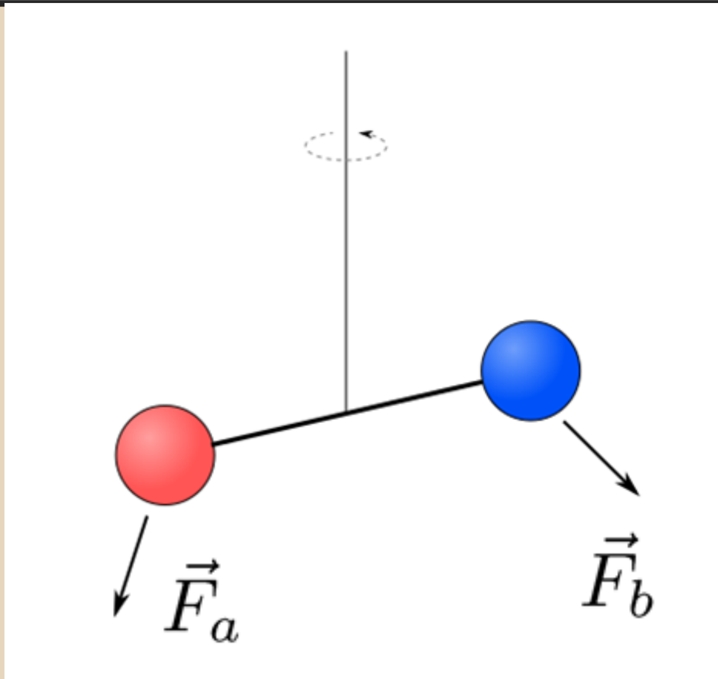
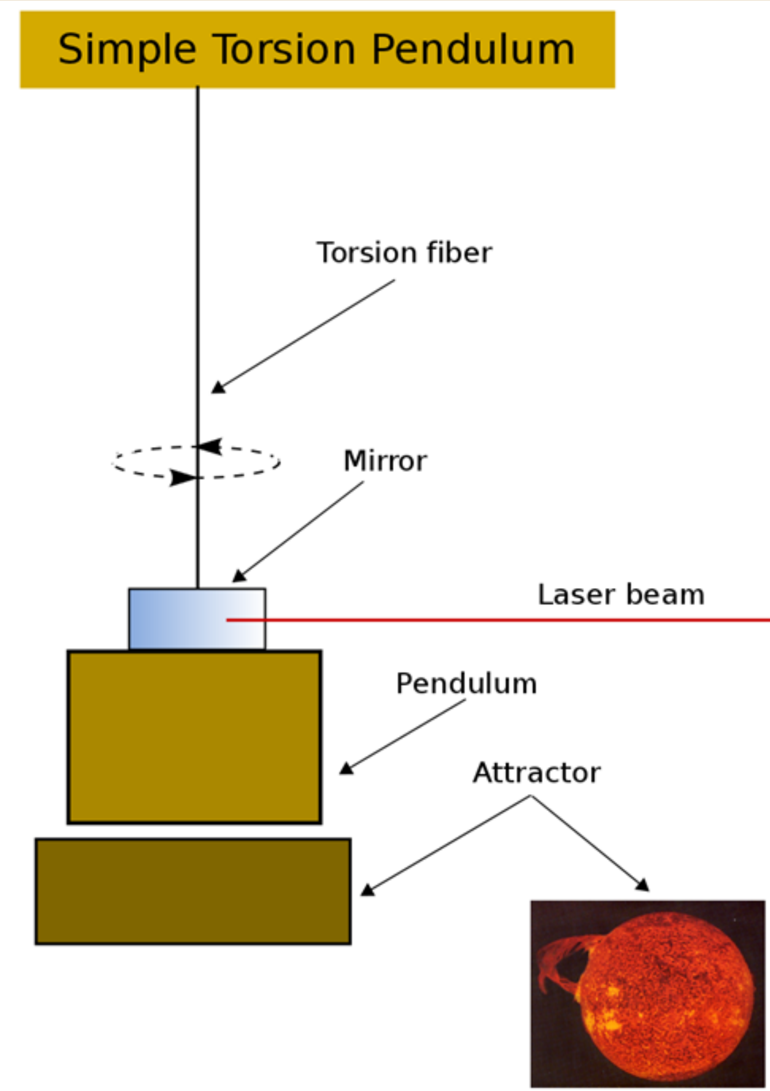
Torsion Balances: An Introduction

- Mass suspended from fiber
- Measures torque due to an attractor
- Can detect force equal to one trillionth the weight of a stamp
- Either the attractor or the test mass is rotated to make the torque oscillate, so it is detectable over constant torques



Torsion Balances: An Introduction

- Test fundamental physics at macroscopic scale
- We get much better sensitivity using Avogadro's number of particles rather than just one, if we shield from forces we don't want
- The trick is to design a pendulum/attractor pair that is sensitive to interesting physics



Experimental Motivation

- Some theoretical models predict equivalence principle violations or deviations from the gravitational inverse square law
- Both of these can be tested to high precision using a torsion balance
- Composition dipole test mass for equivalence principle (to test universality of freefall)
- Test mass and attractor with patterns of holes to test inverse square law violation at small separation (down to cm so far)

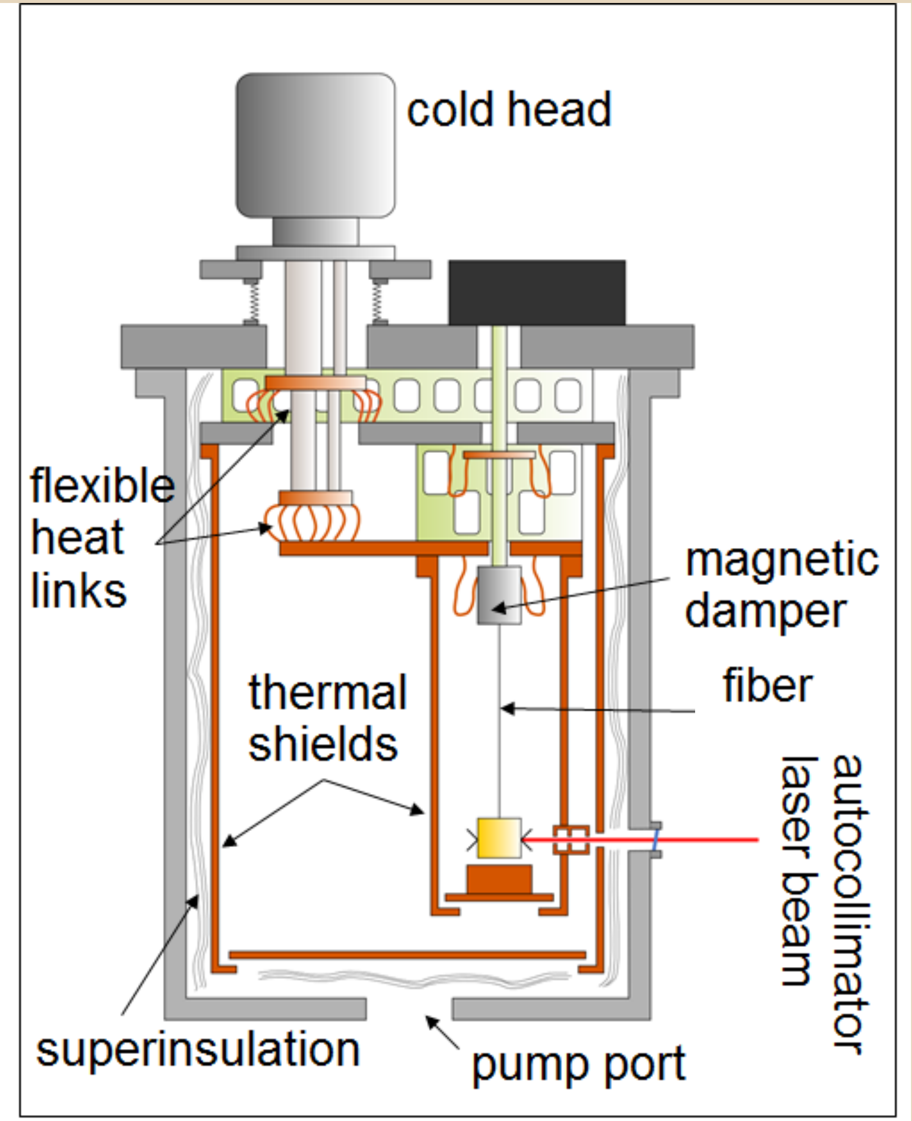
Advantages of Low Temperatures

- Noise scales as:

$$\tau^2(\omega) \propto 4\frac{kT}{\kappa Q \omega}$$

- We are interested in temperature (T) and quality factor (Q)
- Other parameters are Boltzmann's constant, spring constant, and frequency
- Lowering temperature also gives higher Q, so you get a 2-for-1 deal

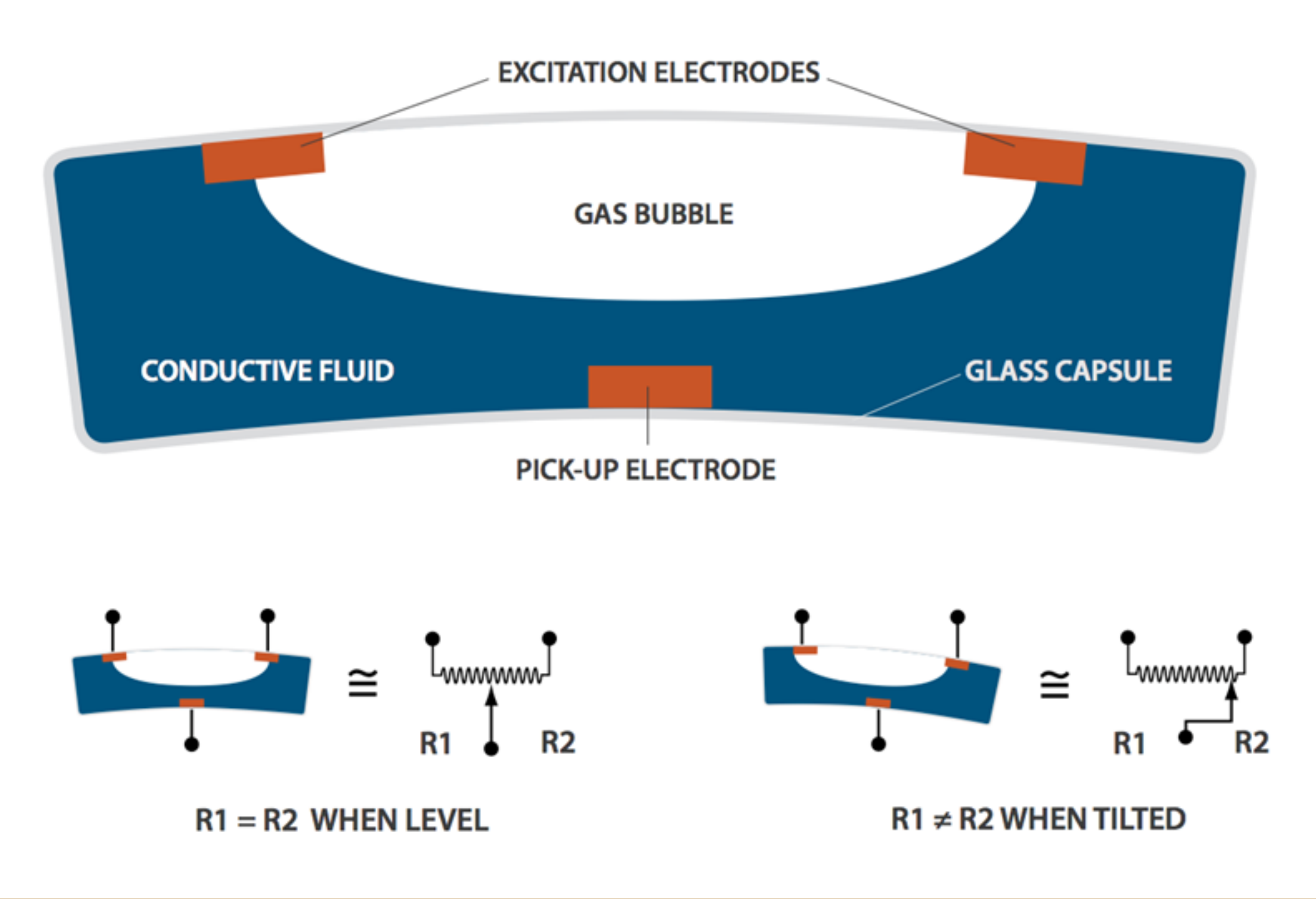
The Cryogenic Torsion Balance



Why Tilt Matters

- Tilt is the biggest source of systematic error for a nonrotating torsion pendulum
- The increased sensitivity at lower temperatures makes the effects of tilt even more significant
- Small changes in tilt near the fiber attachment can cause small rotations in the torsion balance
- If tilt changes periodically, it can mimic the signals we're looking for

Measuring Tilt: A Commercial Tiltmeter

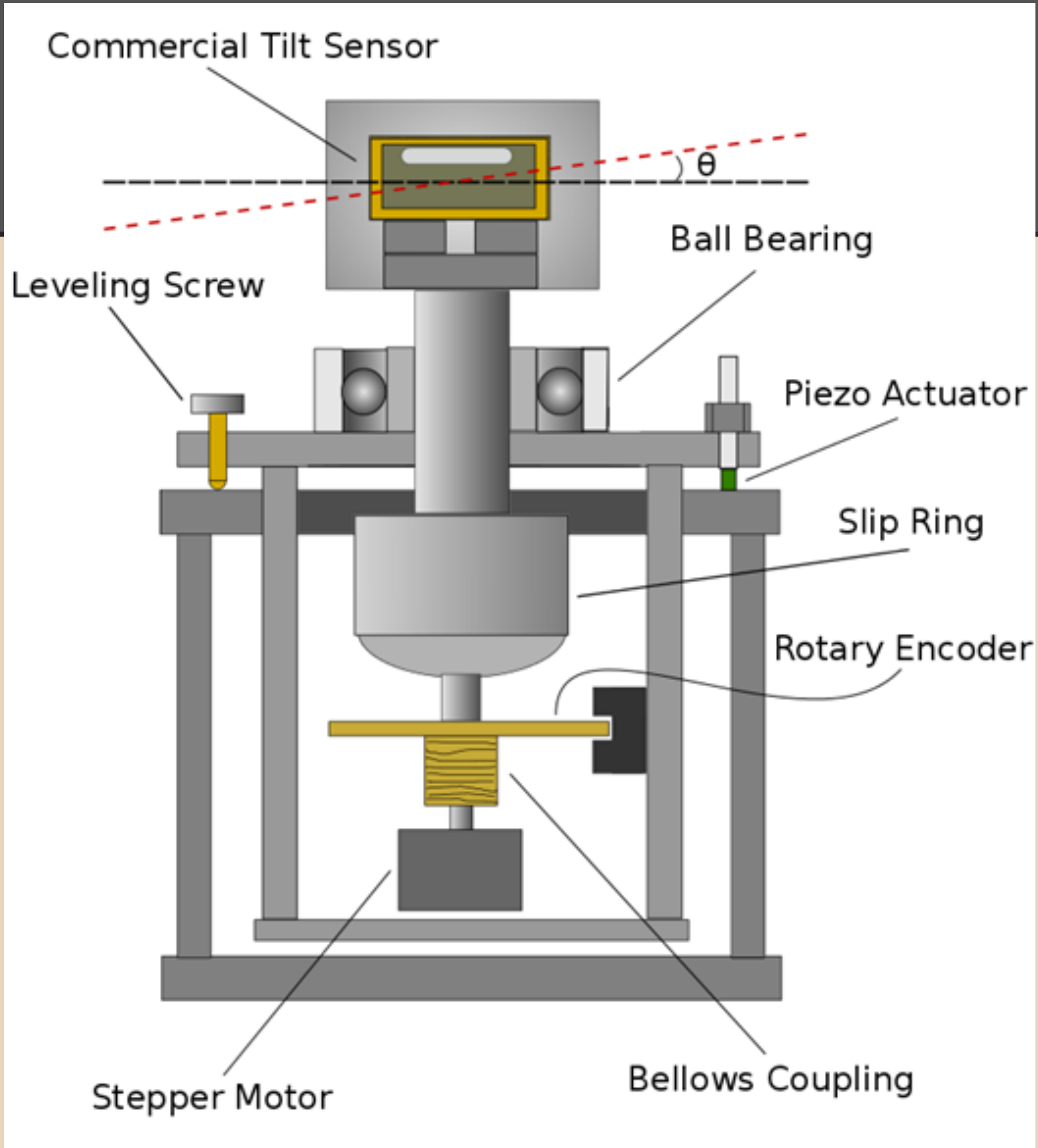


http://pdf.directindustry.com/pdf/applied-geomechanics-incorporated/2011-agi-catalogue/29986-105900-_5.html

Measuring Tilt: Difficulties

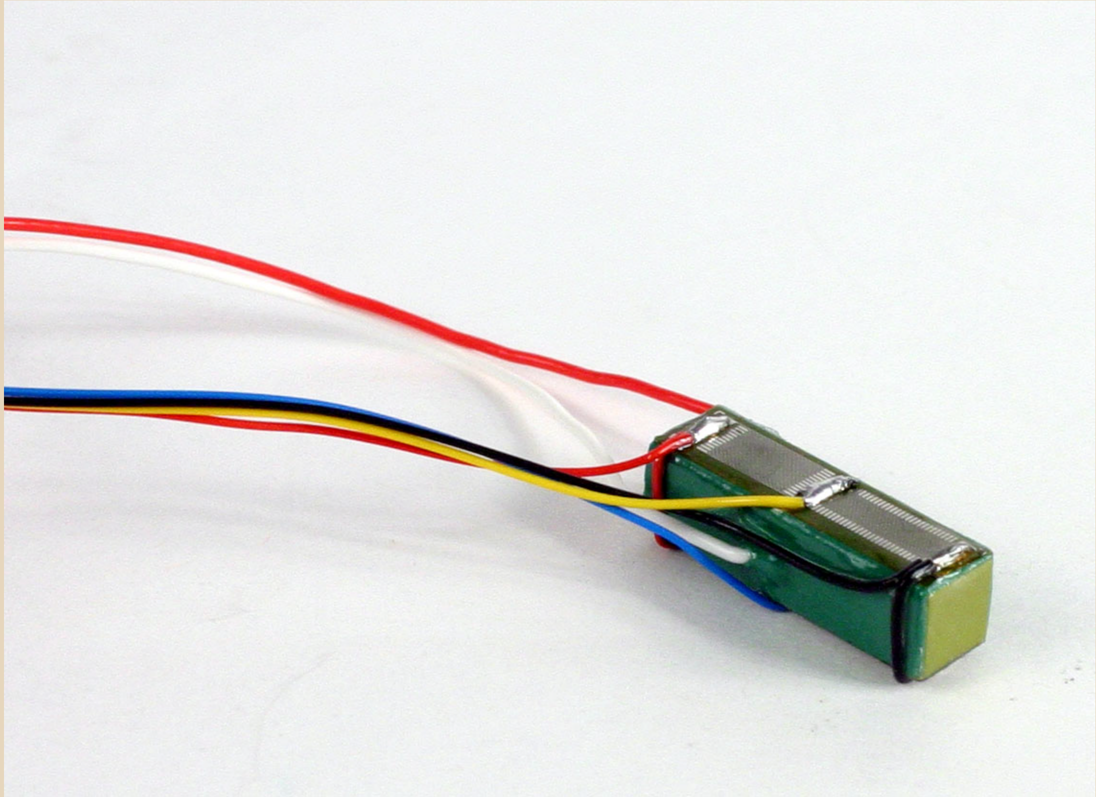
- The AGI tiltmeter is sensitive to better than a microradian but suffers from two problems that must be accounted for
  - Zero point drift: the readings slide up and down over time
  - Gain drift: the sensitivity changes over long timescales
- We rotate the tiltmeter to remove zero point error and periodically tilt it by a known amount using a piezo actuator to remove gain drift

The Setup

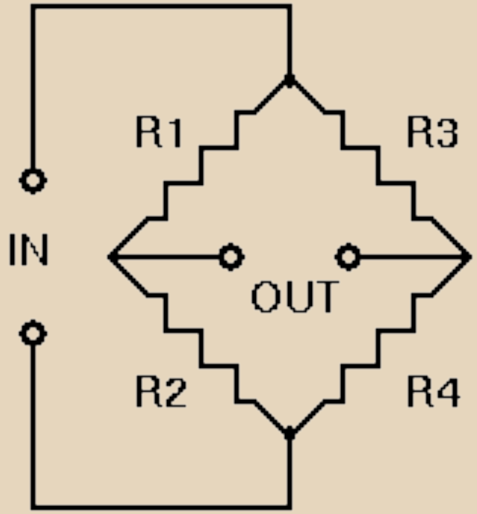

Commercial Tilt Sensor
θ
Ball Bearing
Leveling Screw
Piezo Actuator
Slip Ring
Rotary Encoder
Stepper Motor
Bellows Coupling

The Piezo Actuator

Thorlabs PZS001



http://www.thorlabs.us/Thorcat/16000/PZS001-Manual.pdf

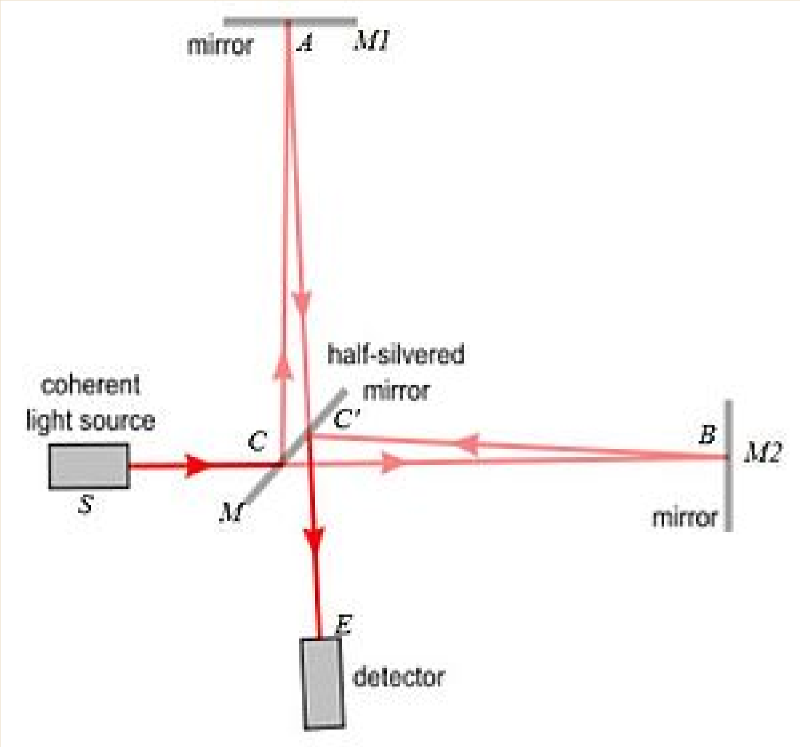


Wheatstone Bridge

http://www.play-hookey.com/dc_theory/

The Piezo Actuator

- Change in length was calibrated using a Michelson Interferometer

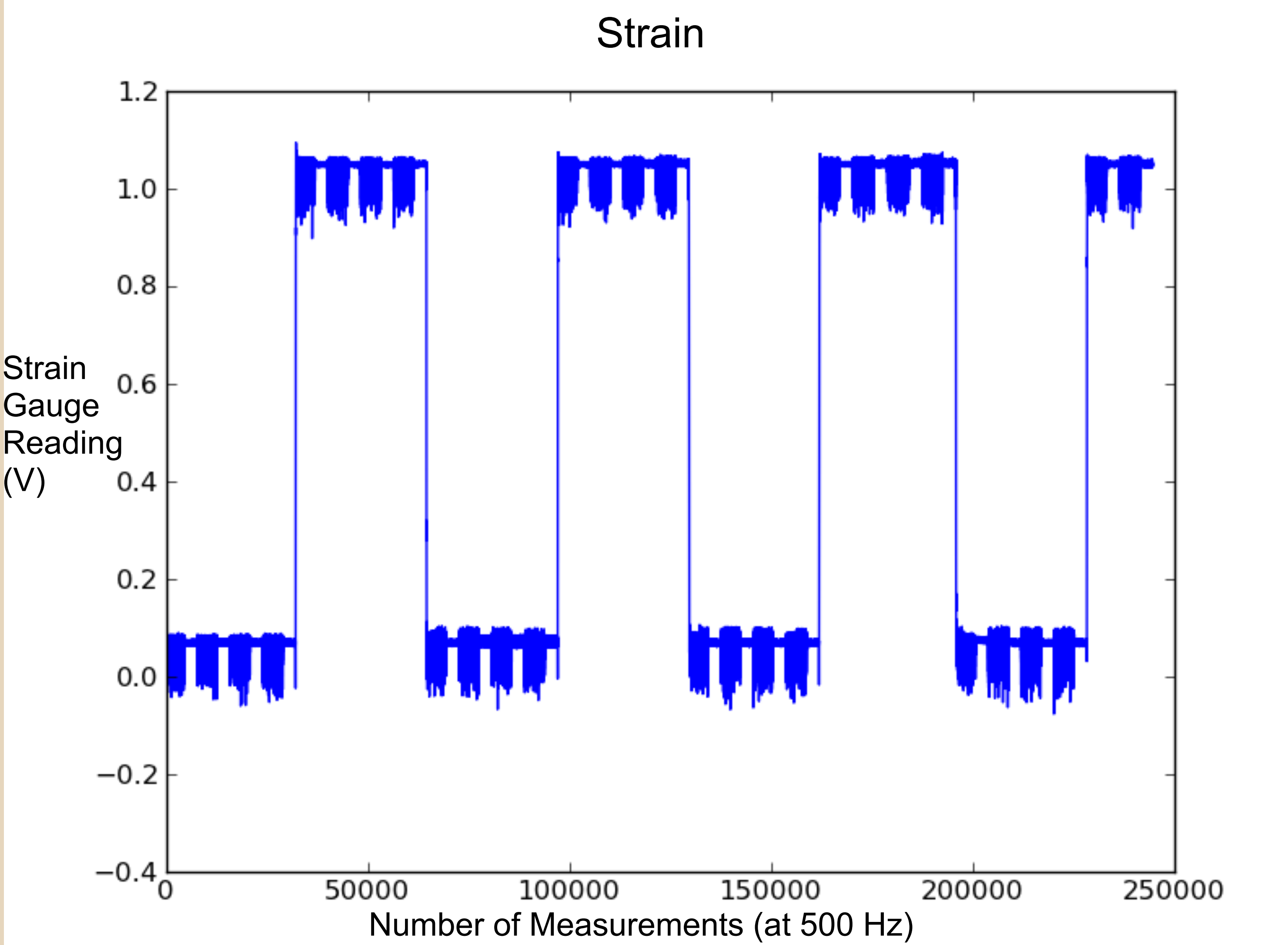


http://upload.wikimedia.org/wikipedia/commons/a/a9/Michaelson_with_letters.jpg

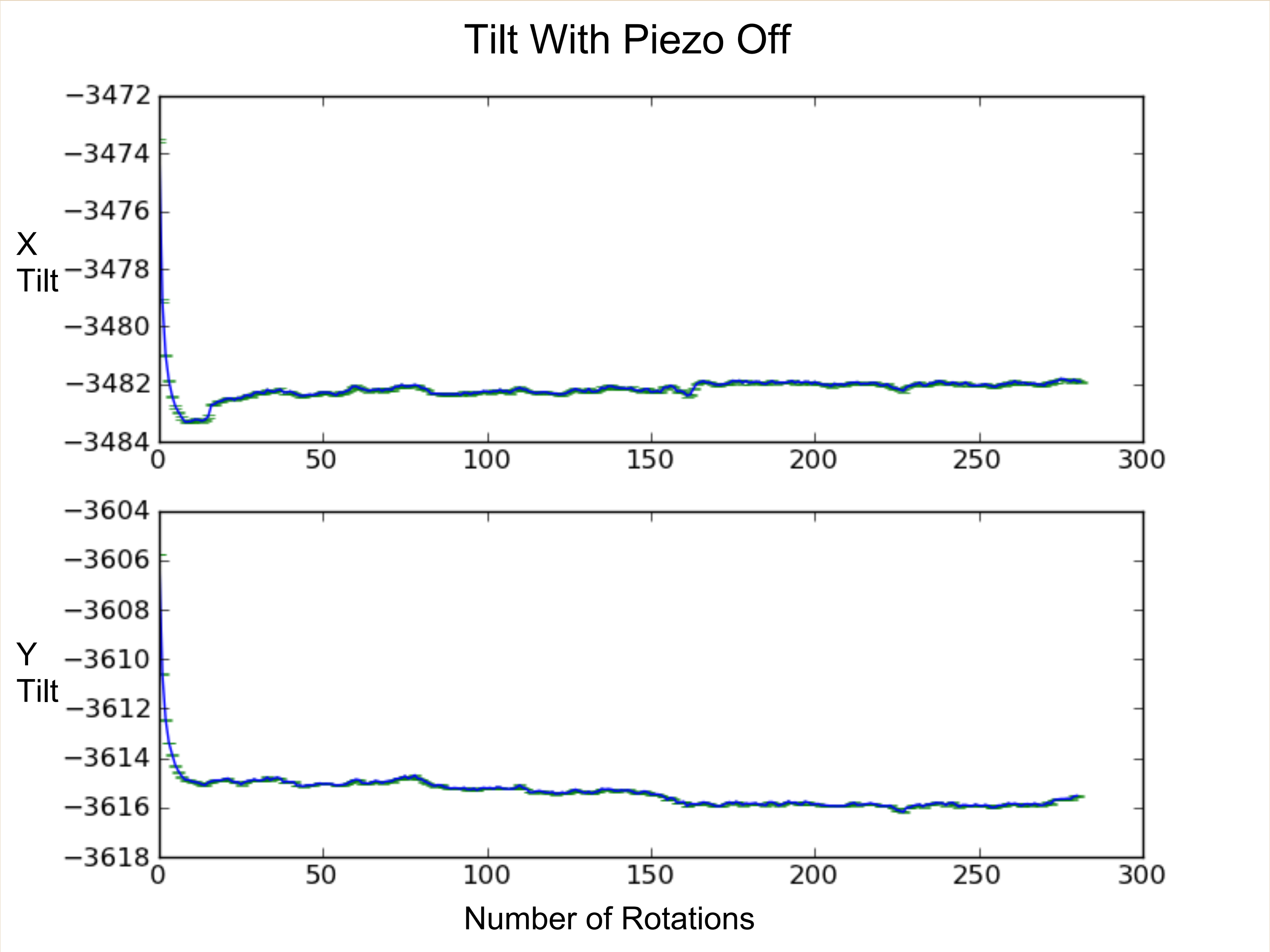
Controlling the Device

- Atmel microcontroller drives the stepper motor
- Data acquisition and piezo feedback loop are run by National Instruments DAQmx software written in C#
- Piezo switches between two lengths in order to calibrate the tiltmeter and avoid errors due to drift in the gain of the tiltmeter

Piezo Repeatability



Preliminary Tilt Results



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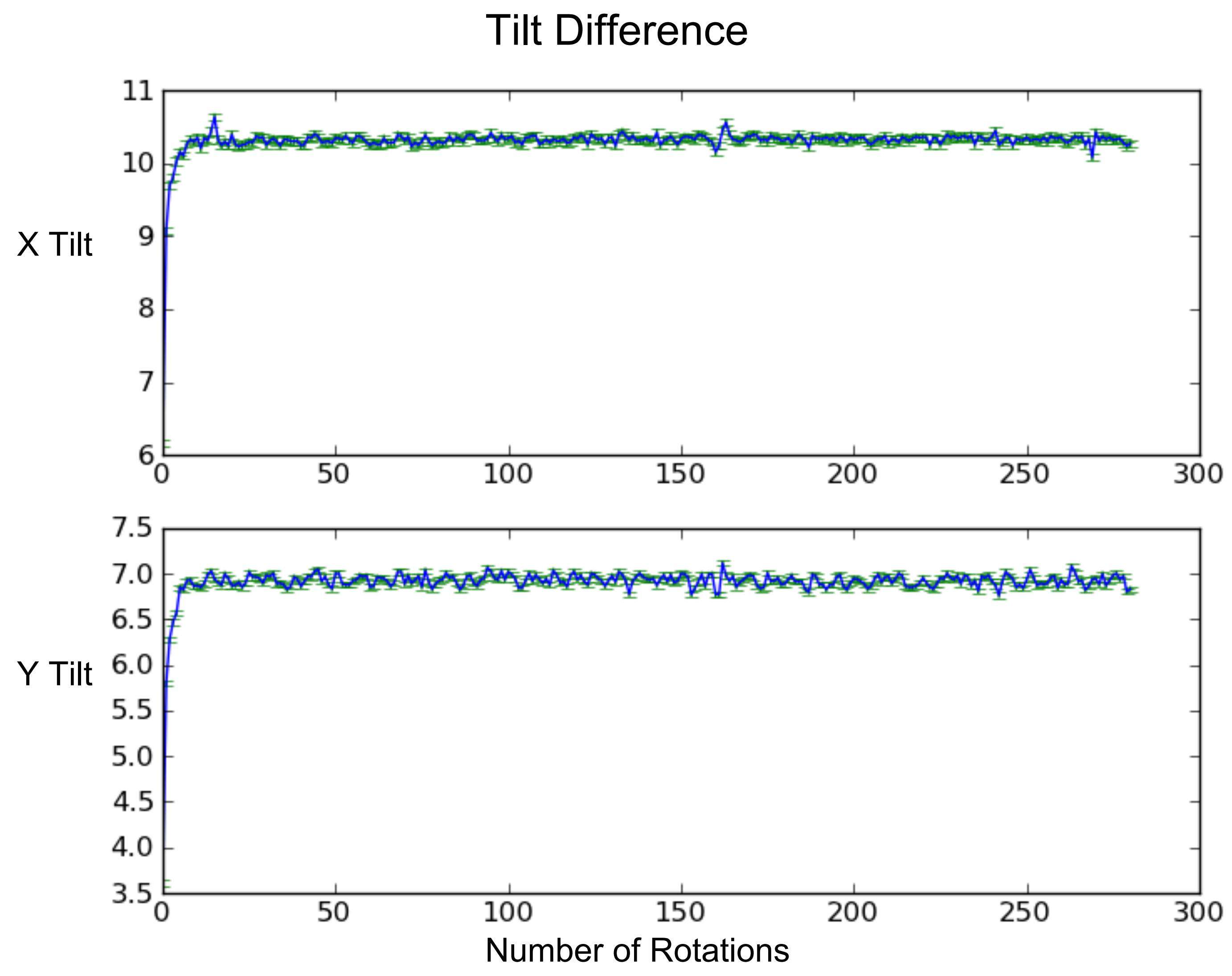
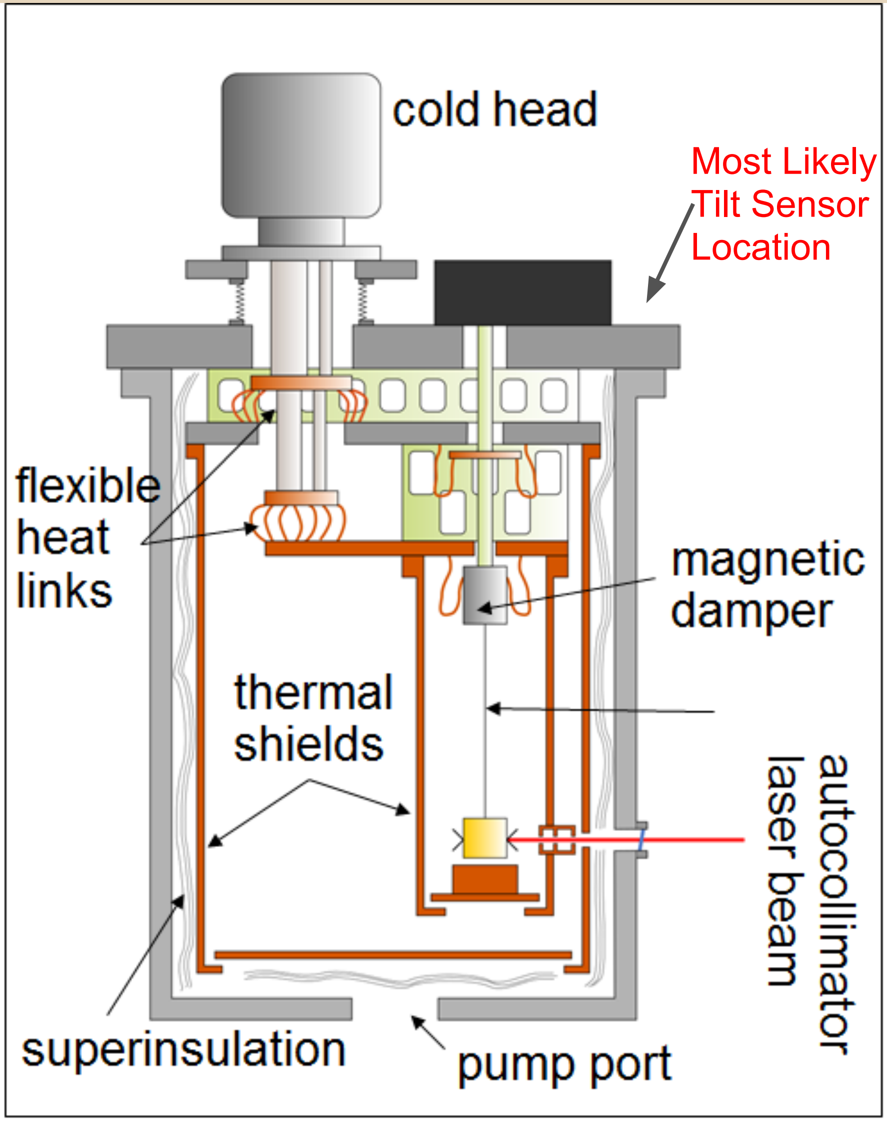


Future Work

- Design a more compact version of the rotating tiltmeter setup
- Integrate the data acquisition and feedback software into the existing software for the cryogenic torsion balance
- Mount the rotating tiltmeter setup on the cryostat, as close as possible to the upper fiber attachment

Future Work


cold head
Most Likely
Tilt Sensor
Location
flexible
heat
links
magnetic
damper
thermal
shields
autocollimator
laser beam
superinsulation
pump port

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