Suspension Design for LIGO and the 40m Interferometer

Viewgraphs for Science/Integration meeting on May 26, 95

LIGO-G950034-00-D

June 1, 95

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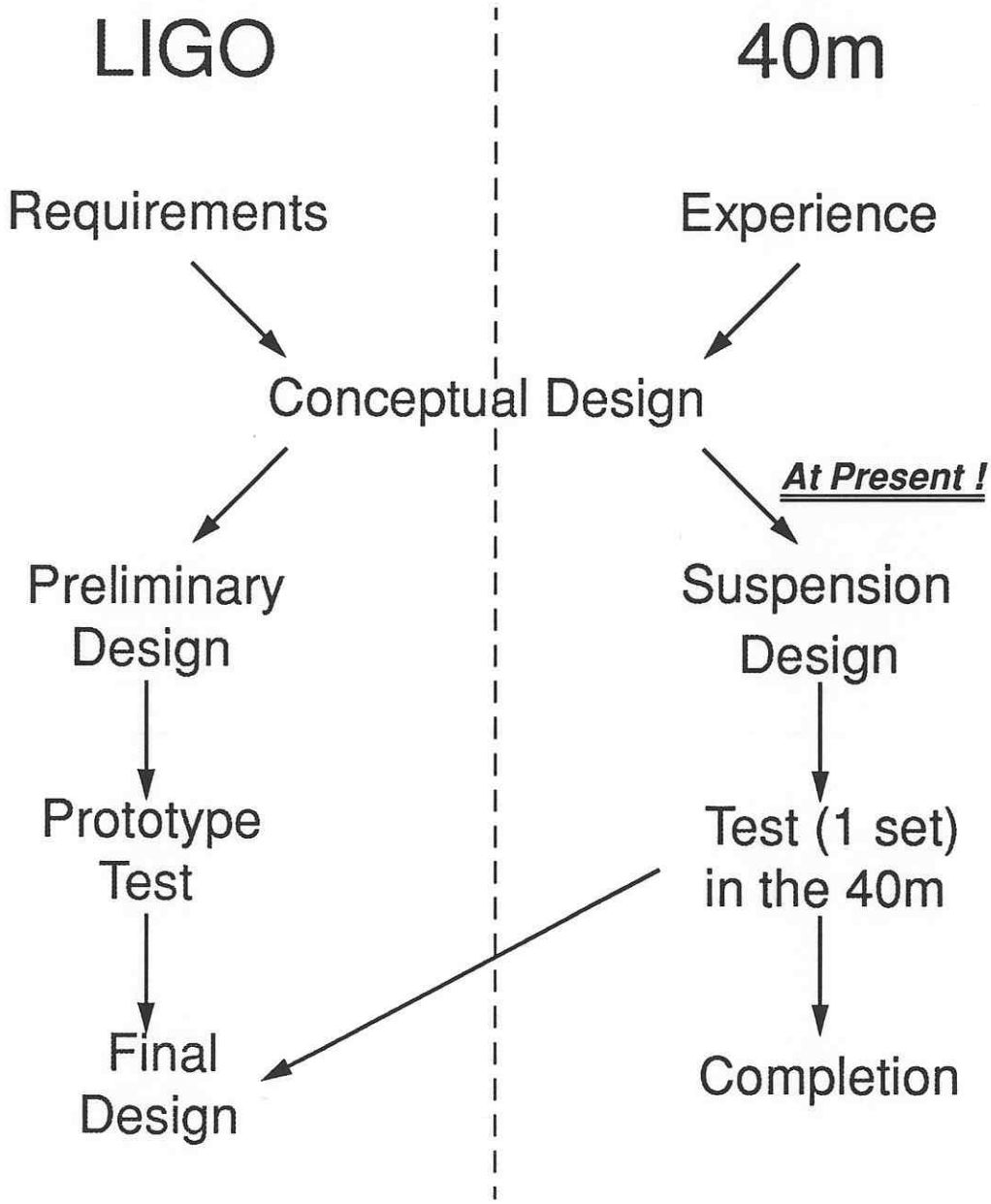
Suspension Design for LIGO and the 40m Interferometer



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Requirements for the LIGO Suspension

- Dynamic Range of Actuator
  - ›› Longitudinal --- 10 μm_{pp}
  - ›› Angular --- 2 $mrad_{pp}$
- Control Noise
  - ›› $5 \times 10^{-20} m/\sqrt{Hz}$ at 40 Hz, $7 \times 10^{-21} m/\sqrt{Hz}$ at 100 Hz per mass
- Thermal Loss
  - ›› Internal mode --- 4×10^{-7}
  - ›› Pendulum mode --- 3×10^{-6}

Experience (Bad Design) from the R&D Suspension (I)

- Independently Mounted Suspension Structure and Head Holder
  - ››Hard to install
- Control Block / Two loops of Wire
  - ››Poor accessibility
  - ››Resonance frequency around 100 Hz
- Big Vane / Slot Sensor / Active Stabilization
  - ››Low resonance frequency
  - ››Additional thermal loss
  - ››Fragility
  - ››Too small clearance
  - ››Complicated circuit causing frequent misbehavior (?)

Experience (Bad Design) from the R&D Suspension (II)

- Preamplifier Attached to Head
  - ››Potential risk of contamination and breakdown
- Wire Slipping on Wire-standoff
  - ››Unstable test mass equilibrium orientation
- Electrostatic Force from Safety Cage
  - ››Wanted! Brilliant idea!

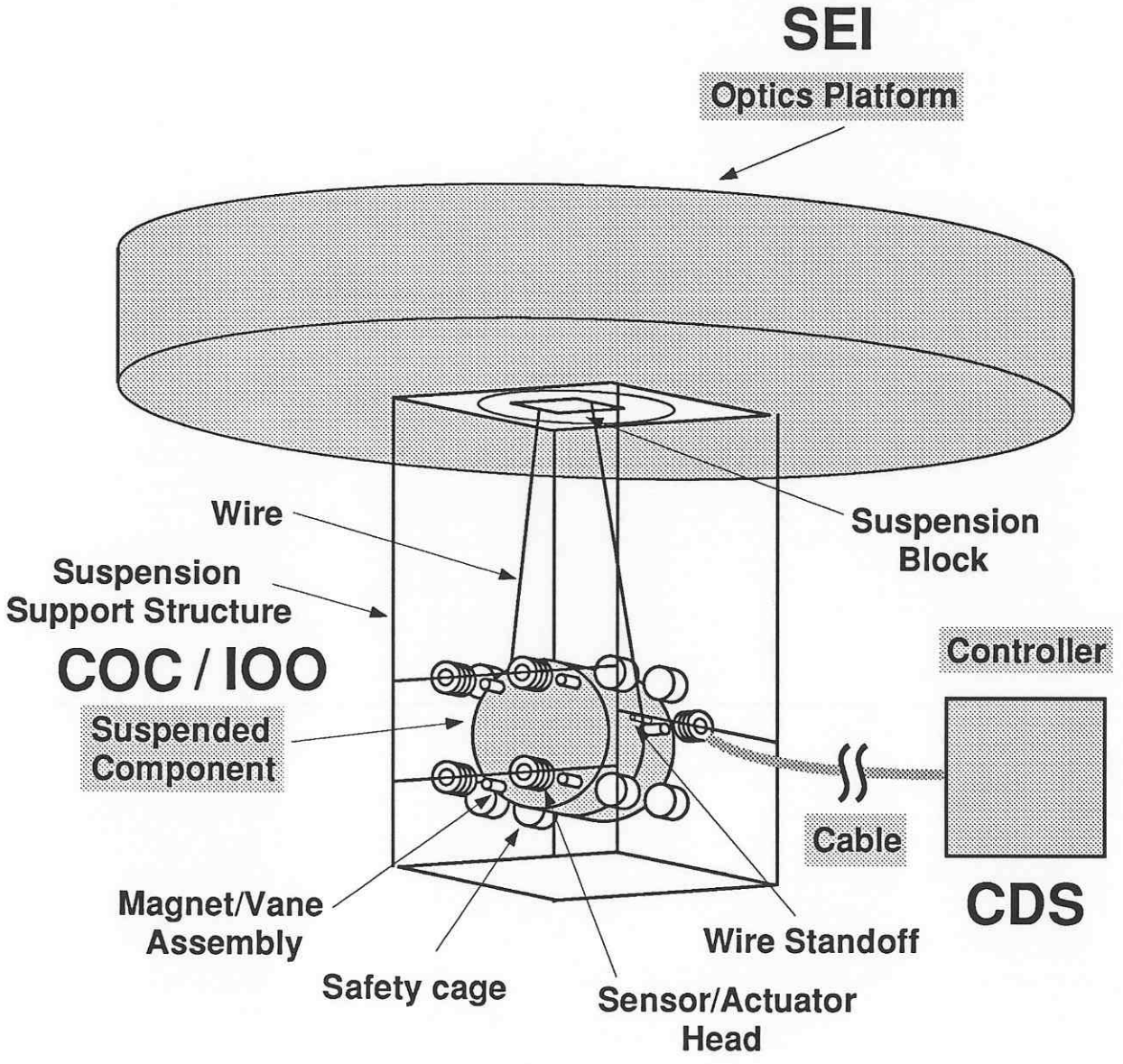
Importance of Reliability, Simplicity, and Robustness

- ~10% of the 40m (w/ 5 suspensions) access time has been used for:
  - ››Installation/adjustment of the suspension system
  - ››Daily alignment
  - ››Investigation/repair of malfunctioning suspension system
- There will be 15 to 20 suspensions per site in LIGO.

Therefore

- To provide a good duty cycle, the LIGO suspension must be:
  - ››Reliable
  - ››Simple
  - ››Robust

Conceptual Design of the LIGO Suspension



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One-body Modular Suspension Assembly

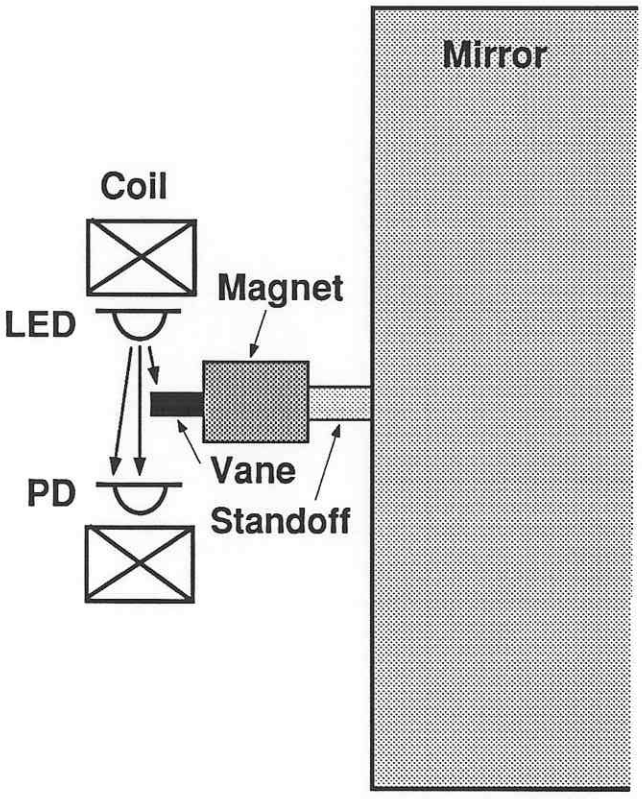
- Modular Suspension Assembly Consists of:
  - ››Suspension Support Structure
  - ››Sensor/actuator head holder
  - ››Suspension block
  - ››Safety cage
  - ››Stray light shield (TBD)
- Advantages:
  - ››Assembly and adjustment on the bench
  - ››Transfer into the tank
  - ››Easy adjustment in the tank

One Loop of Wire with No Control Block

- Advantages:
  - ››Easy access
  - ››Simple mechanism
  - ››Simple transfer function
  - ››No resonance around 100 Hz
  - ››Less cross-coupling into pitch motion

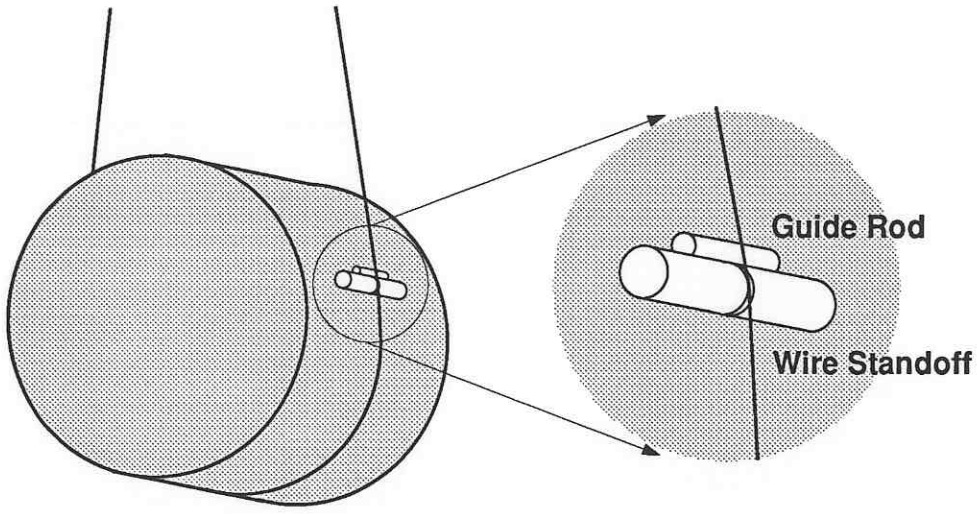
Edge sensor with No Active LED Control

- Results of Investigation:
  - PD output limited by shot noise (~$1 \times 10^{-10} \mathrm{m}/\sqrt{\mathrm{Hz}}$) above 50 Hz
  - Degradation of < 5% for 1.5 years (20 LEDs) at ISAS
- Advantages:
  - No big vane necessary
  - High resonance frequency
  - Less thermal loss
  - Less fragile
  - Good clearance
  - Simple



Preamplifier Located outside Tank

- Results of Investigation:
  - ››No line spikes at PD output
- Advantages:
  - ››Better contamination
  - ››Easy access to the preamplifier for repair
  - ››Good visibility for alignment (from back of the head)



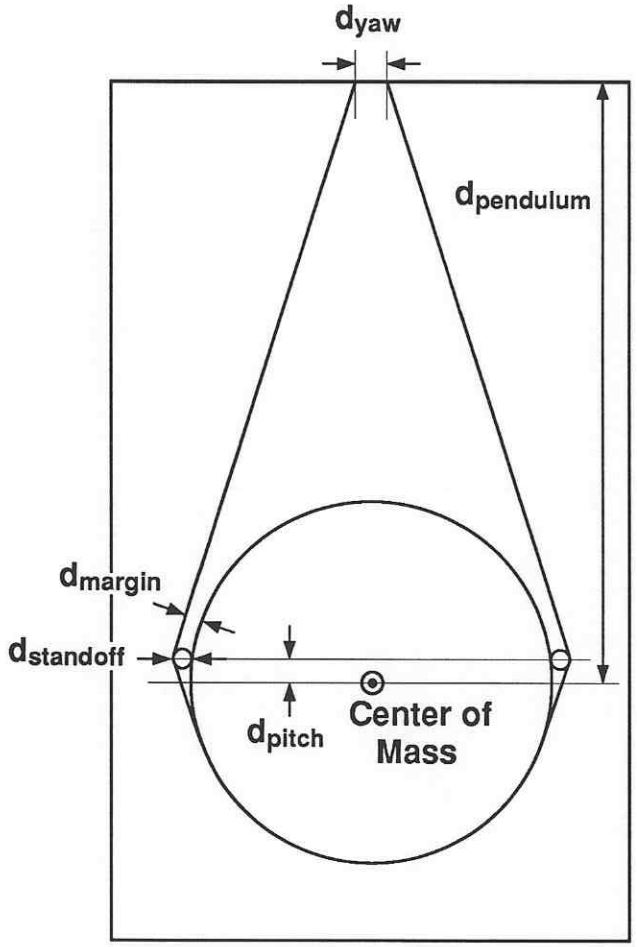
LIGO-G950034-00-D

Groove on Wire-standoff and Guide Rod

- Results of Investigation:
  - ››No degradation in the pendulum mode loss
  - ››No degradation in the internal mode loss
- Advantages:
  - ››Better stability in balance (pitch)
  - ››Easier balancing within 0.1 mrad for the LIGO test mass (with PZT buzzer)
- Problem:
  - ››Difficult to put groove on quartz rod

Suspension Configuration

Table 1:



	Physical Quantity	*LIGO TM*	*40m TM*
	Pendulum Frequency	0.74 Hz	0.84 Hz
	Pitch Frequency	0.5 Hz	0.5 Hz
	Yaw Frequency	0.5 Hz	0.5 Hz
	$d_{pendulum}$	45 cm	35 cm
	d_{pitch}	5 mm	1.3 mm
	d_{yaw}	34 mm	18 mm
	$d_{standoff}$	3 mmD	1 mmD
	d_{margin}	0.5 mm	0.8 mm

Sensor Noise and Loop Gain (Test Mass Side Control)

- Sensor Noise --- $1\times10^{-10}\mathrm{m}/\sqrt{\mathrm{Hz}}$ above 40 Hz
  - ››Experimentally verified
- Crosscoupling from transverse to longitudinal force --- 0.01
  - ››Probably possible !
- Servo loop gain --- 5×10^{-8} at 40 Hz and 7×10^{-9} at 100 Hz
  - ››Possible !

Driver
Noise and Dynamic Range

- Driver Noise --- $1.5\times10^{-12}\,\mathrm{A}/\sqrt{\mathrm{Hz}}$ (0.02 N/A) above 40 Hz
  - ››Corresponding to Johnson current of 5 kΩ
- Actuator Dynamic Range --- 100 mA_{pp} (0.02 N/A) below 0.15 Hz
  - ››Corresponding to 20 V, 200 Ω or 500V, 5 kΩ
- Big series inductor or high voltage is a solution.

Design
TBD

- Grooved Wire-standoff
- Driver
- No Vane
- Safety Cage
- Stray Light Shield (?)