# OSEM sensor recommendation: requirements and decision process

K. A. Strain

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# How the requirements arise

- Flowdown from Advanced LIGO Systems Design Requirements
  - via suspension DRD
    - total noise per suspension (evaluated at 10 Hz in science mode) figures from NAR based on latest models
    - OSEM sensor noise must not lead to an increase of more than 1% in this (noise power)
    - Groups of sensors (in one DOF) evaluated to set a noise limit 1/10$^{th}$ of amplitude
    - include effects of filtering at 10 Hz

# Primary requirements (local control)

- Sensor noise at 10 Hz for OSEMS for
  - Local control on 6 DOF
  - grouped into
    - horizontal acting (long, yaw, pitch*)
    - horizontal transverse
    - vertical transverse (vert, roll, pitch)
  - Local control of 4 SUS types
    - TM, BS=FM, RM, MC
- Sensor range
  - we agreed to work with 3 mm range as a conservative starting point (more on this later)

* pitch control via horizontal actuators in quads is assumed

# Primary requirements (local control, reaction chains)

- Sensor noise requirements much relaxed
  - no direct sensitivity to reaction chain motion
  - only via coupling through actuators
- Range requirement as per main suspensions

* pitch control via horizontal actuators in quads is assumed

# Primary requirements (global control)

- Sensor noise low enough to allow
  - transfer function measurements/calibration of suspensions
  - some level of diagnostic of excess noise
  - no particular reason to do better than ~1e-10m/rtHz
- Sensor range
  - requirement (although TBD) on relative alignment of main and reaction chains will me *much* tighter than 3 mm pk-pk (to allow electrostatic and stronger electromagnetic actuators to operate with near-constant "force constant")
  - the 0.6 mm range of Initial LIGO OSEMs (or similar) probably adequate

* pitch control via horizontal actuators in quads is assumed

# Relaxations: tolerating noisy sensors

- Control transfer
  - certain DOFs on TMs under interferometer control in science mode (turn down/off local controls)
    - long, yaw, pitch
    - no noise requirement during science mode
    - just “RMS” requirements for acquistion
- Eddy current damping
  - certain DOFs on TMs, BSs, FMs are able to be passively damped during science mode (at least)
    - vert, roll, pitch
    - requirement as above

# Relaxations (continued)

- Feedback noise at 10 Hz can be less than sensor noise
  - reduce gain 10 to 15 dB in science mode (typically reduces *rms* velocity/acceleration of optic)
  - allow extra ~20 dB of noise filtering in science mode
  - all sensors can be up to 30 times noisier than basic requirement
    - note that changes to the suspension design will affect the estimate and TM suspensions are not yet fixed

# Performance requirements assuming two sensor designs

- A: High sensitivity design requirements
  - limiting noise at 10 Hz
  - limiting control-band noise
    - important control band noise (assessed as *rms* velocity or acceleration) is the contribution in a ~1 Hz band around ~1 Hz [at lower frequencies the SEI noise dominates]
- B: Low sensitivity design "requirements"
  - aim for something needing ~ no development
    - sensor similar to Initial LIGO/ GEO /Hybrid OSEM
    - ~1e-10 m/rt Hz at 10 Hz
  - use wherever that is safe

# Other OSEMS

- Transverse horizontal
  - all low sensitivity
- Reaction pendulums
  - all low sensitivity
- Global feedback OSEMs with sensors
  - all low sensitivity (also for reasons of fit)

# Requirements table – noise at 10 Hz (m/rtHz)

| SUS | MC | MC | RM | RM | TM | TM | BS/FM | BS/FM |
|---|---|---|---|---|---|---|---|---|
| DOF | L | V | L | V | L | V | L | V |
| No. | 2 | 3 | 2 | 3 | 2 | 3 | 2 | 3 |
| DRD | 3.00E-18 | 3.00E-15 | 4.00E-17 | 2.00E-14 | 1.00E-20 | 1.00E-17 | 2.00E-18 | 2.00E-15 |
| TR | 3.70E-06 | 4.90E-04 | 6.10E-06 | 4.50E-04 | 2.10E-07 | 1.20E-04 | 9.40E-07 | 2.30E-03 |
| 1 | 5.73E-13 | 3.53E-12 | 4.64E-12 | 2.57E-11 | 3.37E-14 | 4.81E-14 | 1.50E-12 | 5.02E-13 |
| 2 | 1.72E-11 | 1.06E-10 | 1.39E-10 | 7.70E-10 | 1.01E-12 | 1.44E-12 | 4.51E-11 | 1.51E-11 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

- Shaded regions show requirements removed by switching to ISC feedback and (optionally, as examples) eddy current damping. Basic sensors are probably adequate in some of the cases marked (yellow).
- DRD – documented, TR from Norna, 1 – direct calculation, 2 – allow factor 30 reduction in controller noise feedthrough from gain and better filtering than used to estimate TR.

# Requirements table – noise at 10 Hz (m/rtHz)

| SUS | MC | RM | TM | BS/FM | |
|---|---|---|---|---|---|
| DOF | TH | TH | TH | TH | |
| No, | 1 | 1 | 1 | 1 | |
| DRD | 3.00E-15 | 2.00E-14 | 1.00E-17 | 2.00E-16 | |
| TF | 4.00E-06 | 6.00E-06 | 2.00E-07 | 1.00E-06 | |
| 1 | 7.50E-10 | 3.33E-09 | 5.00E-11 | 2.00E-10 | |
| 2 | 2.25E-08 | 1.00E-07 | 1.50E-09 | 6.00E-09 | |
| | | | | | |
| | | | | | |
| | | | | | |

- Basic sensors are adequate in all cases (yellow)
- DRD – documented, TR from Norna, 1 – direct calculation, 2 – allow factor 30 reduction in controller noise feedthrough from gain and better filtering than used to estimate TR.

# Sensor types investigated

- Interferometric sensors
  - most obvious route to high sensitivity
- Geometric sensors
  - split-detectors, modulation/demodulation to reduce 1/f noise, optical amplification of the displacement signal, etc.
- Basic shadow sensors
  - like the designs employed in Initial LIGO and GEO 600

# Interferometric sensors

- semiconductor diode laser (visible or NIR)
- polarisation scheme
- 3 outputs: two differences give quadrature fringe signals with mean about zero (lissajous figures)
- measured performance of benchtop mockup <5e-13m/rtHz at 10 Hz
- working range >3mm pkpk
- tilt working range ~ mrad pkpk
- can be miniaturized
- technical report follows

# Advanced geometrical sensors

- high power NIR LED
- modulation/demoduation scheme (~10 kHz)
- split detector
- regulation of light output
- doubling prism can be added
- working range 2~3mm pkpk
- noise performance disappointing (suspect that OD50L emitter has problems, failed to find alternative)
- potentially 1~2 e-11 m/rtHz, but only demonstrated at null
- technical summary follows

# Basic geometrical sensors

- like Initial LIGO OSEMs or Hybrid LIGO/GEO OSEMs
- IR LED and single detector
- range 0.6mm or more (pkpk)
- ~1 e-10 m/rtHz
- development required (materials of hybrid sensor, or geometry of Initial LIGO sensor)

# Risk assessment table

| | Interferometer | Shadow/imaging |
|---|---|---|
| sensitivity | 5e-13 | 2e-11 (but only at null) ?over whole range? |
| range | >3 mm | 2~3 mm |
| Thermal | No issue | Probably OK |
| Cables | Fine | Fine unless we regulate emitter with AC to stabilize (radiates noisy AC) |
| Size Cylinder <40mm by <70 mm | Small risk * | No risk |
| Reliability | Laser (worse? Soak test? 2 for redundancy?) | LED (better?) |

# Proposal

- fit interferometric sensors in high sensitivity locations
  - removes the need for eddy current damping (makes it optional rather than mandatory)
- fit modified basic sensors everywhere else
  - low cost (development and production)

# Other requirements considered

- alignment difficulty/adjustment requirements
- vacuum compatibility (number of materials requiring approval)
- electrical compatibility
- thermal compatibility
- compatibility with actuator (fit)
- magnetic compatibility

Please ask for detail/status on any of these