Evaluation of EPI Approaches

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EPI Design Review #2

Evaluation of EPI Approaches

- HEPI is the default or primary approach
  - » MEPI was conceived as backup to reduce risk
- Both systems appear to meet requirements
  - » both systems have pros and cons
  - » Both have remaining uncertainties
  - » It is reasonable & responsible to revisit the choice of a hydraulic actuator (chosen for adv. LIGO) in this application for initial LIGO
- Evaluation
  - » Comparison to PEPI is needed to insure that the increment in performance justifies the cost
  - » Factors have been proposed with the intent of choosing between HEPI or MEPI
  - » There are differences of opinion on the relative importance of these factors and the on the evaluation of some of the factors
  - » Answers are not currently known to all evaluation questions

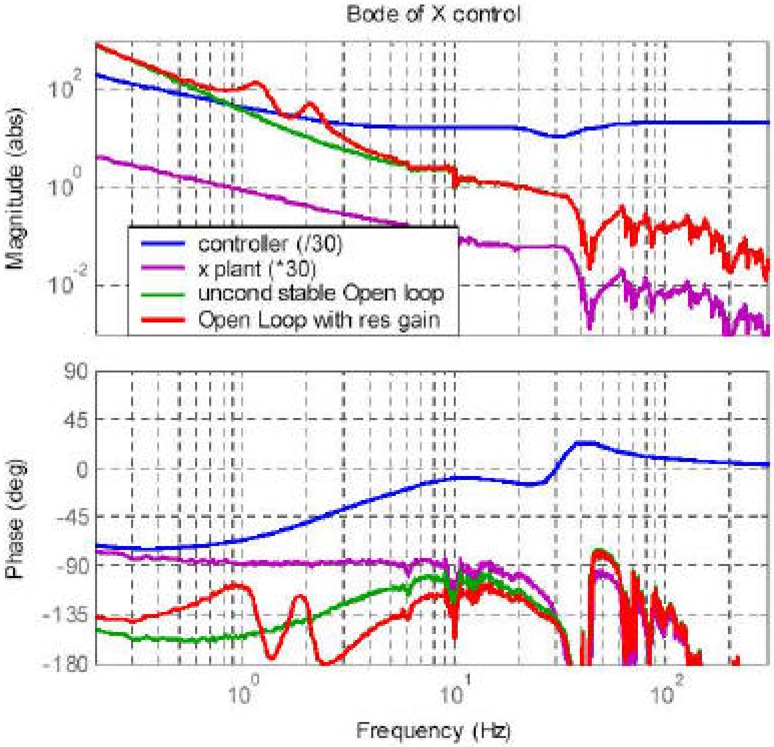
Evaluation of EPI Approaches

- Sensing
  - » All rely upon interferometric sensing for tidal correction
  - » All rely upon the STS-2 for microseismic sensing
  - » PEPI uses a GS-13 geophone mounted near the actuator, but atop the crossbeam
  - » HEPI and MEPI both use co-located and co-axial eddy current position sensors and L4C geophones; i.e there is no difference in the sensing

Evaluation of EPI Approaches

- HEPI/PEPI/BSC Dynamics & Control
  - » Both PEPI and HEPI are "stiff", displacement actuators
  - » HEPI/BSC system has passive, critically damped modes to 40 Hz (except for the pier resonance)
  - » The HEPI actuator has a bellows breathing mode resonance at 47 Hz and can't actuate beyond this frequency
  - »The BSC has a high Q first bending mode at 23 Hz
    - –The associated phase loss represents a limit to the upper unity gain, unless this feature is inverted in the control or the pier is significantly stiffened (which may not be practical)
    - –Since the greatest contribution to the rms velocity of the optic is from the microseismic peak and the first 2 stack resonances, the 23 Hz pier resonance is not a serious problem
  - »Perhaps possible to add a resonant gain stage to HEPI in the vertical direction to provide some isolation at the suspension vertical bounce modes? (12 Hz for LOS, 15 Hz and 16 Hz for SOS)

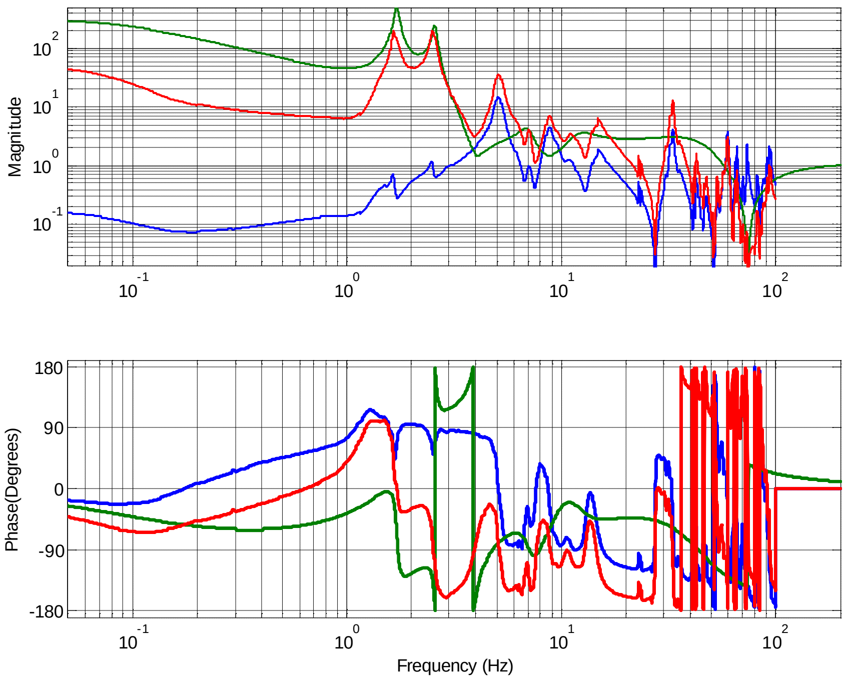
Sweet!



Evaluation of EPI Approaches

- MEPI/HAM Dynamics & Control
  - » MEPI is a “soft”, force actuator
  - » The MEPI system has high Q modes associated with the offload springs (rigid body modes)
    - – On the HAM, these modes are from 3 to 10 Hz
    - – Left as is, these modes amplify the ground motion and increase the rms velocity of the optics

Sour!



»The HAM platform has elastic modes from 13 Hz as well as elastic compliance in the “rigid body” modes (i.e. quasi-rigid body modes)

–Either system must address these modes either through structural modifications (stiffening &/or damping) or through active control

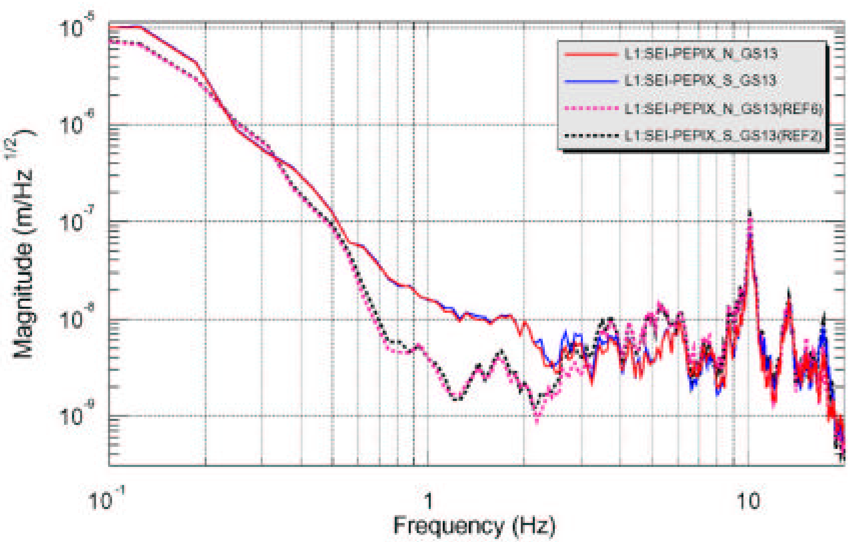
»MEPI deals with these elastic modes by damping them or filtering to avoid exciting the higher order modes, i.e. with control complexity

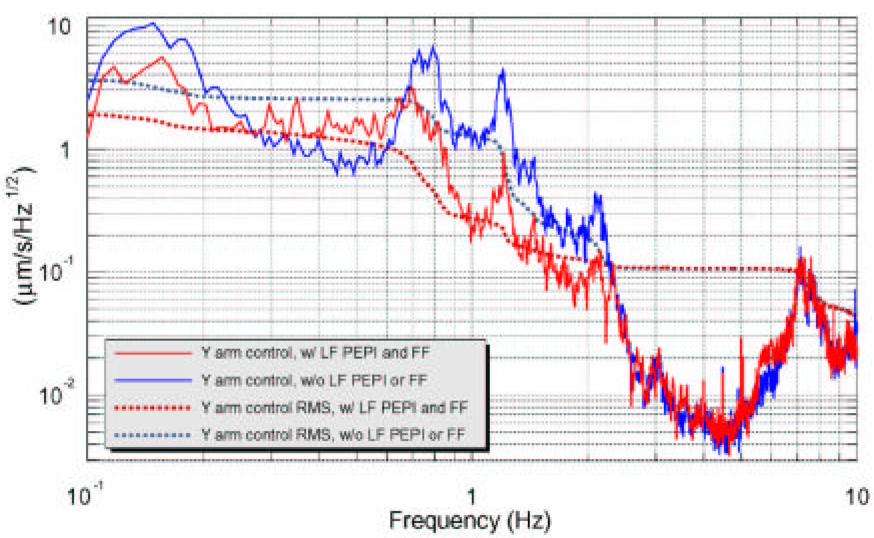
Evaluation of EPI Approaches

- Tidal & Mircoseismic Performance
  - » One expects PEPI, HEPI and MEPI to all perform about equally well for tidal and microseismic correction:
    - – All rely upon the IFO for tidal sensing
    - – All rely upon the STS-2 for microseismic sensing
    - – All are adequate DC actuators
    - – This actuation is below the dynamics of the system
  - » PEPI and to a lesser extent HEPI and MEPI have performed microseismic compensation
    - – Loop shaping for the lower unity gain point has not been a priority in LASTI testing
- Drift
  - » PEPI and HEPI are OK
  - » MEPI is susceptible to thermal expansion & E(T) induced drifts
    - – Spring deflection under load is about 6mm x <1% ΔE = <0.06mm, OK
    - – Spring length is 1m x 11 microns/m/C x +/-2C = +/-0.02 mm OK

Evaluation of EPI Approaches

- Stack Modes (1 to 3+ Hz)
  - » PEPI has achieved an attenuation factor of ~7 in rms motion at the crossbeam
  - » … and a factor of ~4 in relative velocity between the ITM and ETM

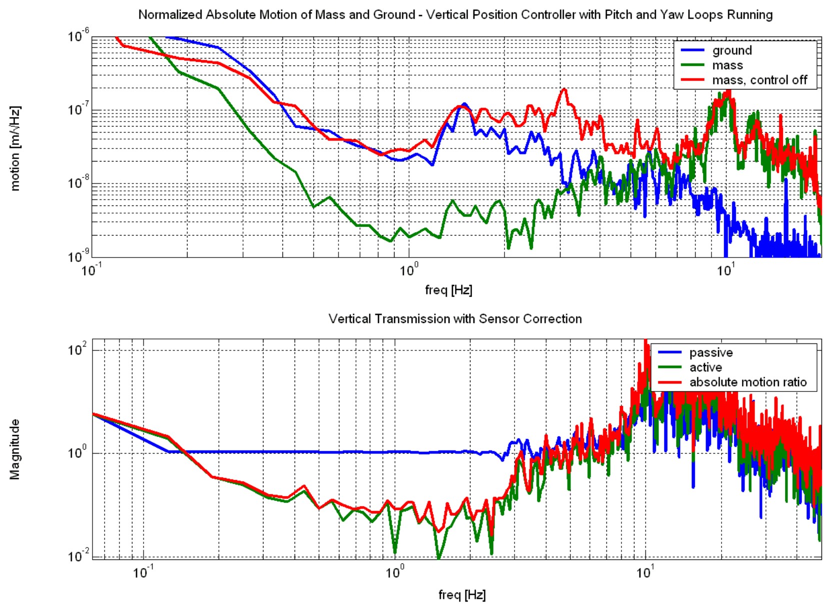




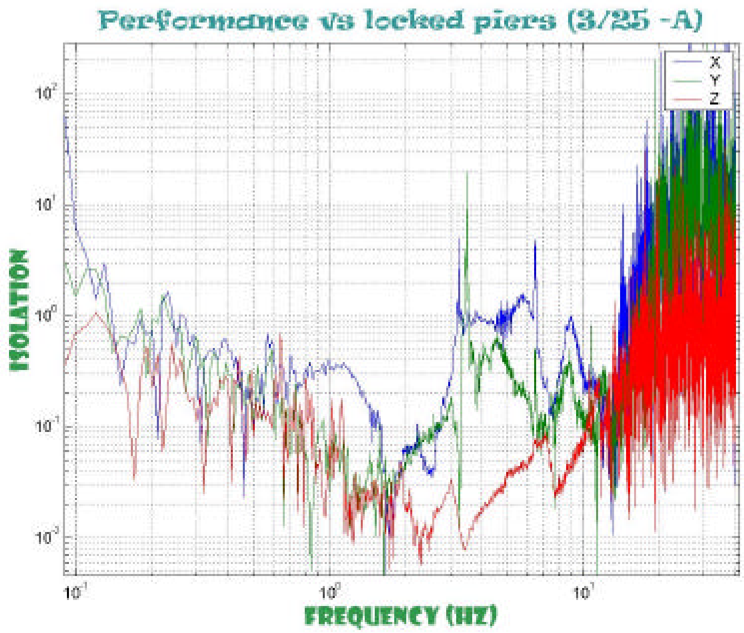
Note: microseismic compensation was off during this data capture

Evaluation of EPI Approaches

- Stack Modes (1 to 3+ Hz) [continued]
  - » Both the HEPI and MEPI systems can achieve a broadband attenuation factor of ~15 in rms motion at the crossbeam
  - » more isolation at stack modes when resonant gain stages are added at the two lower stack mode frequencies



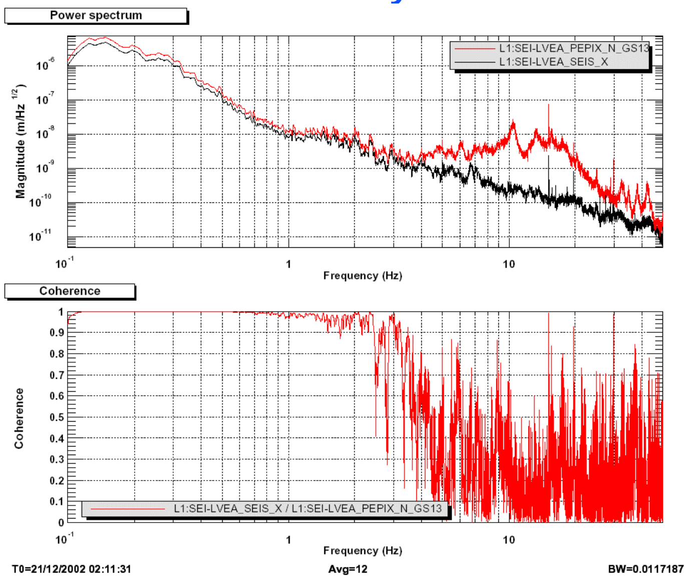
HEPI/BSC to the support table

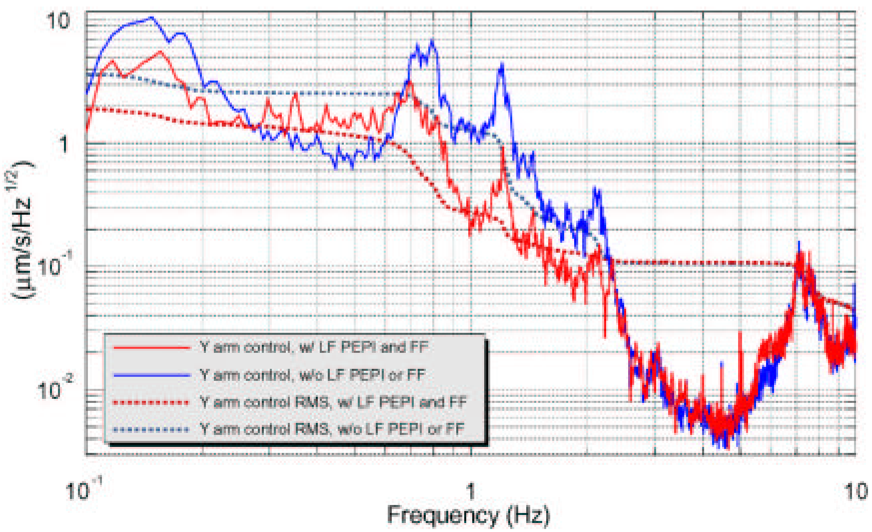


MEPI/HAM to the optics table

Evaluation of EPI Approaches

- "High" Frequency Noise (>4 Hz)
  - » Considerable amplification of ground motion from ~4 Hz to ~25 Hz (up to a factor ~40) is apparent in both the HAM and BSC isolation responses, including PEPI
  - » Apparently due to dynamics of the piers, crossbeams, etc.
  - » However, this does not contribute significantly to the test mass rms velocity





Evaluation of EPI Approaches

- Isolation Robustness
  - » Low frequency (<0.5 Hz) isolation with position sensor correction is common to all the EPI concepts
    - – Some evidence that the performance is not stationary? (for all EPIs)
  - » Velocity Feedback Control
    - – HEPI control (to date) only uses the vertical geophones
      - Simple control laws
      - Good phase and gain margins
      - Robust to plant changes (were any to occur)
    - – MEPI control uses horizontal and vertical geophones
      - Complex control laws (partial plant inversion, elliptic LP filters)
      - Multiple unity gain crossings, generally low to moderate phase & gain margins (for the performance reported); the margins can be increased with some degradation in performance
      - Not Robust to plant changes – but do plant changes occur? [see next page]

Evaluation of EPI Approaches

- Plant Changes?
  - » Sensitivity to environment (dE/dT, αdT), creep → negligible
  - » Reconfiguration (adding or shifting positions of payload) is very infrequent
    - – After initial installation, this has been done only a few times to fix positional errors at the ~1cm level (may not have altered the plant significantly)
    - – About to be done again to correct the Schnupp asymmetry
  - » Macroscopic re-alignment (~ mrad) is infrequent
    - – Tried twice(?) with current coarse actuation systems during initial installation
    - – Used to align the APS port telescope without a vent
  - » load redistribution of the platform (adjusting offload spring tension,re-leveling of the support platform)
    - – Only done on initial installation
  - » Is the infrequent macroscopic table re-alignment due to a poor existing capability, or the lack of a need to do so? (I think the later)
- Consequences?
  - » For HEPI – nada
  - » For MEPI:
    - – Re-measure transfer functions, experts redesign/tweak the control laws, and re-test

Evaluation of EPI Approaches

- Alignment Robustness (angular and translation)
  - » Support control re-allocation from the suspensions
    - – ~100 rad, or ~0.2 mm actuator range
  - » Desirable to have large actuation range:
    - – Long duration locks (~ months) where more range may be required than predicted for tides and estimated thermal effects
    - – Allow for intentional de-centering of optics (to find optimal position for minimizing thermal noise)
  - » HEPI actuators provide ±1 mm range with low (10W) power dissipation
  - » MEPI actuators provide ±0.19 mm range with low (16W) power dissipation (ΔT = 4.9C at actuator)

Evaluation of EPI Approaches

- HEPI Hydrocarbon Contamination:
  - » Using clear, water soluble, non-toxic, non-flammable fluid with bio and corrosion inhibitors
  - » Exposure to a high irradiance, optical cavity indicates no measurable absorption or scattering change to the level required in LIGO
  - » No leaks at LASTI (3 months testing)
  - » Have sensitive level monitoring for leak detection; can seal pump station and exchange air directly with exterior rather than the building air
  - » Low pressure (100 psi) system with high reliability seals
  - » Bottom line: low risk

Evaluation of EPI Approaches

- MEPI Magnetic Field Contamination:
  - » Requires shielding (to be designed)
  - » Requires linear power supplies, or supplies placed in mechanical room with long cables
  - » Bottom Line: not a problem

Evaluation of EPI Approaches

- Costs
  - » The costs indicated for stiffening and damping modifications are for “modest” changes, i.e. not intended to damp all the modes ‘created’ by the addition of MEPI
    - – For the HAM: the stiffening beams plus passive tuned dampers
    - – For the BSC: don’t know

		Costs ($K)	
		per Chamber	5 BSC Chambers 3 HAM Chambers
1A	MEPI Mechanics	$104	$833
	MEPI Electronics	$55	$438
	MEPI Subtotal	$159	$1,271
1B	HEPI Mechanics	$193	$1,547
	HEPI Electronics	$56	$450
	HEPI Subtotal	$250	$1,997
2	HAM Stiffening	$4	$32
	HAM Damping	$2	$16
	HAM Mods Subtotal	$6	$48
3	BSC Stiffening	$8	$64
	BSC Damping	$2	$16
	BSC Mods Subtotal	$10	$80
		per Table	3 ISC Tables
4	ISCT Isolation	$35	$105
		TOTALS for LLO:	
		MEPI	$1,504
		HEPI	$2,230

Evaluation of EPI Approaches

- Don't know:
  - » Earthquake response (though not significant for LLO)
  - » Compatibility with advanced LIGO?
    - – HEPI is compatible
    - – Support structure/system dynamics would have to be considered in the internal active isolation system design
  - » Reliability
    - – 3 months experience isn't much, but neither system has had significant problems
    - – Not likely a discriminator
  - » Transient (non steady-state) response
  - » Applicability to LHO wind noise:
    - – Resonant gain stages at SUS vertical bounce mode frequencies?

Evaluation of EPI Approaches
Conclusions?

- If performance, robustness and range alone are the key criteria, then HEPI is the likely choice
  - » Particularly if some reduction of the vertical bounce modes were possible
- If cost and reduction of hydrocarbon contamination risk are key criteria, then MEPI is the likely choice
- No/little simulation of HEPI/HAM and MEPI/BSC have been done to date
  - » If an immediate decision is required for selecting a system with maximum confidence of success, then the likely choice is HEPI
  - » Best is to choose a system and test it on the other platform