Suspension Diagonalization in LIGO I

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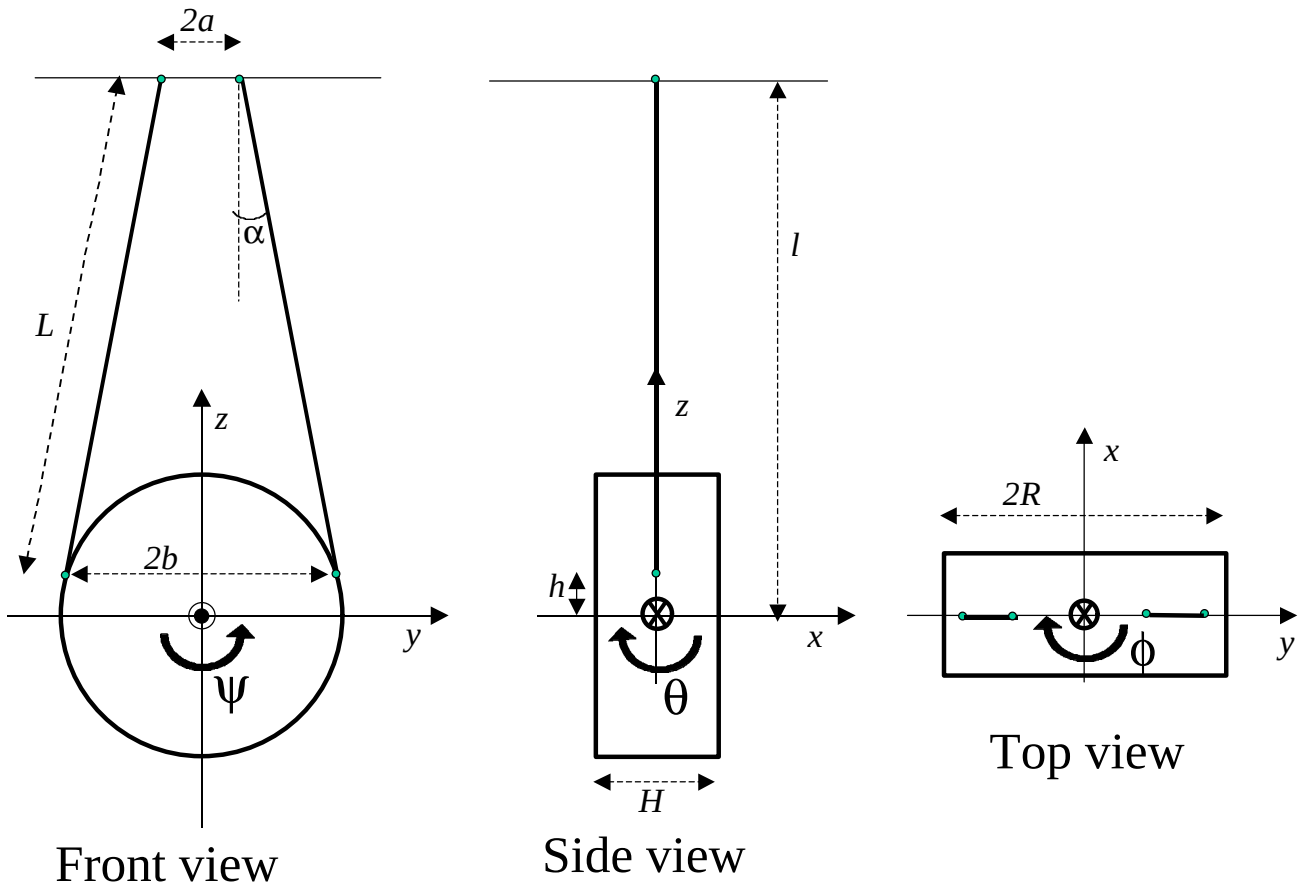
D. Shoemaker, Eric Black, and many others….

LIGO-G000073-00-D


2a
α
L
z
2b
y
ψ
Front view
l
z
h
x
θ
H
Side view
x
2R
y
ϕ
Top view

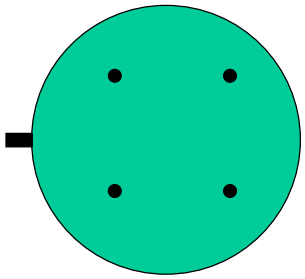
Mirror motion is measured with a “local” or a “global” sensor, and then forces are applied to control the motion.

The local sensors are 4 shadow sensors in the back of the optics and one on the side. The coil-magnet actuators are colocated.

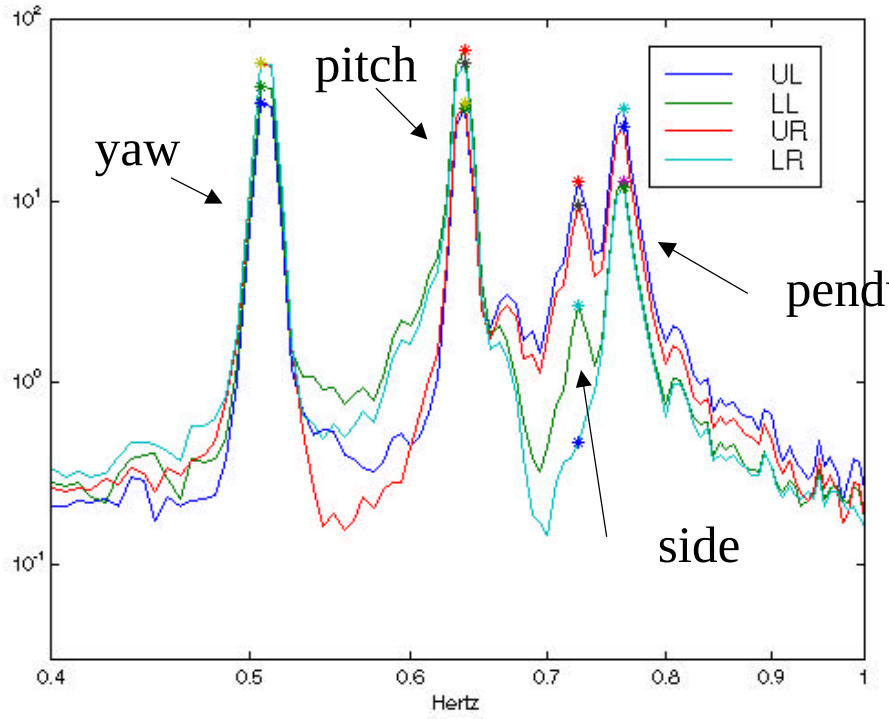
Then,

$UL = x + D\theta + D\phi$
$UR = x + D\theta - D\phi$
$LL = x - D\theta + D\phi$
$LR = x - D\theta - D\phi$

$F = F_{UL} + F_{UR} + F_{LL} + F_{LR}$
$N_\theta = F_{UL} + F_{UR} - F_{LL} - F_{LR}$
$N_\phi = F_{UL} - F_{UR} + F_{LL} - F_{LR}$

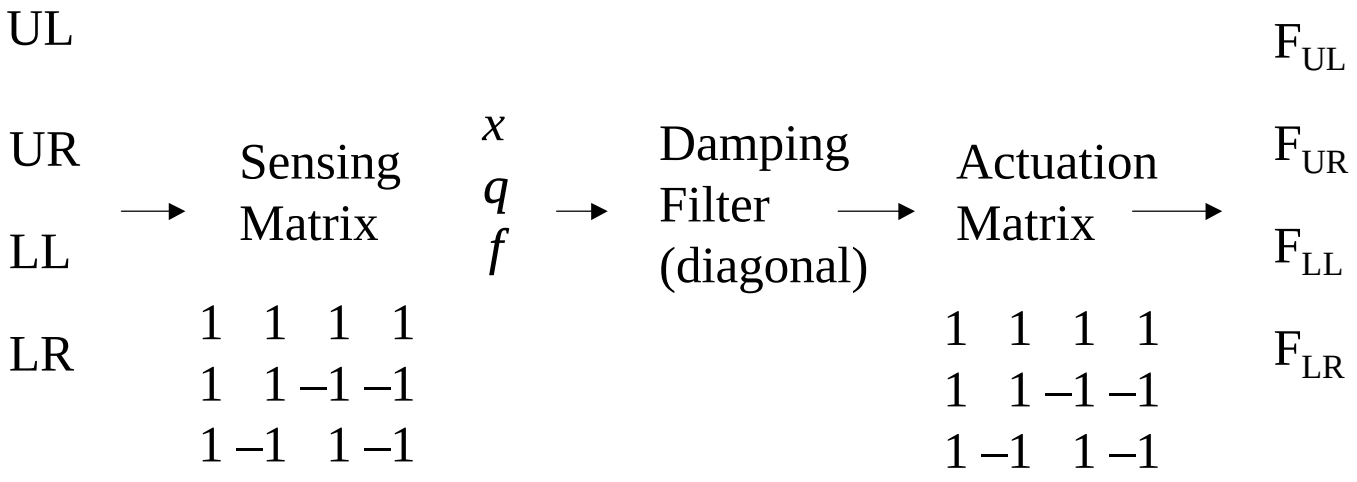


However, shadow sensors have in general different sensitivities, and (in LIGO I OSEM sensors) they are sensitive to transverse motions.

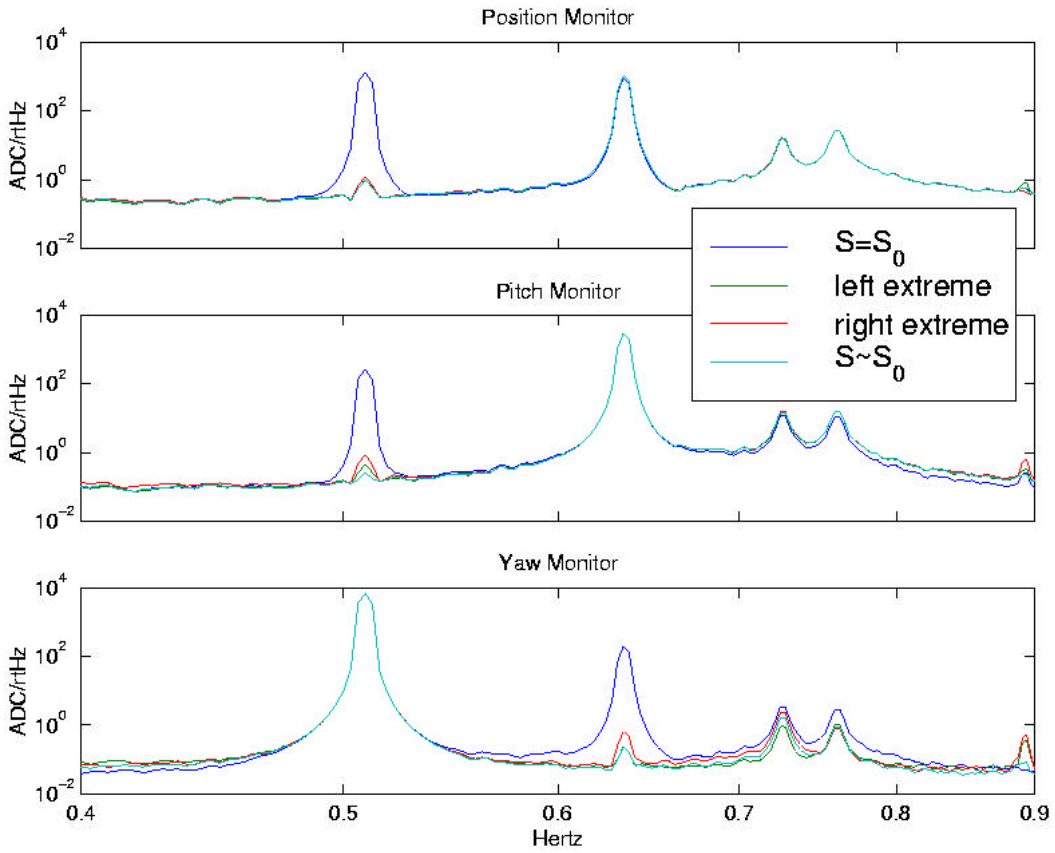


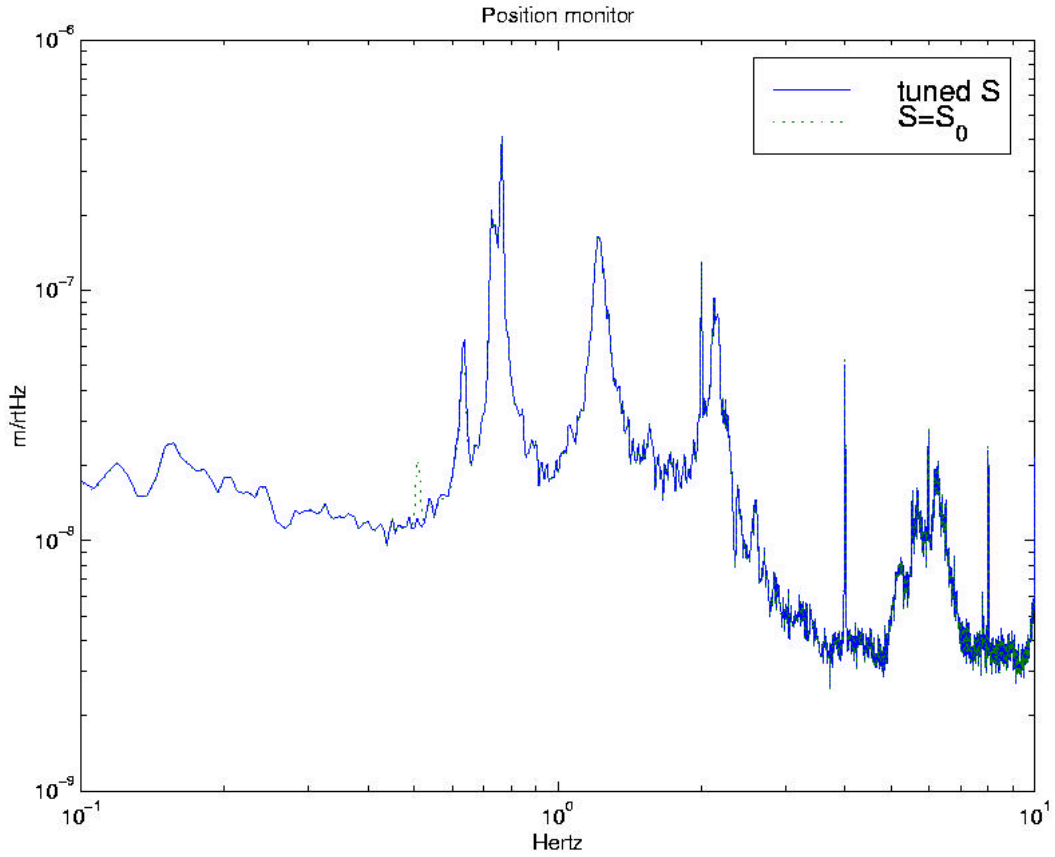
In LIGO I, local damping is done as “modal damping”
(not point-to-point), so the “wrong signals’ get transformed into
“wrong forces” through the local servo.

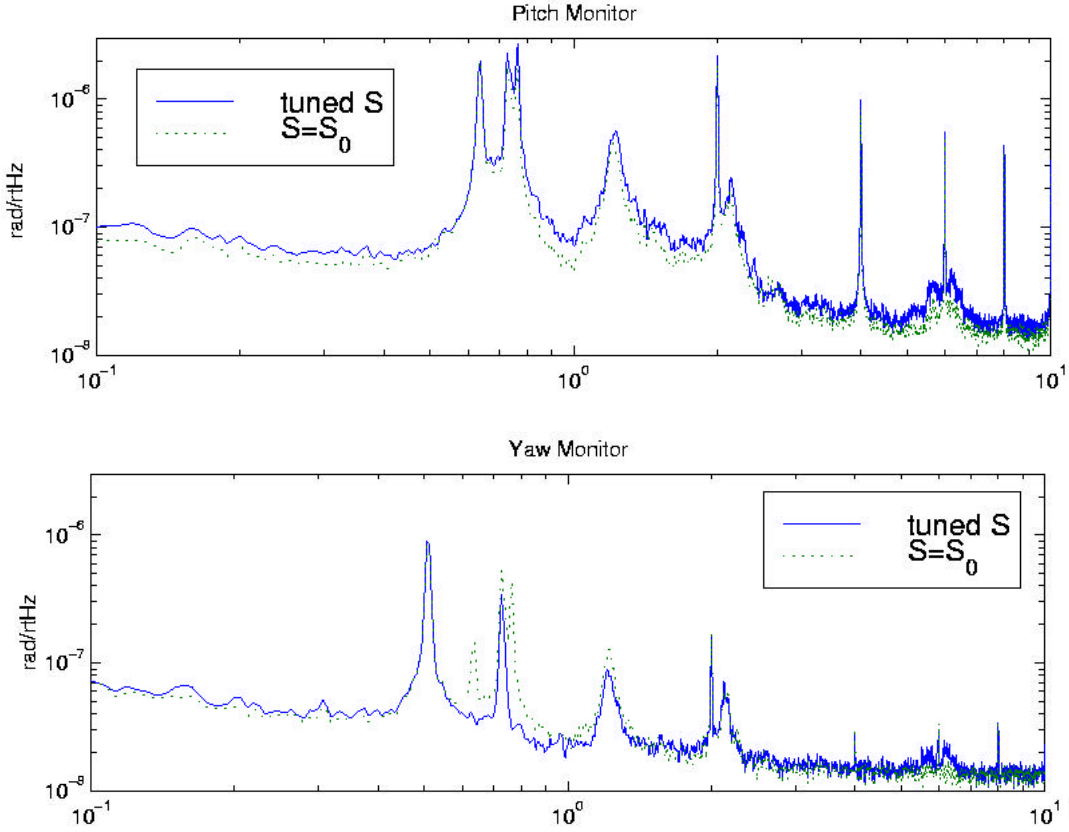
Solution: “diagonalization”
We use variable digital gains in suspension controllers.

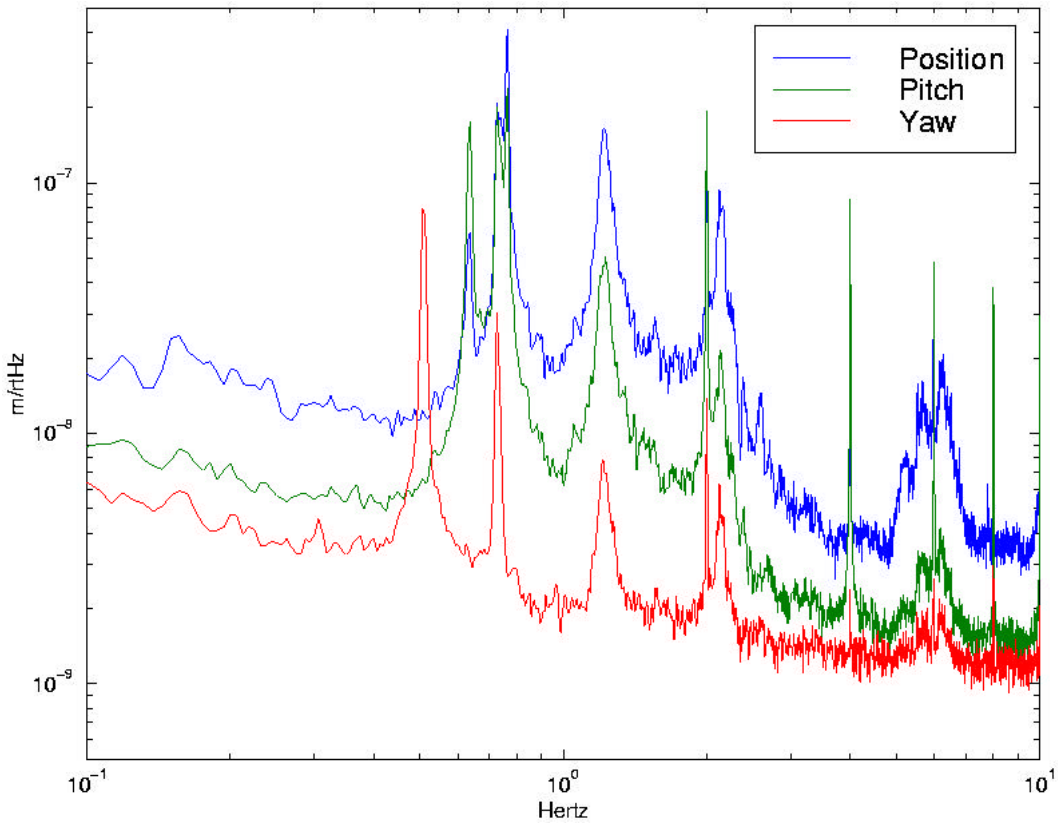


Tuned sensors:



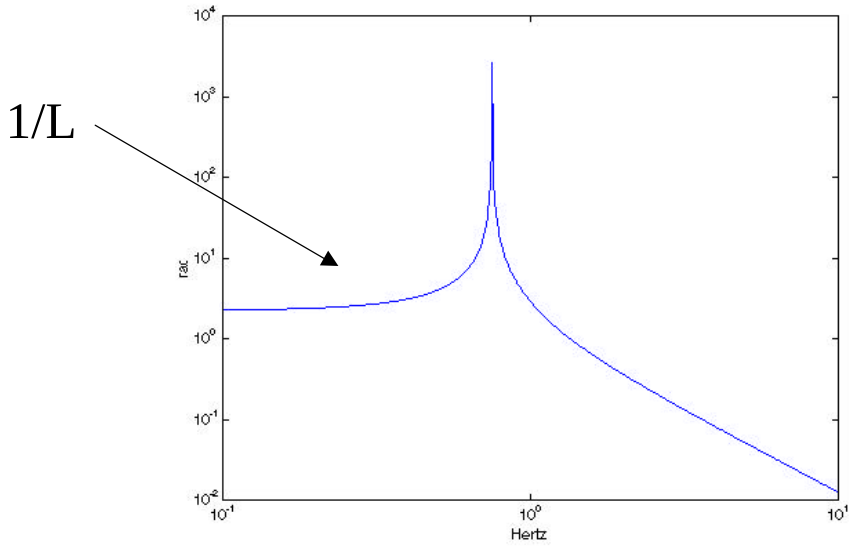

Position monitor
tuned S
S=S0
m/rtHz
Hertz
10^-6
10^-7
10^-8
10^-9
10^-1
10^0
10^1


Pitch Monitor
tuned S
S=S0
rad/rtHz
10^-6
10^-7
10^-8
10^-1
10^0
10^1
Yaw Monitor
tuned S
S=S0
rad/rtHz
10^-6
10^-7
10^-8
10^-1
10^0
10^1


Position
Pitch
Yaw
10^{-7}
10^{-8}
10^{-9}
m/rtHz
10^{-1}
10^{0}
10^{1}
Hertz

A more critical problem:
how to apply forces without introducing angles.

In LIGO I suspensions, there is a non-zero pitch produced by a pure force used to produce a displacement



… for example, when locking an optical cavity

We solve this by using the actuation matrix to introduce a compensating torque for every force, making it “non-diagonal” in a specific way.

However, we then introduce spurious angular noise at higher frequencies.

⇒Mode-dependent matrix (lock acq. vs detection)

….or freq. dependent actuation matrix

For these and other reasons, LIGO I is building a 2^{nd} generation of suspension controllers.

Conclusions:
Questions for LIGO II

Are these issues important in LIGO II,
with multiple pendulum modes strongly coupled by design?

Can we anticipate alignment problems and angular noise?