HAM Seismic Attenuation System (SAS)

System Description, Requirements for Mechanical Fabrication and Assembly

Riccardo DeSalvo

Laser Gravitational Wave Observatories (LIGO)
California Institute of Technology

The LIGO challenge

- The challenge is that the transduction of the stellar motion will generate mirror movements of only 10^{-18} to 10^{-20} m in the frequency band between 10 Hz and 1 kHz
- Additionally, for interferometric reasons, absolute positioning within 10^{-12} m is needed
- This must be achieved against the background of ~ 10^{-6} m natural seismic motion.

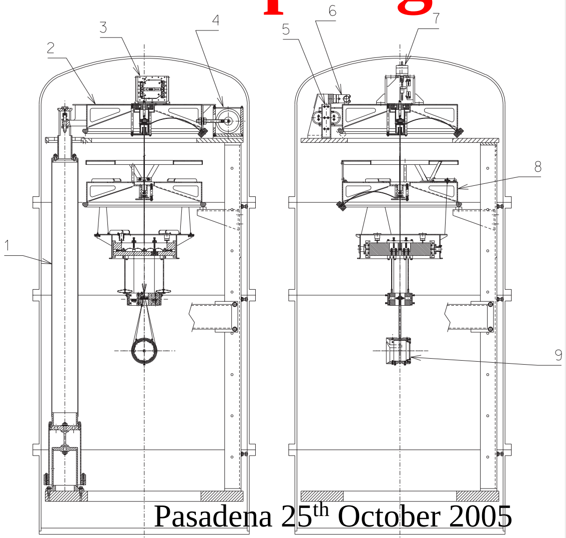
The GWD challenge

- Only if properly seismically isolated,

  suspended masses will

  transduce

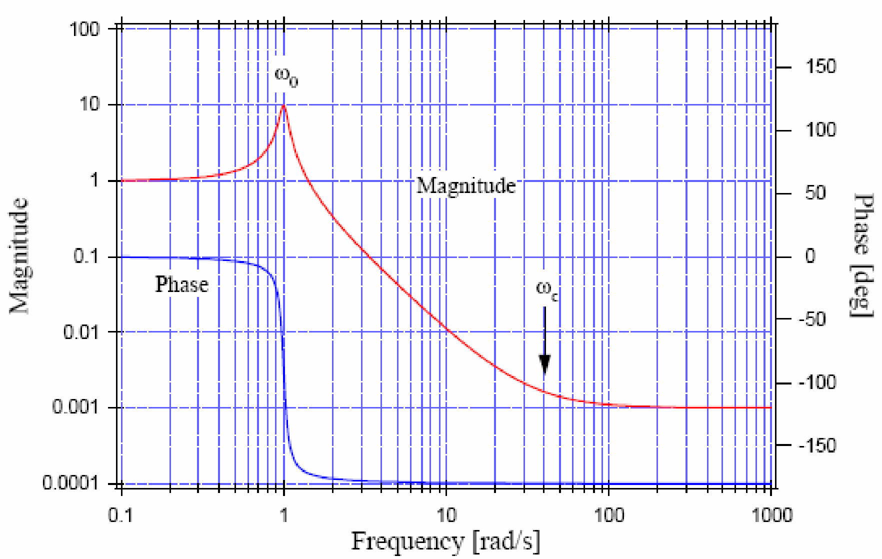
the movements of **colliding or collapsing compact stars**



How is seismic isolation achieved?

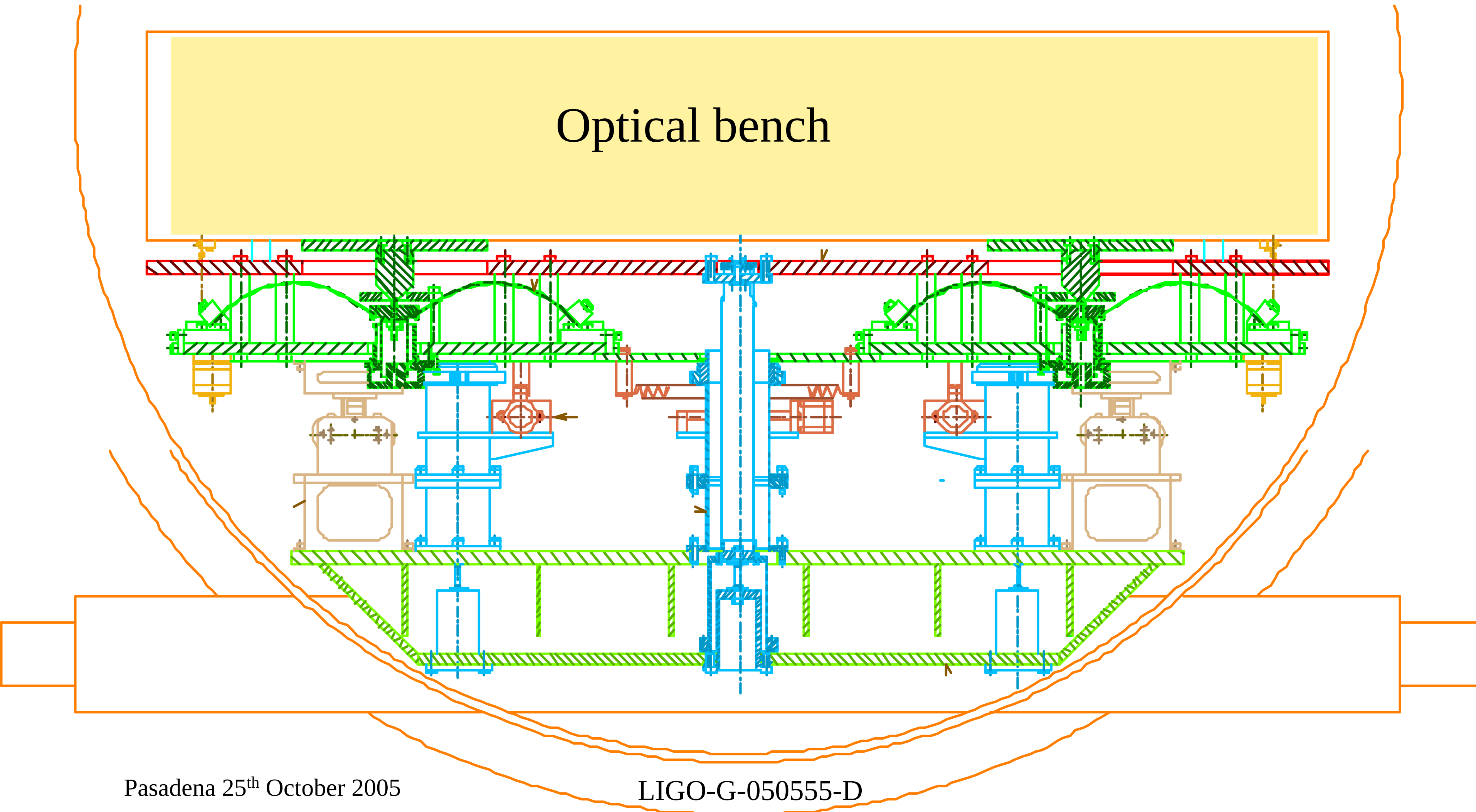
- Mechanical attenuation by a chain of low resonant frequency mechanical oscillators

- Attenuation power ~ $$\frac{1}{(f - f_o)^2}$$



The secret is to achieve Low resonant frequency f_o

This is what we want to build an attenuation bench



Pedigree

- The present LIGO optical benches
- The Virgo passive Superattenuators
- The TAMA SAS filter and IP know how
- Further advances in Inverted Pendula (IP)
  - => 80 to 100 dB
- Further advances in Geometric Anti Spring filters (GAS)
  - => 60 to 80 dB

Requirements outline

- The mechanics, weldments, and all components must be Ultra High Vacuum compatible
- Construction, Cleaning, Assembly, Tuning will be made by the winning bidder with the assistance and guidance of LIGO
- Some Testing will be made by LIGO at the company premises
- Finished assembly shipped for installation in sealed, dry atmosphere packaging and crates
  - Optical table, general assembly, support tubes shipped separately

Construction tentative program

- Phase 1:
- Build prototype for LASTI (LIGO lab@Boston)
  - Awarded after proposal evaluation
- Hiatus while LIGO laboratory evaluate the prototype at LASTI

Construction tentative program

- If the implementation of the concept and it's implementation is positive, and sufficient funds allow, then:
- Phase 2 a:
- Build three units for the Output Mode Cleaner(OMC)
  - (2@ Hanford, 1@Livingston)
- Hiatus while Adv-LIGO gets approval and funding

Construction tentative program

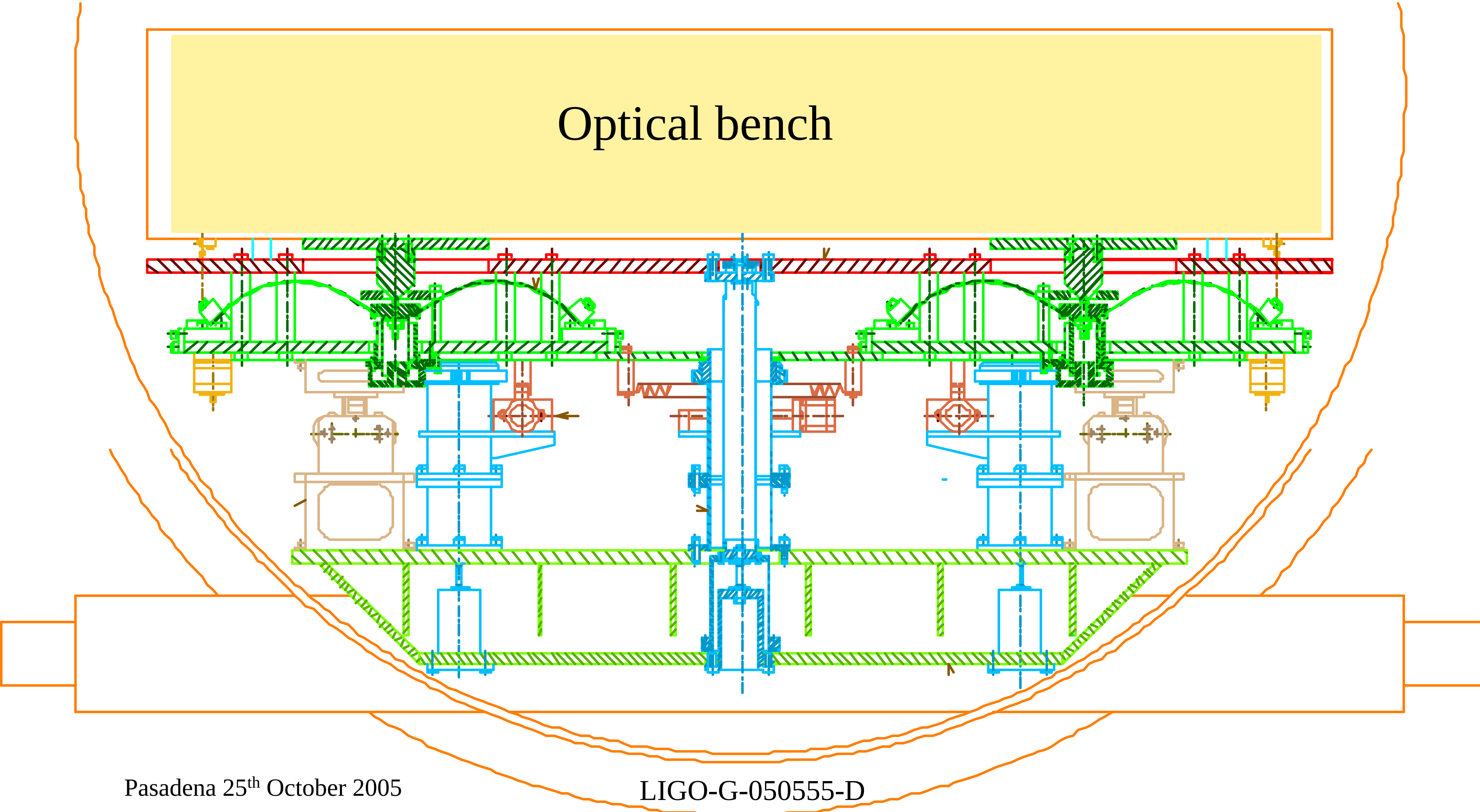
- If the OMC implementation is successful, this approach may be chosen for Advanced LIGO, subject to Adv-LIGO funding availability.
- Phase 2b:
- Build three groups of 5 to 6 units each for the three Ad-LIGO interferometers
  - (2x Hanford, 1x Livingston)
- Plus, possibly 2 more units for LASTI, for a total of 15 to 20 units

Aim of the phase 1

1. Validate the Seismic Attenuation System performance
2. Perfection the design for subsequent production

- Expect no significant changes in design
- The manufacturer will suggest design corrections/revisions where necessary

Detailing the components and functions of HAM SAS

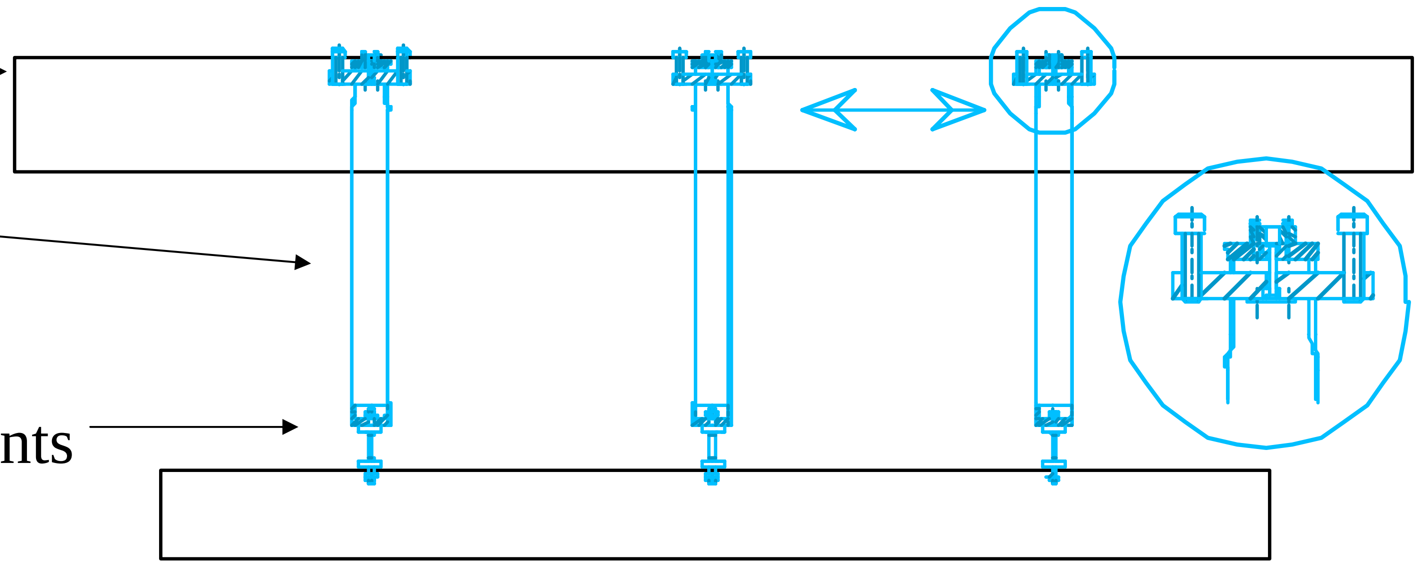


Horizontal direction, x, y, φ the Inverted Pendula

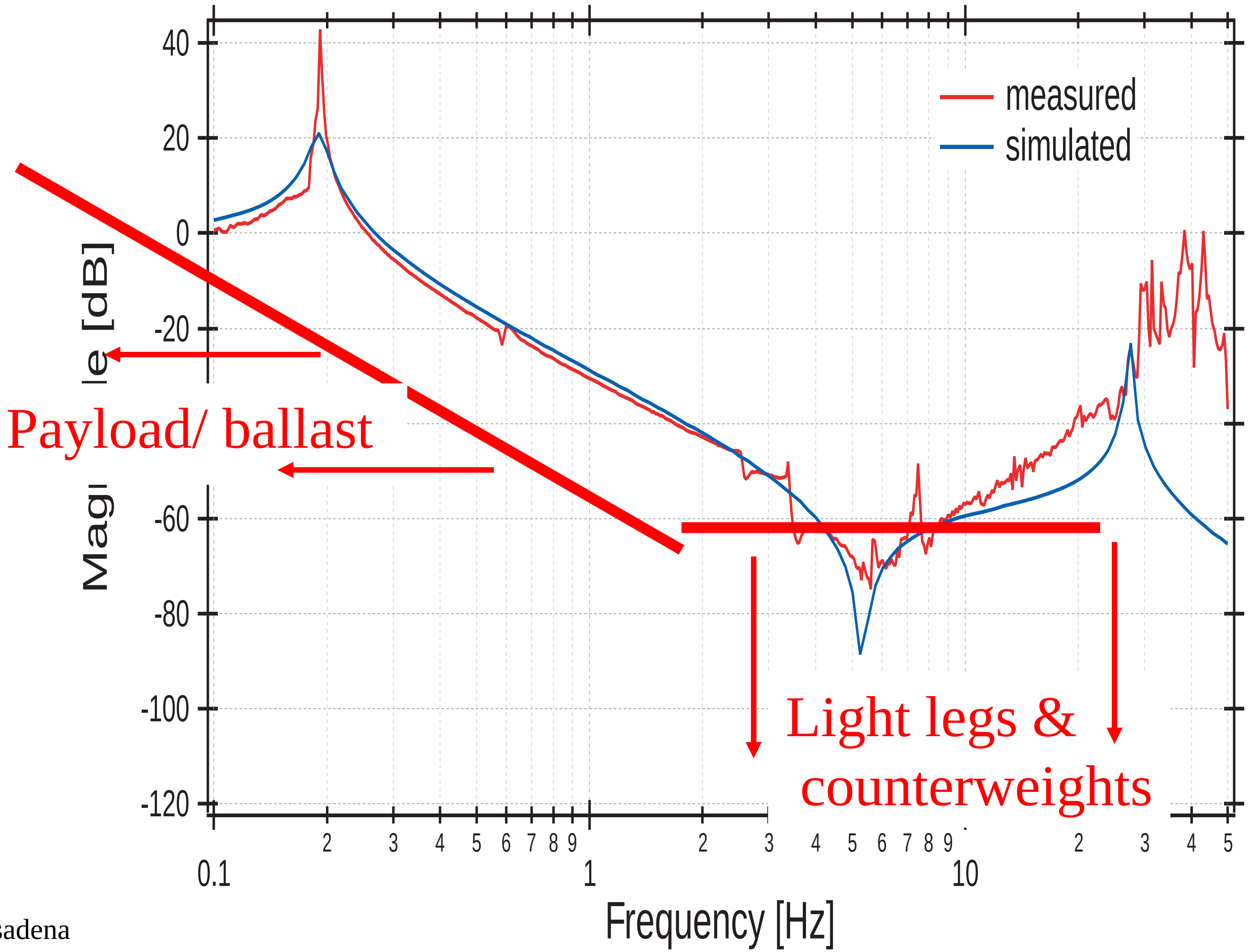
Intermediate springbox platform

legs

Flex joints



SAS Horizontal performance

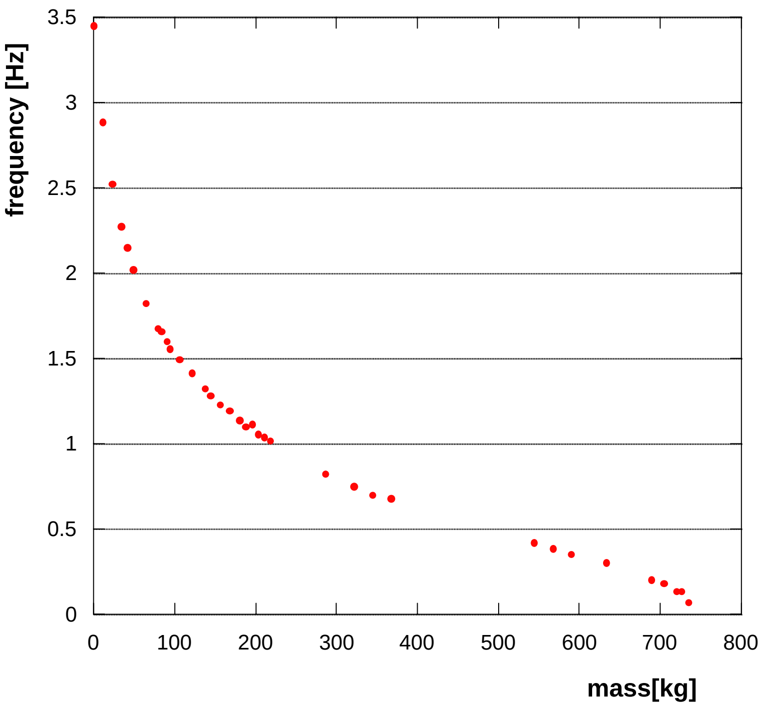


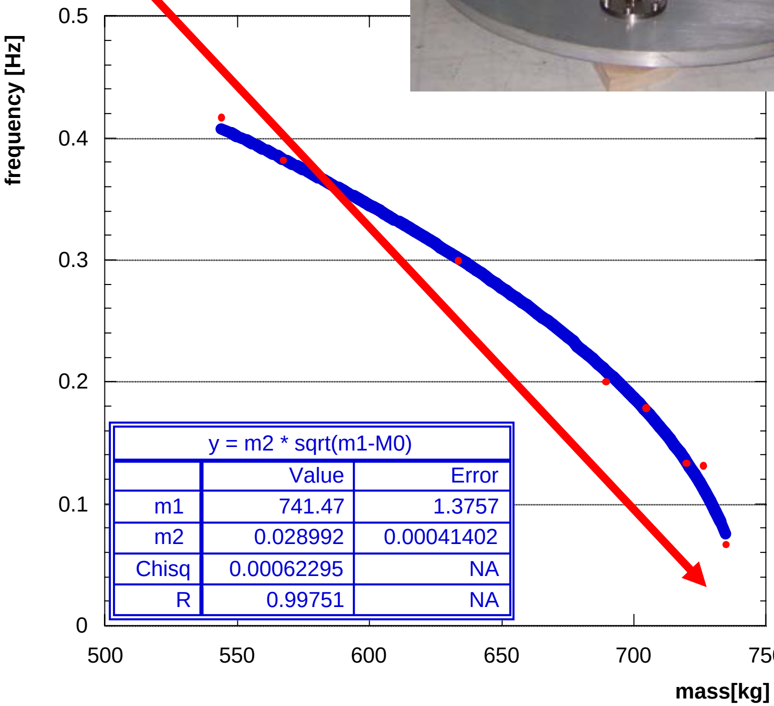
How to tune the IP frequency

- Dimension the flex joint for the required load
- Add ballast mass to tune the frequency

Frequency/Load curve

<30 mHz tune on stable ground





What limits the IP performance and How to improve it

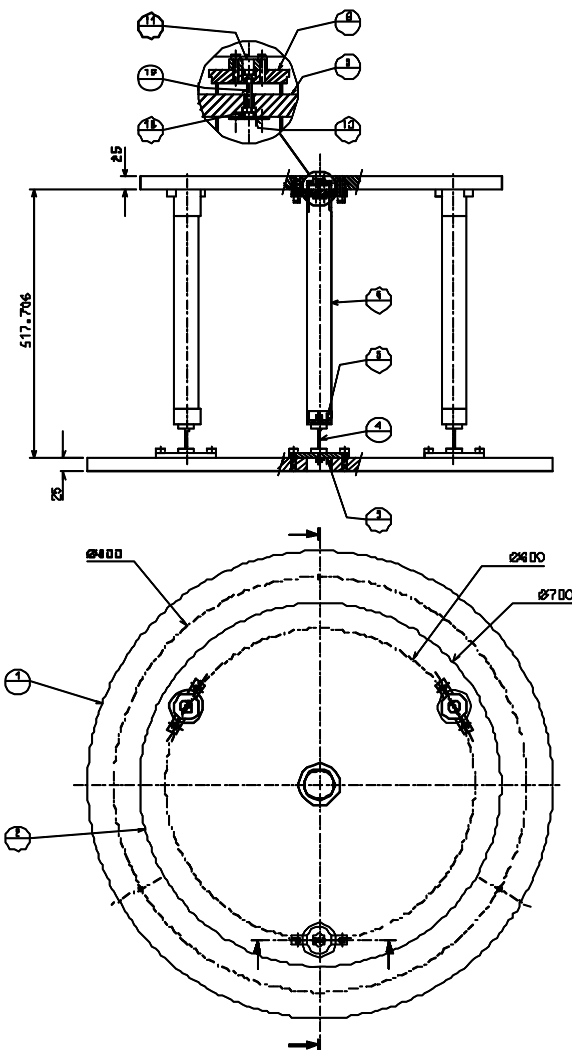
- The attenuation limitation comes from the leg's momentum of inertia,

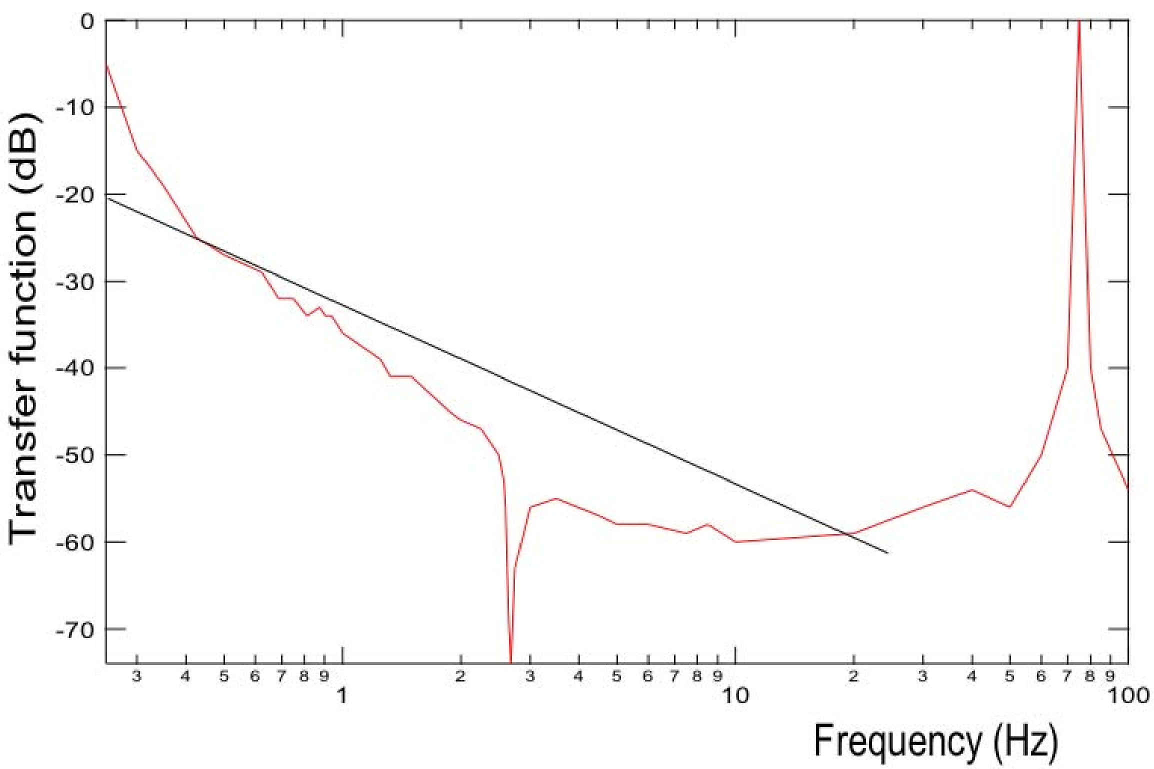
  Center Of Percussion effect COP

- Minimize the mass of the legs
- Add accurately tuned counterweights to null the COP effect

Light legs no counterweights HAM IP first tests

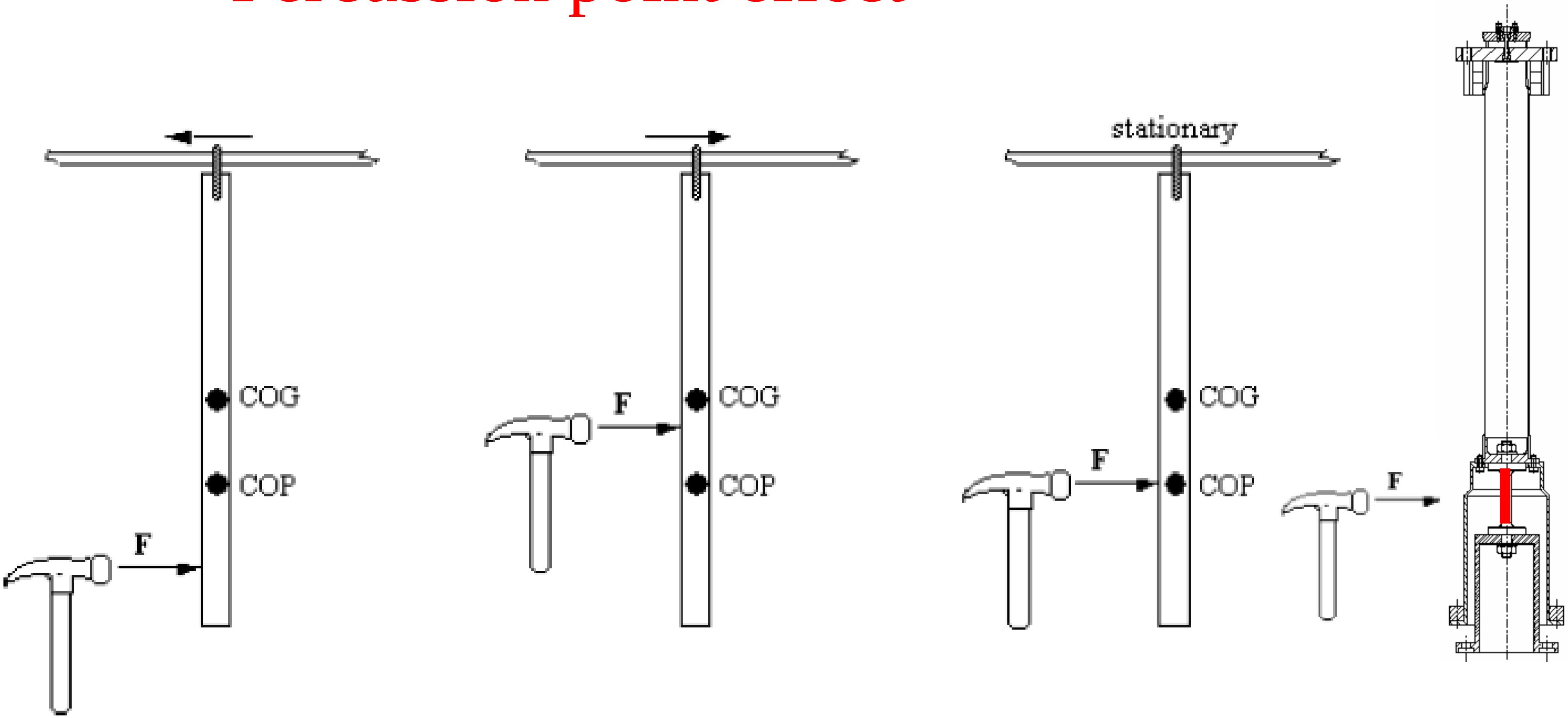
- Preliminary test results
- 60 dB achieved without CounterWeight
- 1/8 payload (8 times better at full payload)
- Further improvement with CW





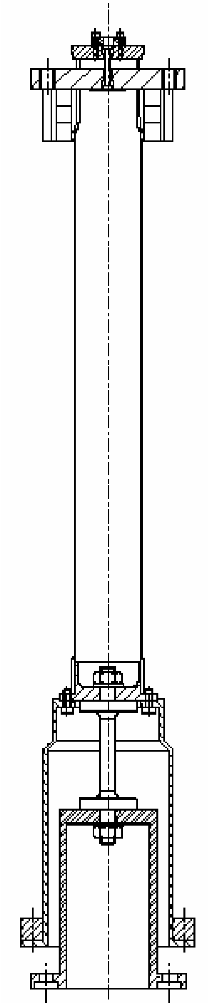
the C.O.P.
attenuation saturation

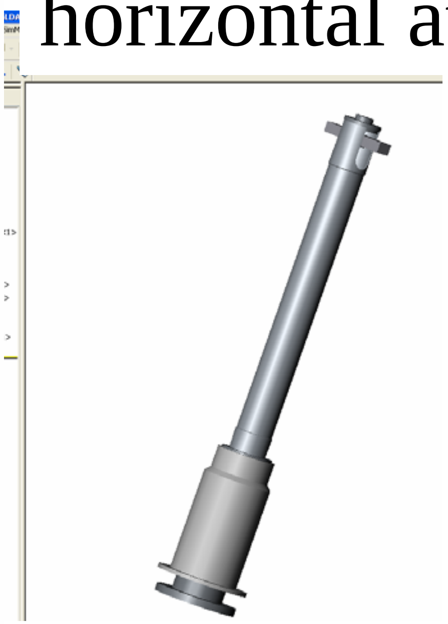
- Some shaking energy transmits due to the Percussion point effect

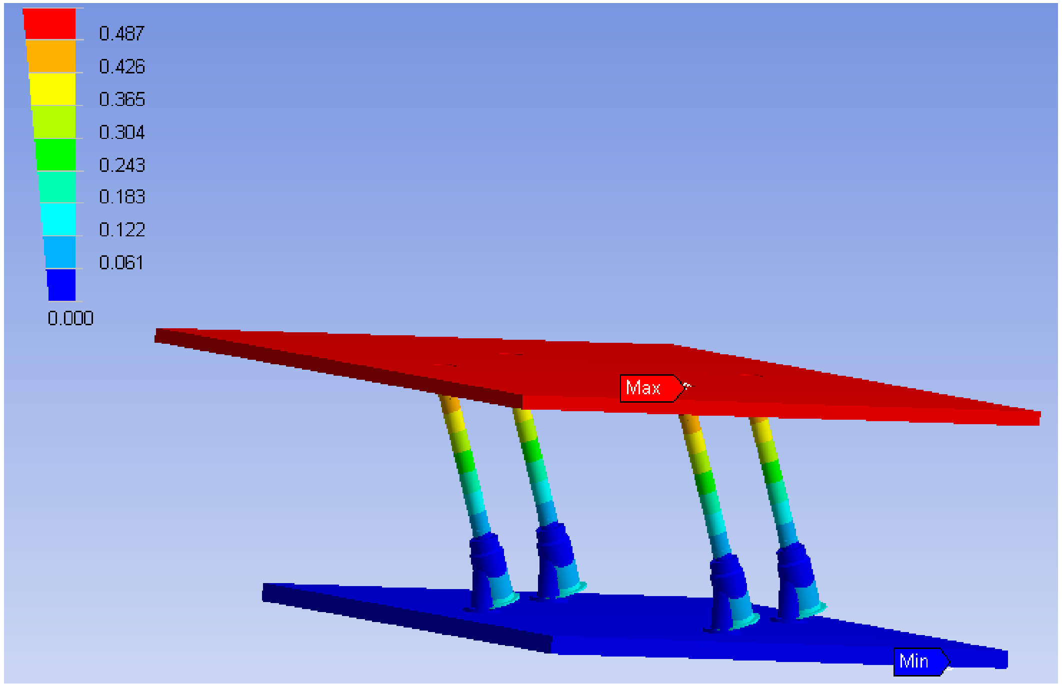


Introduction of counterweights

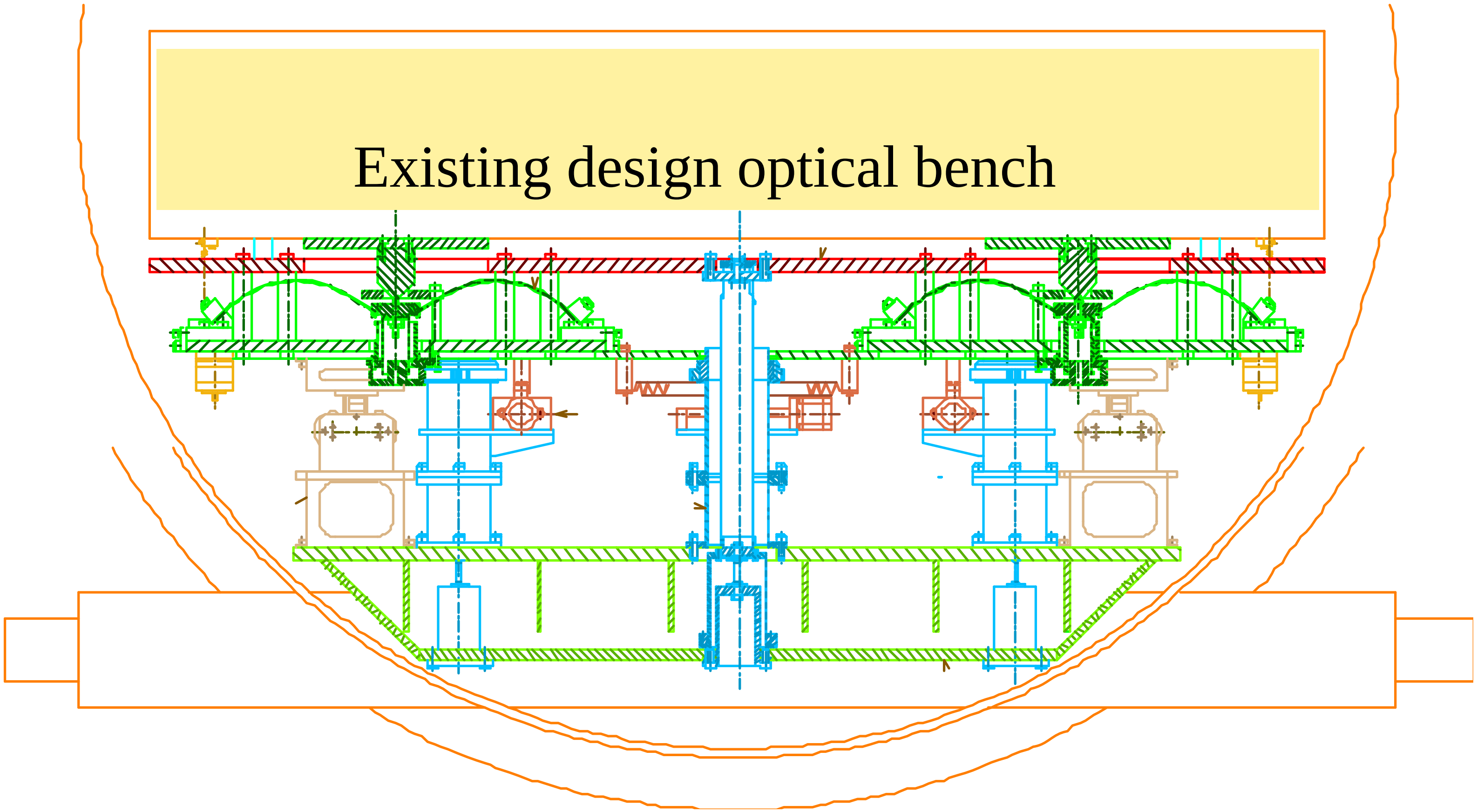
from 80 dB to 100 dB
horizontal attenuation







HAM implementation



How to tune the Counter Weights

Shaker shaking tower

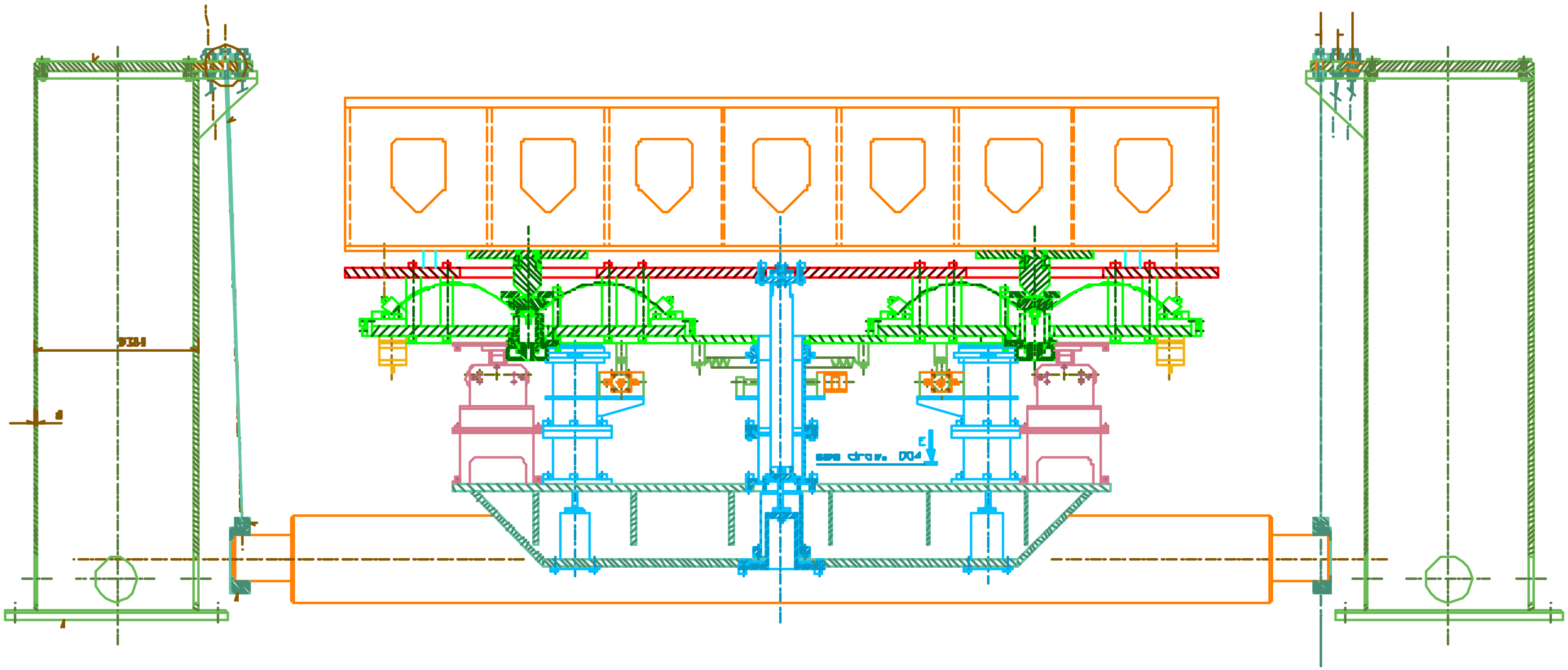
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

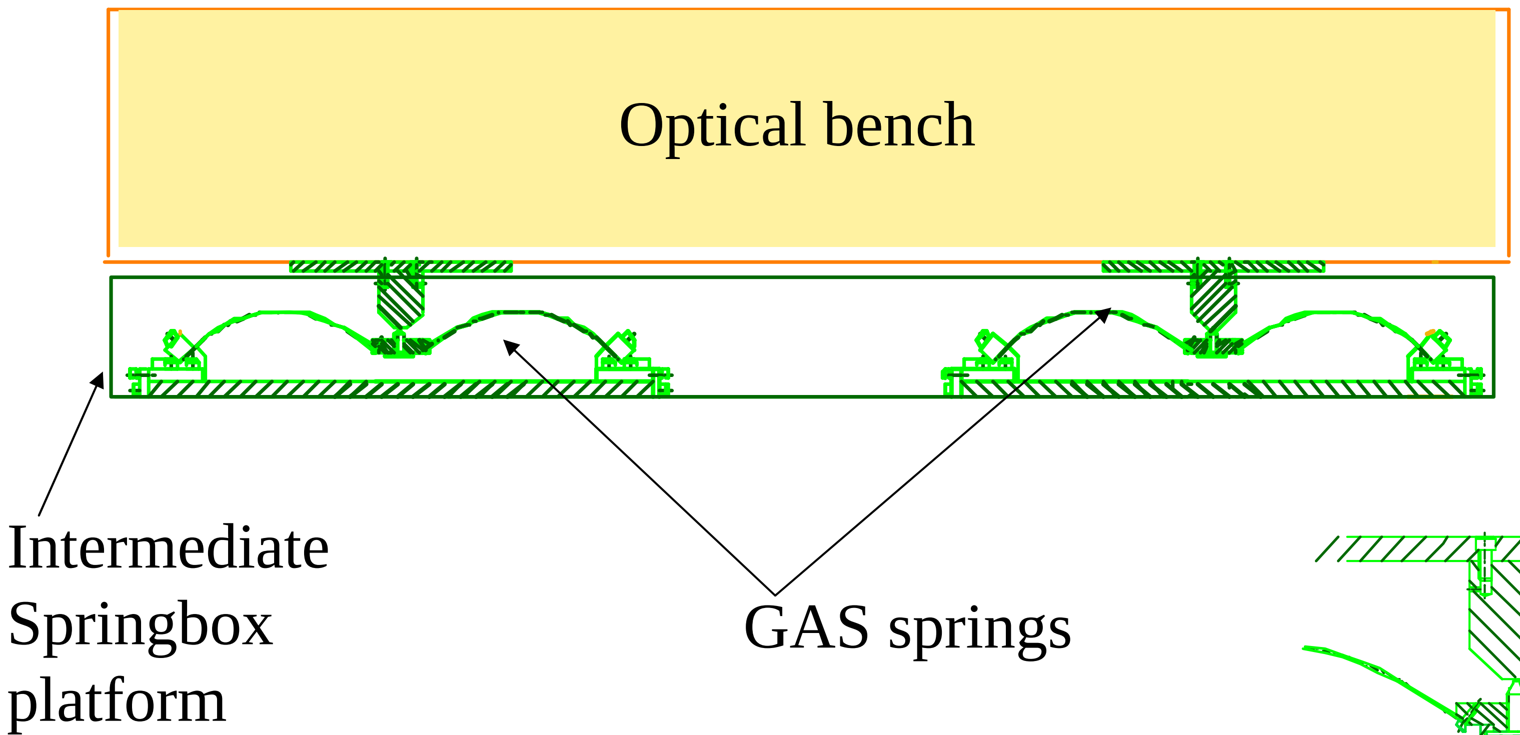
How are we going to do it for HAM SAS

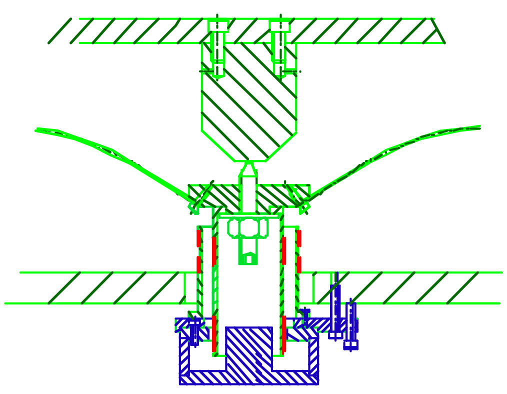
- Using a similar device that allows shaking the entire attenuator and measure its performance
- Do the tuning in the dirty stage
  - NOTE: The manufacturer will be asked to provide 500 Kg of stainless steel blocks to load the bench in sizes and shape to be specified (not in RFP), to be eventually delivered in UHV compatible form

Calibrator tools



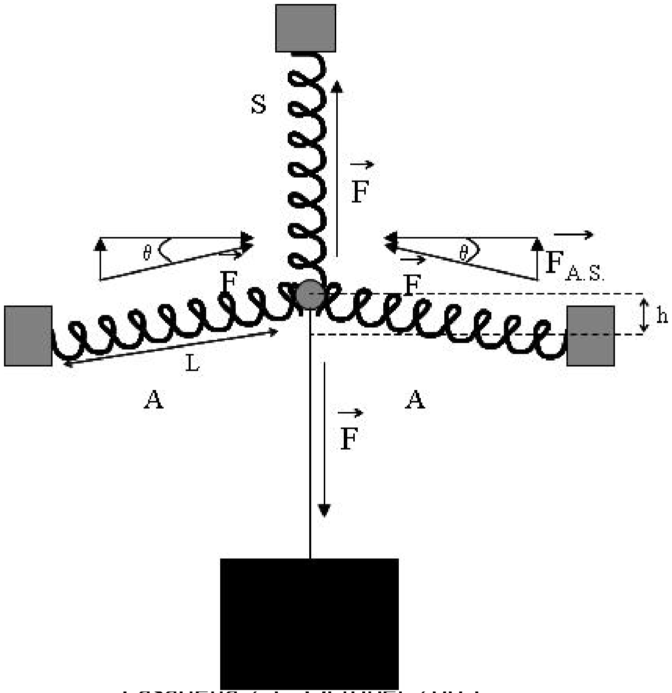
Attenuation in the vertical direction, the GAS springs

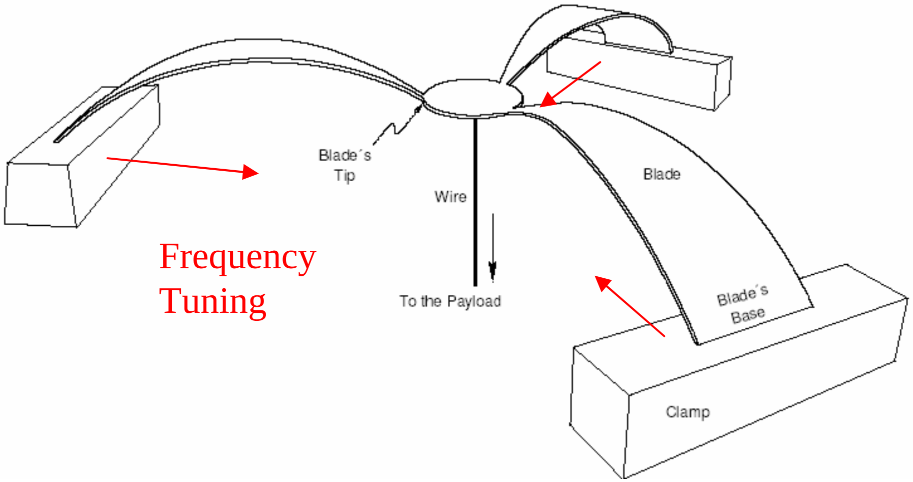




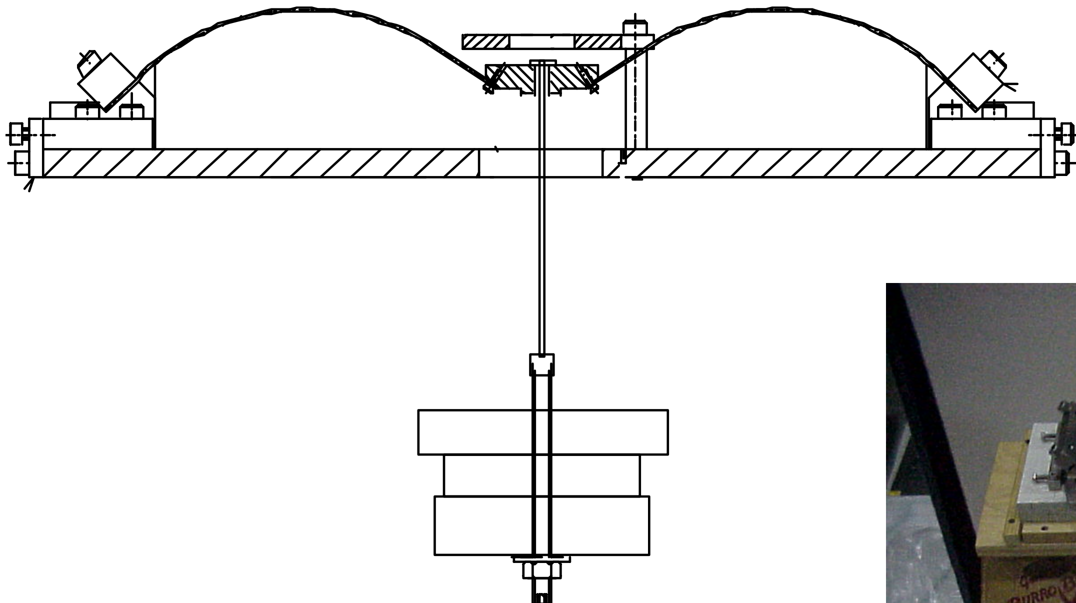
Vertical Attenuation
the GAS filter

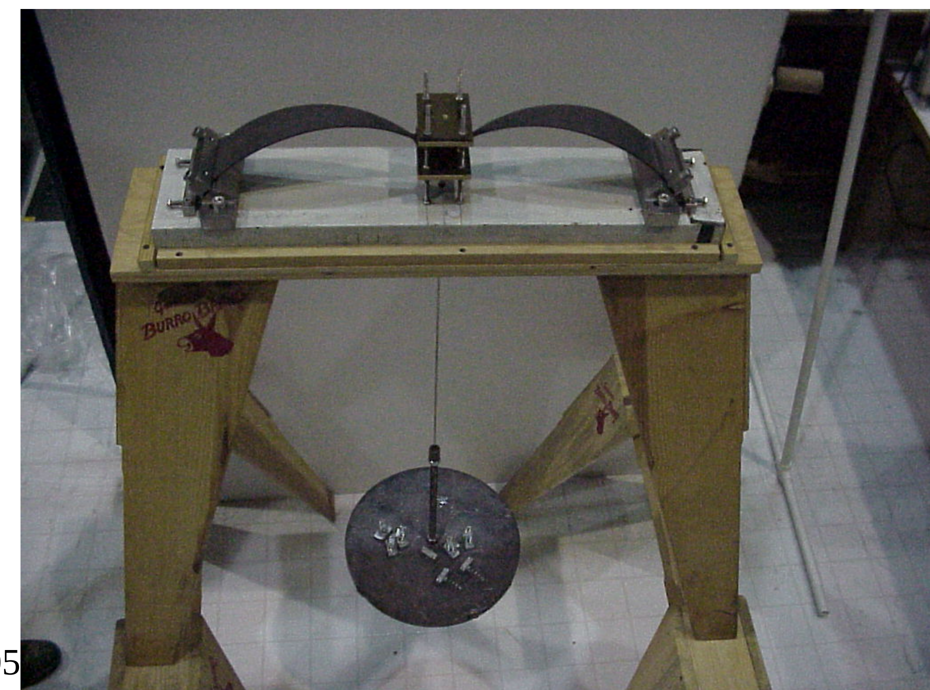
- The resonant frequency reduction is obtained by radially compressing opposite cantilever springs





vertical attenuation the Geometric Anti Spring (GAS) filter





The GAS functionality

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Construction notes

- The blades are maraging steel which occasionally has long delivery times
- For speed sake we ordered and will provide maraging plates in the precipitated (hardened) phase sufficient for production of the prototype blades by means of water jet or laser cutting
- We will also provide ground maraging rods for the production of the double nail end wires, in the resolubilized form to allow for lathe machining
- We expect the manufacturer to provide the maraging steel for the subsequent production

Construction notes

- The RFP specify a number and selection of blades sufficient to cover the complete range of payloads that the HAM SAS will satisfy.
- The payload carried by each blade is strongly dependent on the blade thickness and was found to vary from batch to batch.
- The choice of number and width of the blades will be decided during assembly, after measuring the load carried by the first few blades

Construction notes

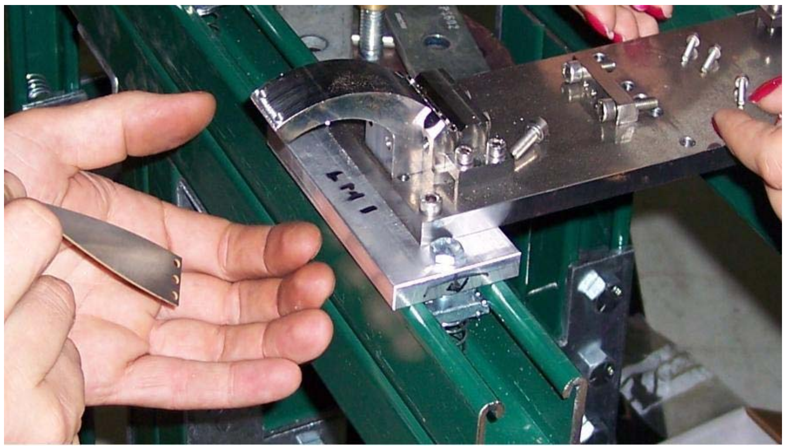
- The maraging components must be heat treated by the manufacturer with a 100hr long bake @435^{o}C in Argon atmosphere.
- Blades must be sandwitched between thick metal plates to maintain planarity
- Wires should be supported on “trays” supporting the entire length of the wire and their heads
- If wires and blades are supported in few points, they sag under baking and a catenarian shape is frozen in

How do we assemble a GAS filter?

- There is a lot of mechanical energy stored in a bent blade
- The blades work at ~50% of plasticity limit, overstressing a blade during assembly wrecks it

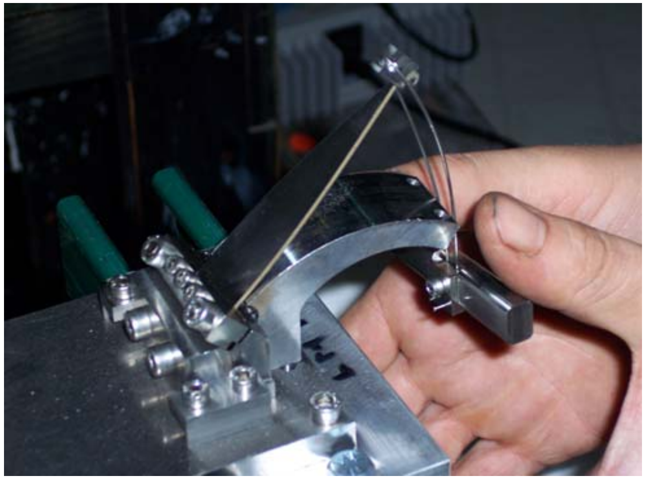
- Assembly procedure, a small scale example:

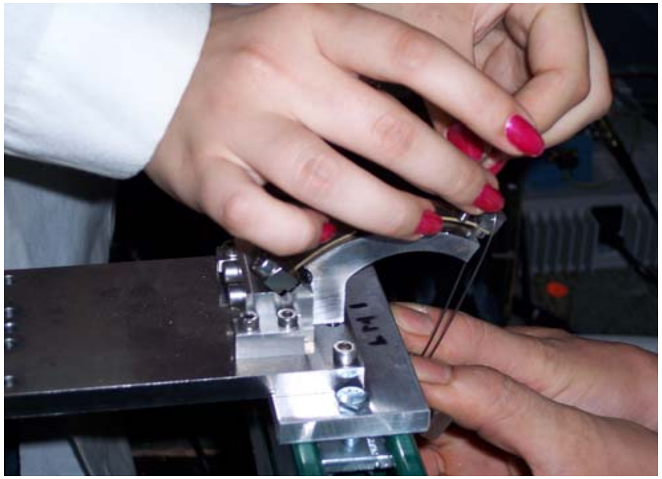
Bending Glassy metal blades



1. Support for bending, blade and blade clamp
2. Screwing in the blade to the support
3. Tightening

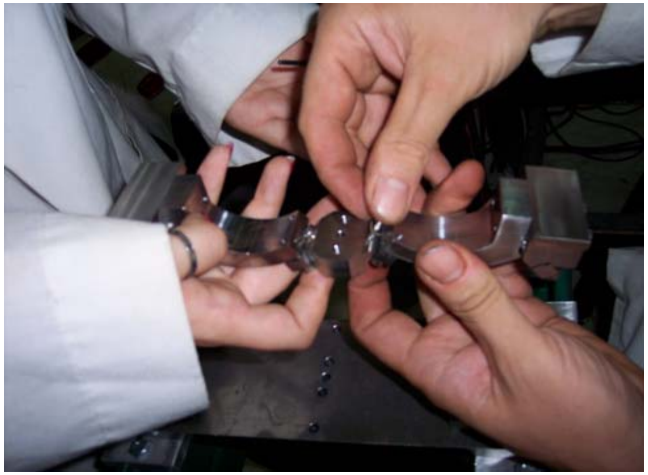
Bending Glassy metal blades



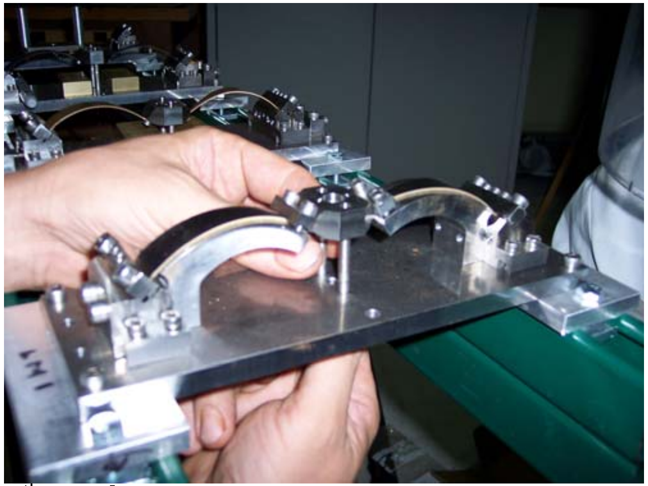


4. Blade tip holder and tool with wire for bending
5. Screw in blade clamp while bent.
6. Notice tip holder in hand and blade holder in place

Bending Glassy metal blades

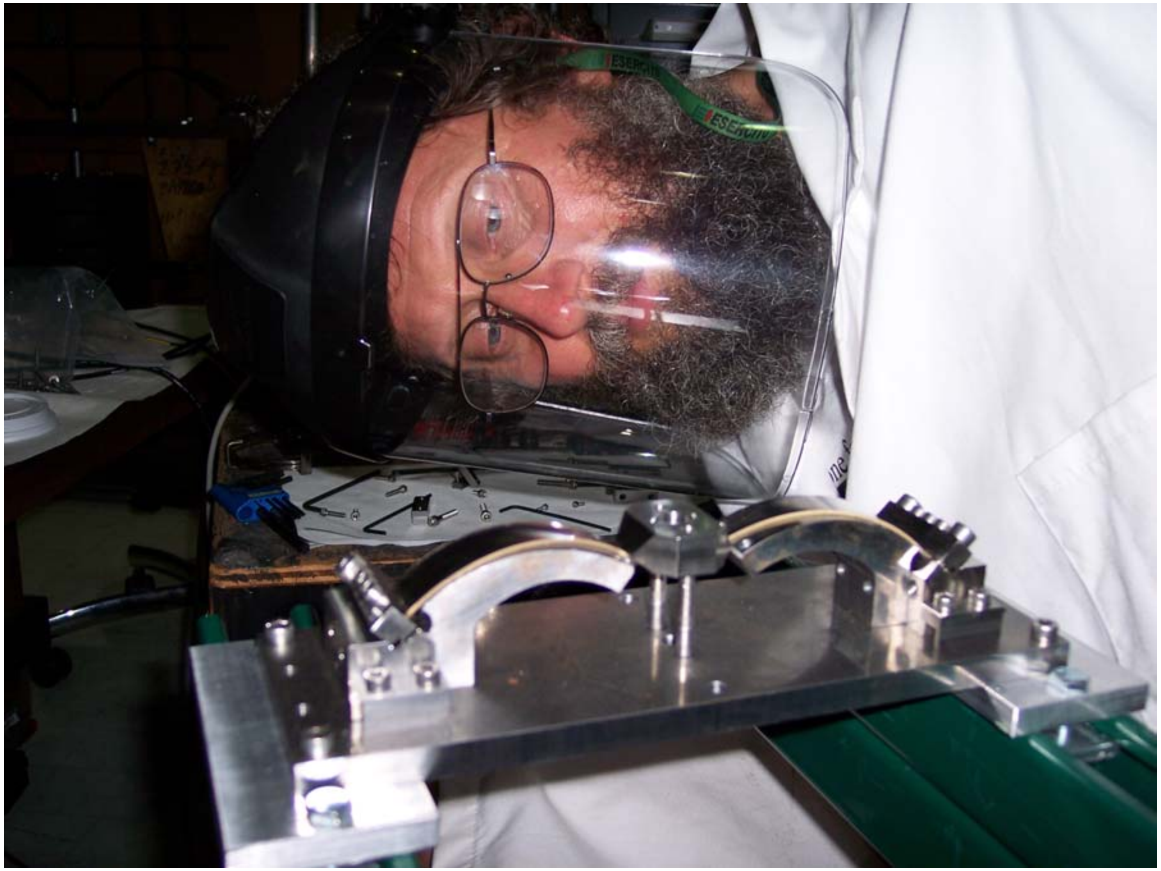


7. Attach two blades to the keystone.



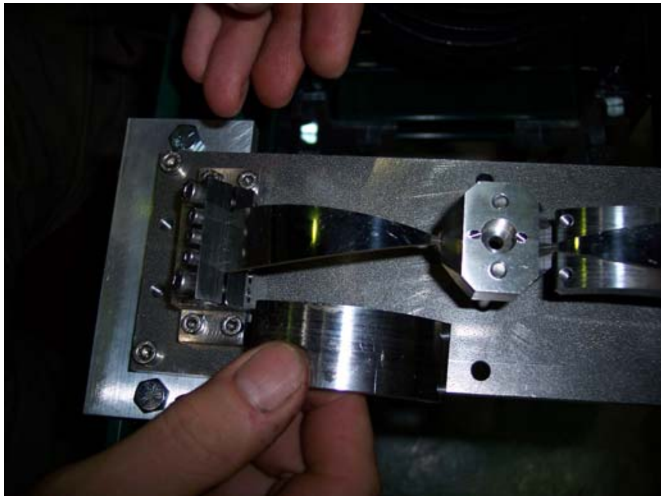
8. Retainer screws bolt from bottom to hold down the keystone so that the blade supports can be removed.

Bending Glassy metal blades

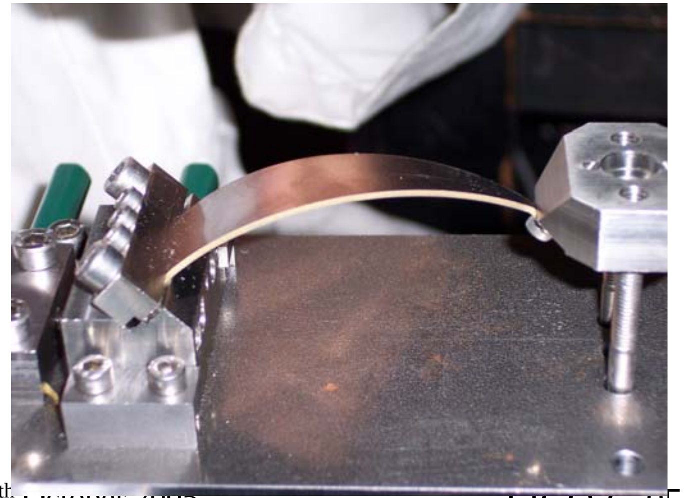


"Looks good"

Bending Glassy metal blades

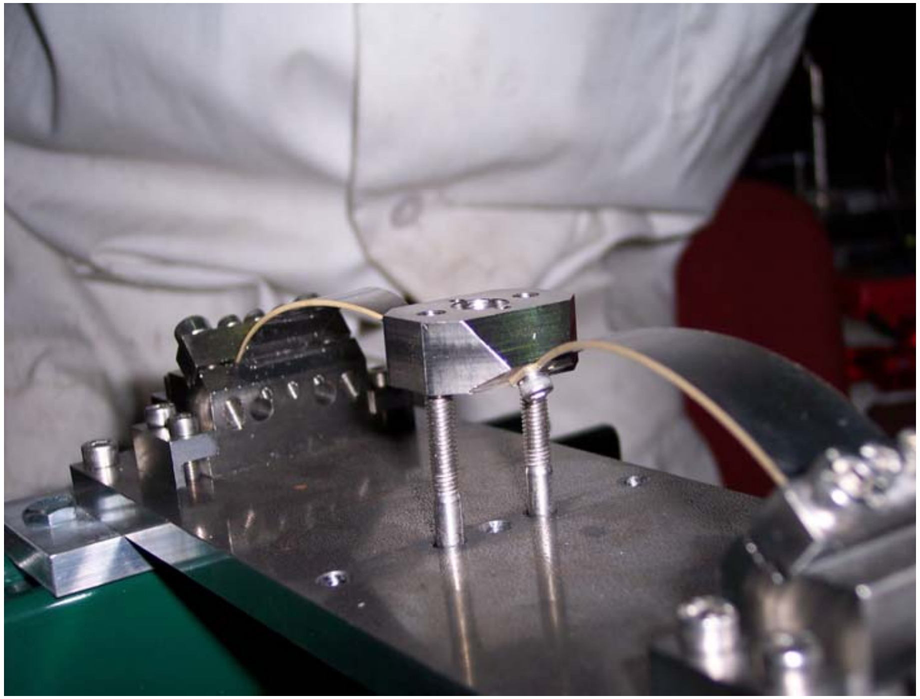


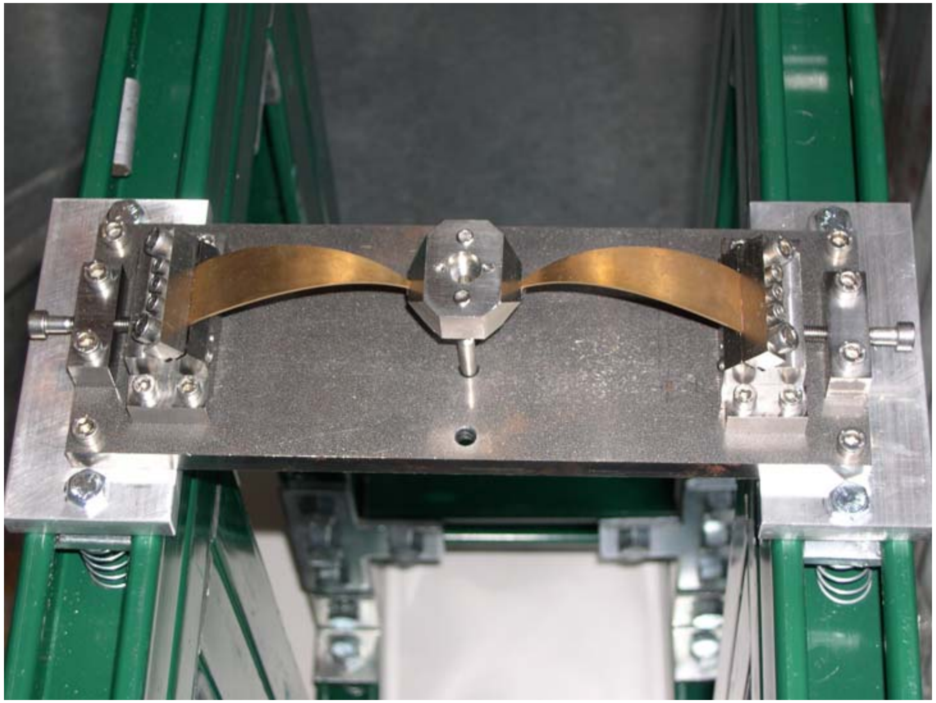
9. Remove blade clamp and bending supports



10. Load stands on the retainer screws

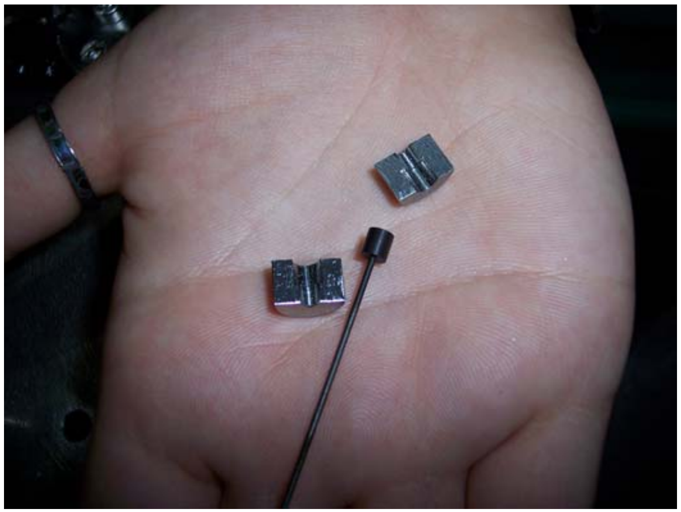
Blade Assembly



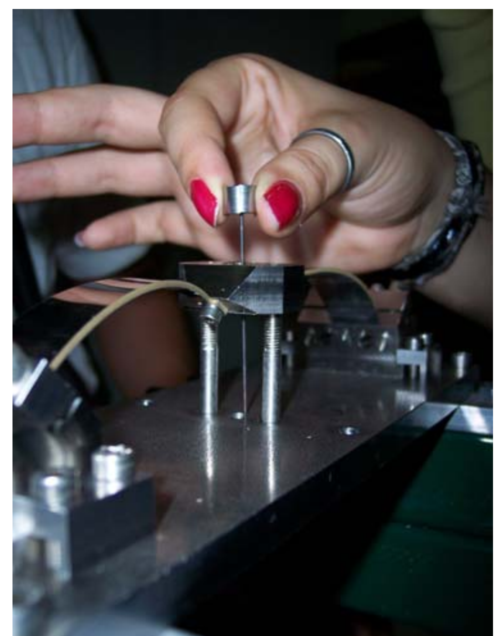


Completed blade assembly

Hanging the Mass & transfering load

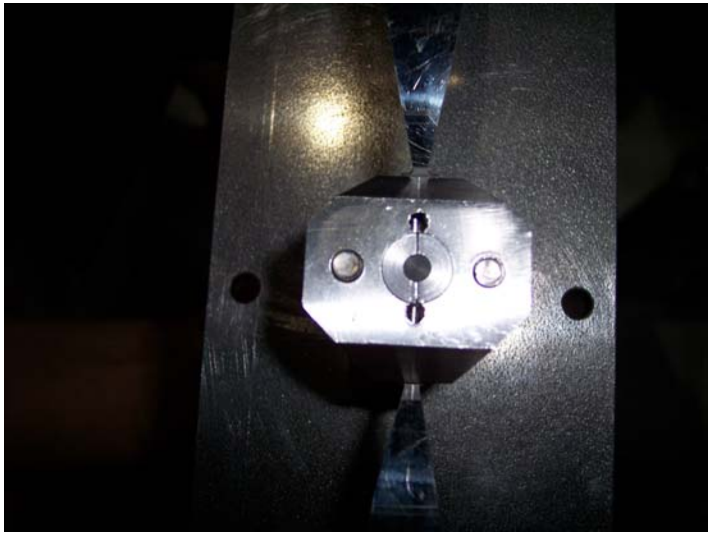


1. Half cups and steel wire for hanging mass.



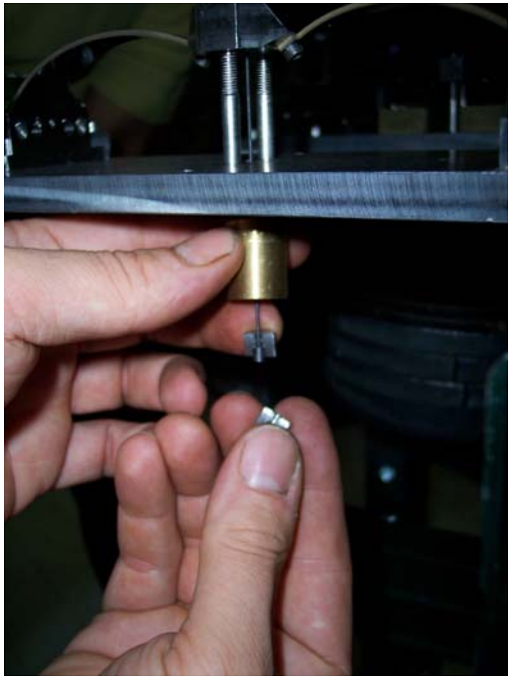
2. Insert wire into center hub carefully to avoid breaking a beautiful pink nail.

Hanging the Mass



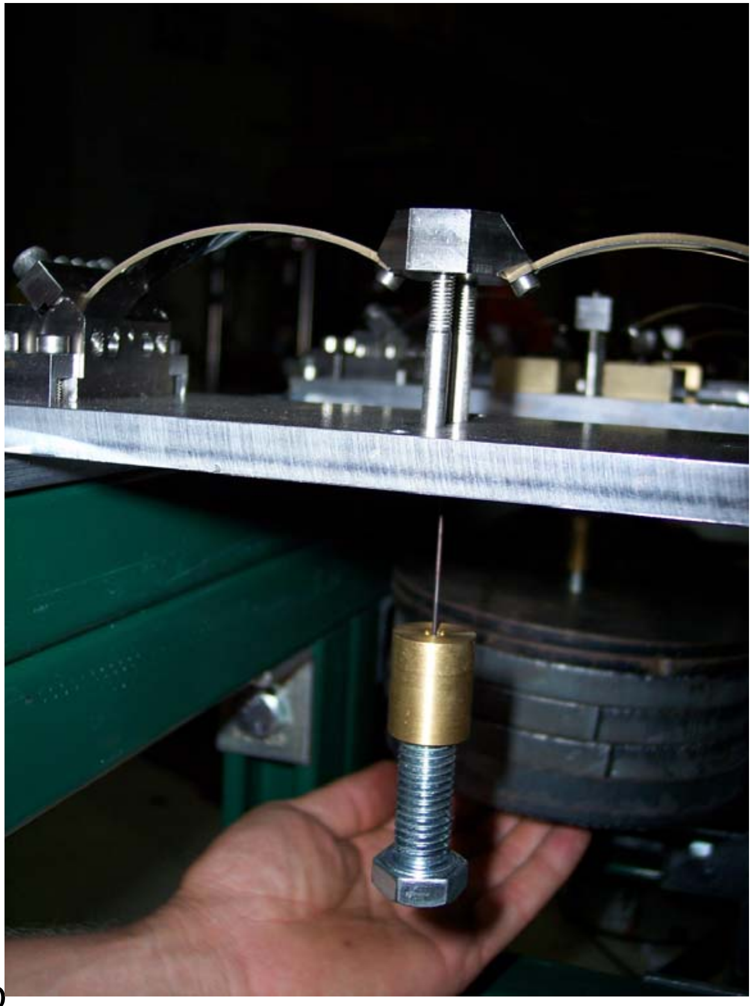
3. Half cups and steel wire happily seated in the keystone.

4. Attach brass fitting to bottom of wire using two more half cups.



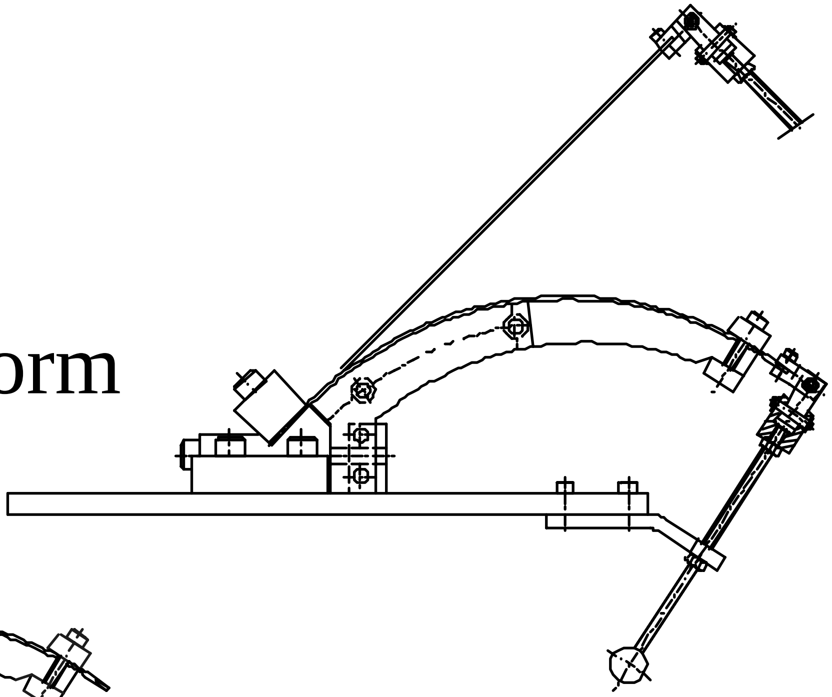
Hanging the Mass

5. Now mass can be added and removed easily with a threaded bolt.
6. Once the load is floating, the retainer screws can be removed

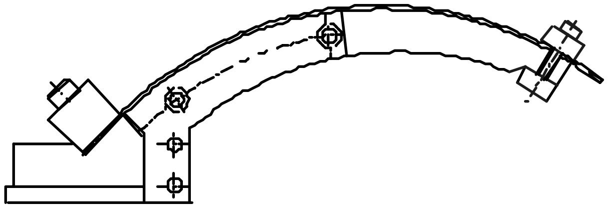


How in HAM SAS

- A much larger system
- More stored energy
- Otherwise the same

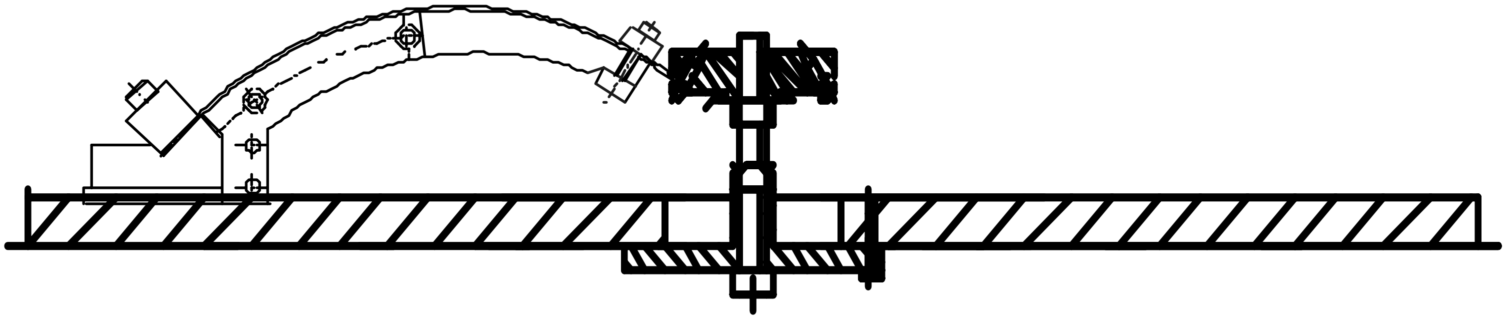


- Pull the blade over a form
- Clamp for transport

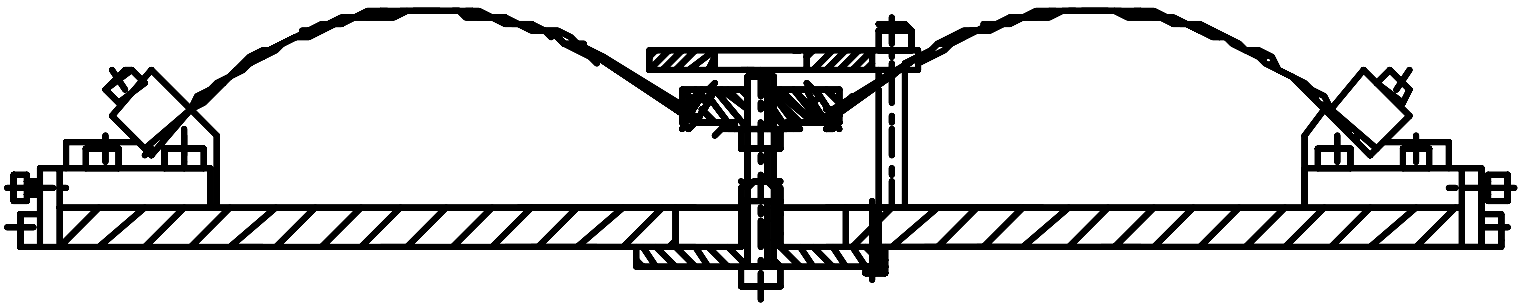


How in HAM SAS

- Mount on the base and against the keystone



- Transfer the load and tune



How to tune the load

- Different benches have different loads.

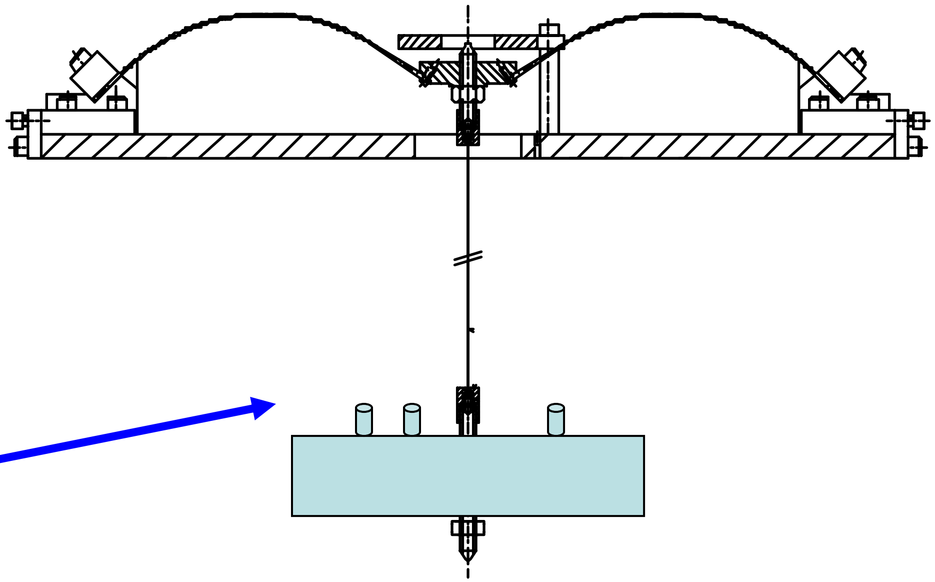
- Match the GAS filter to required load by mounting 4, 6, or 8 blades per filter
- The last pair can be 3/4, 1/2 or 1/4 width
- Then add ballast mass to match the load to the spring

How to tune the frequency

- The frequency is a function of the radial compression
- The frequency also changes with vertical working point
- For a given compression the filter works best at the minimum frequency

Tuning the GAS

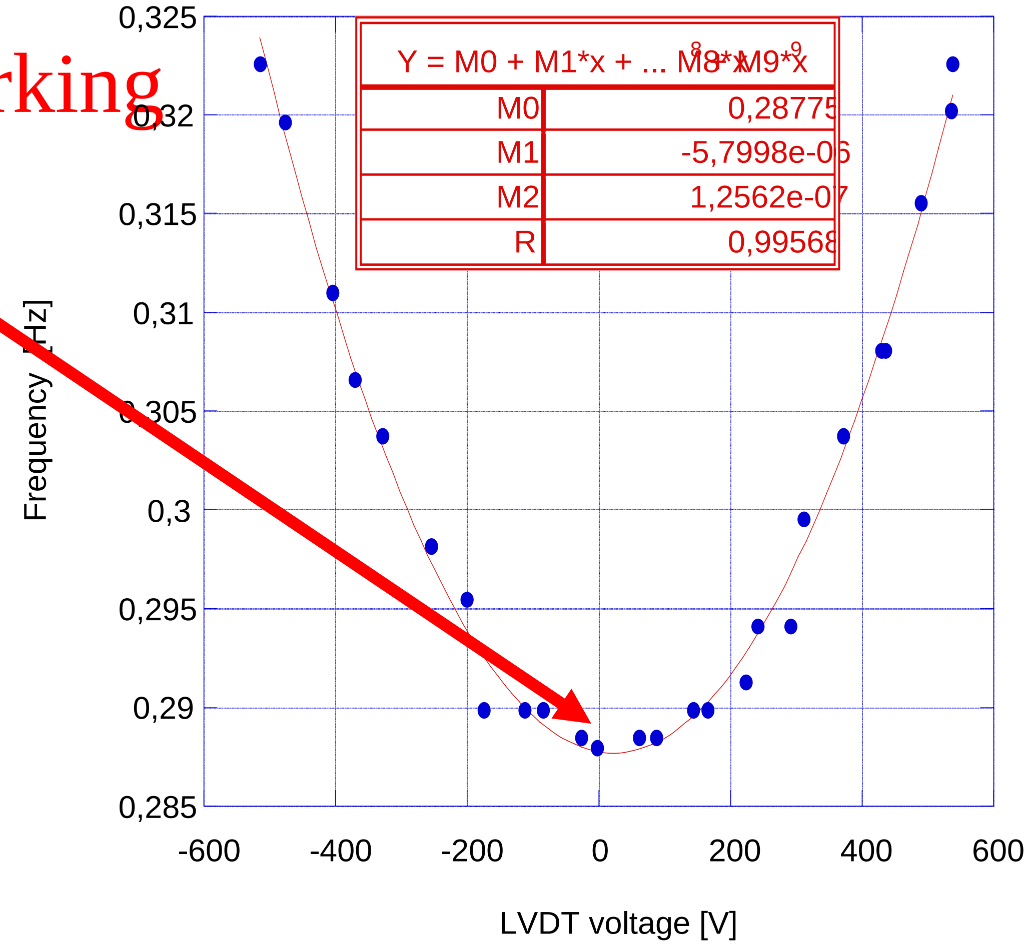
- Use screws for radial compression tuning



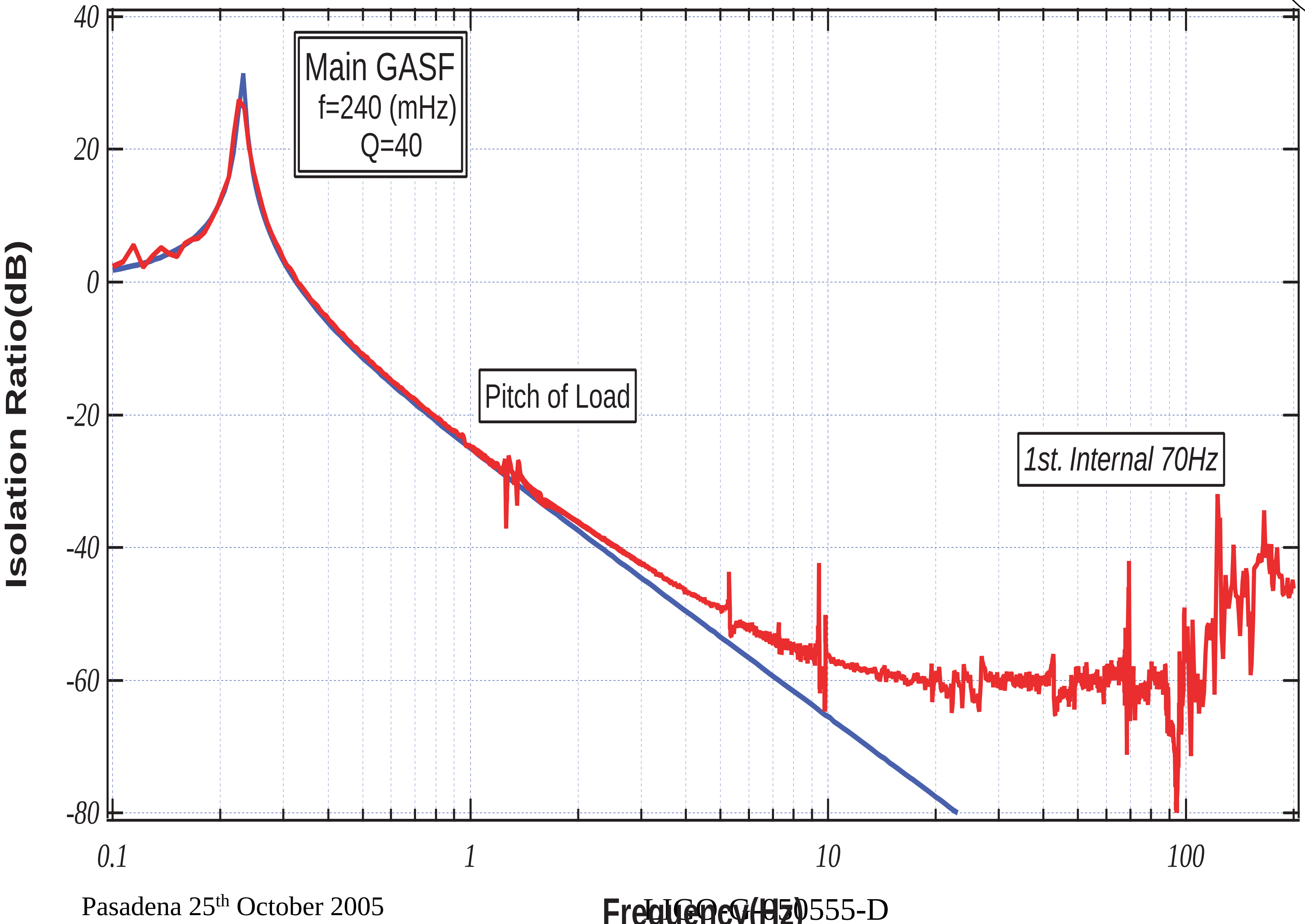
- Add mass to change working point

Resonant frequency vs. load

- Best working point



Passive vertical performance



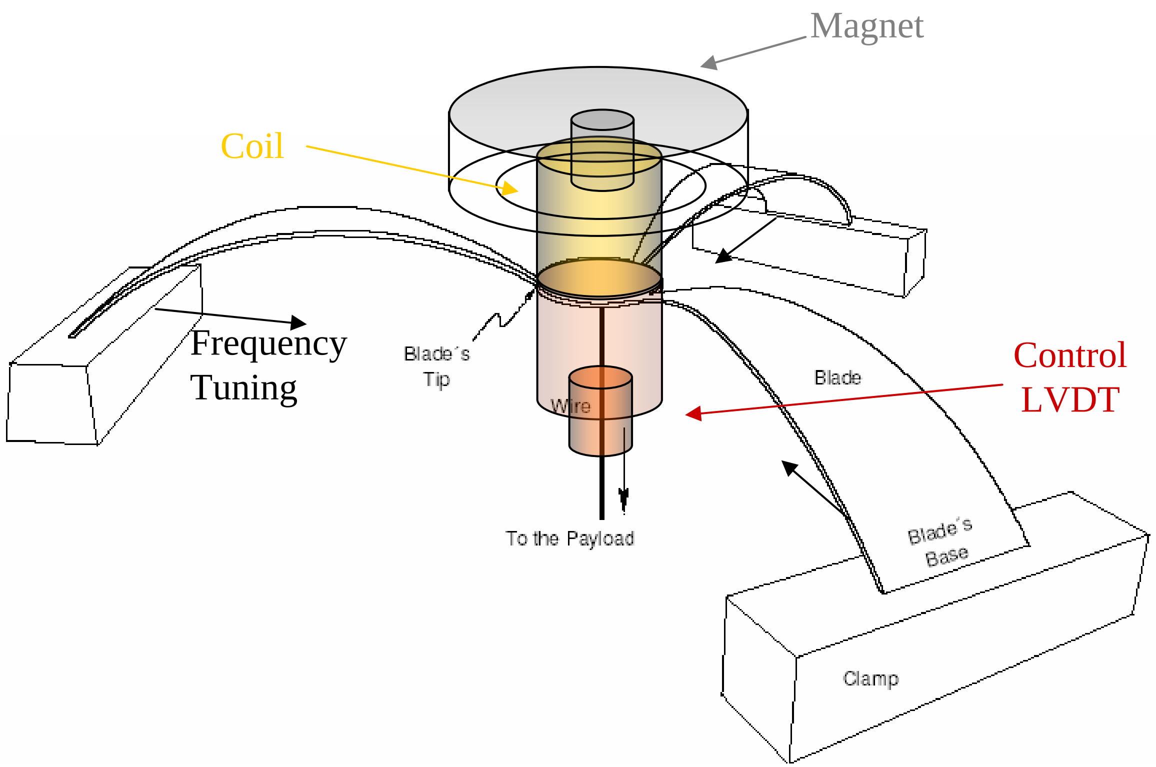
About the GAS filters

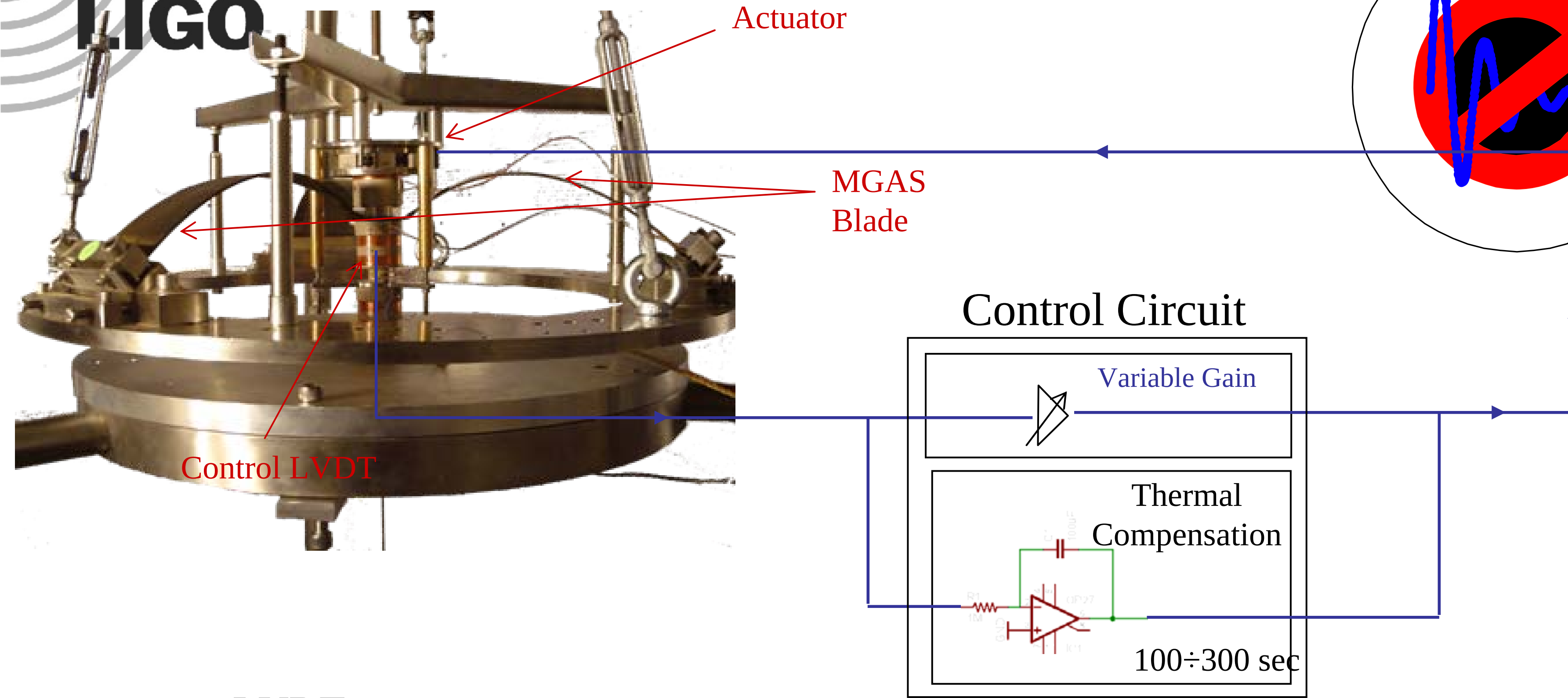
- The HAM SAS GAS filters are built with blades identical to those used for TAMA
- The number and width of blades change to match the required payload mass
- The optical table sits directly on top of the GAS filters on a kinematic mount
- Electromagnetic springs for very low frequency operation
- External Counterweights for C.O.P. compensation
  - Not in RFP, may be added to the contract through negotiation

Passive vertical performance limitations

1. There was a practical low frequency limit (~200 mHz) for purely mechanical GAS spring resonance due to material properties (hysteresis)
2. The attenuation power saturated at ~ 60 dB due to the percussion point of the blades
3. Solutions
   1. Coils for corrective e.m. spring (built but not implemented at the manufacturer’s plant)
   2. External counterweights (not in RFP but may be added to the contract)

Existing MGAS Spring





- LVDT
- Variable Gain
- Amplificator-Voice Coil

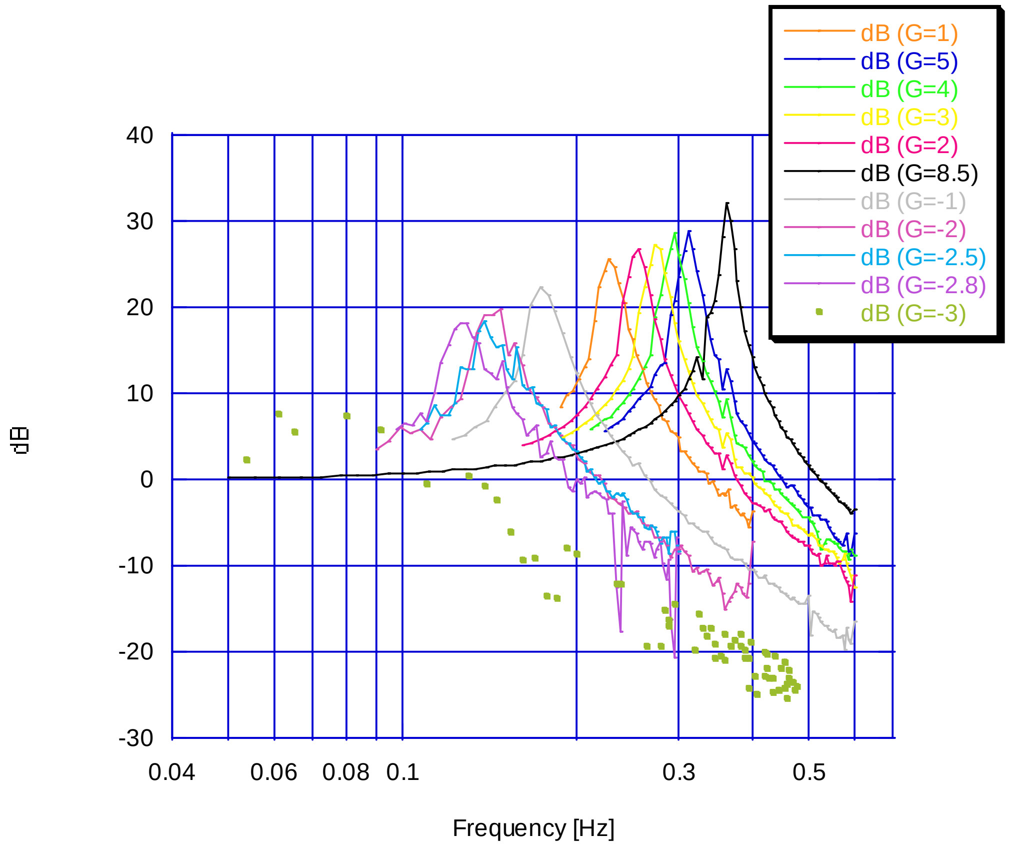
→ Tunable spring in parallel with MGAS spring

(Set Point Integrator → Thermal Drift Correction)

MGAS already neutralize > 90% of cantilever spring stiffness

Circuit corrects the last few per cent of stiffness and stabilizes performance

Transfer Function with Different Gain values

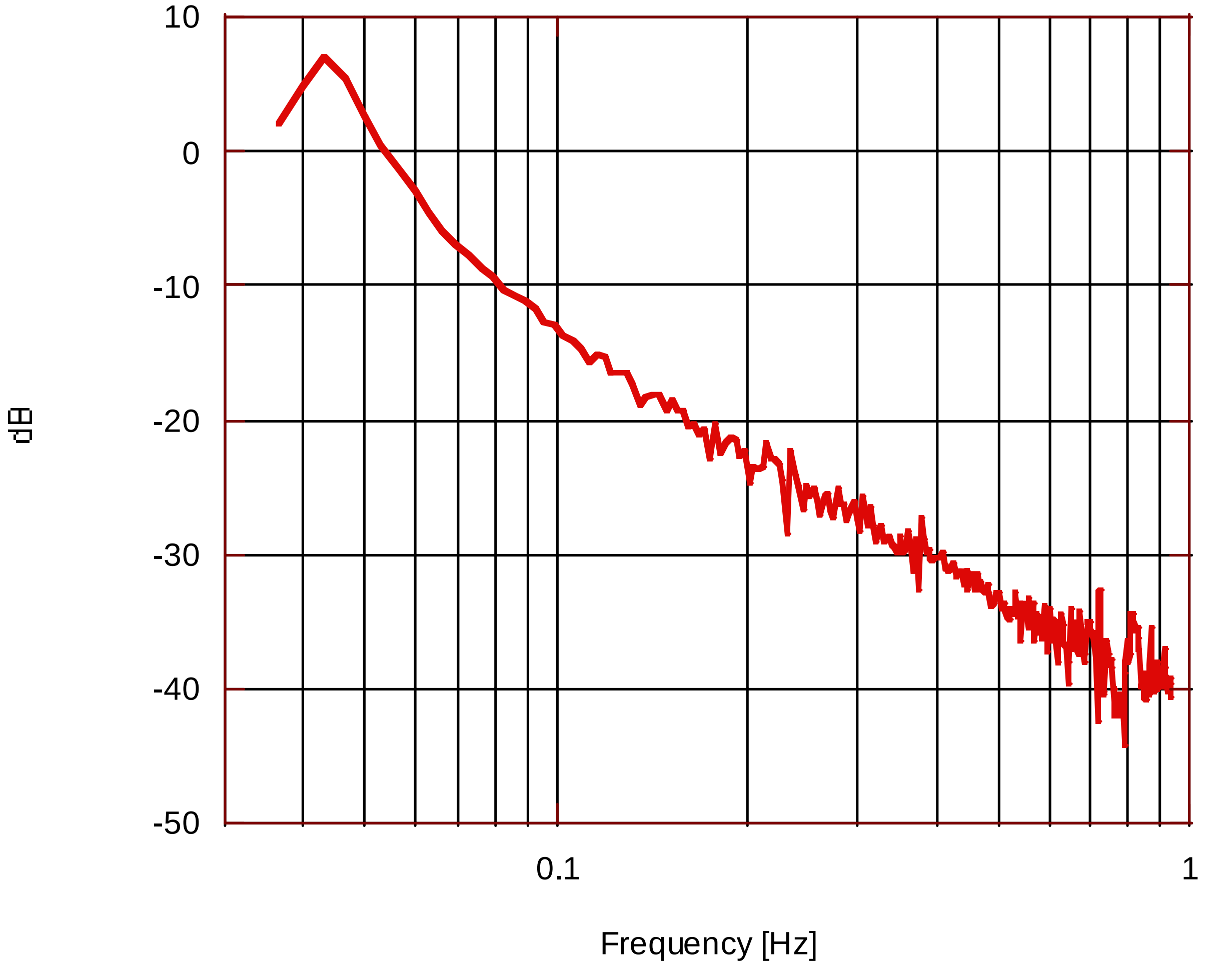


Lowering the system stiffness

As the Transfer Function is shifted to lower frequencies,

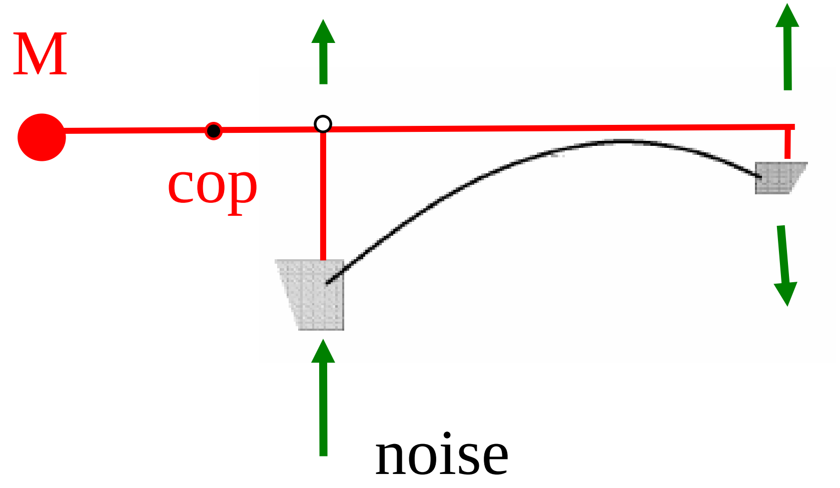
the Q factor decreases

The e.m. springs suitably lowers
The resonant frequency

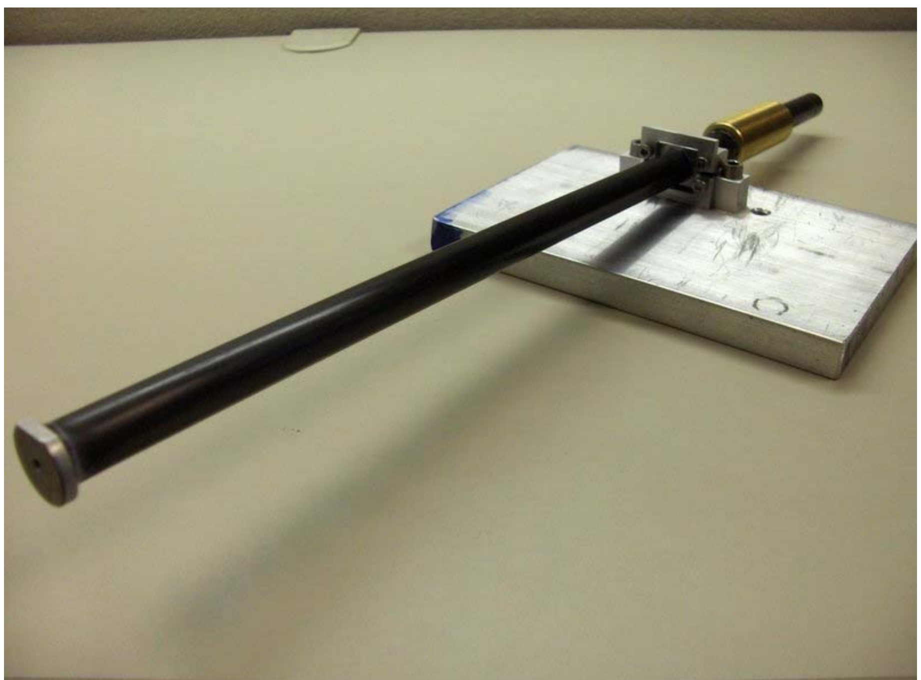


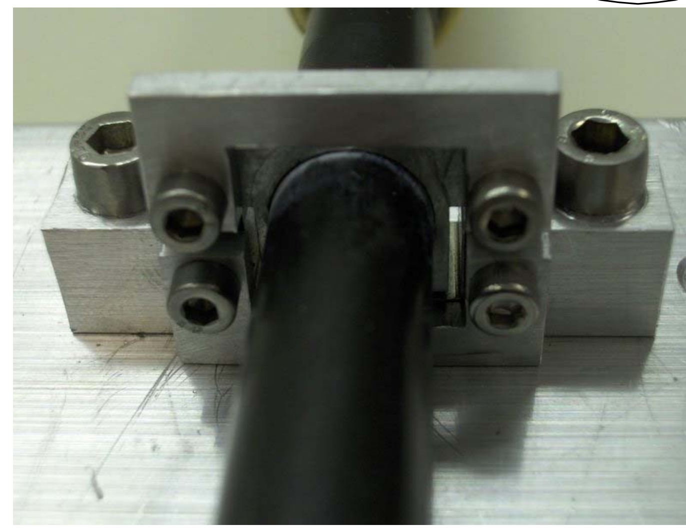
Neutralizing the COP effect in the GAS Springs

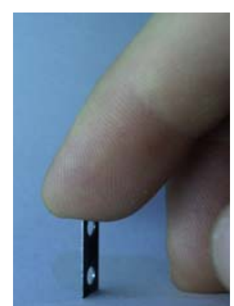
What we want to do



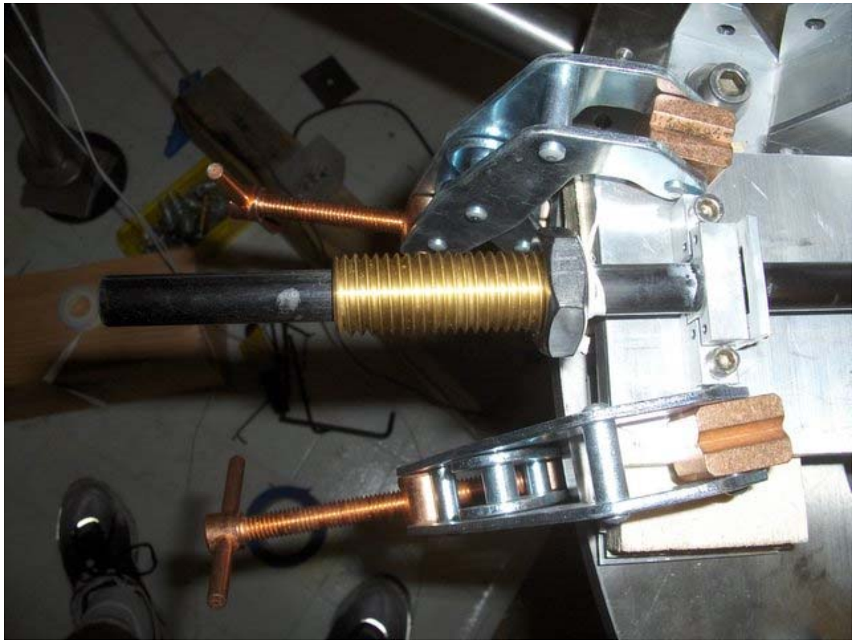
The prototype

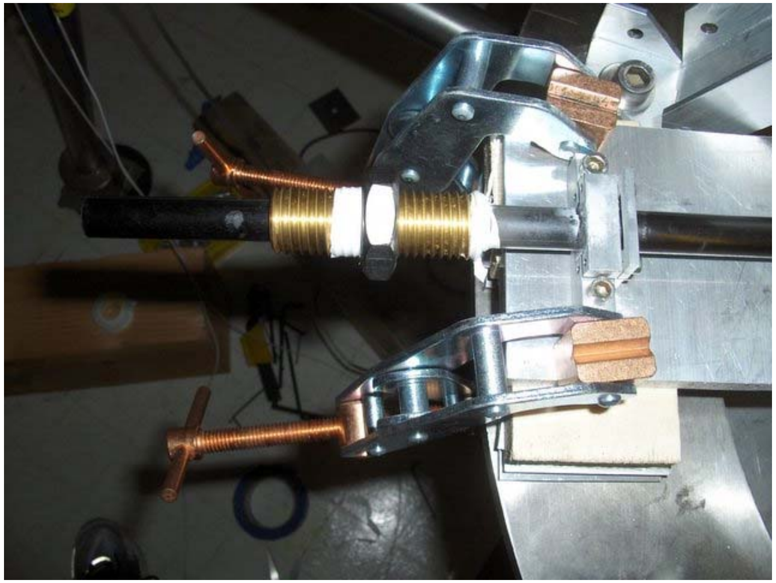




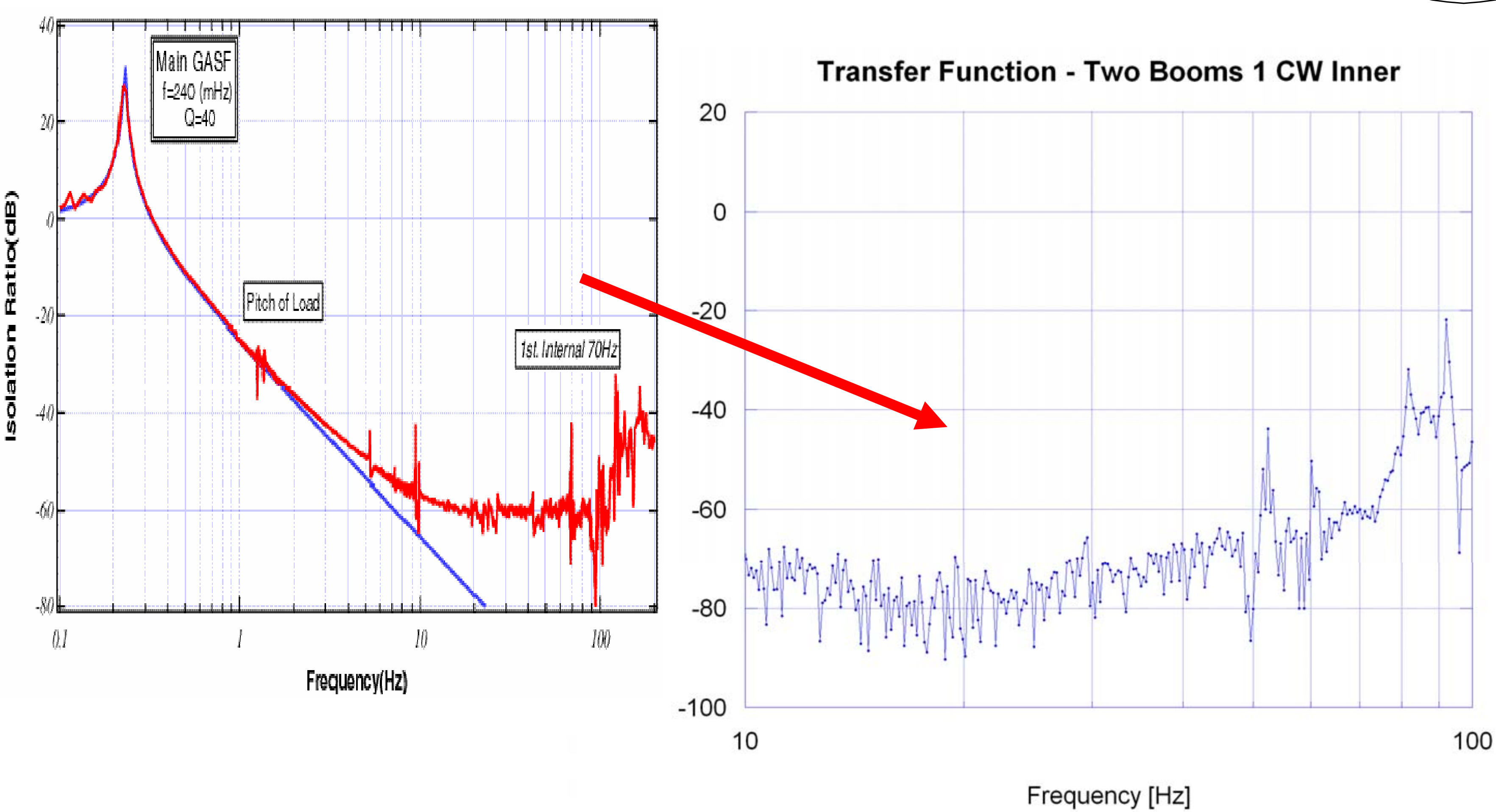


Tuning of the Counterweight



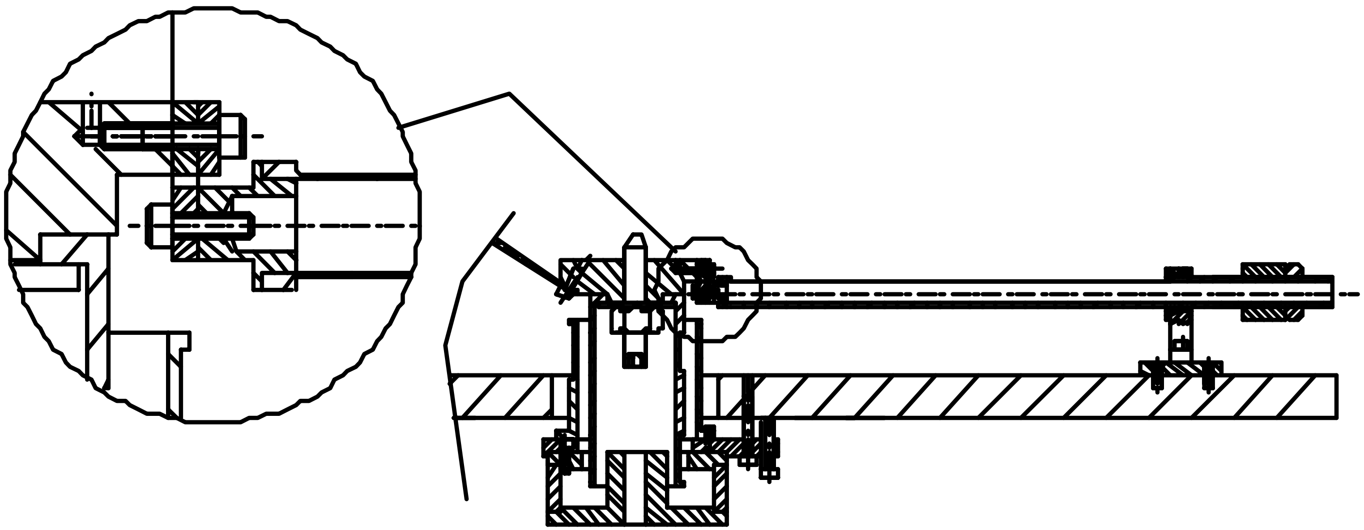


The effect


Main GASF
f=240 (mHz)
Q=40
Pitch of Load
1st. Internal 70Hz
Isolation Ratio(dB)
Frequency(Hz)
Transfer Function - Two Booms 1 CW Inner
Frequency [Hz]

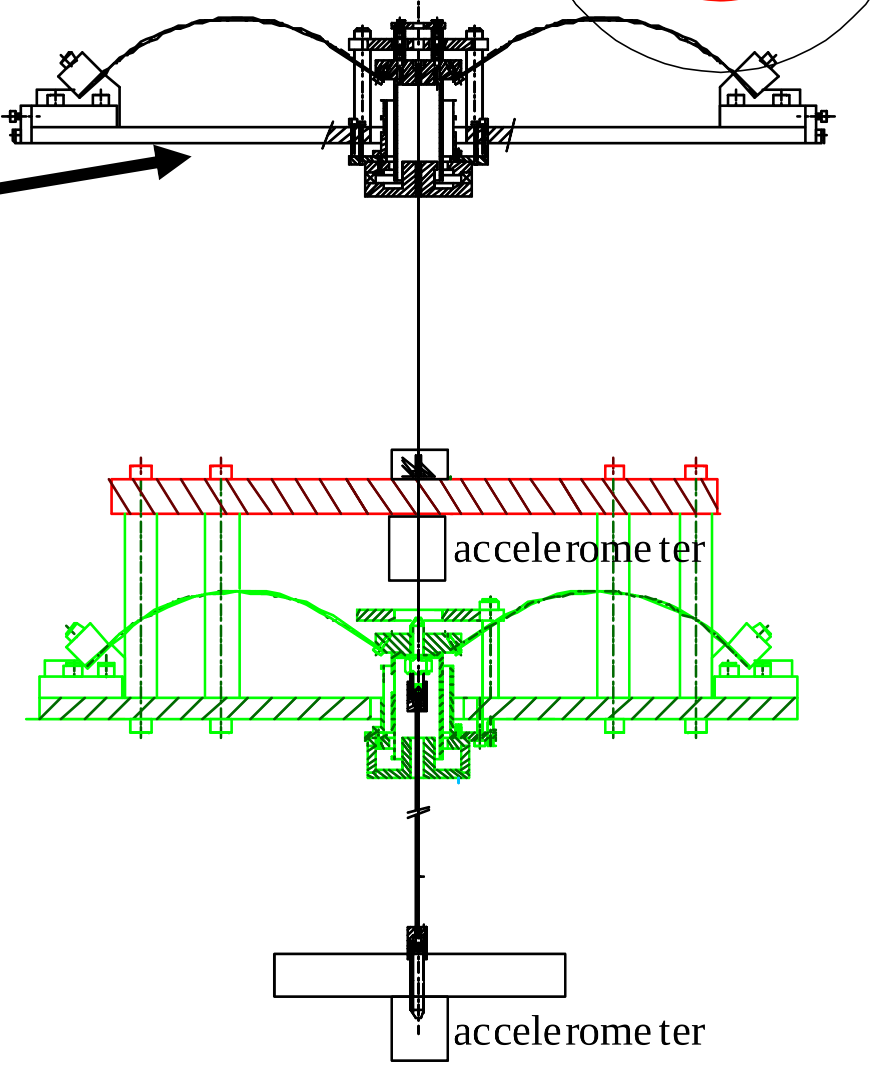
Implementation

- Add compensating counterweight rods



Counter-Weight tuning

- Use a calibrator larger filter to excite a bench GAS filter
- Measure TF
- Mount and adjust counterweights to minimize the TF



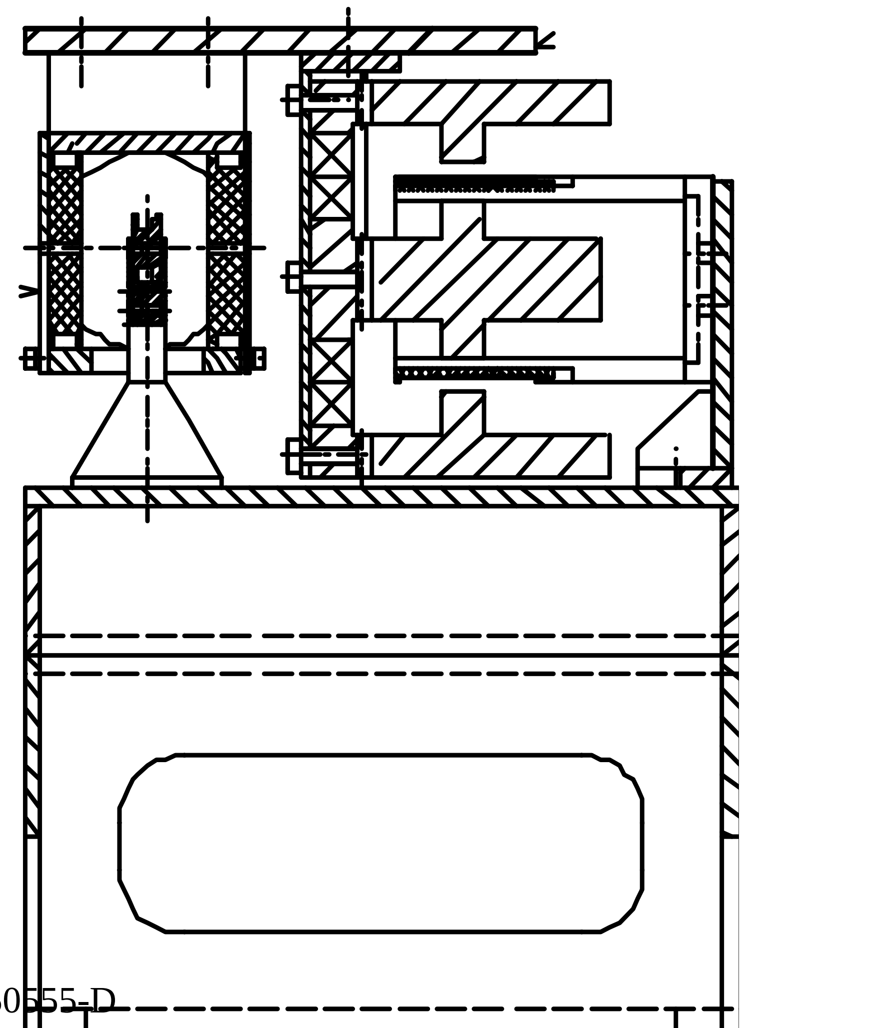
Pasadena 25th October 2005

Assembly notes

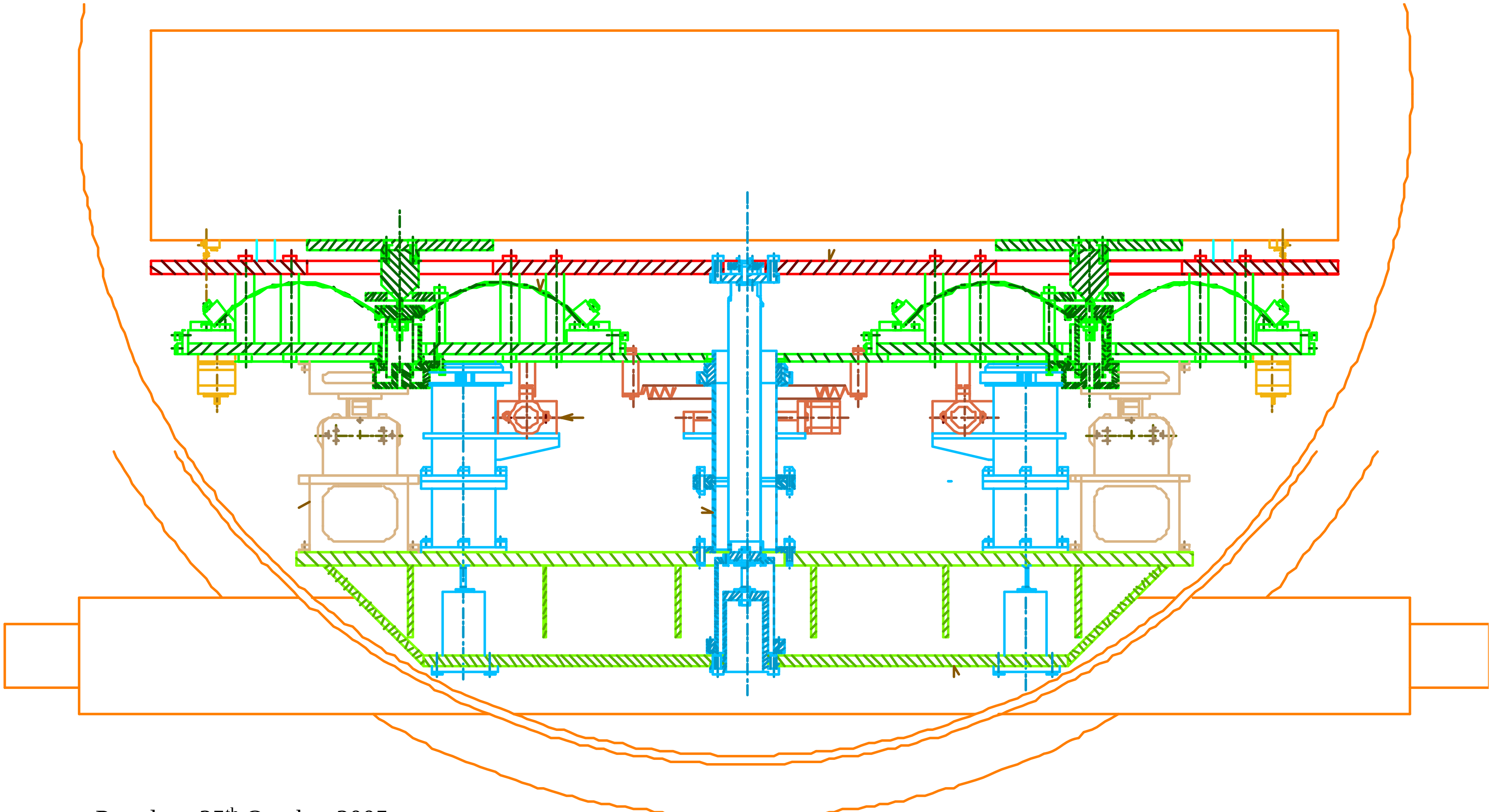
- The blades of GAS springs are mounted under stress and will be subject to a small but measurable creep
- To burn out that creep, the finished and cleaned GAS filters will be baked in clean air or Argon for 100-150 Hrs @150^{o}C
  - This step may be integrated in the UHV processing

Sensors and coil actuators

- Must be produced with UHV compatible materials and procedures
  - Approved Kapton coated wires
  - Peek
  - Dry machining, dry coiling
  - Kapton paint/processing



HAM-SAS
primary seismic attenuation for Advanced LIGO



Questions?

- Visit to the prototypes and test laboratory