Inverted pendulum studies for seismic attenuation

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Introduction

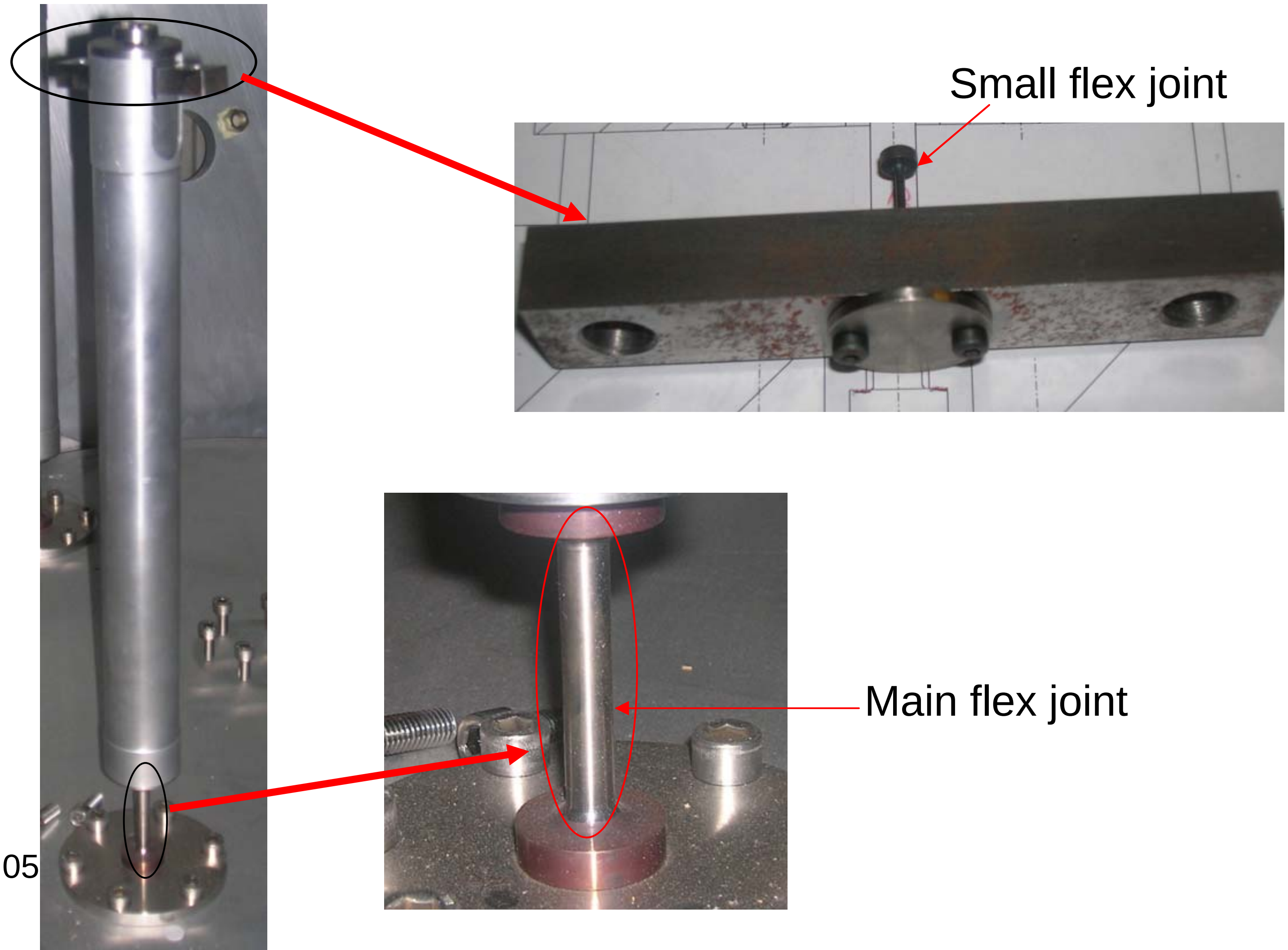
- Seismic noise is one of the most important noise sources that will affect the detector at low frequencies

- There is the necessity to design an adequate isolation system

  An inverted pendulum (IP) is implemented to provide attenuation at frequencies extending down to the micro-seismic peak and to realize a mean to position the entire system without requiring large force

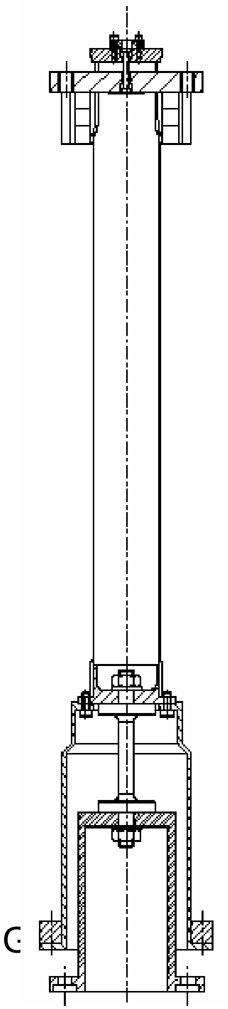
Inverted Pendulum

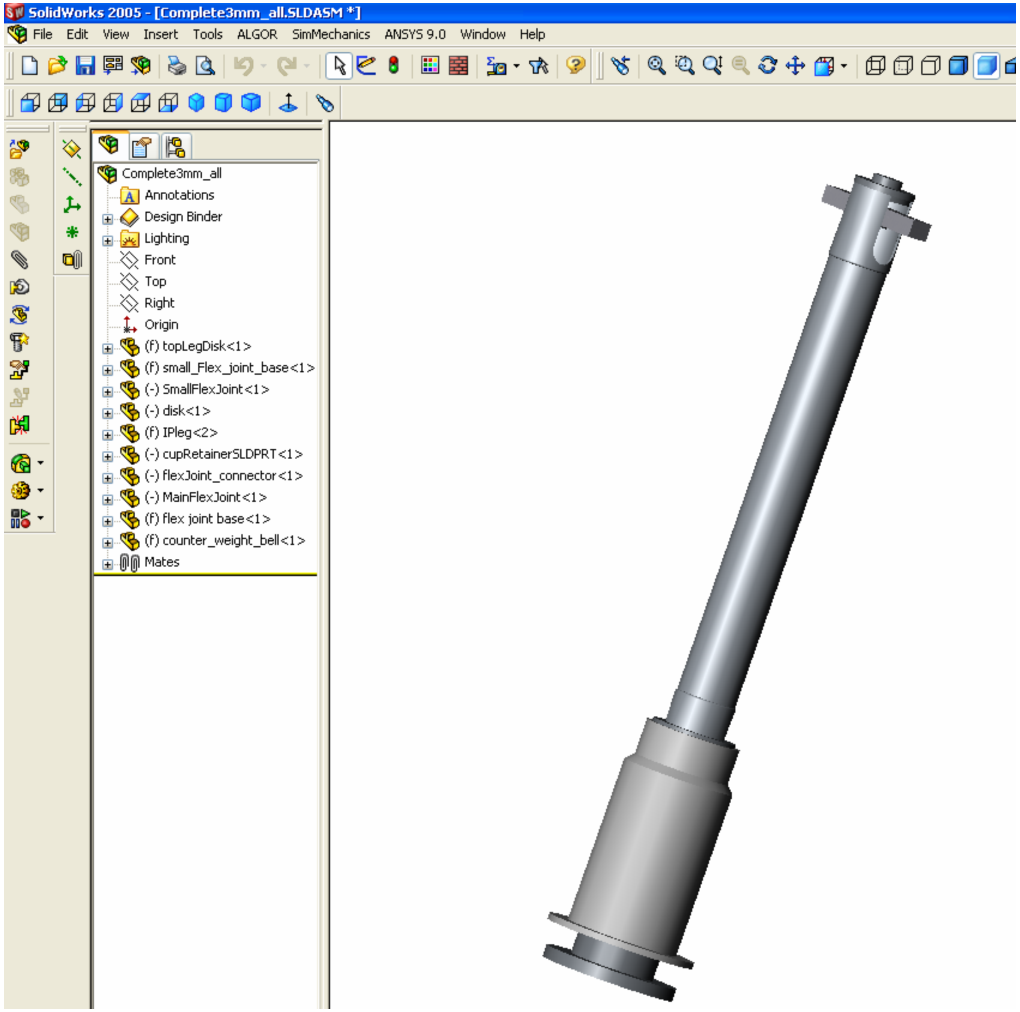
IP is a horizontal pre- isolation stage with ultra-low resonant frequency, typically 30 mHz



IP in ANSYS: First step

- Draw in each detail the individual legs of the inverted pendulum in Solid Solid Works©

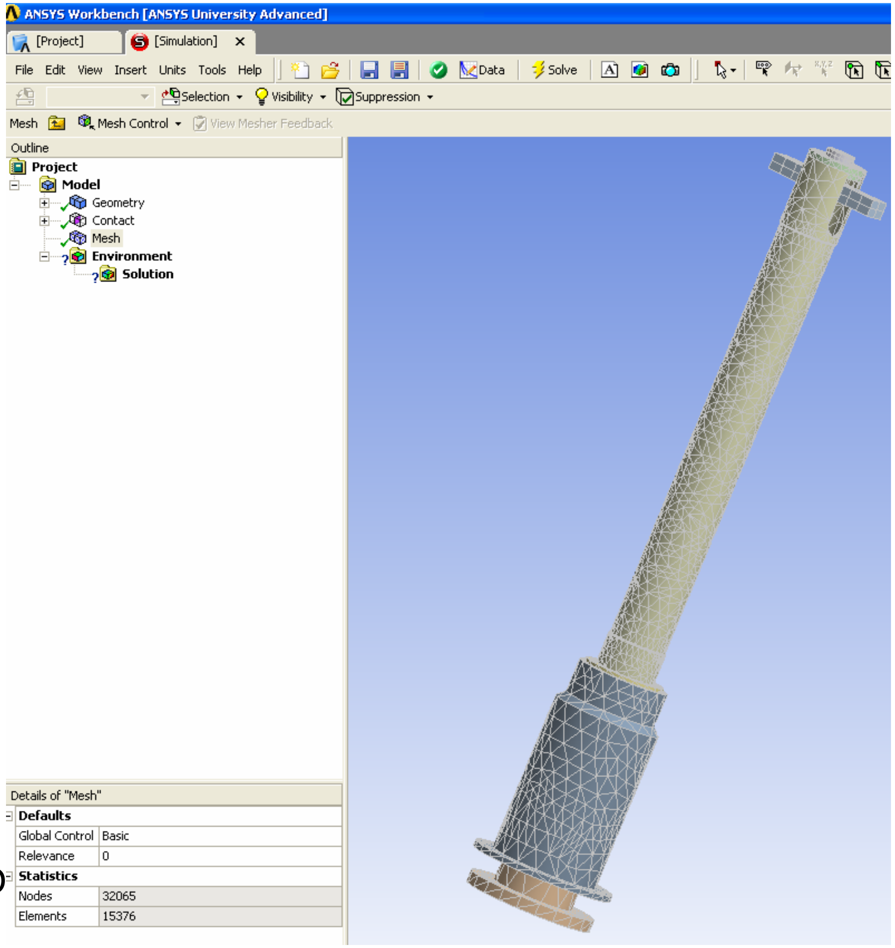




Second step

- Import the pendulum in Ansys©

First operation: meshing

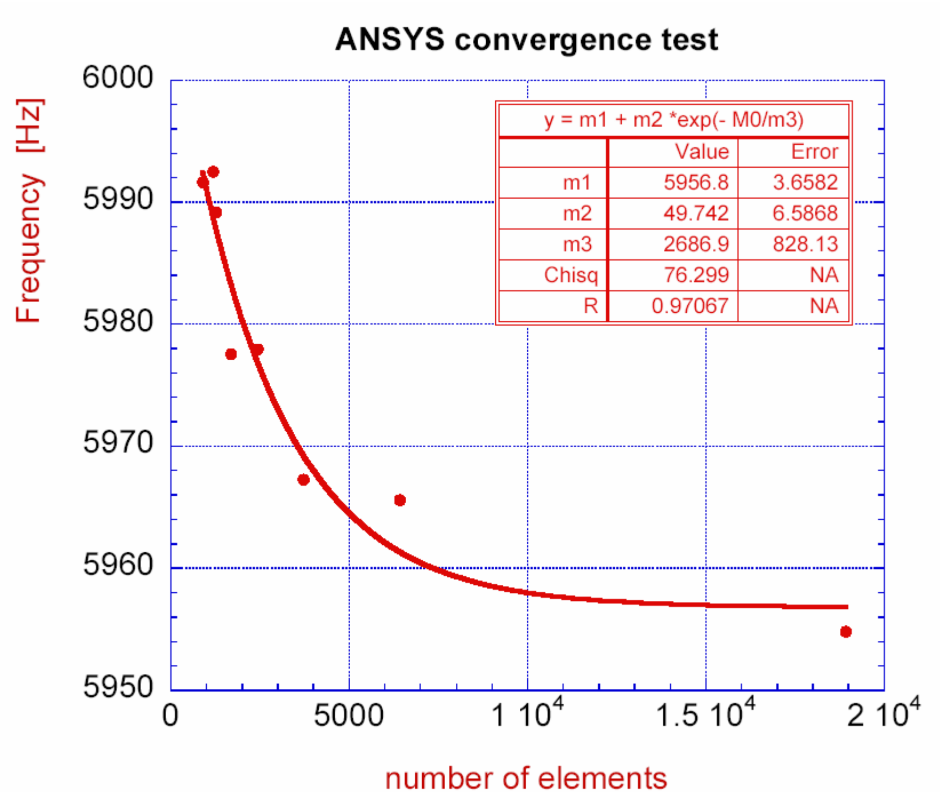


- Ansys is ageneral purpose finite element modeling
- The body can be sub-divided up into small discrete regions known as **finite elements**
- Calculate stress and strain propagated through the mesh

Second step

- Import the pendulum in Ansys©

Second operation: convergence test to check that the model finds stable resonance frequencies

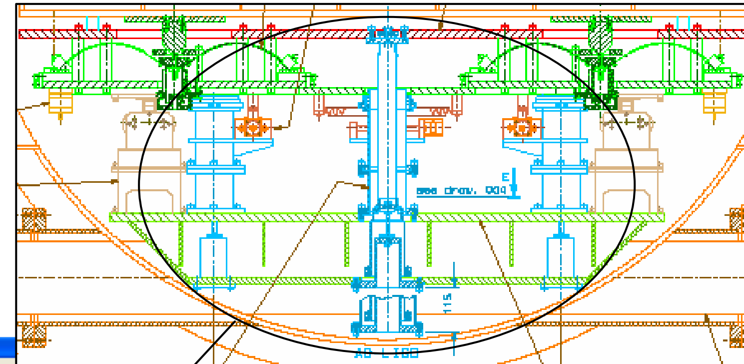


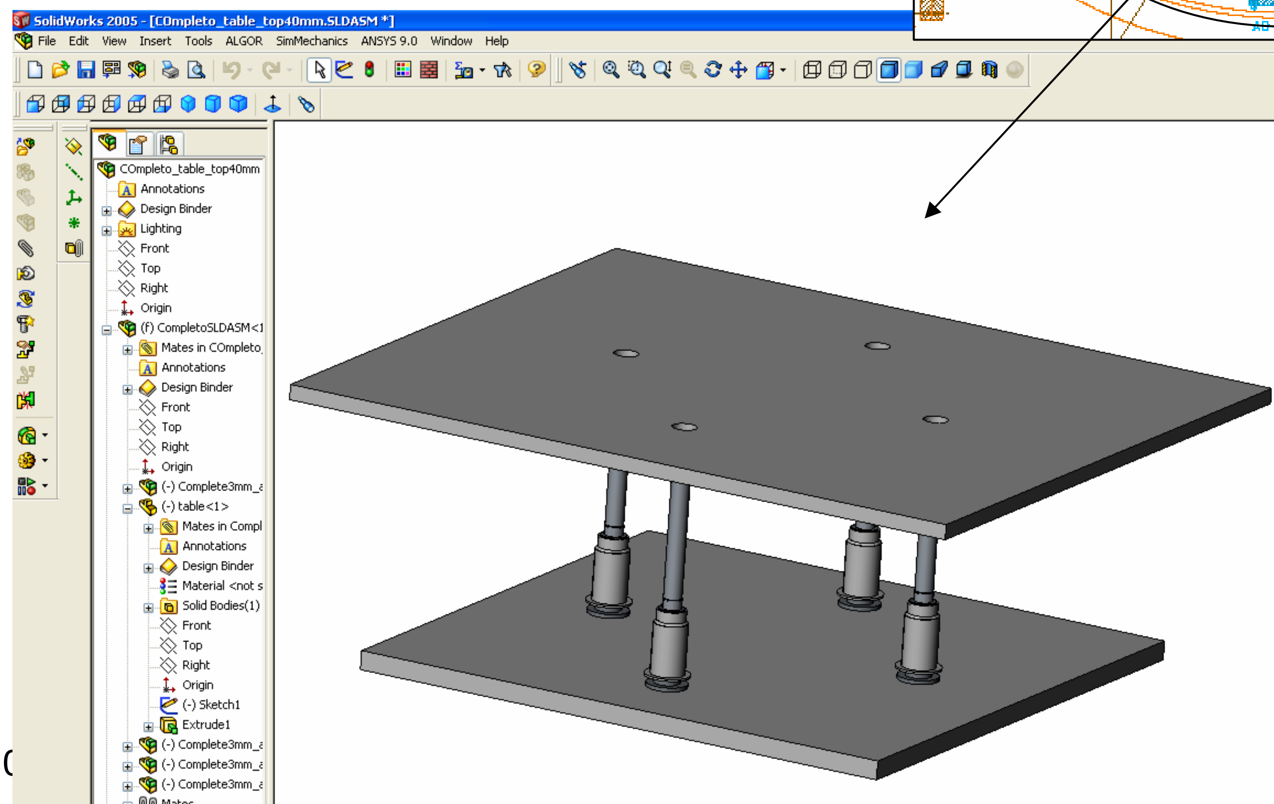
Convergence test for the first 6 frequencies up to 22 MHz

☺ NO problem of convergence

Third step

- Assembly 4 legs into in Solid Works





Fourth Step

- Solve model and analyze first 20 modes in ANSYS

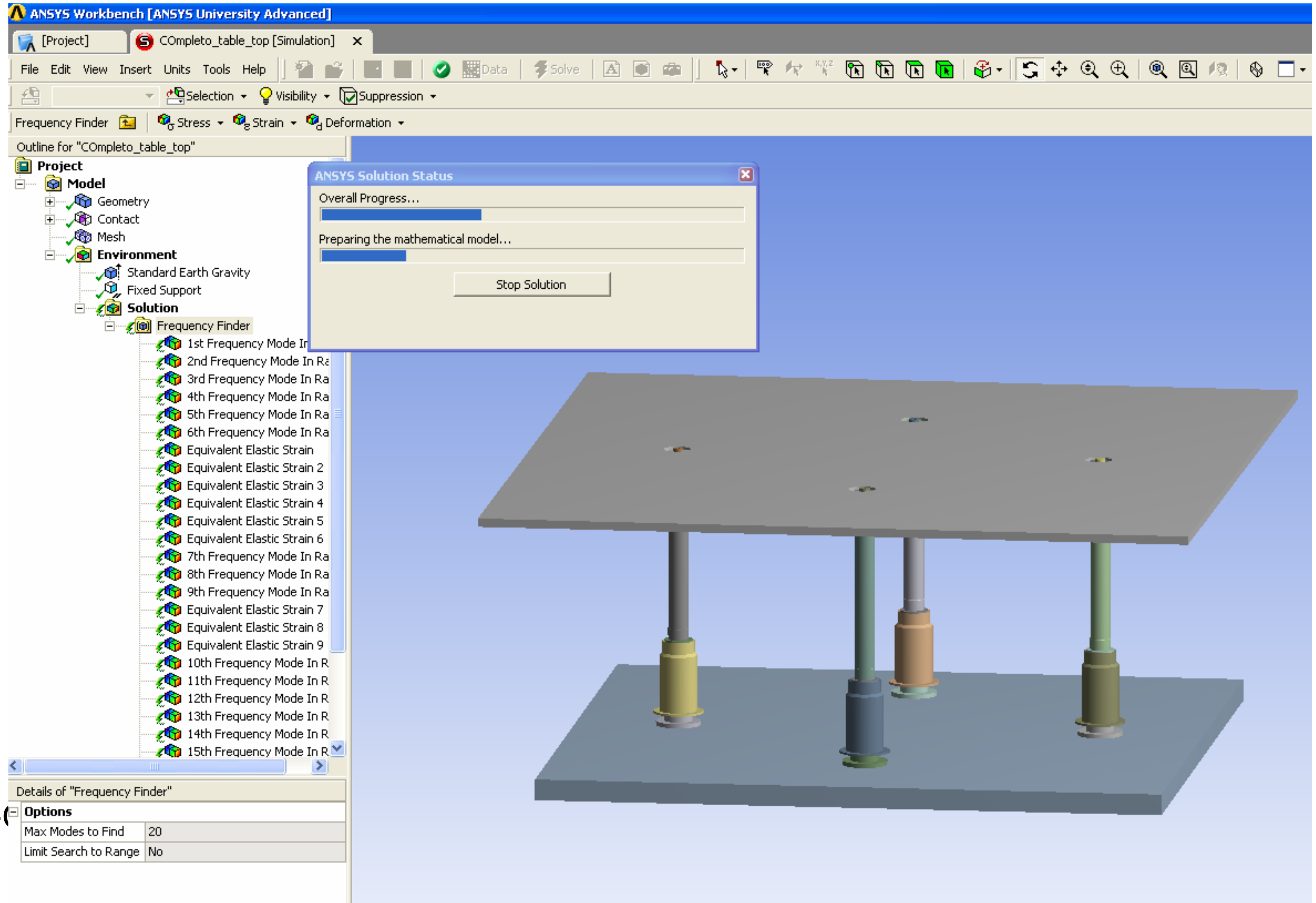
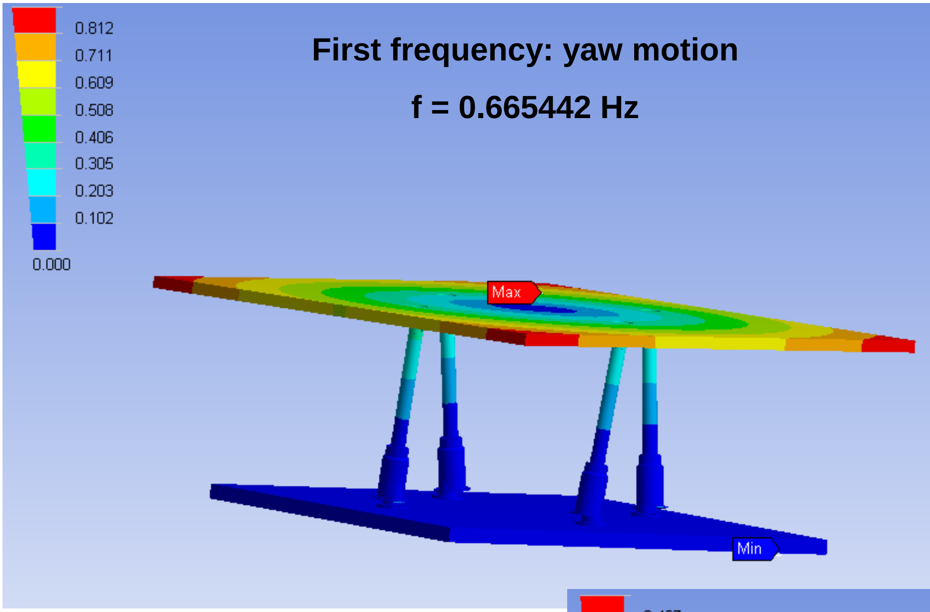
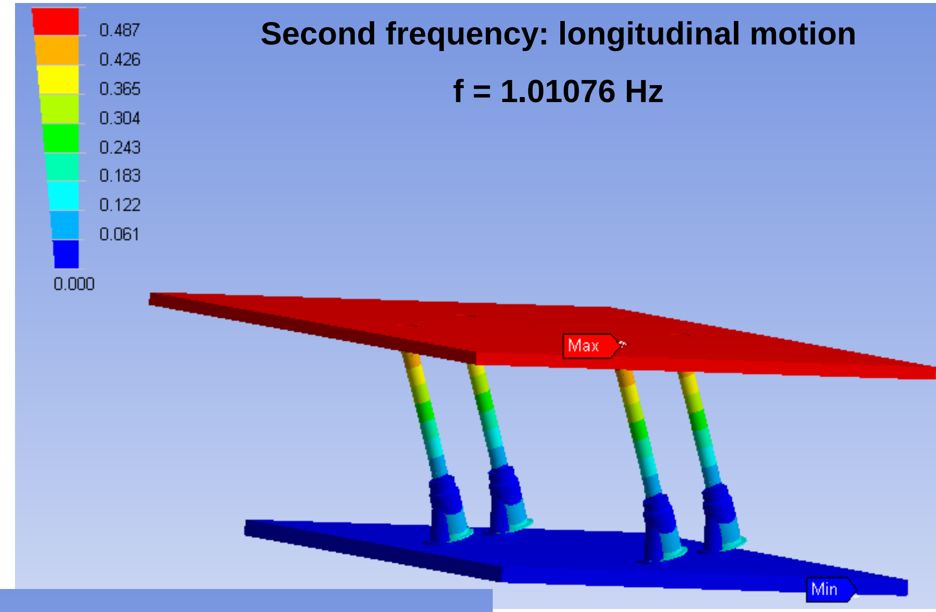


Table normal modes





Third frequency: transversal motion

f = 1.01252 Hz

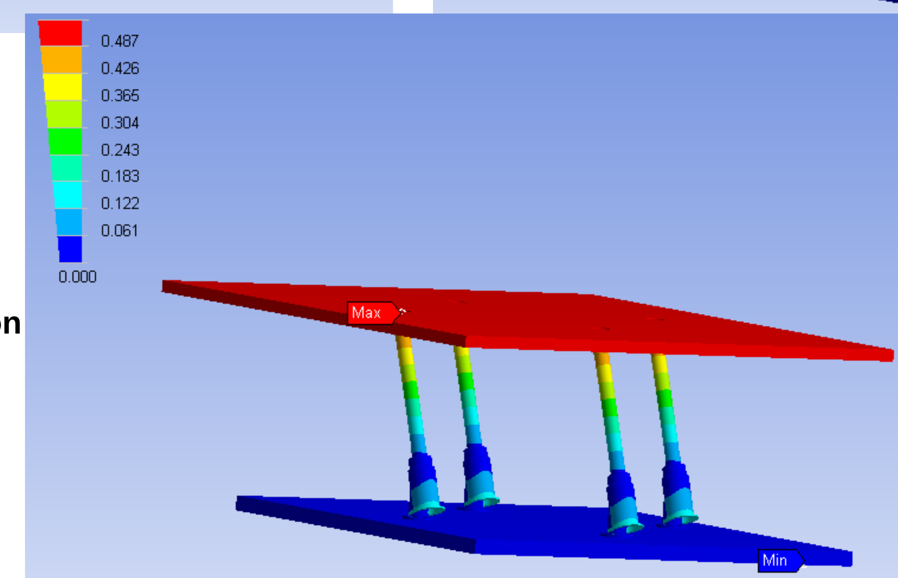


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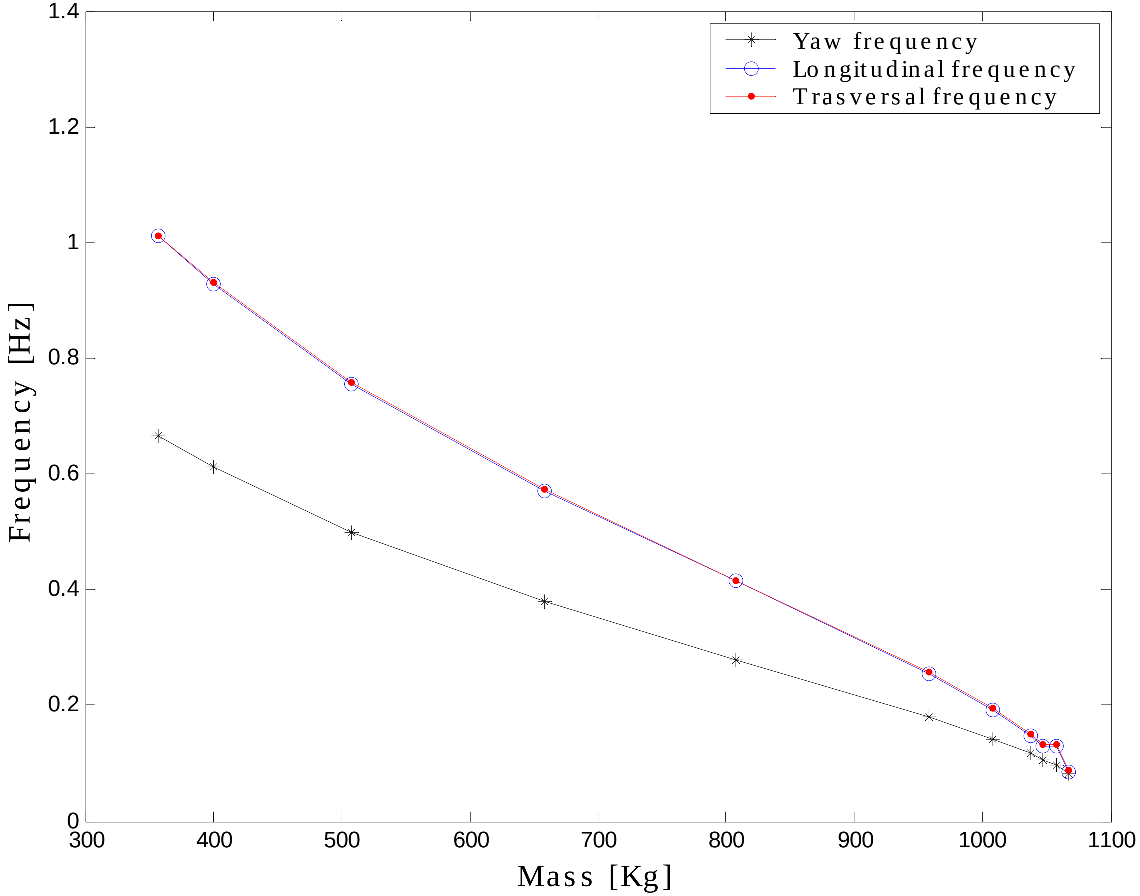
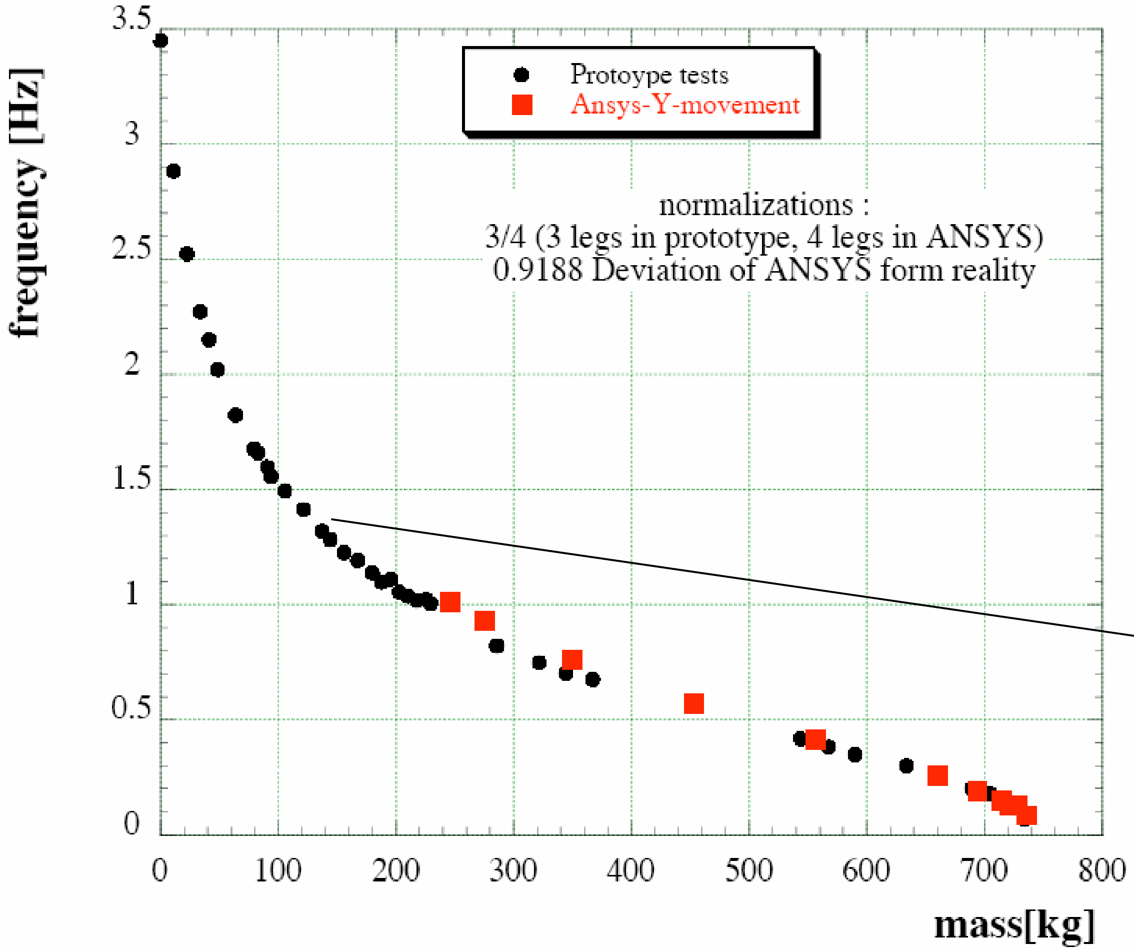
Table normal modes (2)

- Frequency vs load: I changed the mass of the table on the top of the 4 legs



- Longitudinal and trasversal frequencies are identical
- Zero frequency point is the same for all 3 main modes

Validation

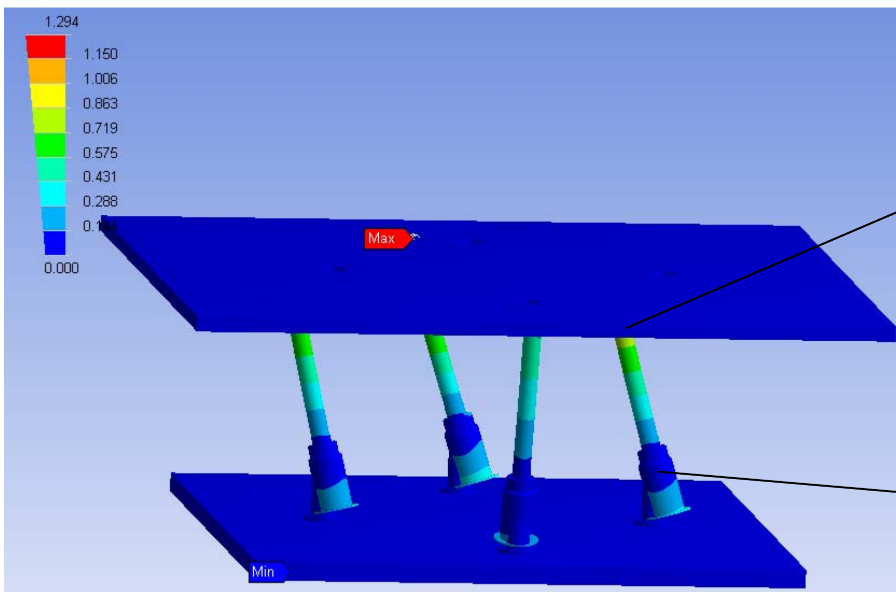


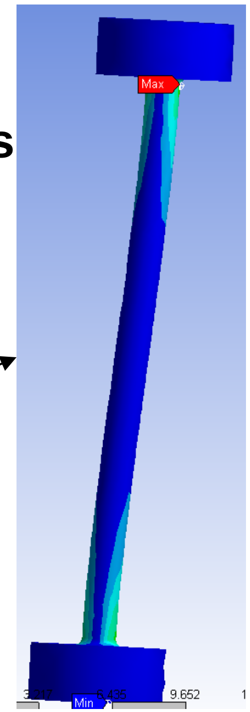
Ansys results are fully validated by the measurement results

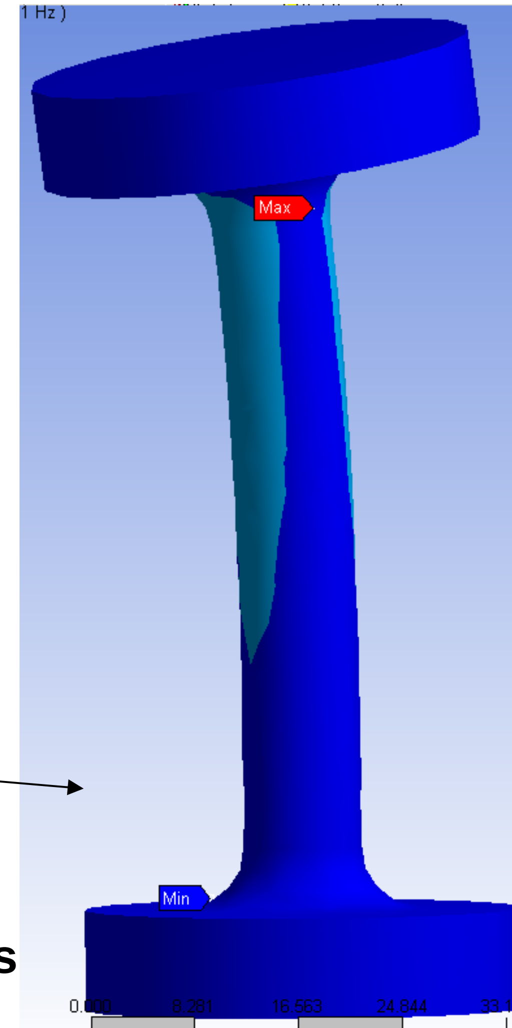
Rigid leg resonances

- Eight degenerate resonances: each leg has 2 resonances

Small flex joint: S- stress



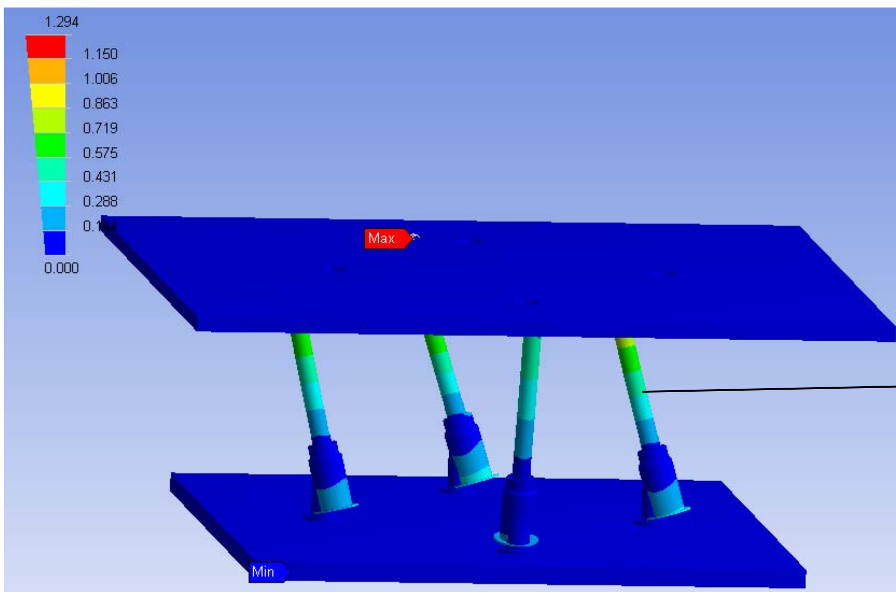


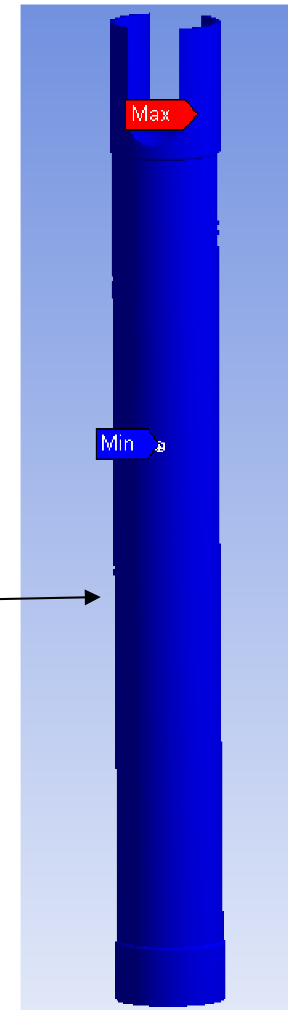


Main flex joint: C- stress

Rigid leg resonances

- Eight degenerate resonances: each leg has 2 resonances





Leg is not stressed

Rigid leg resonances (2)

Mass of counter weight: 1.212 Kg

	Resonance frequency with counterweight	Resonance frequency without counterweight
Diameter of small flex joint: 1.5 mm	~110.6 Hz	~122 Hz
Diameter of small flex joint: 3 mm	~178.3 Hz	~235.3 Hz

Rigid leg resonances (2)

Mass of counter weight: 1.212 Kg

	Resonance frequency with counterweight	Resonance frequency without counterweight
Diameter of small flex joint: 1.5 mm	~110.6 Hz	~122 Hz
Diameter of small flex joint: 3 mm	~178.3 Hz	~235.3 Hz

Measurement of prototype: 103 Hz

20% of discrepance between measurement and Ansys results, within tube tolerancies

Rigid leg resonances (3)

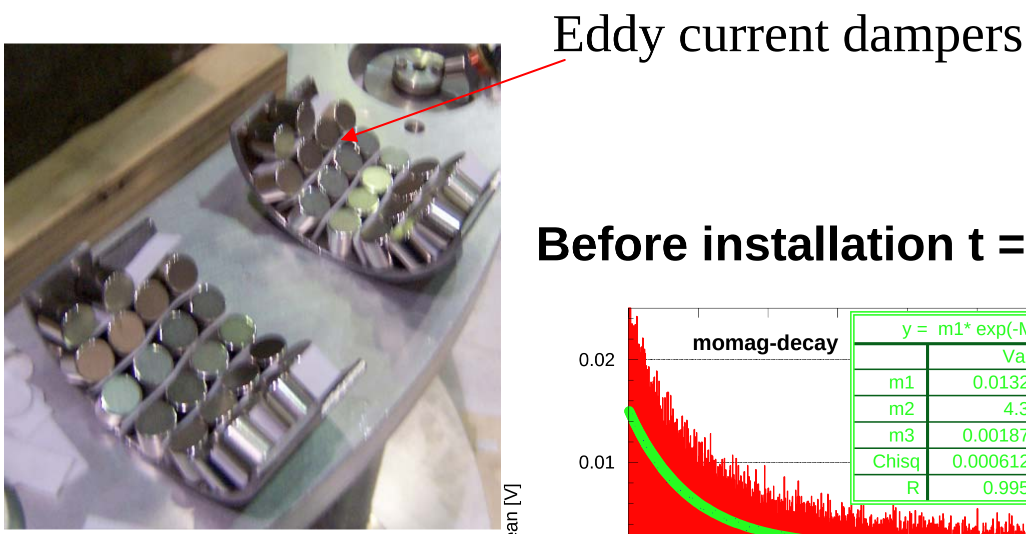
Mass of counter weight: 1.212 Kg

	Resonance frequency with counterweight	Resonance frequency without counterweight
Diameter of small flex joint: 1.5 mm	~110.6 Hz	~122 Hz
Diameter of small flex joint: 3 mm	~178.3 Hz	~235.3 Hz

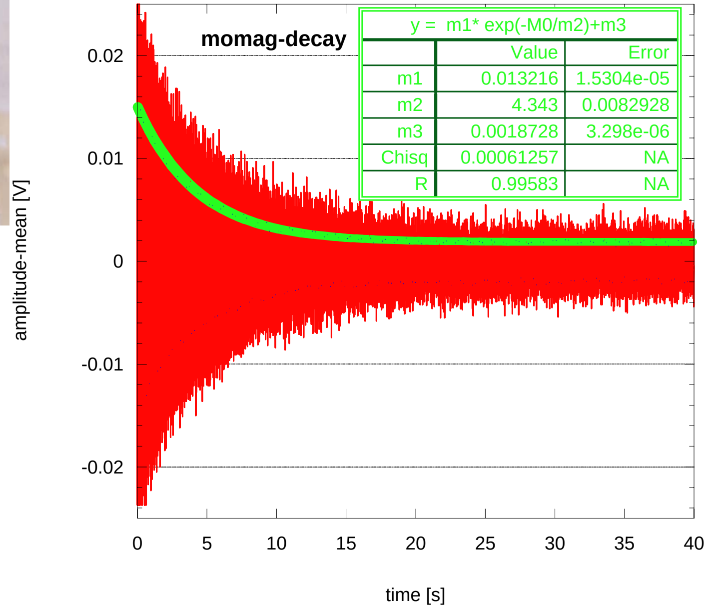
Ansys shows that counter weight doesn’t reduce significantly the resonance, that are dangerous. They can be damped

Solution: Eddy current dampers

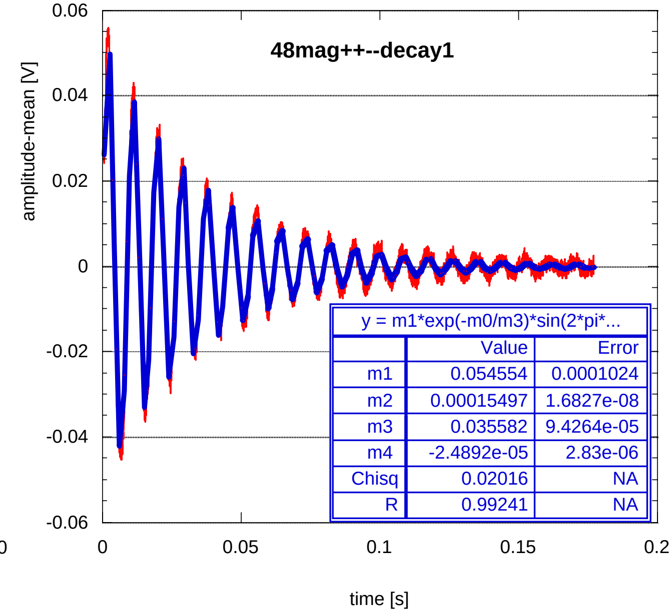
Measured and succesfully damped in a prototype without counter weight



Before installation t = 4.3 s



After installation t = 35 ms



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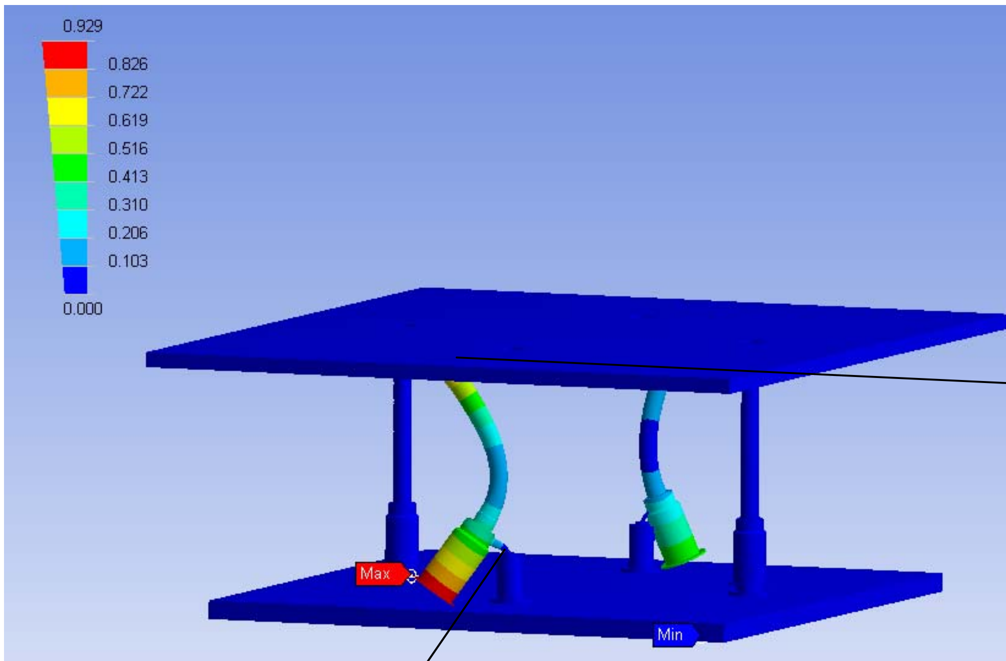
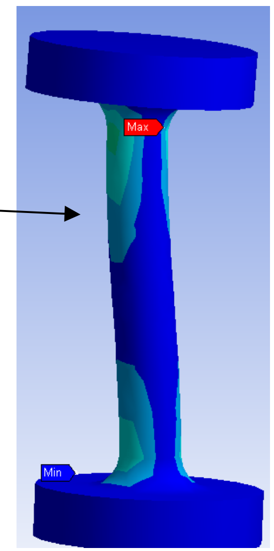
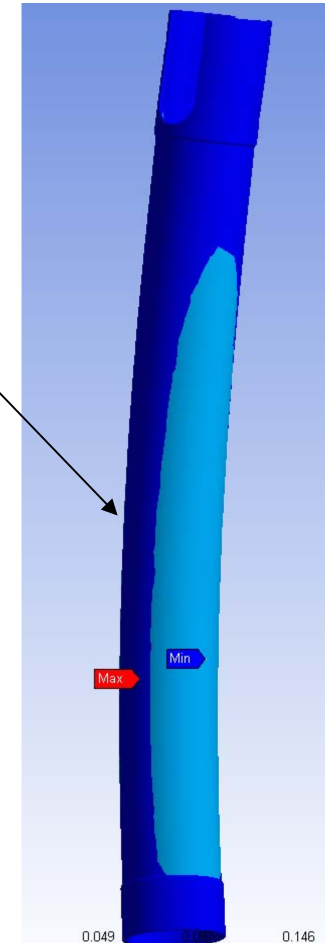
Banana leg resonances

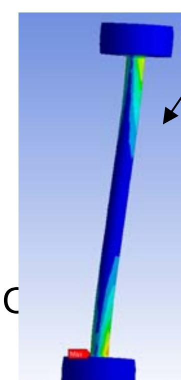
Each IP leg has 2 banana resonances





Main flex joint: S- stress





Small flex joint: S- stress

Banana resonances (2)

Mass of counter weight: 1.212 Kg

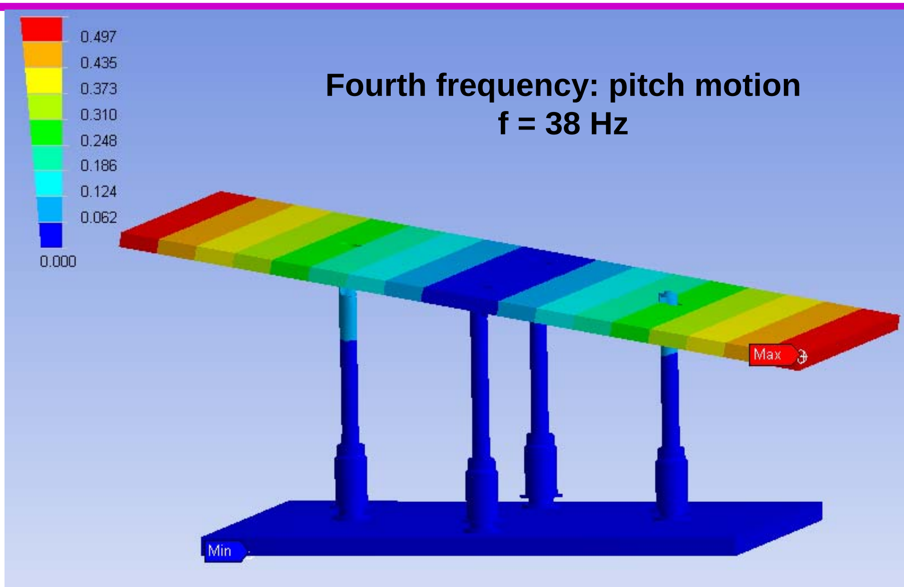
	Resonance frequency with counterweight	Resonance frequency without counterweight
Diameter of small flex joint: 1.5 mm	~210.6 Hz	~415 Hz
Diameter of small flex joint: 3 mm	~253.3 Hz	~424 Hz

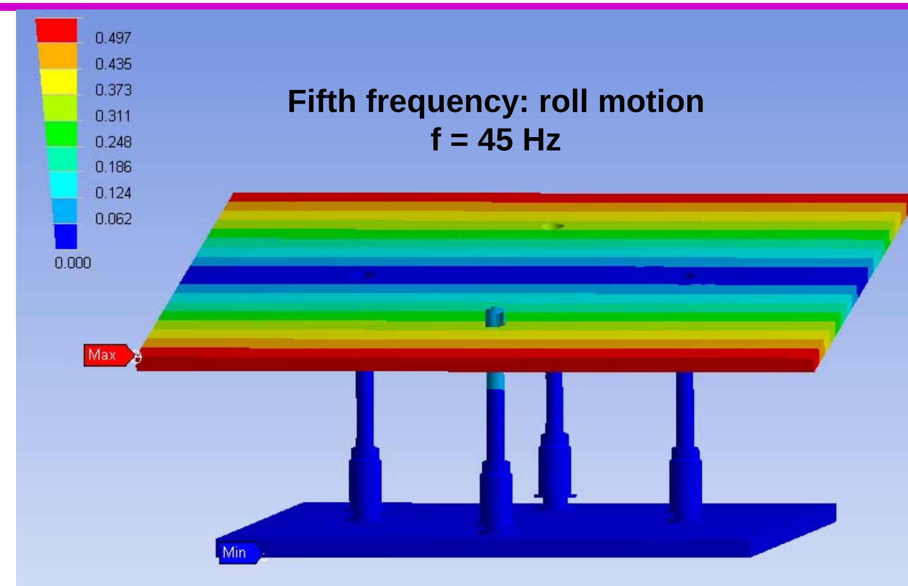
Banana resonances (3)

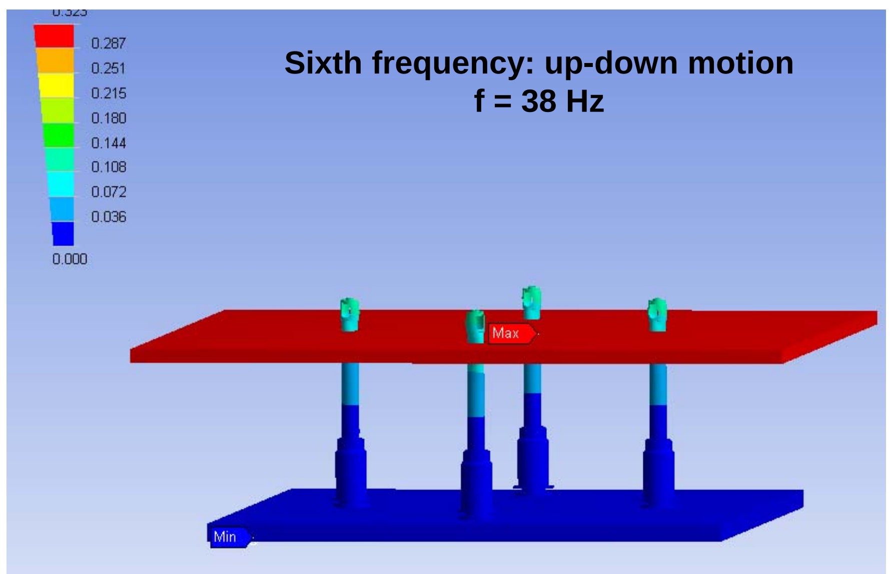
- Higher frequencies
- Resonances move the head of the leg

The damper will be even more effective

Spring box resonances

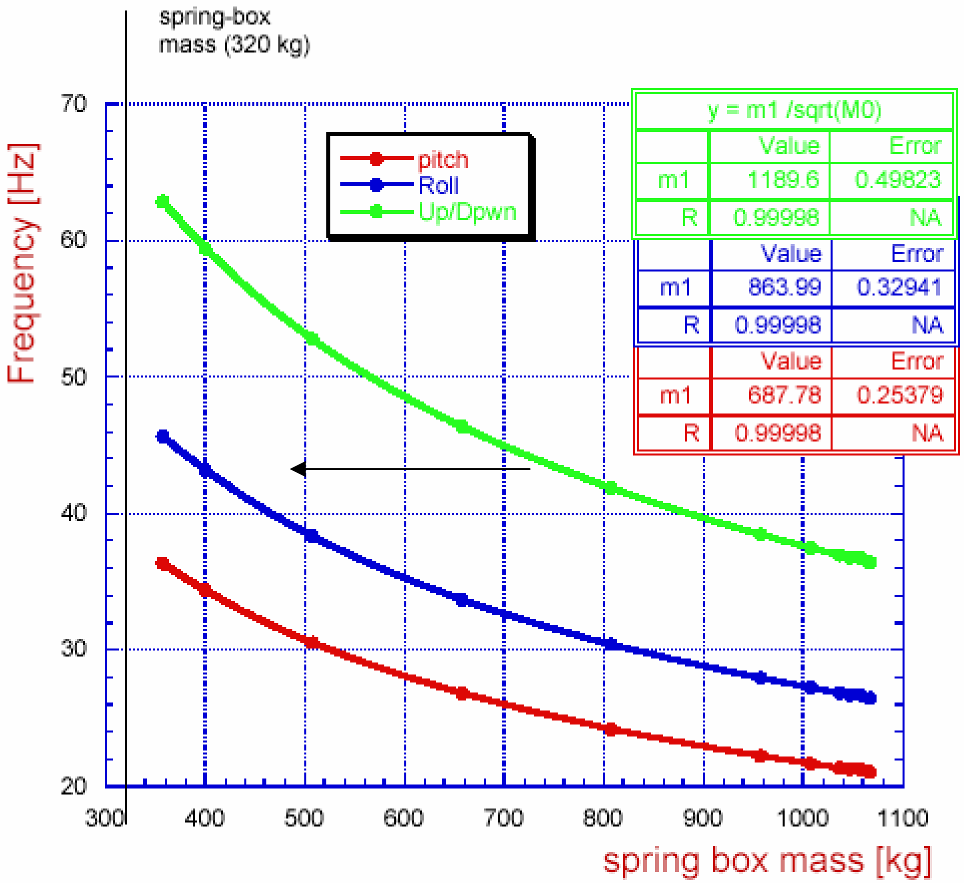






Spring box resonances(2)

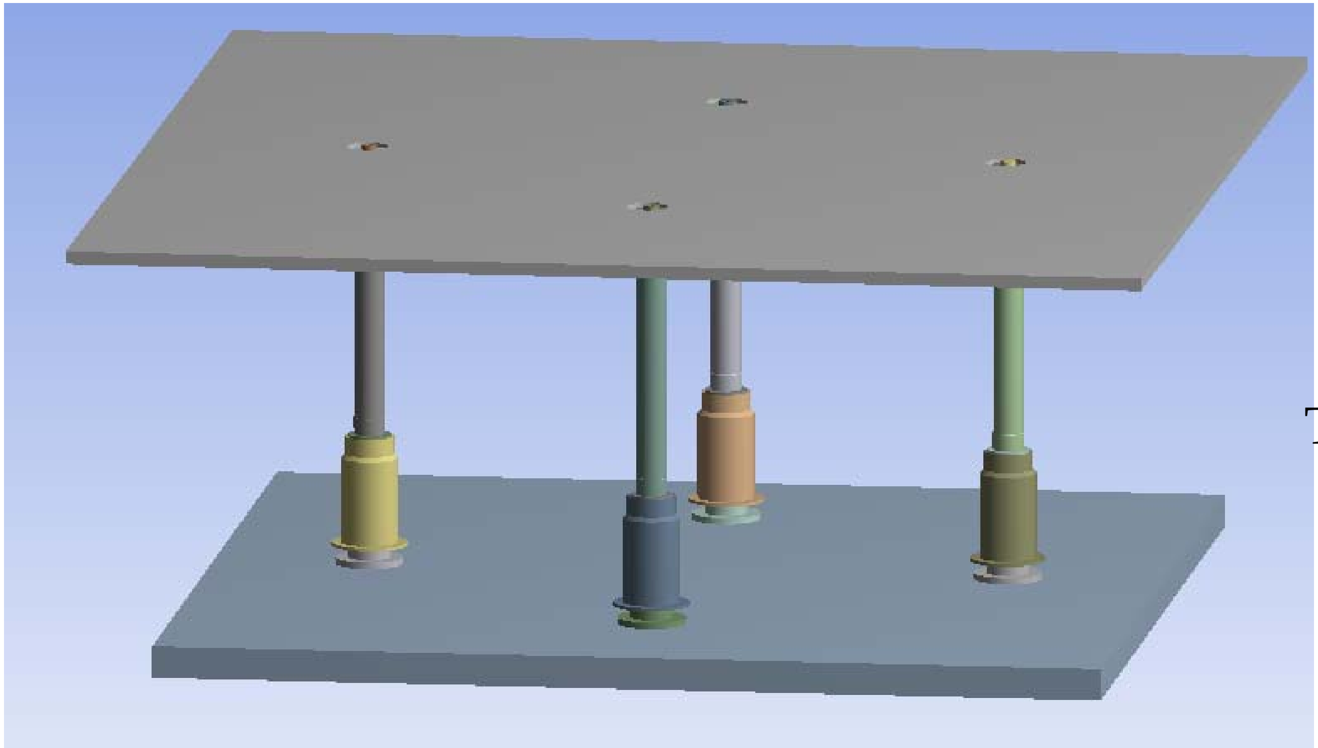
Spring box effective mass 320 Kg



- Leg magnetic dampers may be still effective
- Complementary resonant dampers may be required

IP Transfer Function

Output: monitor resulting movement



$$TF(f) = \frac{\text{Output}}{\text{Excitation}}$$

Excitation

IP Transfer Function

- The aim is to determine the counter weight that neutralize the percussion point effect of the legs
- Prototype measurements indicate that the transfer function saturates at 80 dB without counterweight
- A proper counter weight should allow 100 dB attenuation

Future

- Find a counter weight which allow an attenuation of 100 dB
- Export TF to Sym Mechanic model

Acknowledgments

- Riccardo De Salvo and Calum Torrie

for their help, encouragments and patience

- Juri Agresti and Virginio Sannibale for answering my quick questions
- Innocenzo Pinto for the opportunity he gave me

And…

The sun of California…