Status of Mechanical Stabilization

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Overview

1. Introduction of the context

2. Test possibilities :
   - Instrumentation
   - The experimental setups
   - Numerical approach to increase test possibilities

3. Active control of the structure
   3.1. Active control of a defined point of the structure
   - At given frequencies
   - Dedicated to a bandwidth which corresponds to a resonant mode of the structure
   - Results with the cantilever magnet prototype

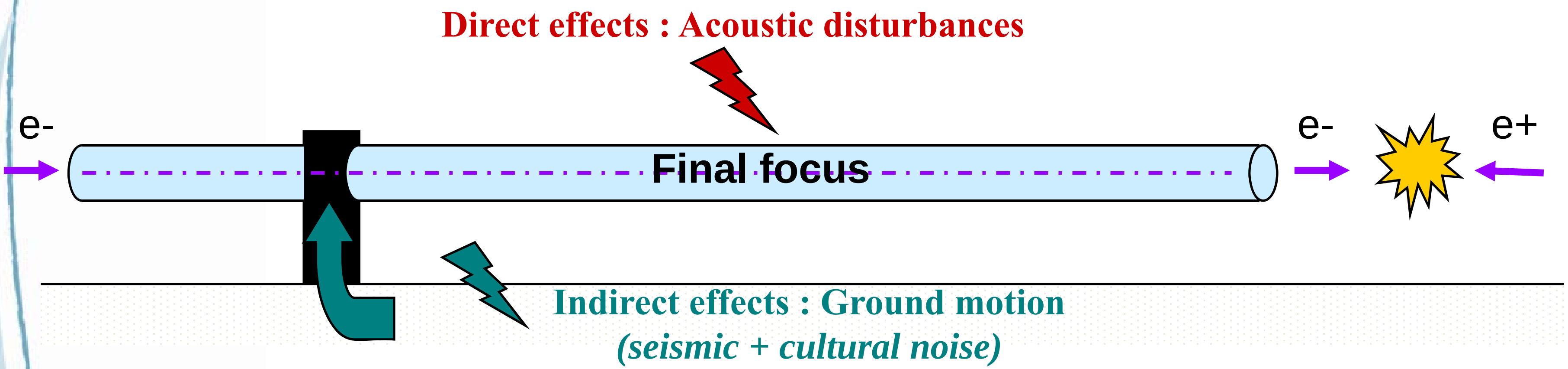
   3.2. Combination of active isolation and active compensation
   - Results using an industrial solution : TMC table of CERN
   - Interest in a low cost and active table dedicated to our needs

   3.3. Active control of the entire structure
   - Investigation of a multipoint control method
   - Next stage : comparison with the distributed collocated control

4. Conclusion and perspectives

The problem of the stabilization

✓ **The sources of the structure motion :**



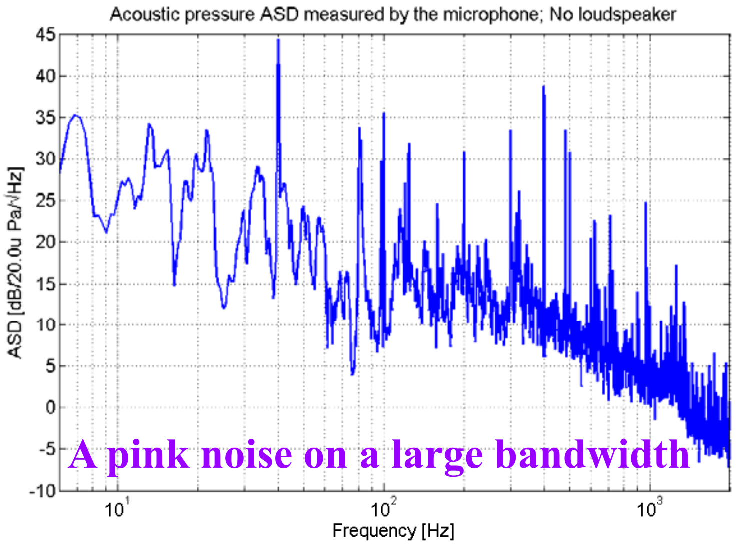
- Direct effects : - excite particularly the resonant modes of the structure
- Indirect effects : - create a vertical displacement of the clamping
  - excite particularly the vertical flexion mode of the structure

✓ **The different required approaches of this problem :**

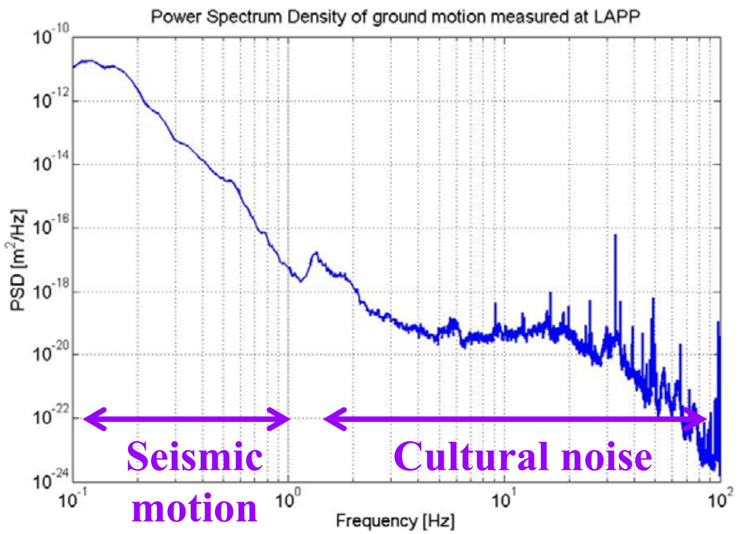
- Active compensation : - maintain the structure in a straight horizontal position along its axis
- Active and passive isolation : - obtain a null absolute displacement of the clamping, so of the entire system.

Example of spectral analysis of different disturbance sources

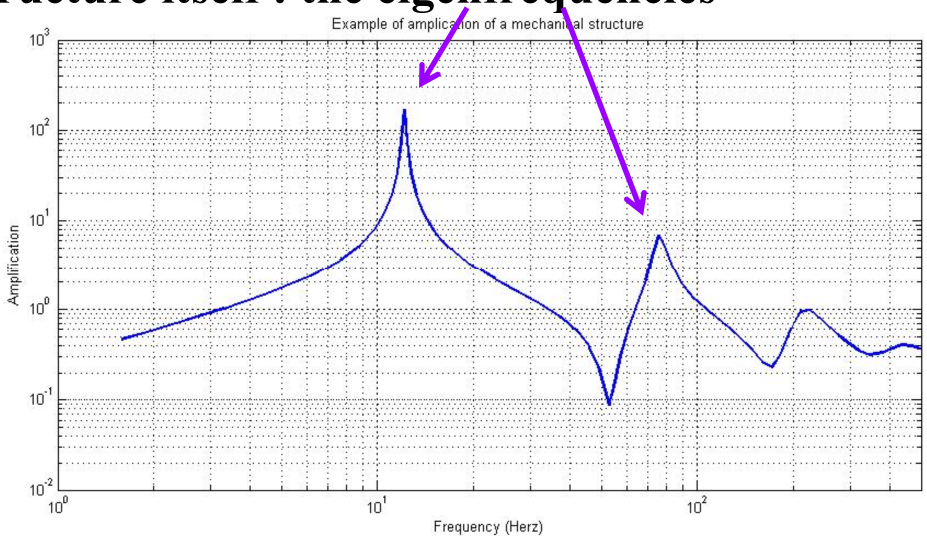
✓ **Acoustic disturbance :**



✓ **Ground motion :**



✓ **Amplified by the structure itself : the eigenfrequencies**



The problem of the stabilization

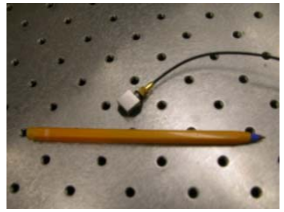
✓ **Vibration sensors acquired by LAVISTA : (PhD thesis of B. Bolzon)**

Type of sensors	Electromagnetic geophone	Electrochemical geophone	Piezoelectric accelerometers		
Model	GURALP CMG-40T	SP500-B	ENDEVCO 86	393B12	4507B3
Company	Geosig	PMD Scientific	Brüel & Kjaer	PCB Piezotronics	Brüel & Kjaer
Sensibility	1600V/m/s	2000V/m/s	10V/g	10V/g	98mV/g
Frequency range	[0.033; 50] Hz	[0.0167; 75] Hz	[0.01; 100] Hz	[0.05; 4000] Hz	[0.3; 6000] Hz
Measured noise (f > 5Hz)	0.05nm	0.05nm	0.25nm >50Hz: 0.02nm	11.19nm >300Hz: 4.8pm	100nm

Sub-nanometre measurements







Non-magnetic

Can be put on a small structure

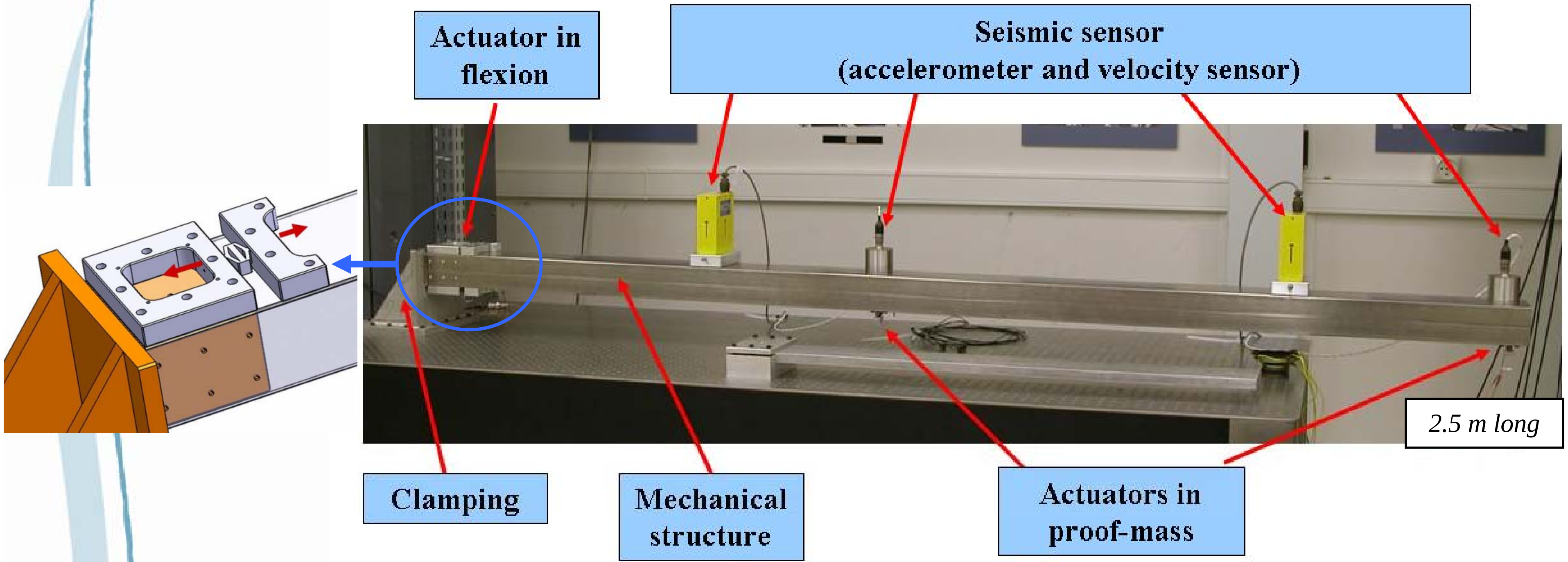
< 100Hz **> 100Hz**

Ground motion measurements

Modal analysis

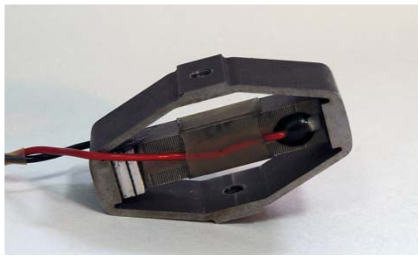
The prototype

✓ **The large prototype and its instrumentation :**



✓ **Actuators used for the active control of vibration :**

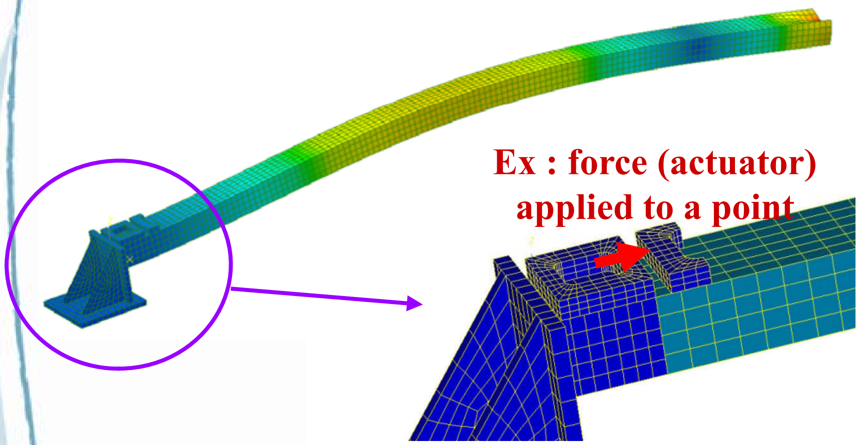
- A stacking of PZT patches -



- Force = 19.3 N
- Maximal displacement = 27,8 µm
- Resolution = 0,28 nm

Tests in simulation
(EUROTeV-Report-2007-054)

✓ **A finite element model of the structure :**



✓ **Dynamics equation :**

$$M.\ddot{u}(t) + C.\dot{u}(t) + K.u(t) = f_p(t)$$

- **M** : Mass matrix
- **C** : damping matrix
- **K** : stiffness matrix

➢ **A prediction of the mechanical structure response**

➢ **Requires an updating to be as representative as possible to the real setup**

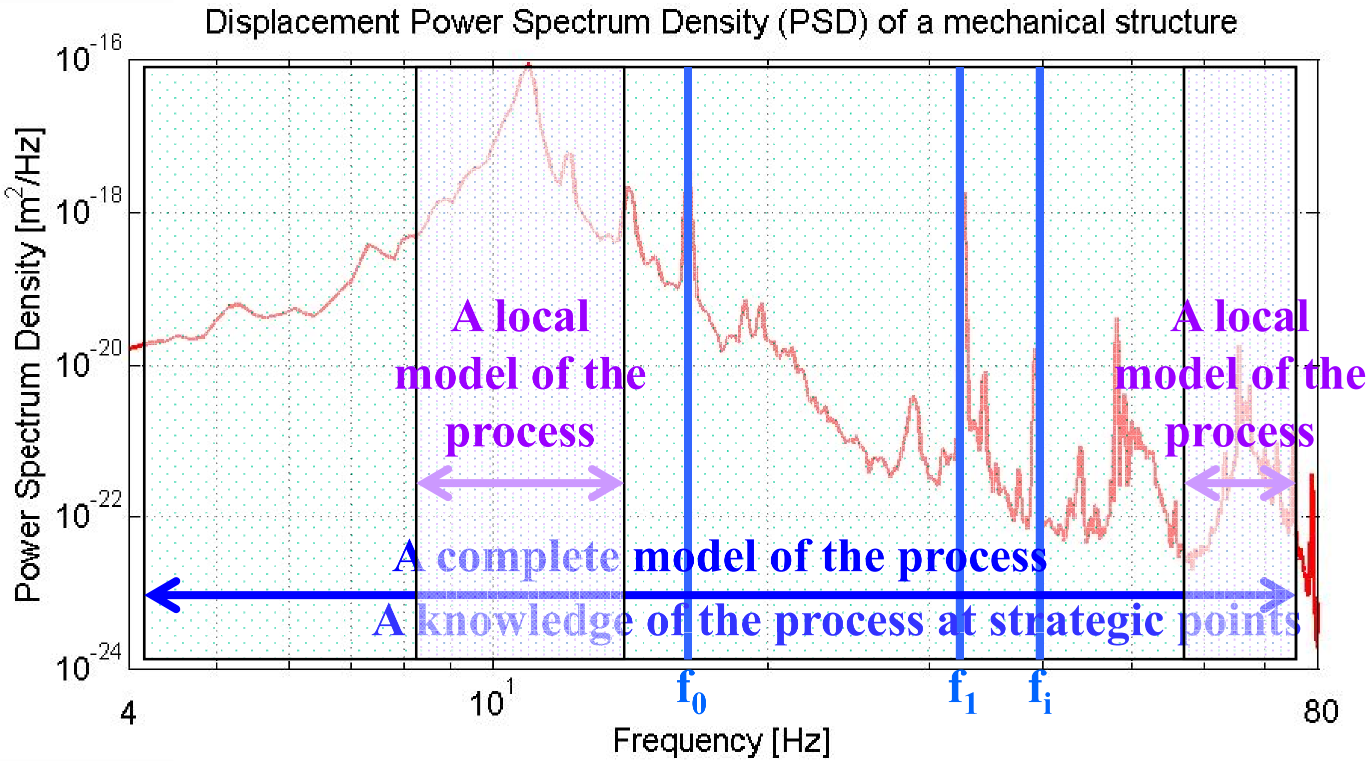
➢ **Available under Simulink, in the form of a state space model in order to test feedback loops.**

✓ **The purpose of the simulation :**

- To adjust the feedback loop
- To increase the test possibilities (multiple configurations for sensors, actuators…)
- To analyse the behaviour of the entire beam

Different approaches of the problem

✓ **The method used to build the controller :**



1 - A knowledge of the structure at strategic points : ***for lumped disturbances***

2 - A local model of the structure : ***for the disturbances amplified by eigenfrequencies.***

3 - A complete model of the structure : ***for the entire structure***

The first developed algorithm
(EUROTeV-Report-2006-097)

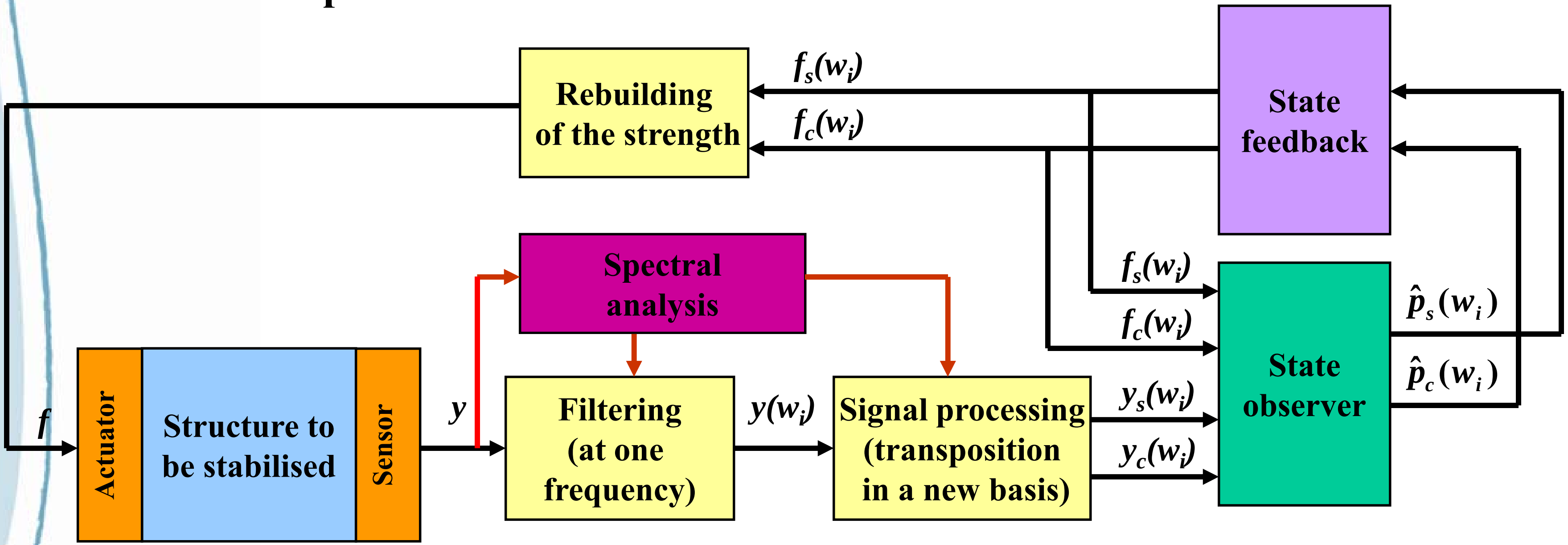
✓ **The originality :**

Not based on a model of the system (classical algorithm), but only on a few characteristics of the system, computed in open loop for each selected frequency :

- The gain and the phases differences between output / input.

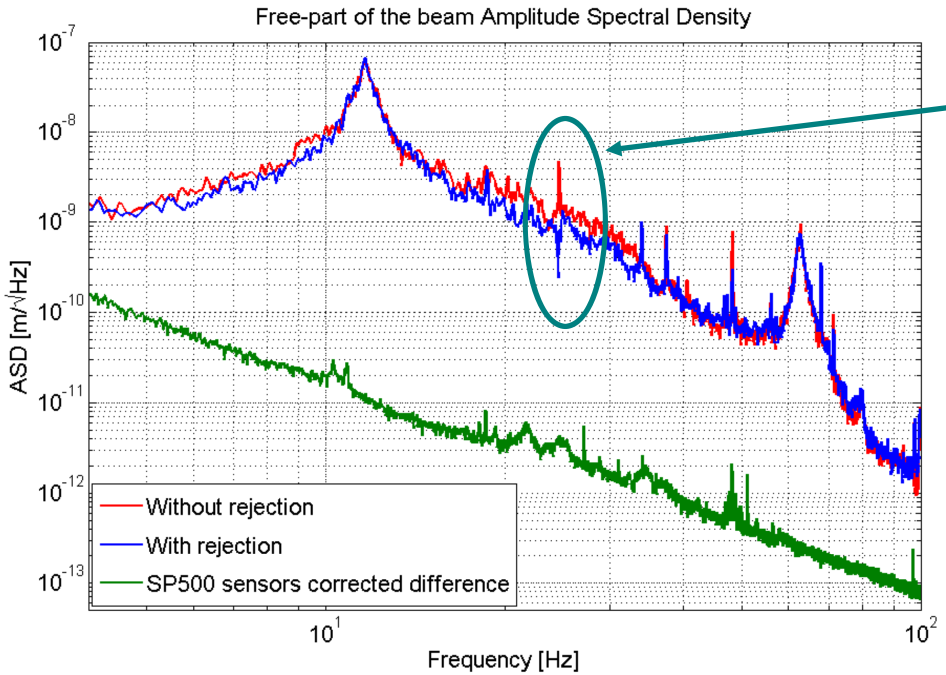
- The setting time.

✓ **The different components :**



Results with the first developed algorithm

✓ **The first results at the nanometer scale :**



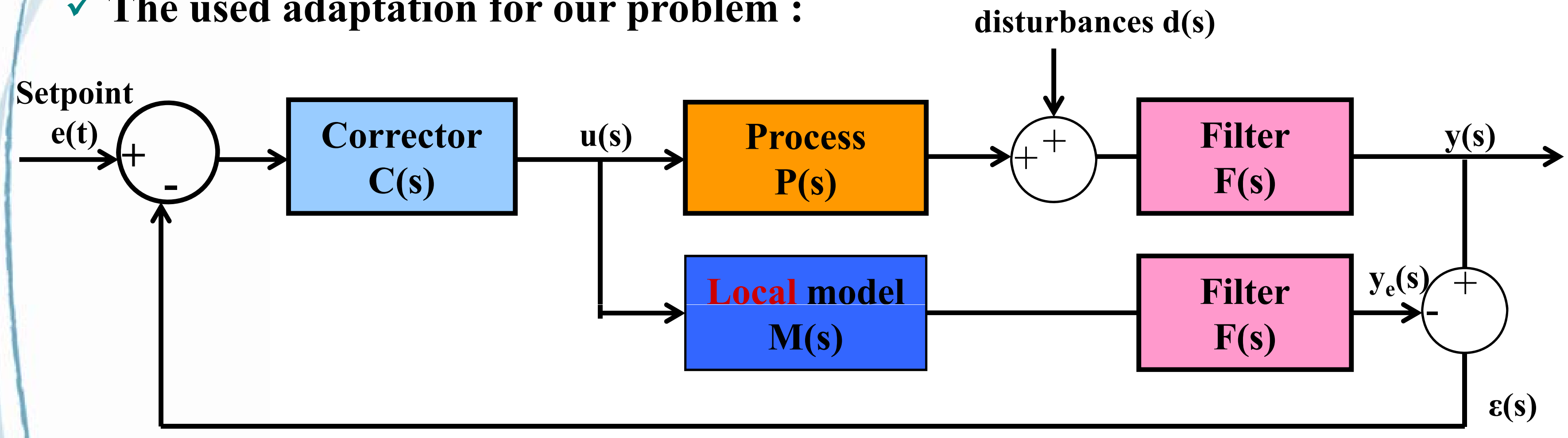
- Example of active compensation of an unknown frequency disturbance, excited by the natural environment (motion of the ground + acoustic noise).
- Possibilities to increase the number of rejected disturbances.

➢ **Active compensation is efficient with the initial algorithm for narrow peaks.**

➢ **For eigenfrequencies, the need of controlling a larger bandwidth.**

Command with internal model

✓ **The used adaptation for our problem :**



▪ The model M(s) is an elementary model, which corresponds locally to the process, so it is defined in function of a basic knowledge of the process :

- The amplification and the phase at the selected resonant frequency.
- The damping of the selected resonant mode (hammer test, in function of the gain)

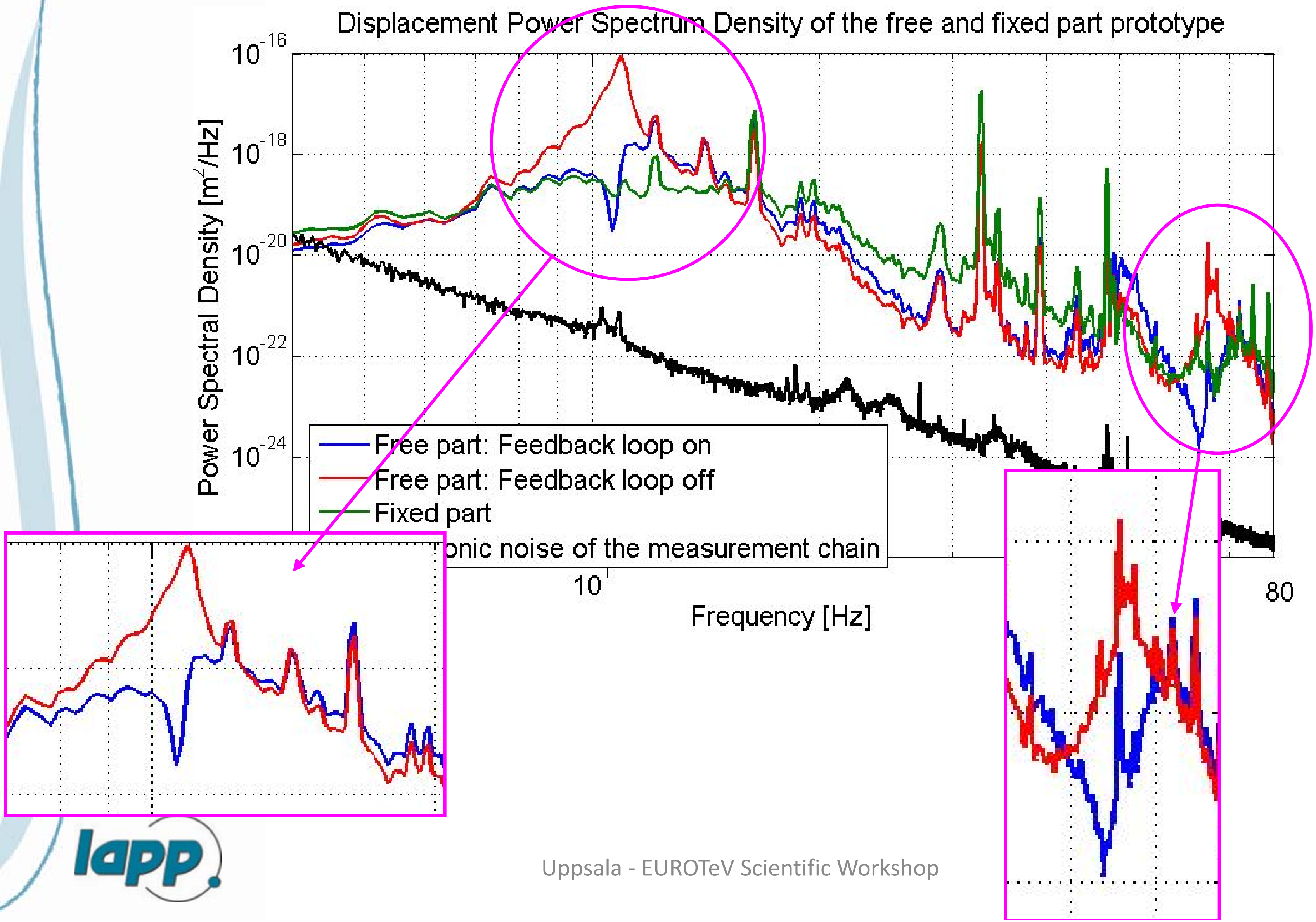
▪ The filter F(s) selects the bandwidth of the algorithm.

→ The requirements of this algorithm are a bit more complex but still basic.

→ There are as many algorithms that run in parallel as there are eigenfrequencies to stabilize.

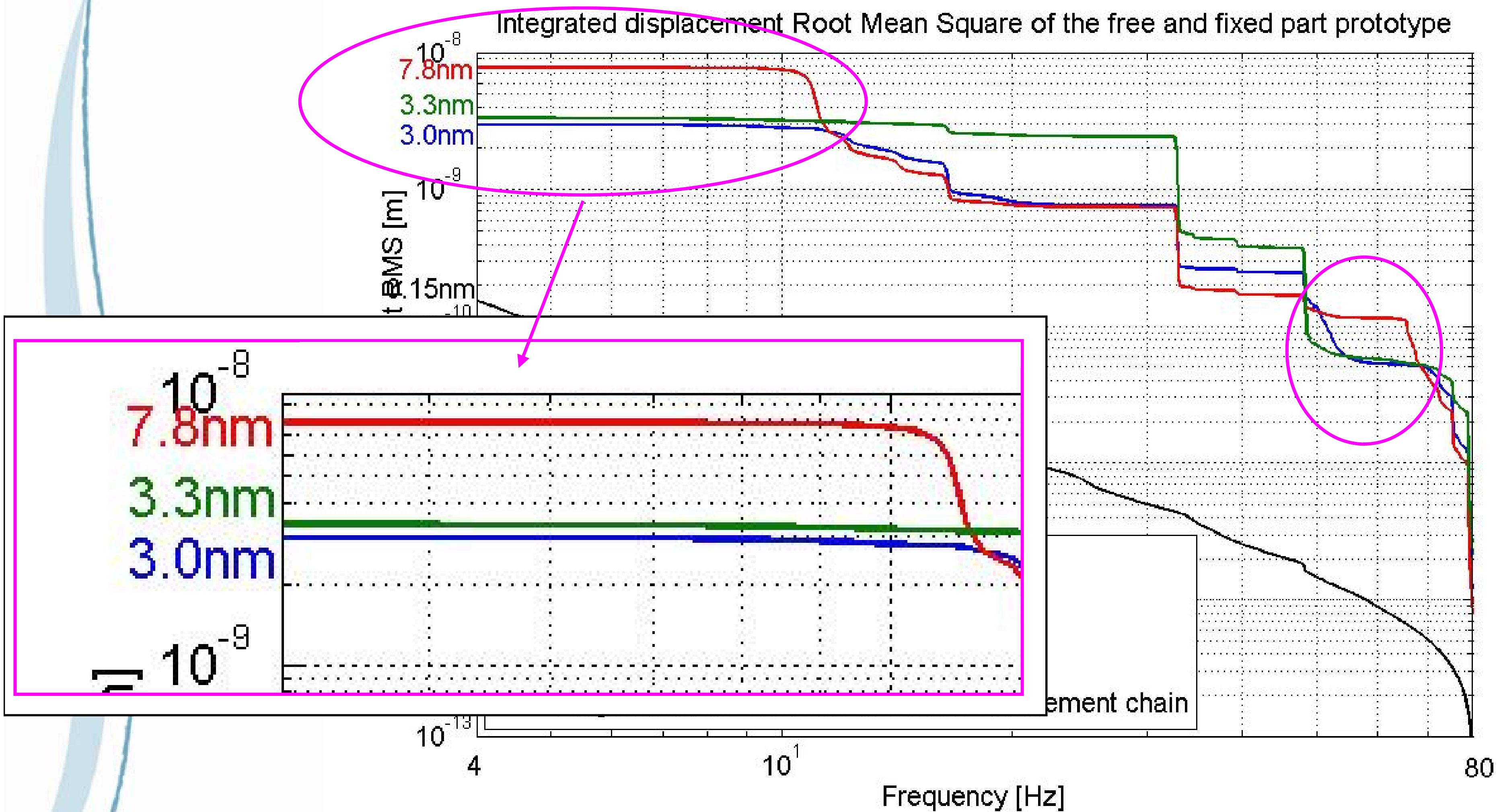
Tests with the large prototype

✓ **Results : Power spectral density**



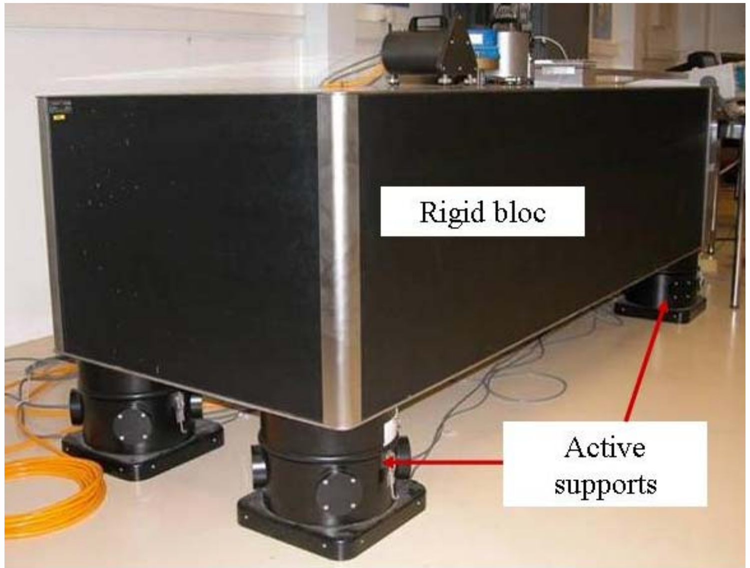
Tests with the large prototype

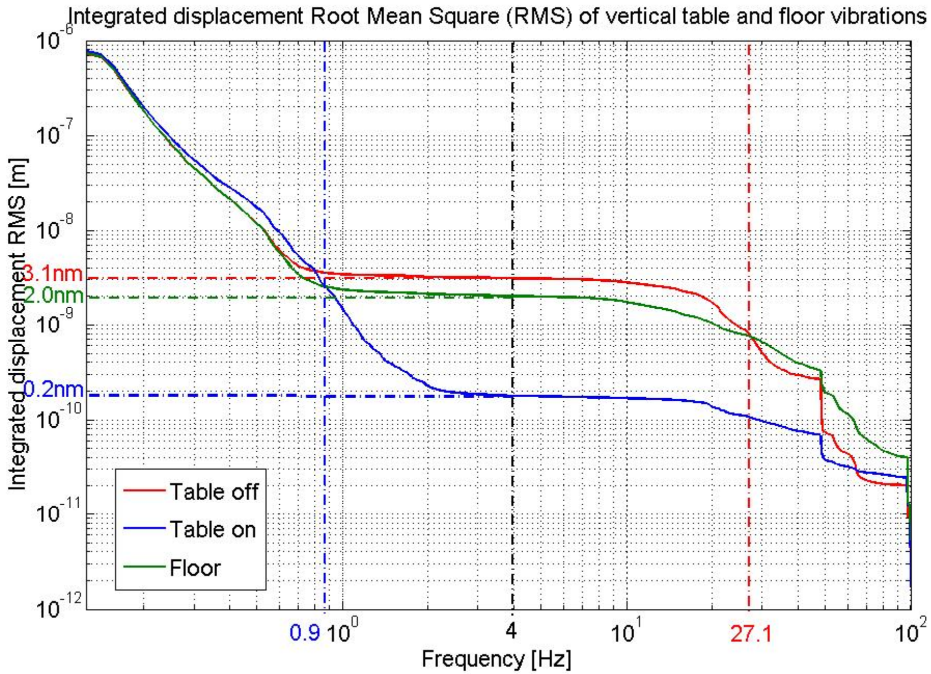
✓ **Results : integrated displacement RMS**



The industrial solution

✓ **An industrial solution : the TMC table of CERN.**



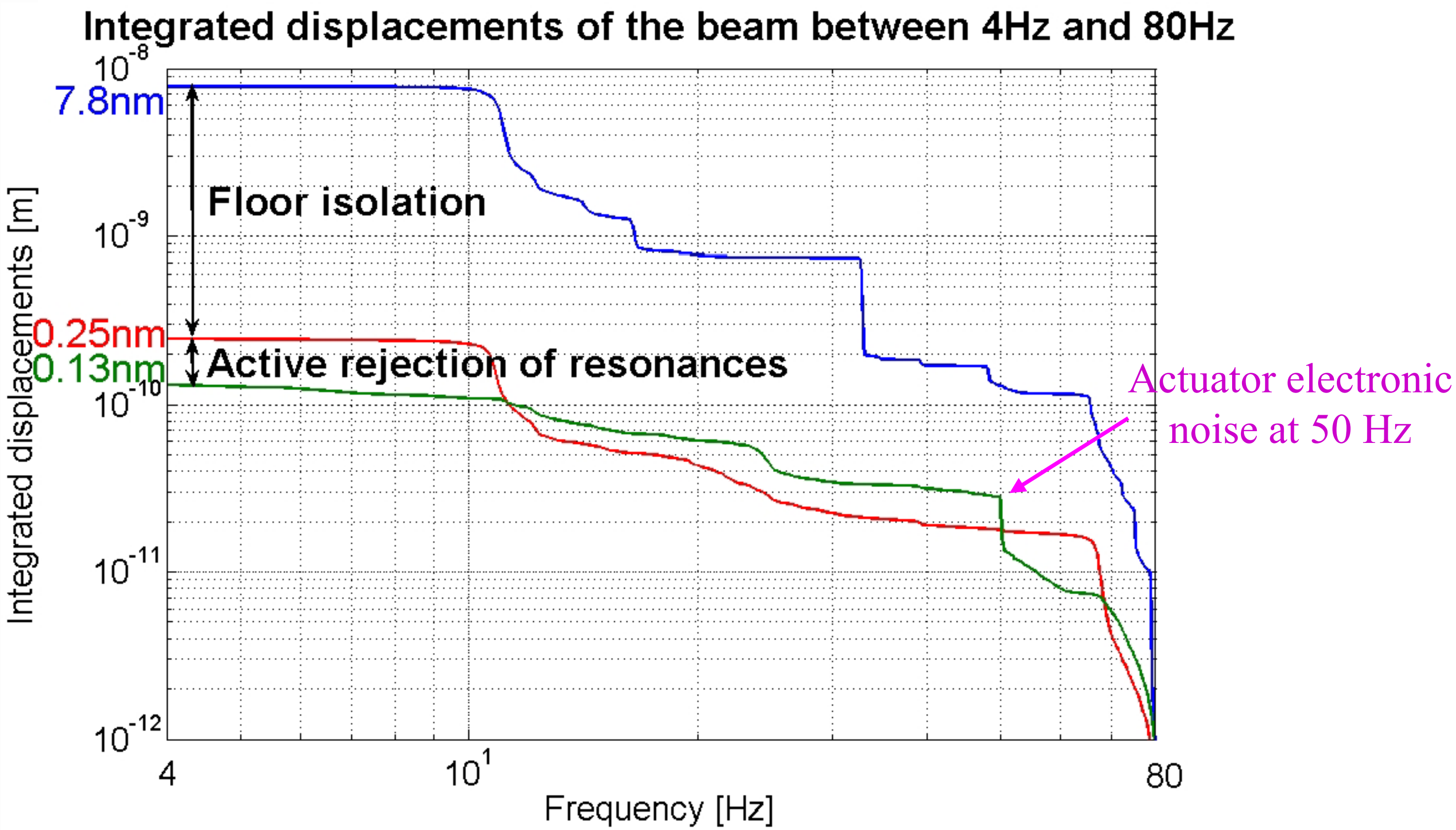


✓ **Composed of a rigid bloc, placed on 4 active feet (STACIS).**

- <u>Passive isolation :</u> attenuates all the high frequency disturbances but amplifies the low frequency disturbances (like a resonant filter).
- <u>Active isolation :</u> attenuates the disturbance amplified by the passive isolation (low frequencies disturbances).

Tests with the large prototype

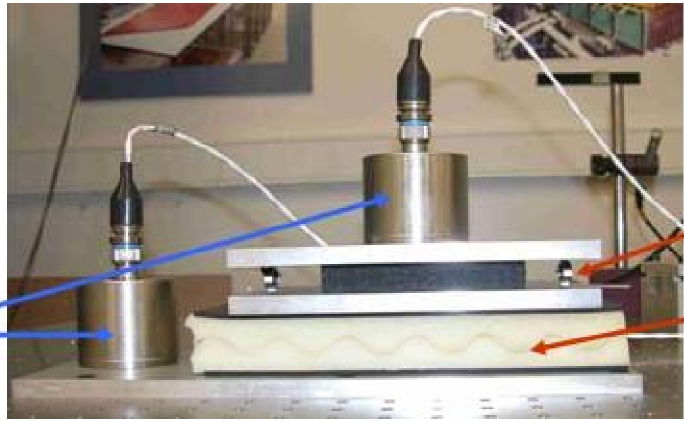
✓ **Results : integrated displacement RMS (with active table ON)**



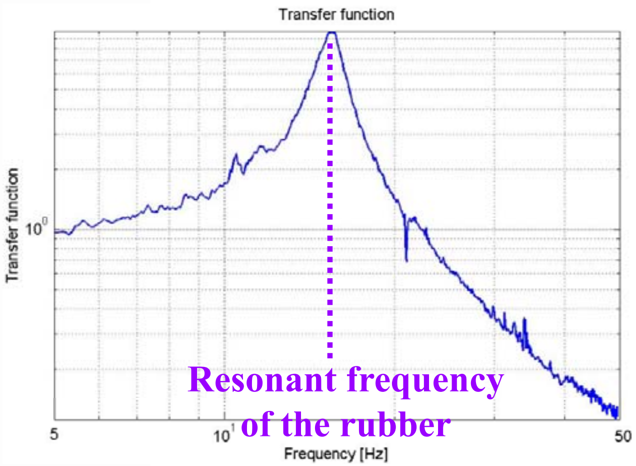
- **No control**
- **With active isolation (TMC table)**
- **With active isolation (TMC table) and active compensation (PZT actuators)**

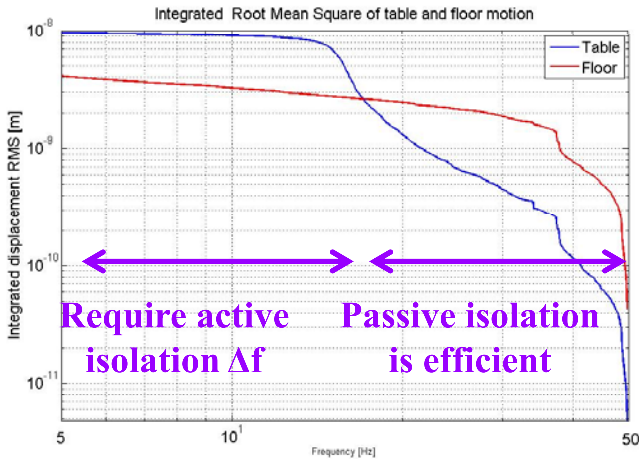
The small and elementary mock-up

✓ **Association of active and passive isolation :**



✓ **The passive layer :**

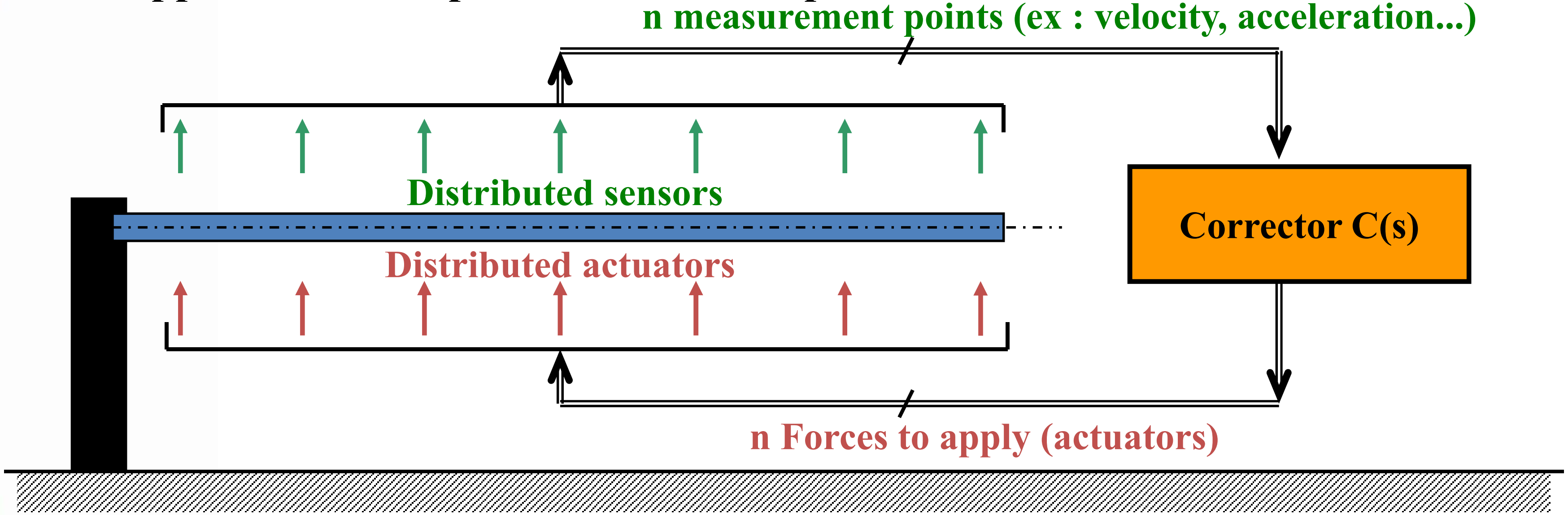




→ Currently tested in simulation, next step: with the small prototype and then with industrial products and realistic size in order to develop maybe a low cost and dedicated active table.

Multi sensors – Multi actuators

✓ **1st approach : a complete control of the process**

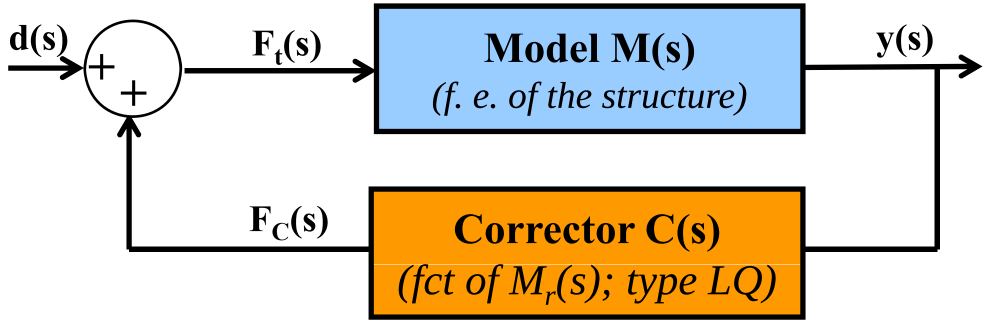


→ The method :

- Develop a complete model M(s) of the structure (using the modelling -finite element) updated as a function of the behaviour of the structure - results in a state space form
- Compute a reduced model $M_r(s)$ which is representative of the structure given by the modelling stage.
- Build a robust corrector with the reduced model, using the method of the placement of poles and zeros.
- Test in simulation, next step: on the prototype.

Multi sensors – Multi actuators

✓ **Test in simulation :**



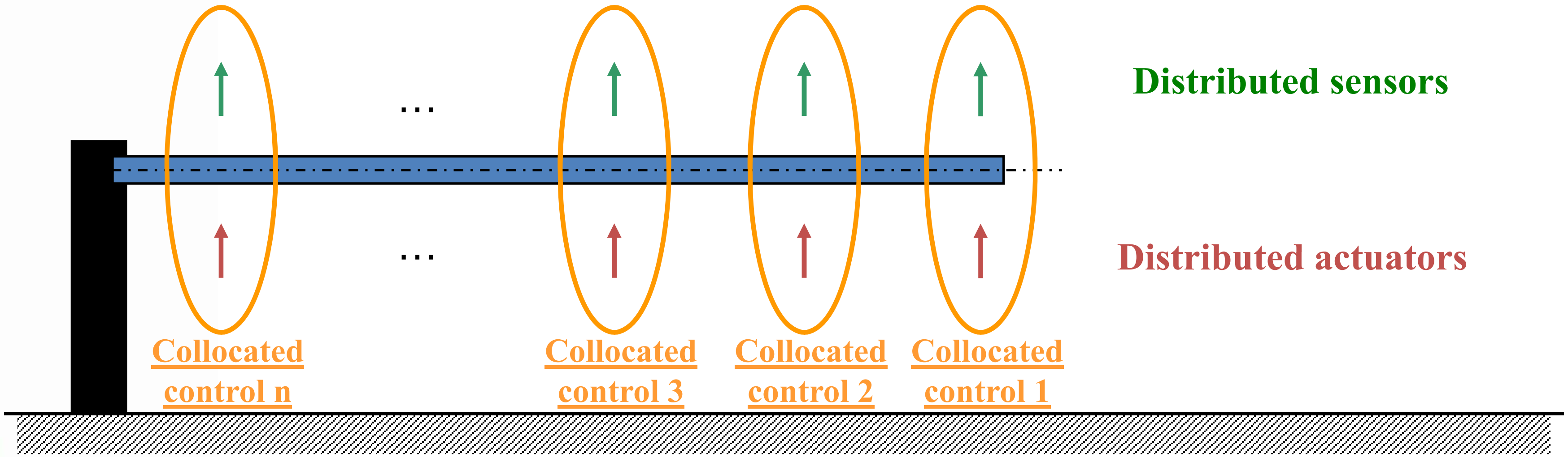
- d(s) : Disturbance forces (ex : simulation of acoustic perturbation with a pink noise).
- $F_t(s)$: Sum of the forces applied to the structure.
- y(s) : Measurement of the velocity or displacement at different points of the beam.
- $F_c(s)$: Forces computed by the corrector (linear quadratic corrector).

➢ **Promising results in simulation.**

➢ **The next target is to test this method on the prototype.**

Multi sensors – Multi actuators

✓ **2nd approach : distributed collated control of the process**



✓ **Comparison :**

- Advantages :
  - Easier to carry out
  - More robust because it depends on an elementary model
- Disadvantages :
  - Each control is independent, so there is no control between 2 points.
  - Less effective ?

✓ **Conclusion : the 2 methods have to be investigated. The choice will certainly depend on the required attenuation.**

Conclusions and perspectives

✓ **Hardware :**

- Instrumentation able to manage vibrations at a nanometer scale
- An adapted prototype in order to test our developments

✓ **Control :**

- 2 types of algorithms for active compensation at the end of the beam
- A beginning of study for active isolation
- A current study of an algorithm dedicated to the stabilization of the entire structure

➢ We have succeeded in stabilizing an elementary structure at a sub-nanometer scale in a natural environment.

✓ **Future prospects :**

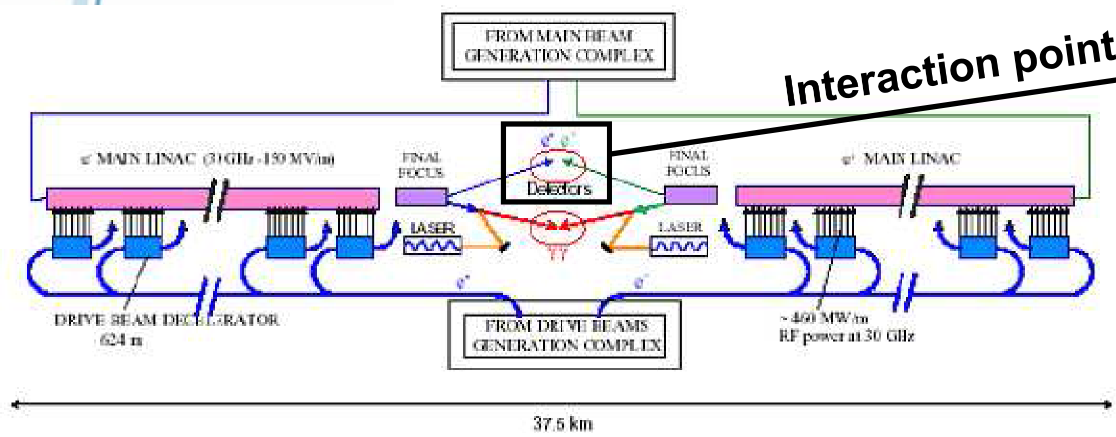
- The stabilization of the entire structure in order to compare the 2 approaches.

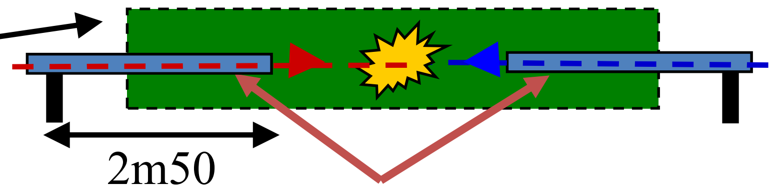
➢ This work is summarized in the EUROTeV report 2008-006 and was presented in a poster session at EPAC 2008.

ANNEXES

CLIC linear collider : futur generation of the circular collider LHC

✓ **The problematic :**





Vertical beam size at the interaction point ~ 10^{-9} m

Tolerance of relative positioning between final doublets to guarantee the collision with the expected luminosity ($10^{35}cm^{-2}s^{-1}$):

1/5 nm for frequencies > ~4Hz

Command with internal model

✓ **Similarities of tuning between the initial algorithm (state space for punctual disturbances) and this one (CIM for large peaks) :**

State space	Command with internal model
▪ Amplification in open loop. ▪ Difference of phase in open loop. ▪ Setting time.	▪ Determinate a model which corresponds to the process for the selected bandwidth with the same : - Amplification in open loop. - Difference of phase in open loop. - Damping of the selected eigenfrequency. ▪ Build a corrector from this model, which is stable, meaning respects the rules of automatic.

✓ To determine the damping values, there are different methods :

- Theoretical : modelling…
- Experimental : hammer test, in function of the amplification…

→ **The requirements of this algorithm are a bit more complex but still basic, so realistic !!**