Feedback Loop on a large scale quadrupole prototype

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Overview

-Brief summary of the last presentation in London

-Transfer of the former studies to a large scale prototype :

- *Description of the prototype with appropriate actuators.*
- *Results of the active vibration reduction*

-Robustness : Development of one frequency tracking in real time

-Technology and location of the instrumentation

-Conclusions

Collaboration with listic esia

Strategy of the approach

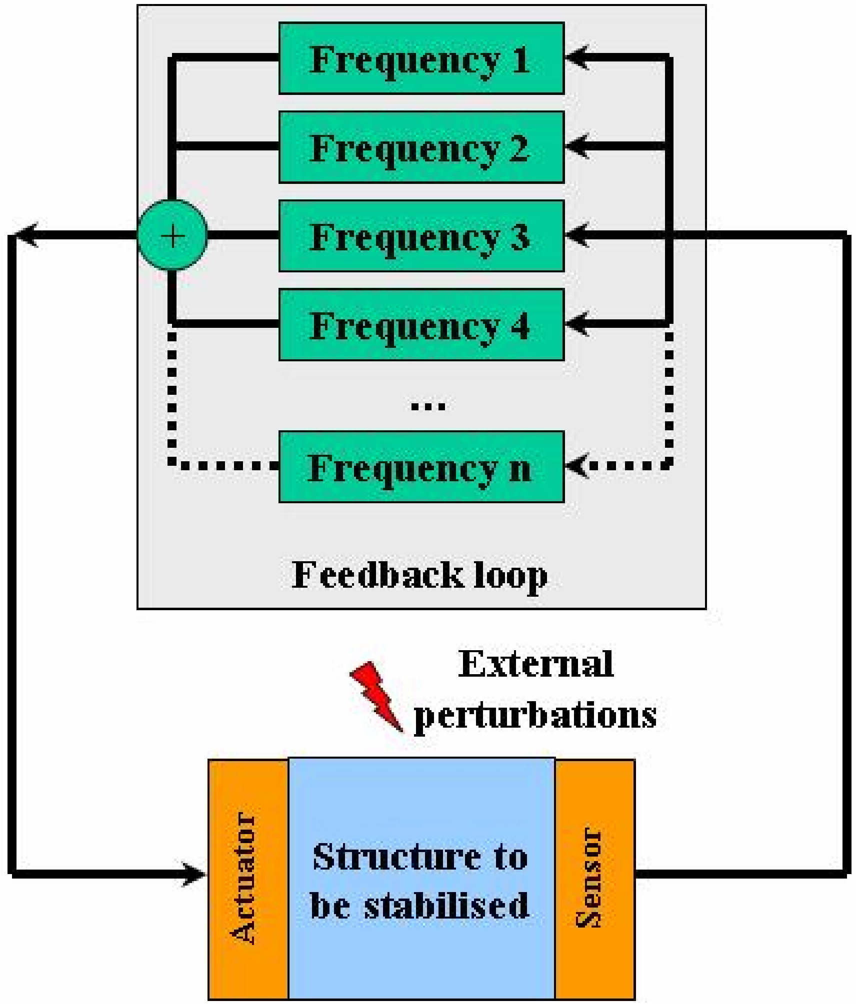
The Spectrum of disturbances is not a white noise
(ground motion, acoustic noise…)

Filtering by the mechanical structure

The global effect of the disturbance contains :

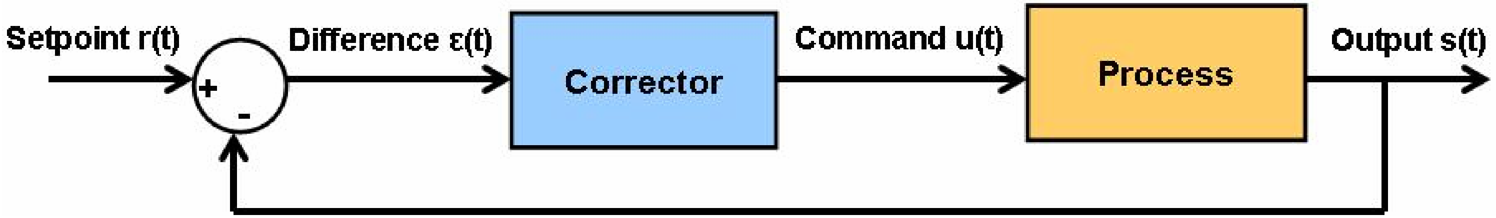
- *Some frequencies which are amplified*
- *All frequencies are independent*

Strategy : to control independently every main frequency

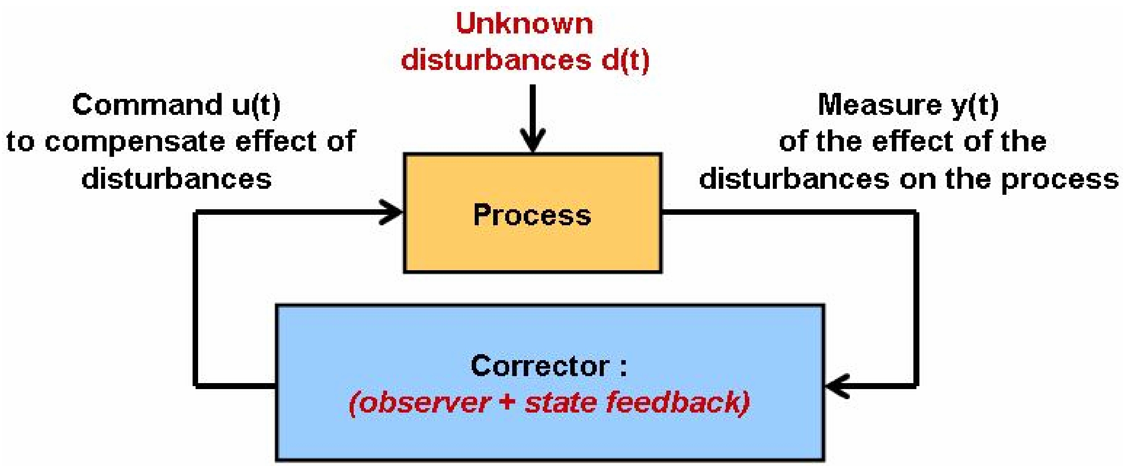


Originalities of the method : the algorithm

- Usually, a classic algorithm (ex : PID), depends on the model of the process :



- **It is not a classic algorithm,** it is a compensation of the disturbance :
(without knowing the model of the process, only its behaviour at certain frequencies)



Originalities of the method : the signal processing

- A non linear problem :

$$f(t) = \alpha \sin(wt + \varphi)$$

(the force to be computed)

- Decompose each resonance as a weighted combination of sine and cosine :
(measurement, disturbance, excitation)

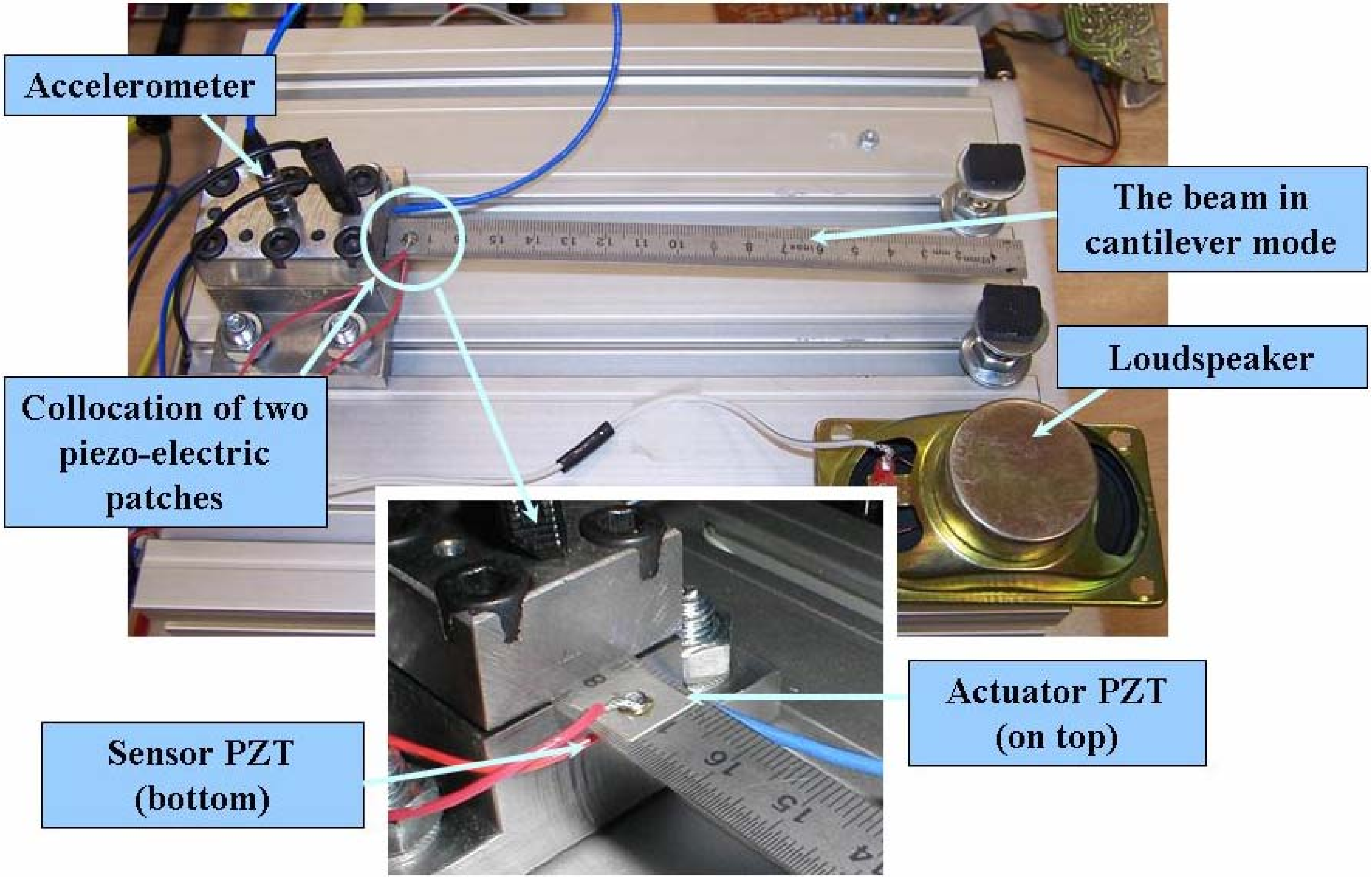
$$f(t) = \alpha \sin(wt + \varphi) \Rightarrow f(t) = f_s \sin(wt) + f_c \cos(wt)$$

where:

$$f_s = \alpha \cos(\varphi)$$
$$f_c = \alpha \sin(\varphi)$$

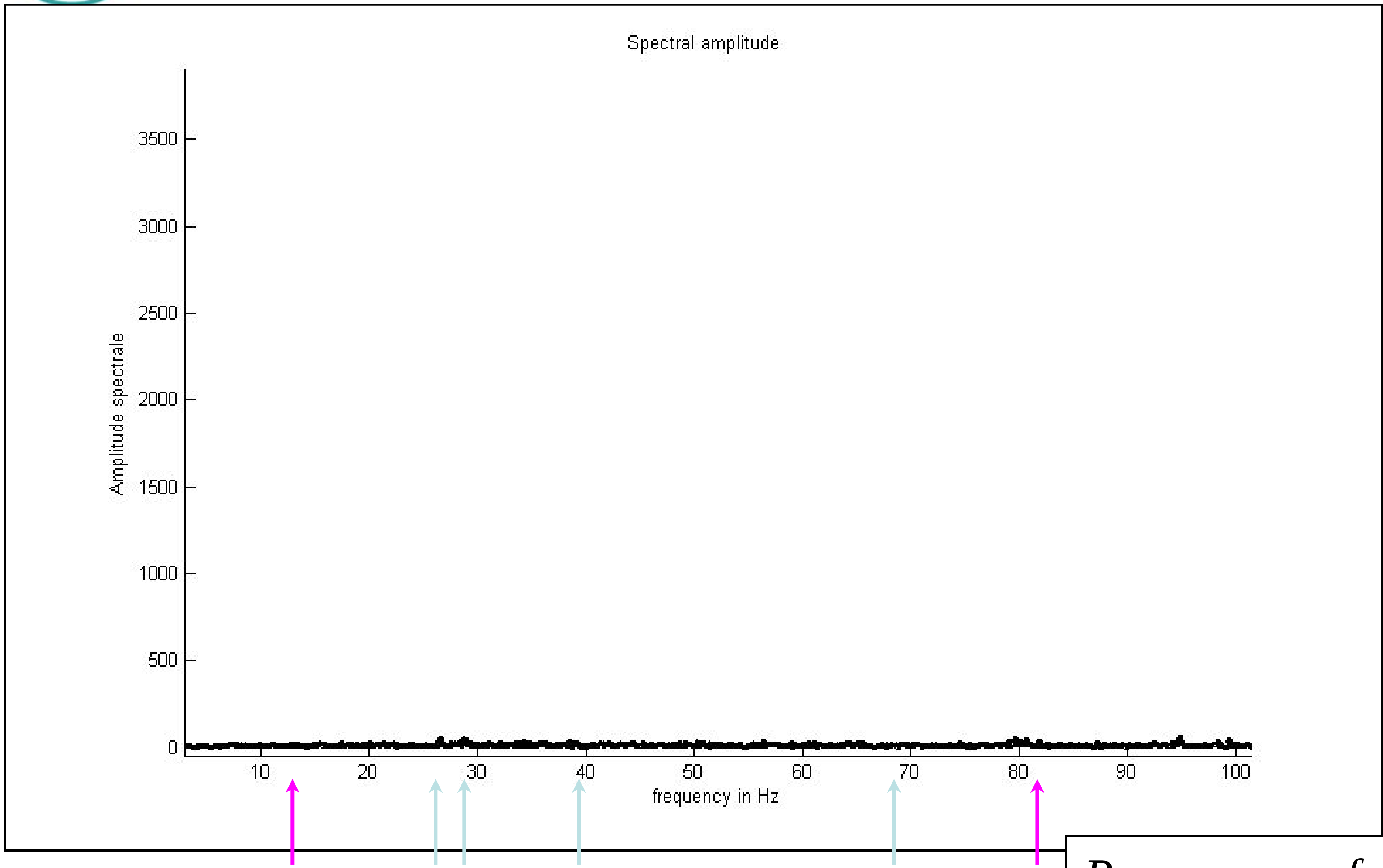
Test the algorithm with a small prototype

<u>Description of the prototype :</u>



Results

Rejection of 6 resonances : (without and with rejection)



Resonances of : -beam
-support

Why a new prototype?

-To validate the algorithm on a large scale prototype, whose size, boundary conditions and eigen frequencies are similar to the final focus.

-**To validate the micro-computing which :**

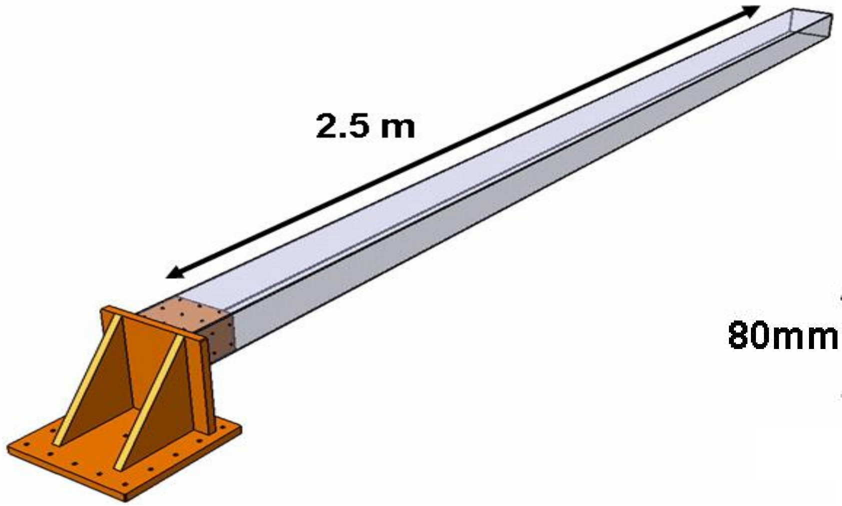
- manages noisy low signal with very high resolution
- computes the appropriate control of the feed-back in a limited time.

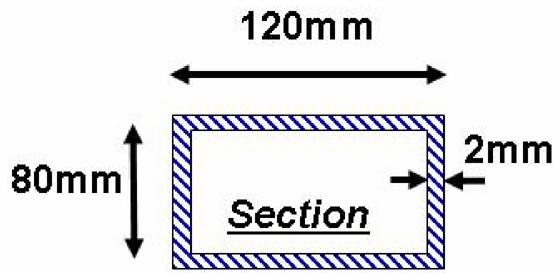
-**To validate sensors and actuators which are performant, compatible and adapted to the final focus.**

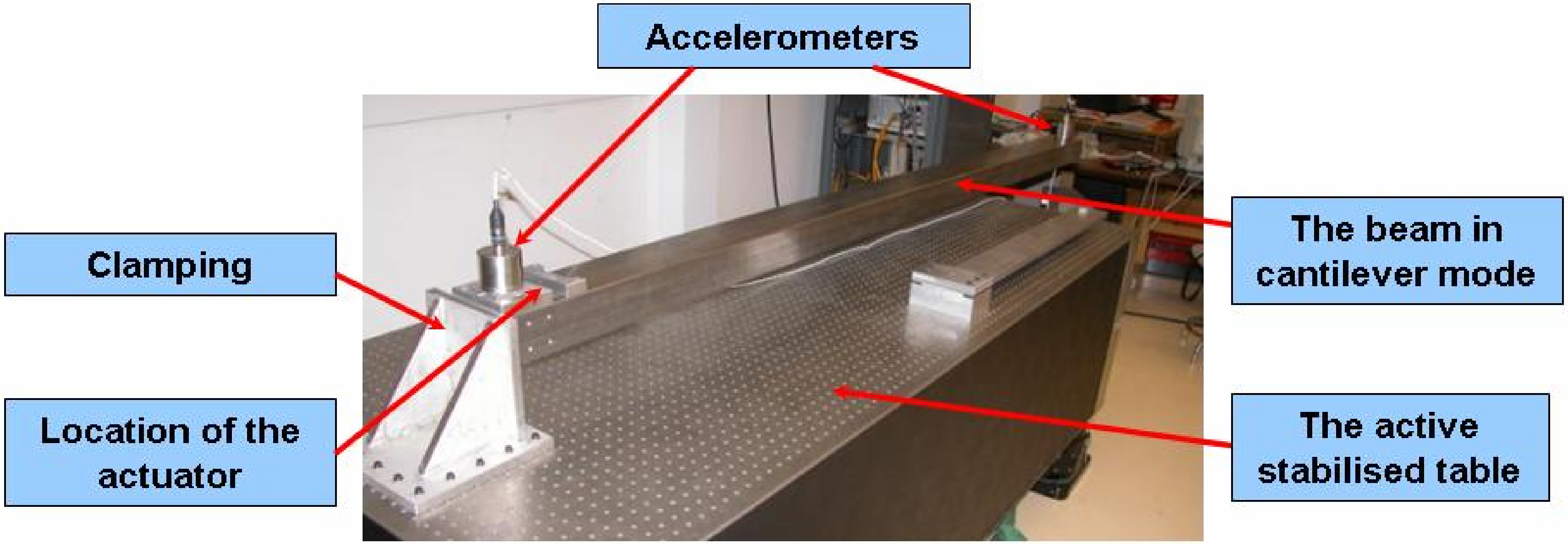
-**To validate the developed simulation for the prediction**.

→ **Movement of a linear mechanical structure < ground motion**

The mock-up :


2.5 m


120mm
80mm
2mm
Section

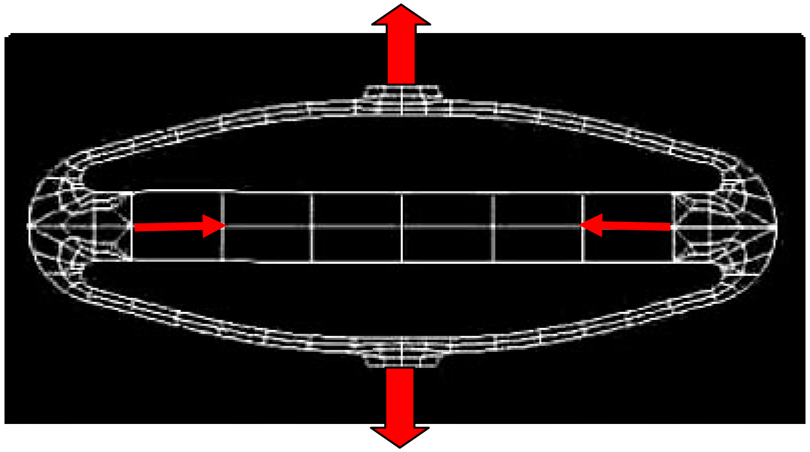

Accelerometers
Clamping
Location of the actuator
The beam in cantilever mode
The active stabilised table

The actuator : description

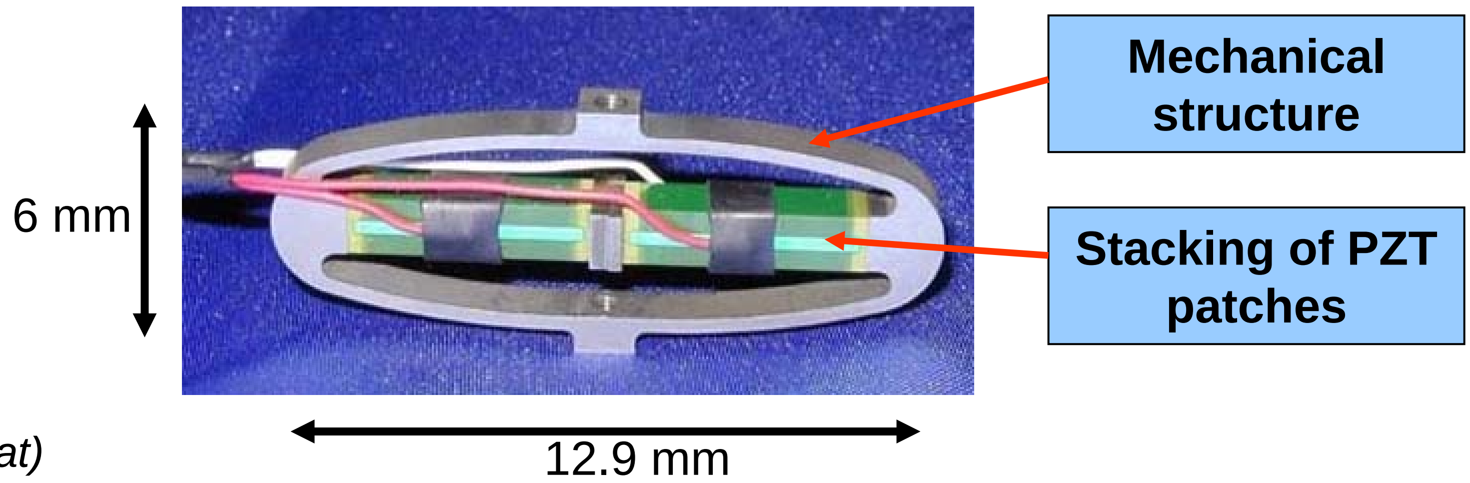
Force = 19.3 N

Maximal displacement = 27,8 µm

Resolution = 0,28 nm

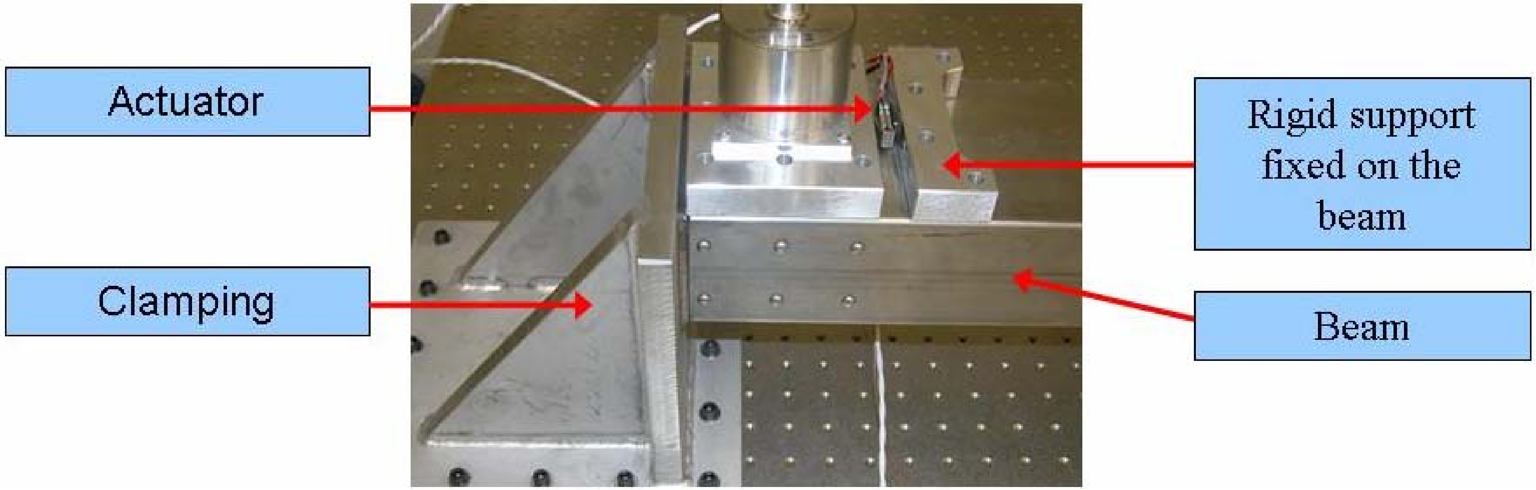


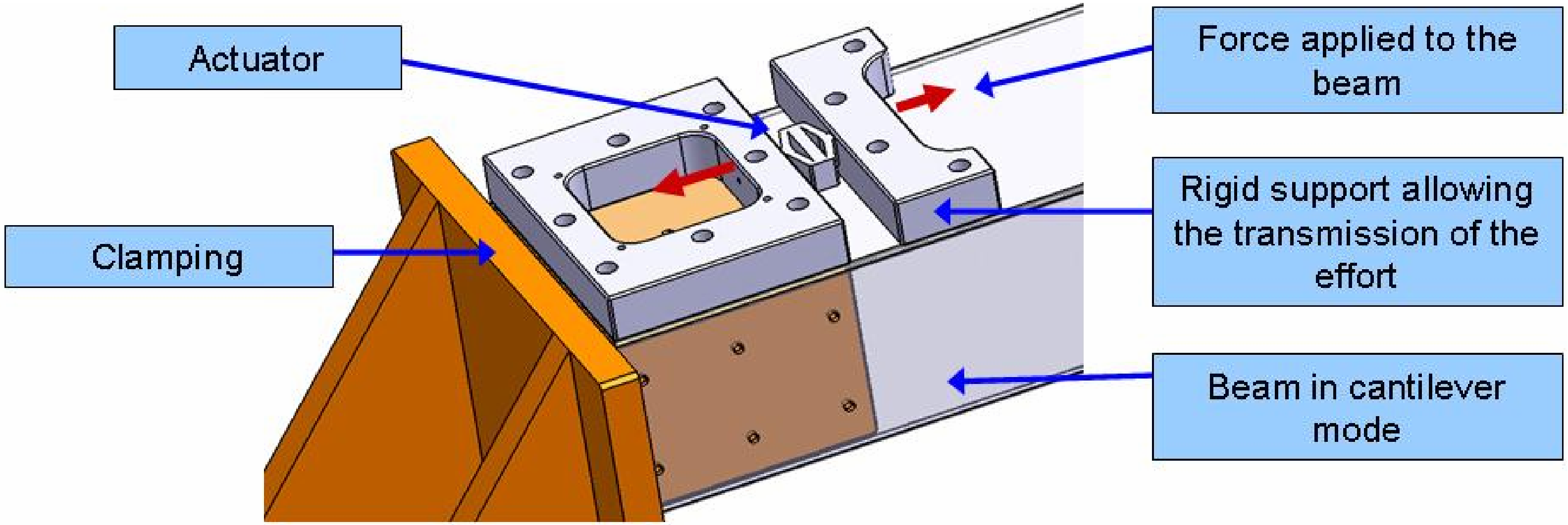
The deformation of the PZT patches is amplified by the mechanical structure



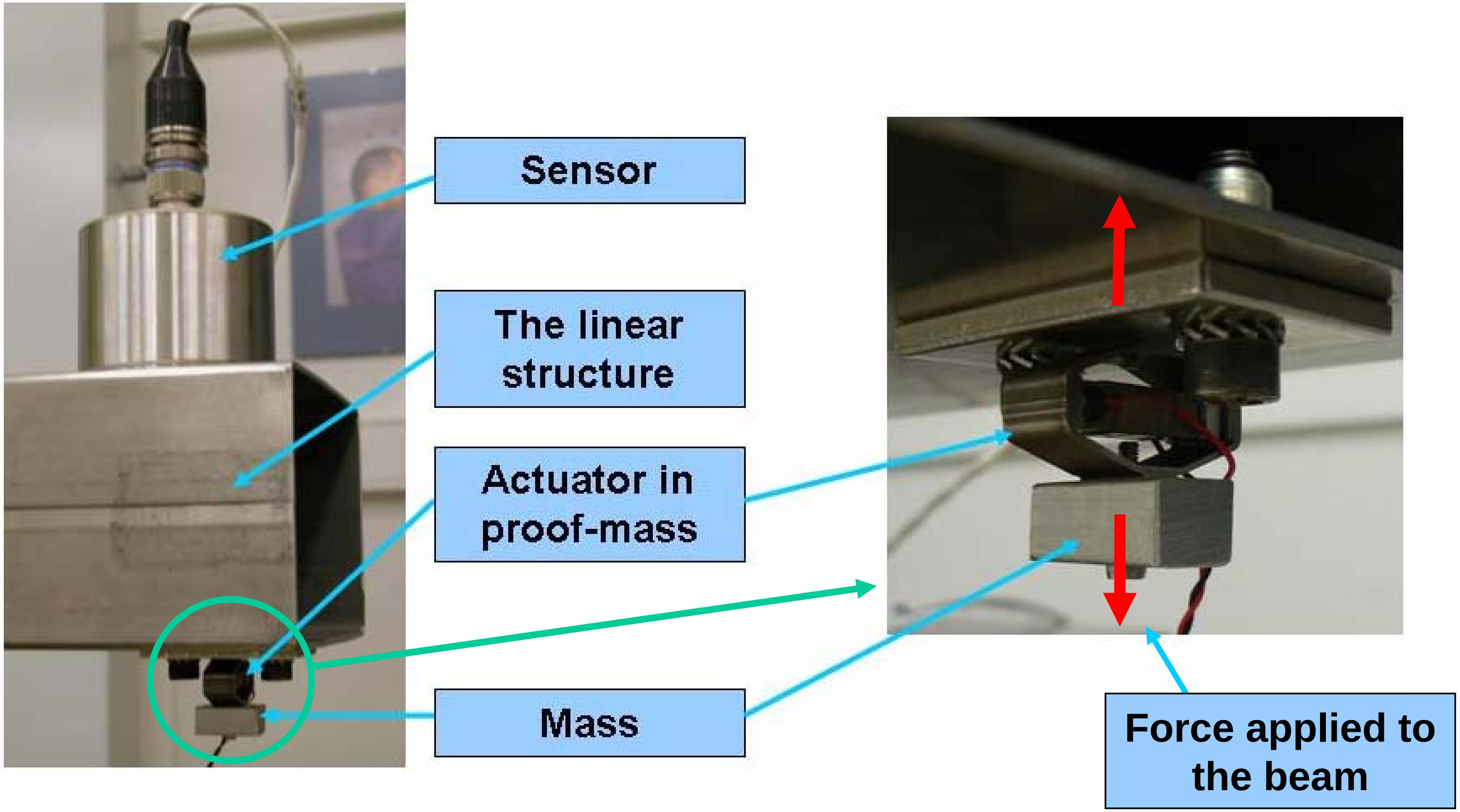
(Produced by Cedrat)

The actuator applies a force in flexion



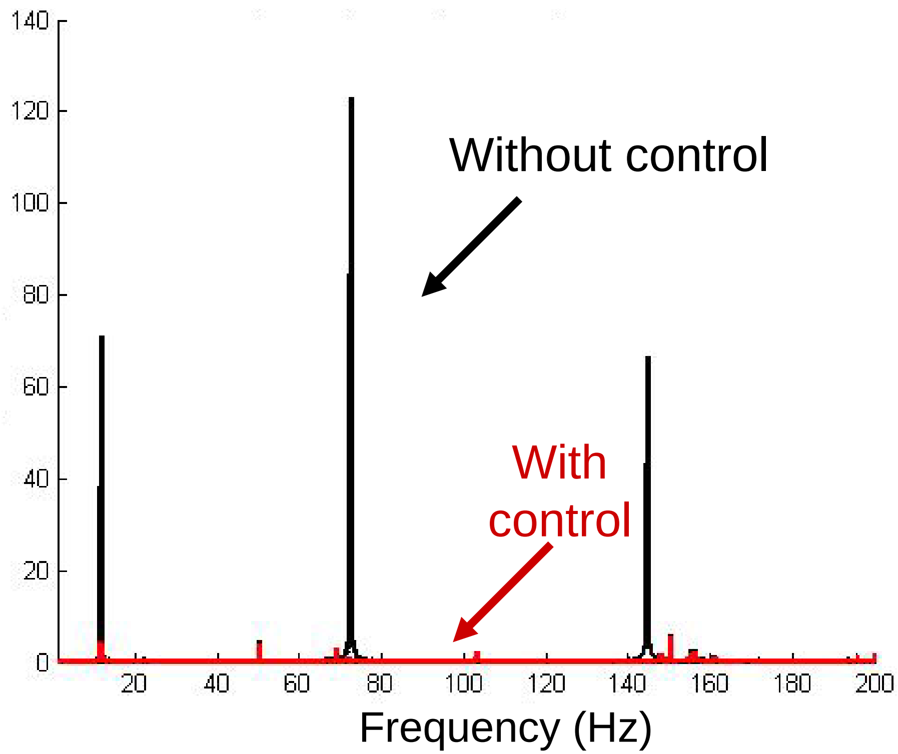


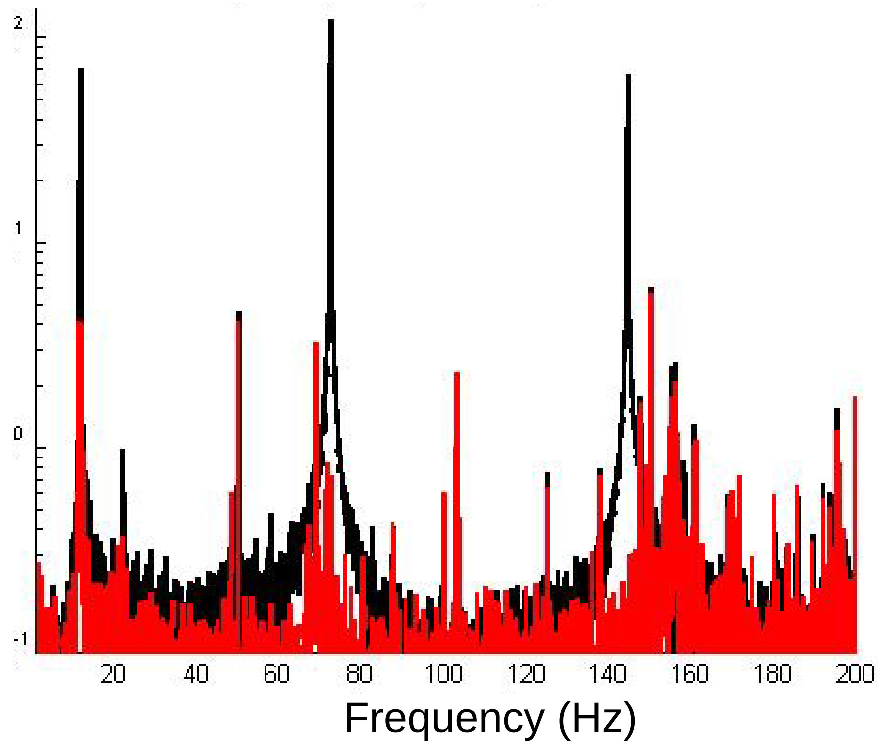
The actuator applies a force in “proof-mass”



Results : rejection of 3 fixed frequencies of disturbances

Spectral amplitude of measured signals

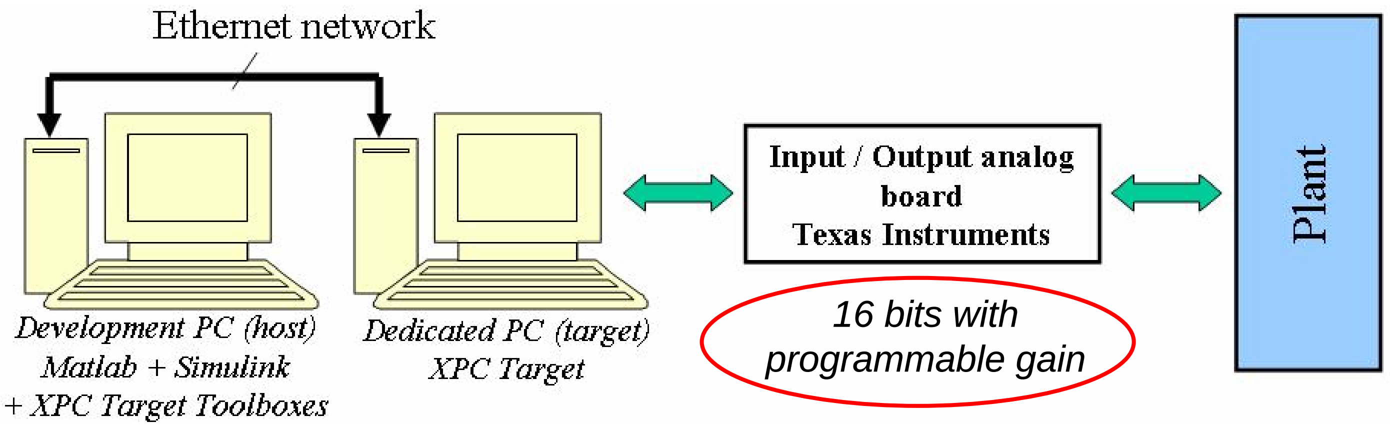




Efficient vibration rejection

Limitations :

<u>Current configuration :</u> Fast prototyping with XPC Target in a dedicated PC



<u>Configuration in test :</u> DSP ("Digital signal processing") of ProDAQ

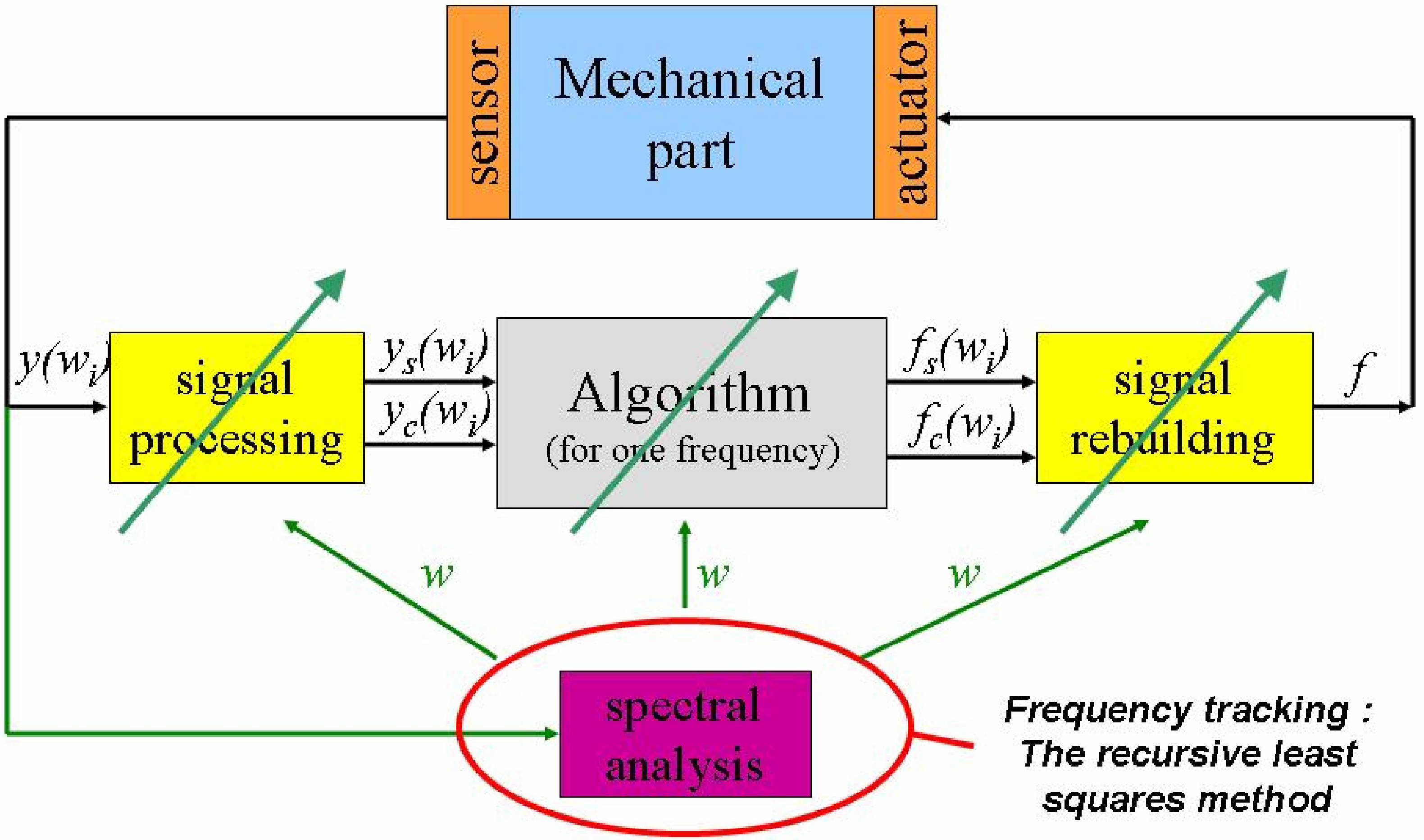
-24 bits resolution

-Programmable gain…

-Adapted electronic for vibrations

→ **possibility to reduce to nanometer scale**

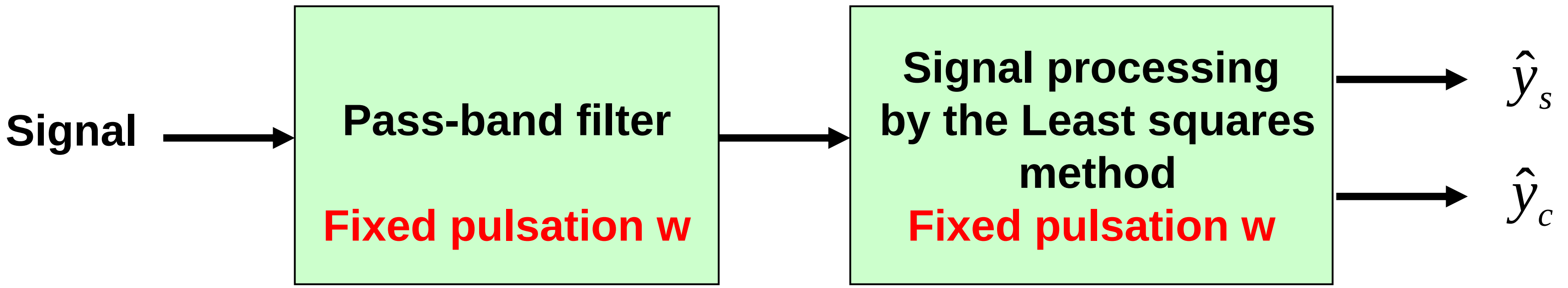
- As each frequency is rejected independently, the robustness depends on the estimation of the real value of the disturbance frequency :



Recursive least squares method

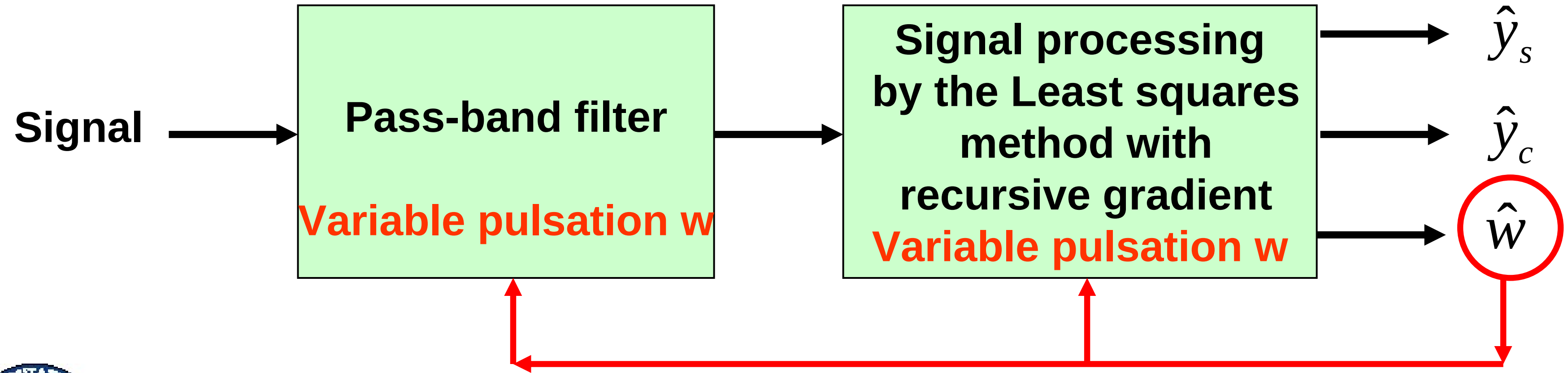
Initial Method of “signal processing” :

$$\hat{y}_i = \hat{y}_s.\sin(wt_i) + \hat{y}_c.\cos(wt_i)$$



Objective:

$$\hat{y}_i = \hat{y}_s.\sin(\hat{w}t_i) + \hat{y}_c.\cos(\hat{w}t_i)$$



Recursive least squares method

Considering the measurement has the following form:

$$y(t_i) = y_s.\sin(wt_i) + y_c.\cos(wt_i)$$

The criterion to be minimized :

$$J(y_s, y_c) = \frac{1}{N}.\sum_{1}^{N}(y_i - y(t_i))^2 \qquad (N : \text{number of samples})$$

Matrix form:

$$\underbrace{\begin{pmatrix} y_1 \\ y_2 \\ \dots \\ y_N \end{pmatrix}}_{Y} = \underbrace{\begin{pmatrix} \sin wt_1 & \cos wt_1 \\ \sin wt_2 & \cos wt_2 \\ \dots & \dots \\ \sin wt_N & \cos wt_N \end{pmatrix}}_{H} \underbrace{\begin{pmatrix} y_s \\ y_c \end{pmatrix}}_{\hat{M}}$$

The matrix M which minimizes the criterion :

$$\hat{M} = (H^T.H)^{-1}.H^T.Y$$

Recursive least squares method

Minimizing the criterion *J* corresponds to minimizing its derivative by the variables to be estimated :

$$\frac{\partial J}{\partial \hat{y}_s}=0 \qquad \frac{\partial J}{\partial \hat{y}_c}=0 \qquad \frac{\partial J}{\partial \hat{w}}=0$$

Recursivity only for w

Which gives :

$$\hat{w}_{j+1} = \hat{w}_j - \lambda \frac{\partial J}{\partial \hat{w}}$$

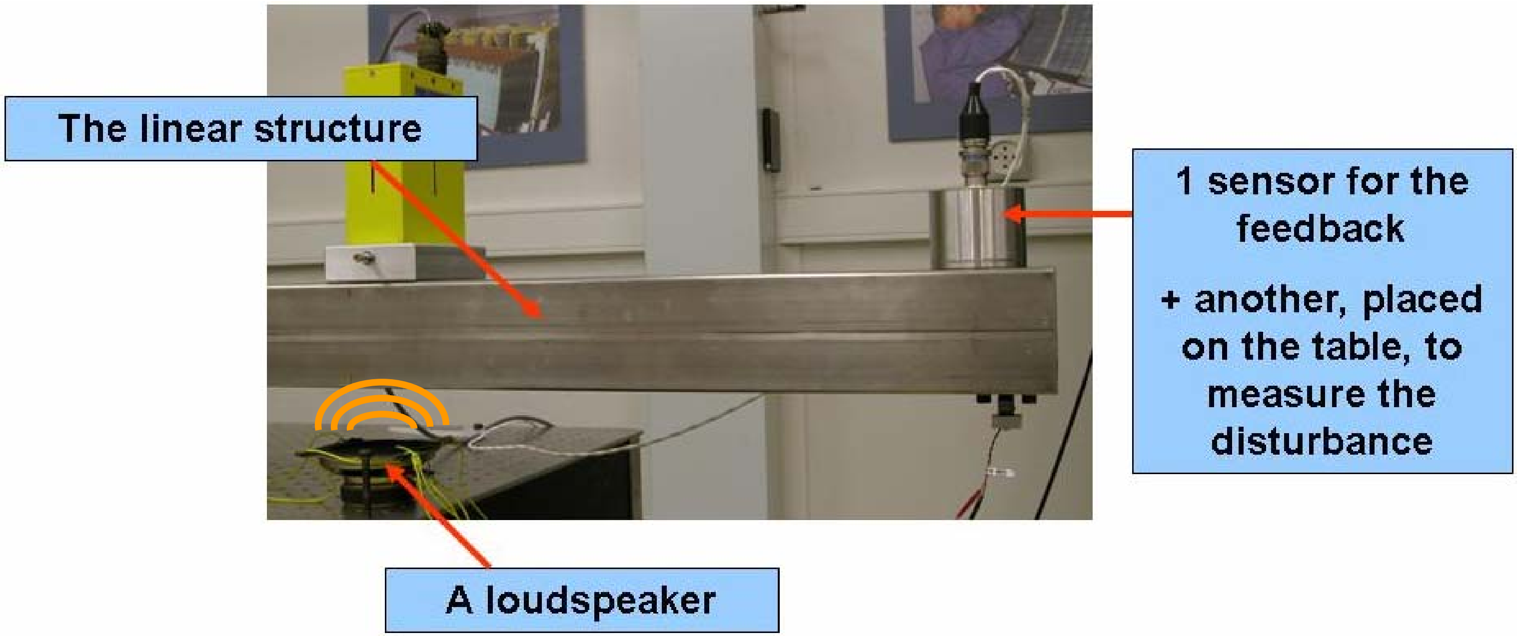
(where λ is the dynamics of the recursivity)

The ending criterion of the recursivity :

$$\frac{J(\hat{w}_{(j+1)}) - J(\hat{w}_{(j)})}{J(\hat{w}_{(j)})} < \varepsilon$$

Test (one example)

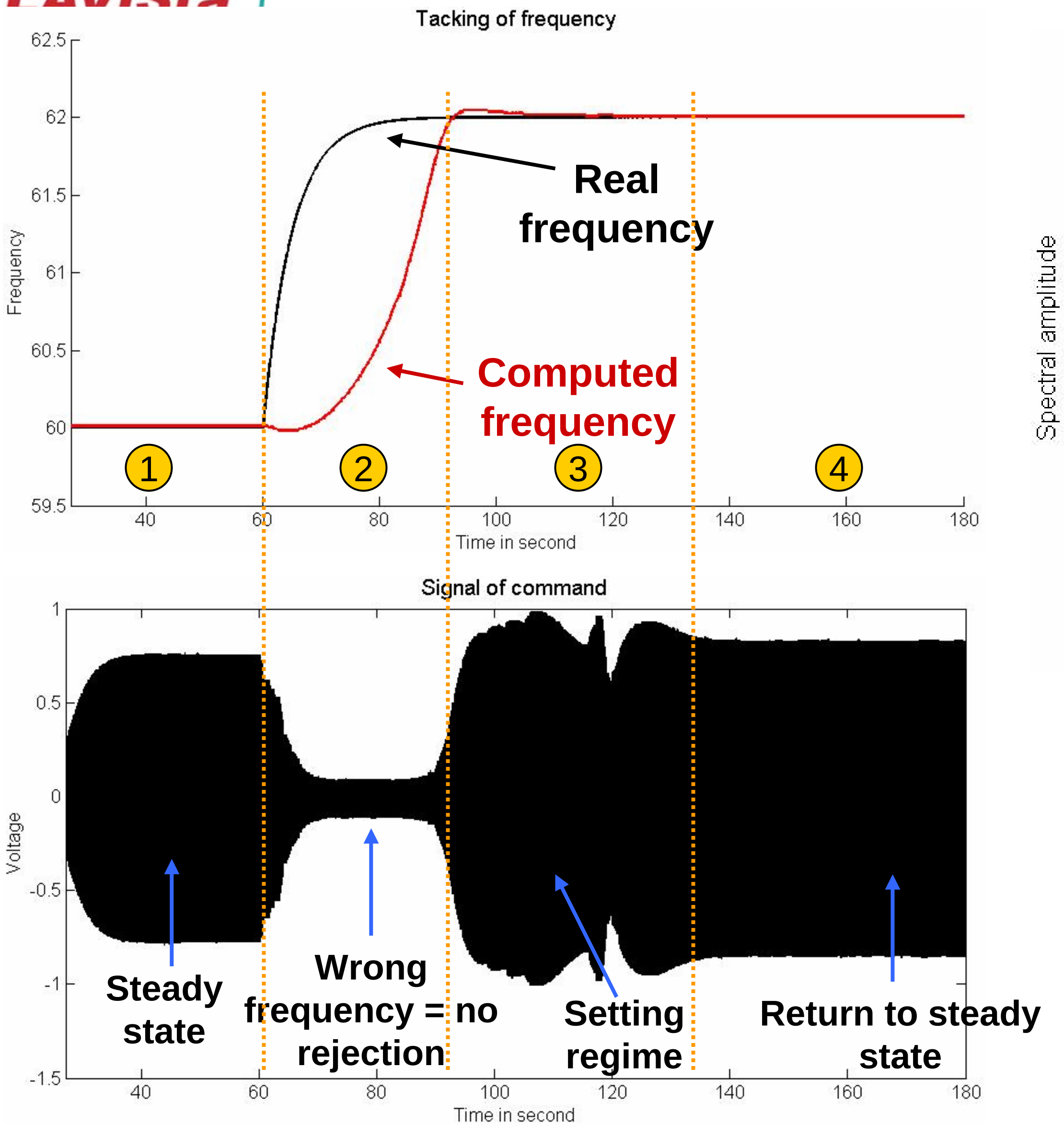
- External disturbance simulation with a step frequency function (response of a 1st order process) :

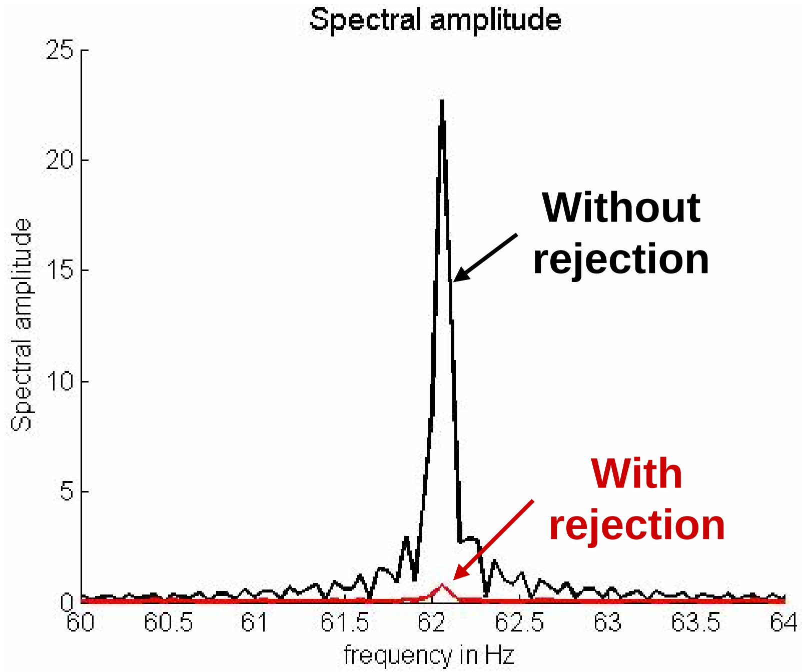


The loudspeaker generates a step of frequency which simulates, for example, a change of speed of a pump near the final focus.

Experimental results

Frequency tracking in real time

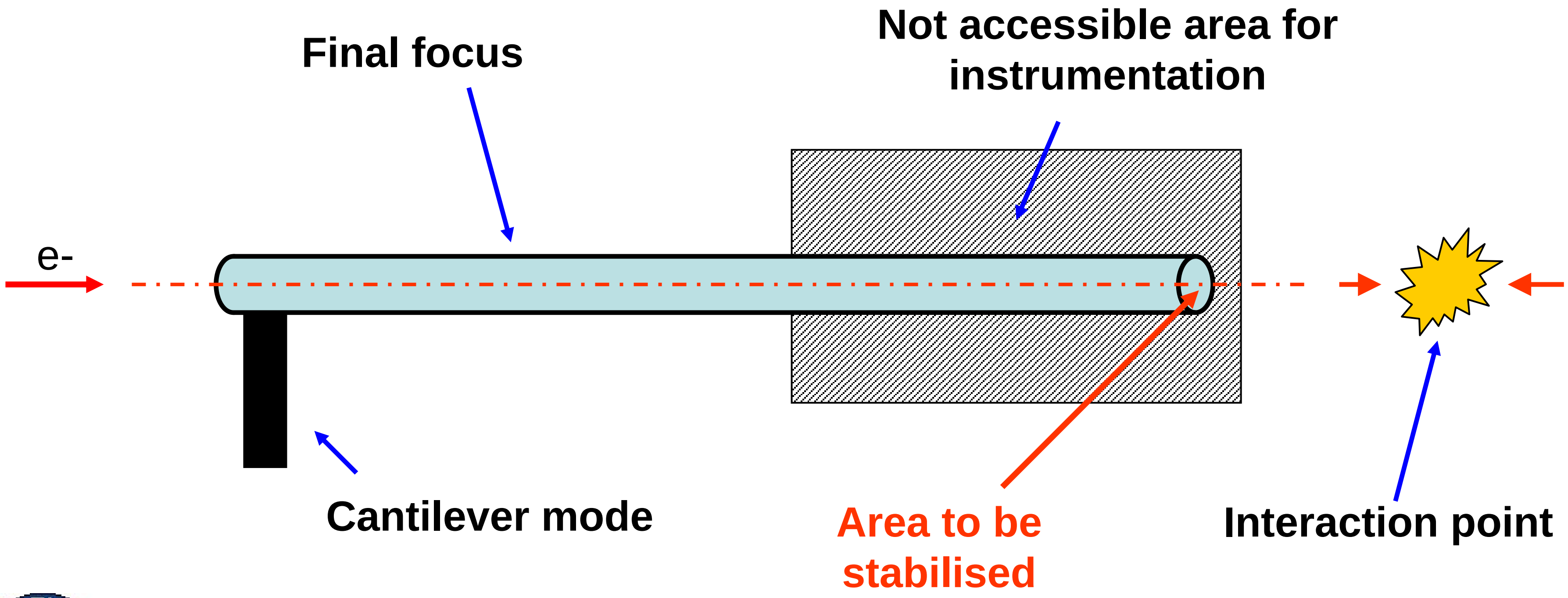




Efficient rejection if the variation is slow

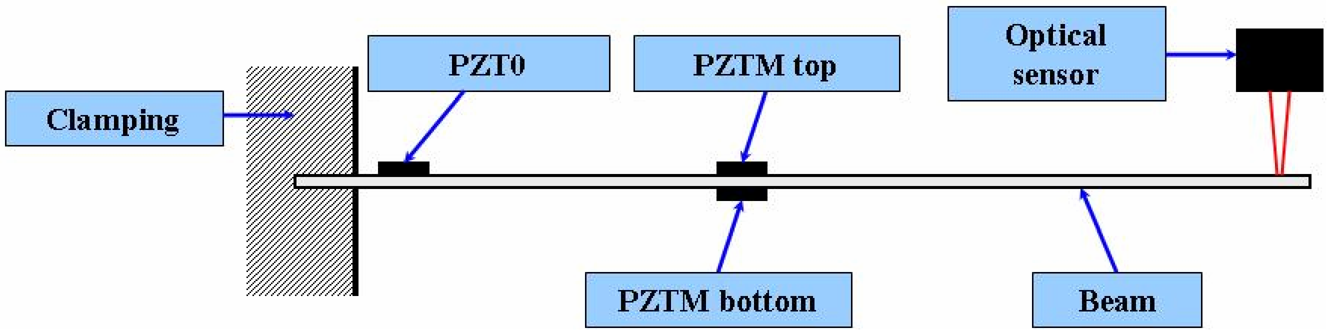
Problem : No access to the area to be stabilised

- Where is the optimal location and what technology for the instrumentation?
- What are the effects of a local control on the global movement of the beam?
- How to be sure that the end of the beam is stabilised in real time?



Small mock-up

The prototype :



Experimental results :

Actuator	Sensor	PZT0	PZTM	Optical
PZT0	PZTM		***VG***	*G*
PZT0	Optical		*G*	***VG***
PZTM	PZT0	***VG***	*VB*	*G*
PZTM	PZTM	*N*	***VG***	*N*
PZTM	Optical	*G*	*VB*	***VG***

Very bad | No effect | Good | Very good

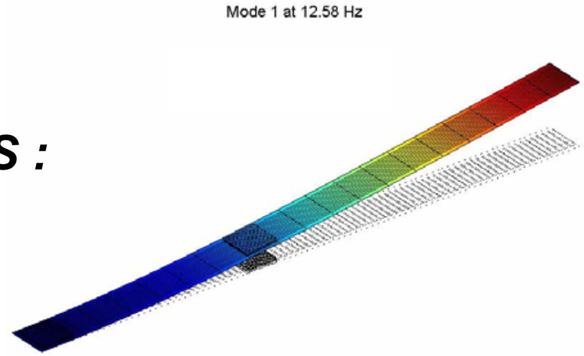
→ **The rejection always works at the measurement point of the feed-back.**

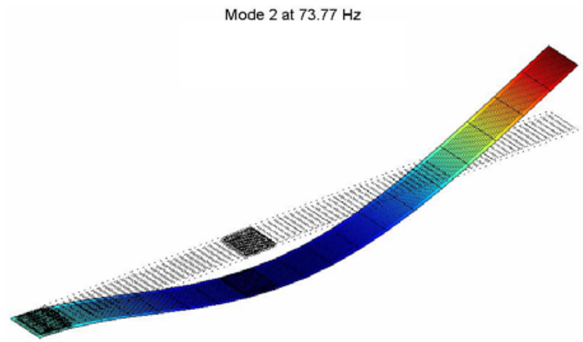
→ **The behaviour of the beam changes with the configuration.**

Numerical simulation of the small mock-up

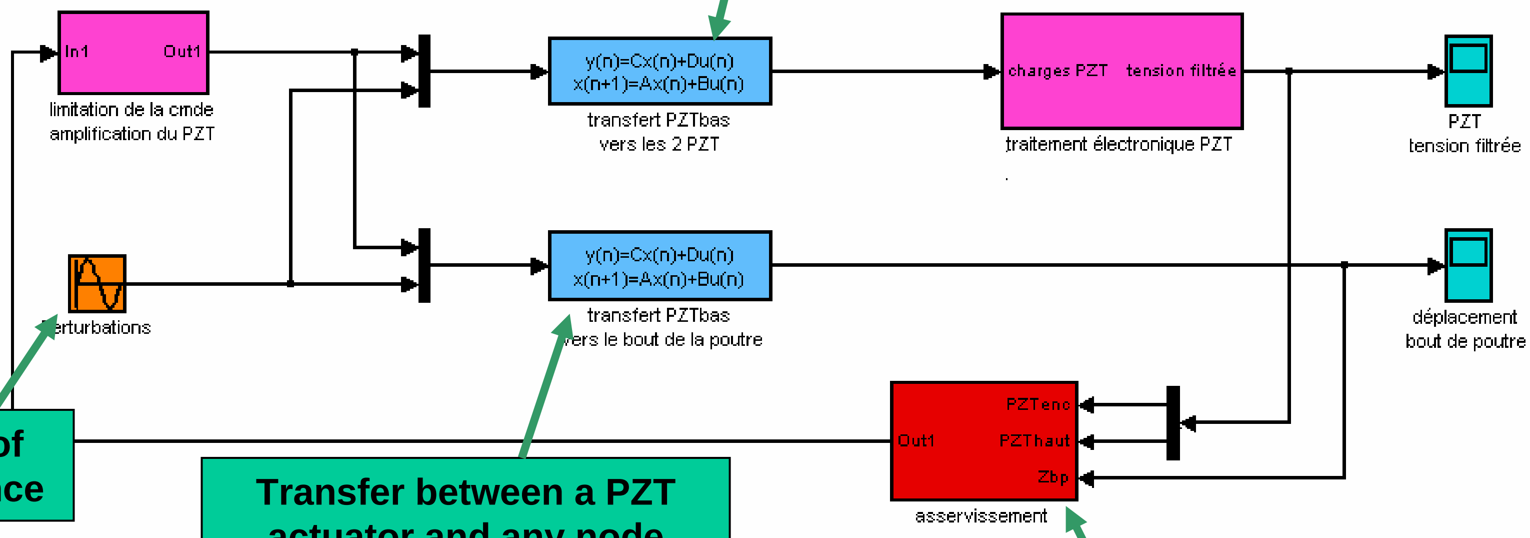
- ***Finite elements with ANSYS :***

  (Collaboration with LMECA)



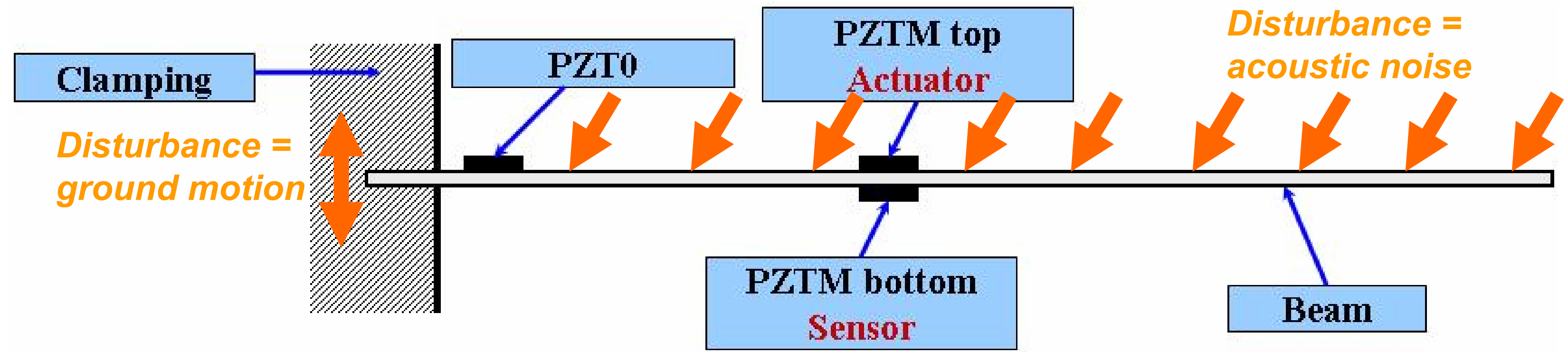


- "Structural Dynamic Toolbox" is used to process the characteristics of the model under Matlab / Simulink environment :



Numerical simulation of the small mock-up

<u>Example of the simulation :</u>



<u>Configuration of the test :</u>

-**Rejection of one disturbance frequency (1st mode of flexion)**

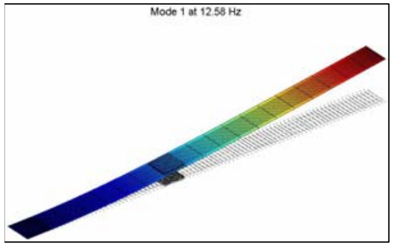
-**“PZTM top” in actuator / “PZTM bottom” in sensor**

-**Monitoring simultaneously of :**

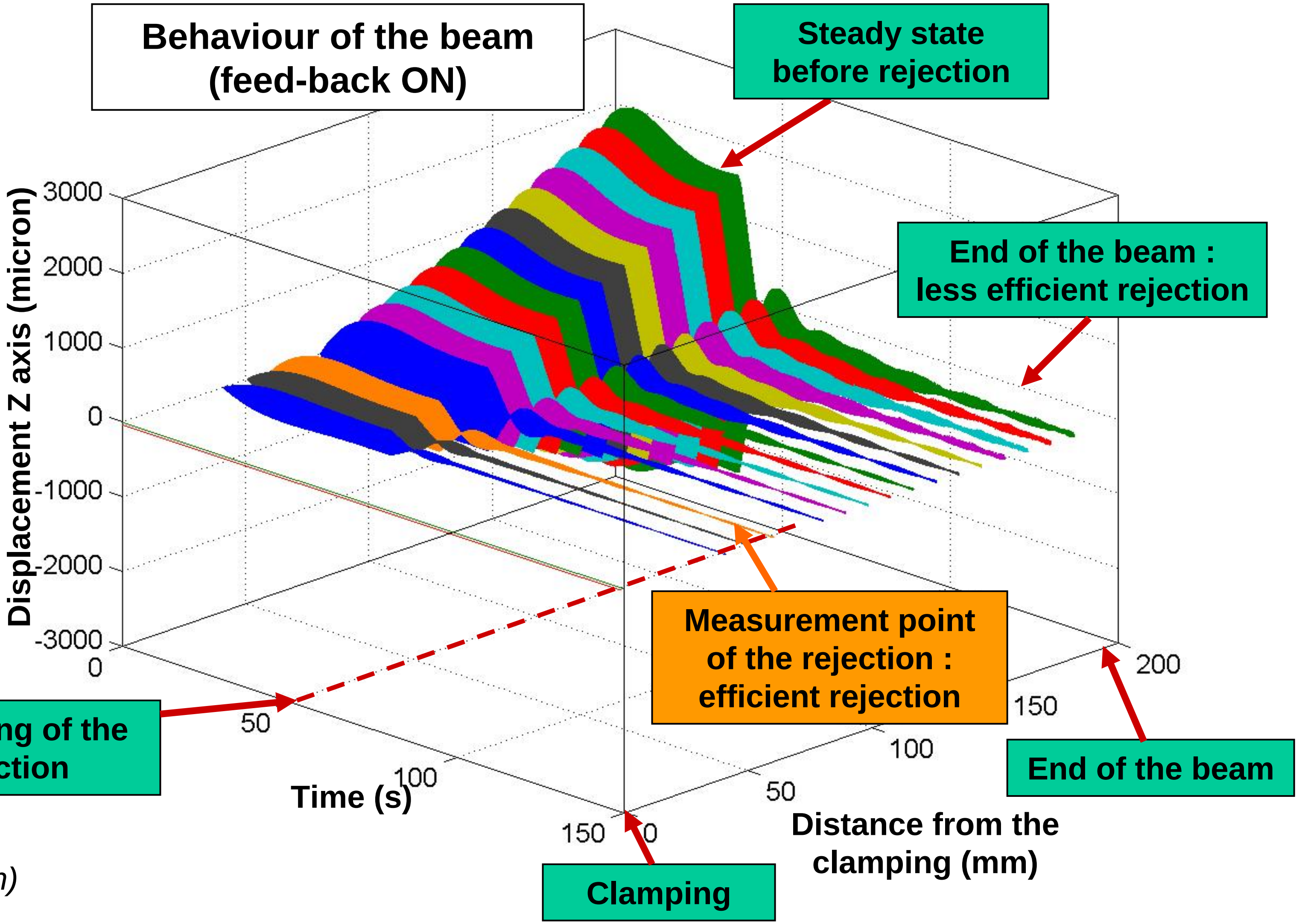
- **each node of the beam**
- **the voltage of each PZT patch**

Numerical simulation of the small mock-up

Results :

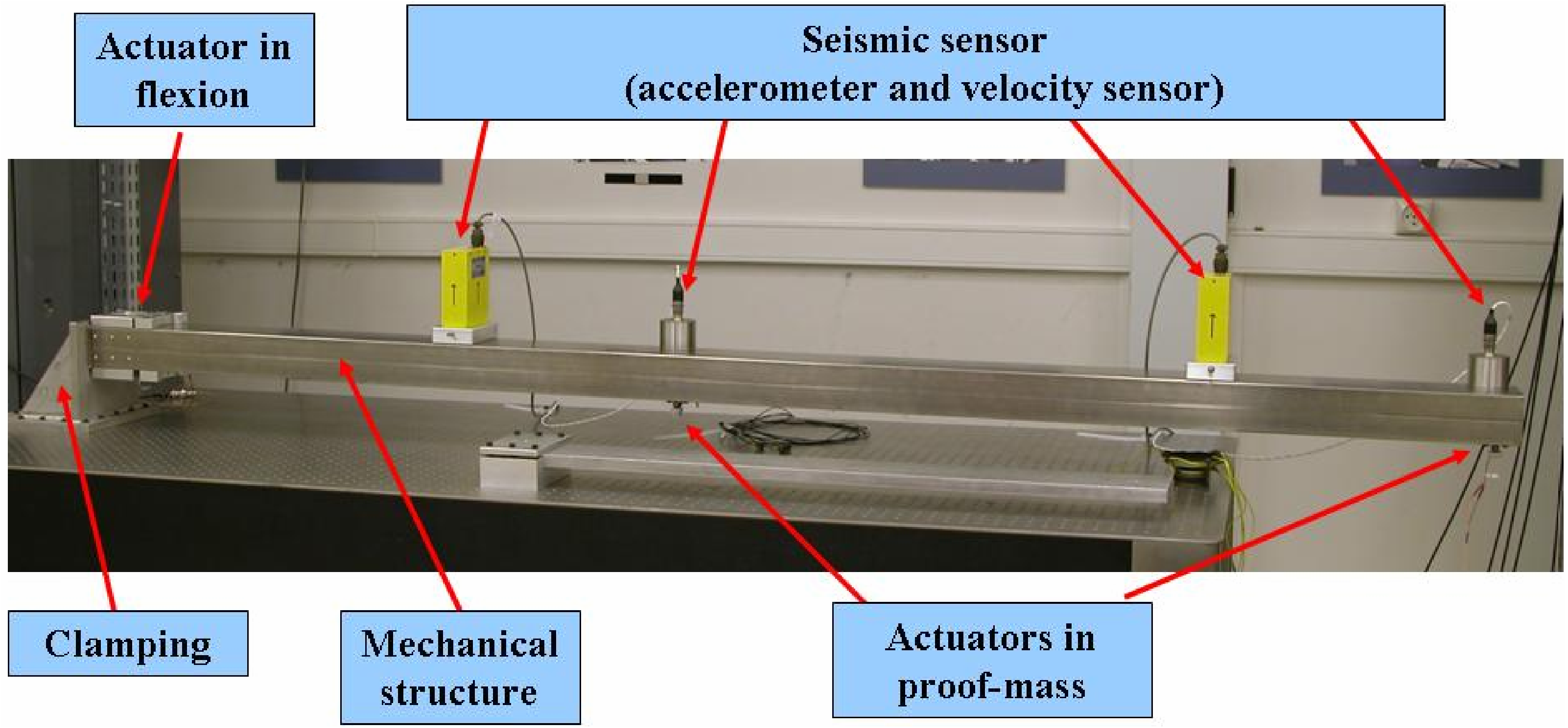


(1st mode of the beam)



Large prototype

The prototype :



Antinode of 3nd mode

Node of 2nd mode

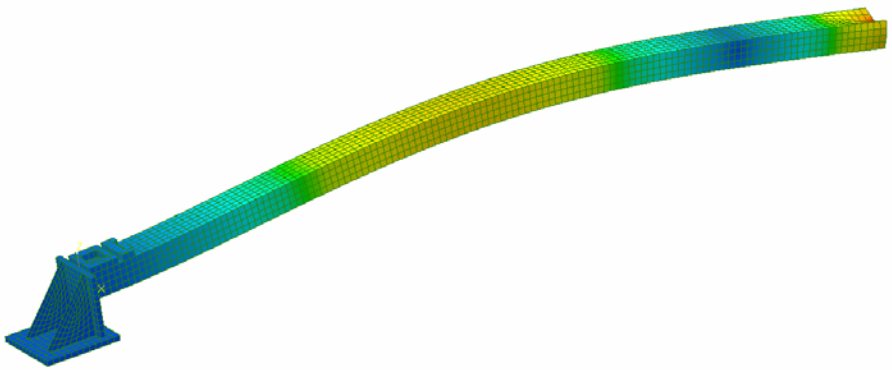
Clamping

Antinode of 2nd mode

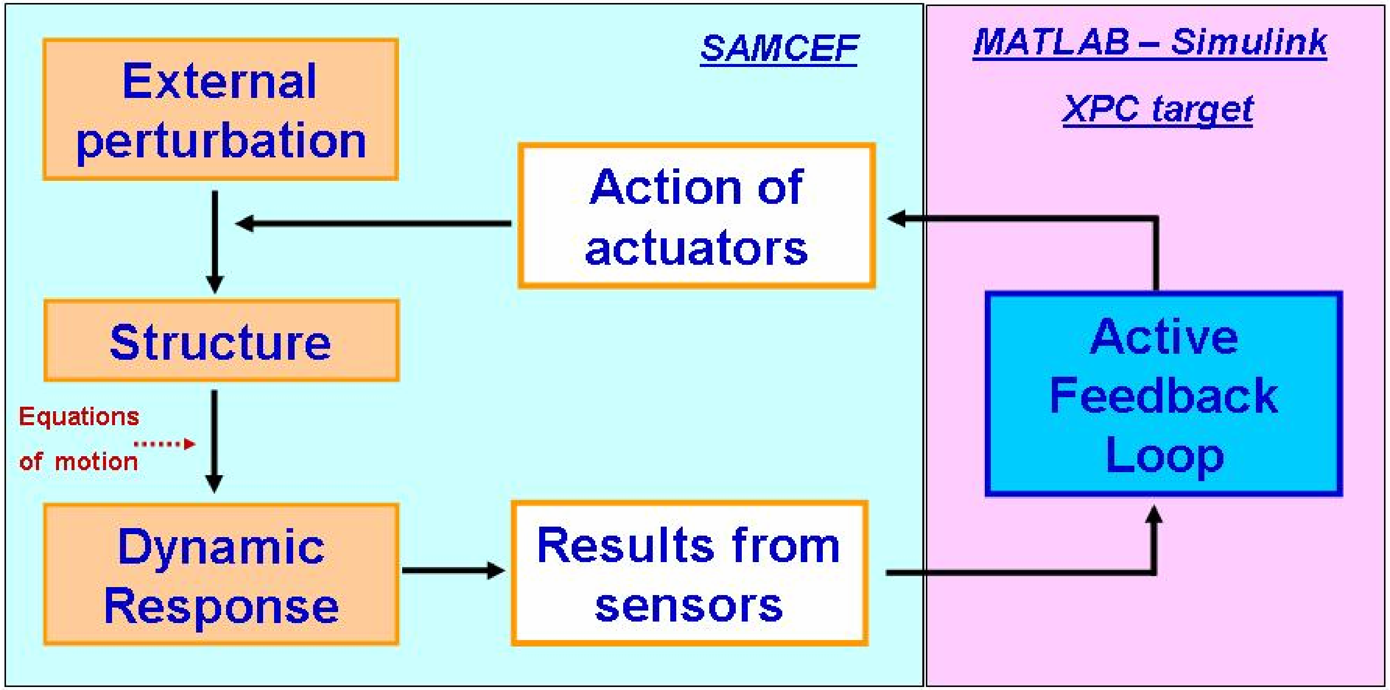
End of the beam

Simulation of the large prototype

- Finite elements with SAMCEF :



- Simulation of the entire system :



Conclusions

- Active feedback loop on a large scale prototype
  - → **Validation of the method for the micrometer scale**
  - → **Validation of the frequency tracking**
  - → **Requirement of an efficient hardware (data acquisition) to get results at nanometer scale**
- Choice of the location and the technology of the instrumentation
  - → **First approach with experimental tests**
  - → **Requirement of simulation for validation (with accurate updating models)**
  - → **Multivariable problem with many sensors and actuators using different technologies**