VI MCRTN Smart Structures Workshop

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Influence of design parameters' changing on the performance of a Smart Structure. Numerical assessment and case discussion

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Index

- Presentation of study case, numerical model and control strategy

- Premise on Smart Structures design

- Design parameter variation, discussion and results

- Conclusions

Study Case presentation

Benchmark

Concrete Car : two acoustic volumes separated by a steel firewall

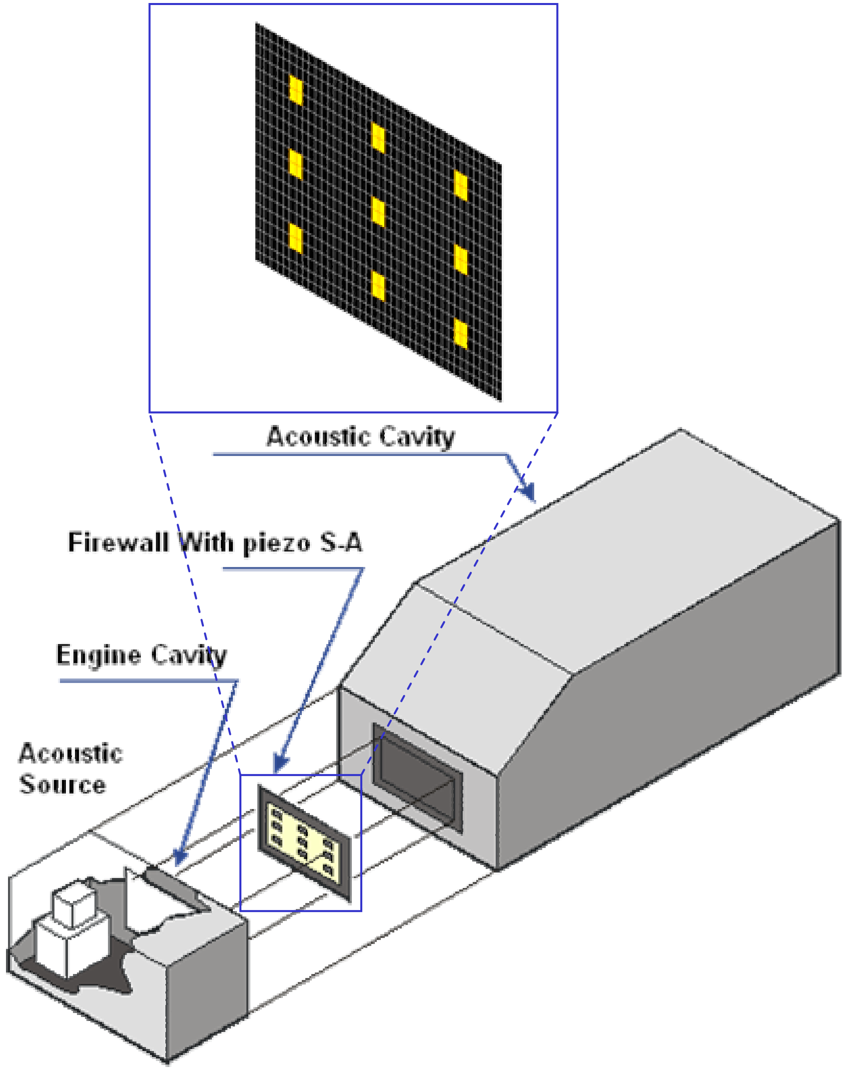
Target

Reduction of SPL of noise @driver's ear position coming from a source placed in the frontal acoustic cavity

Strategy

ASAC (Active Structural Acoustic Control) approach realised through velocity feedback control system

Co-located piezoelectric patches work as sensor / actuator pairs



Numerical Model of the Concrete Car

OUTLINE

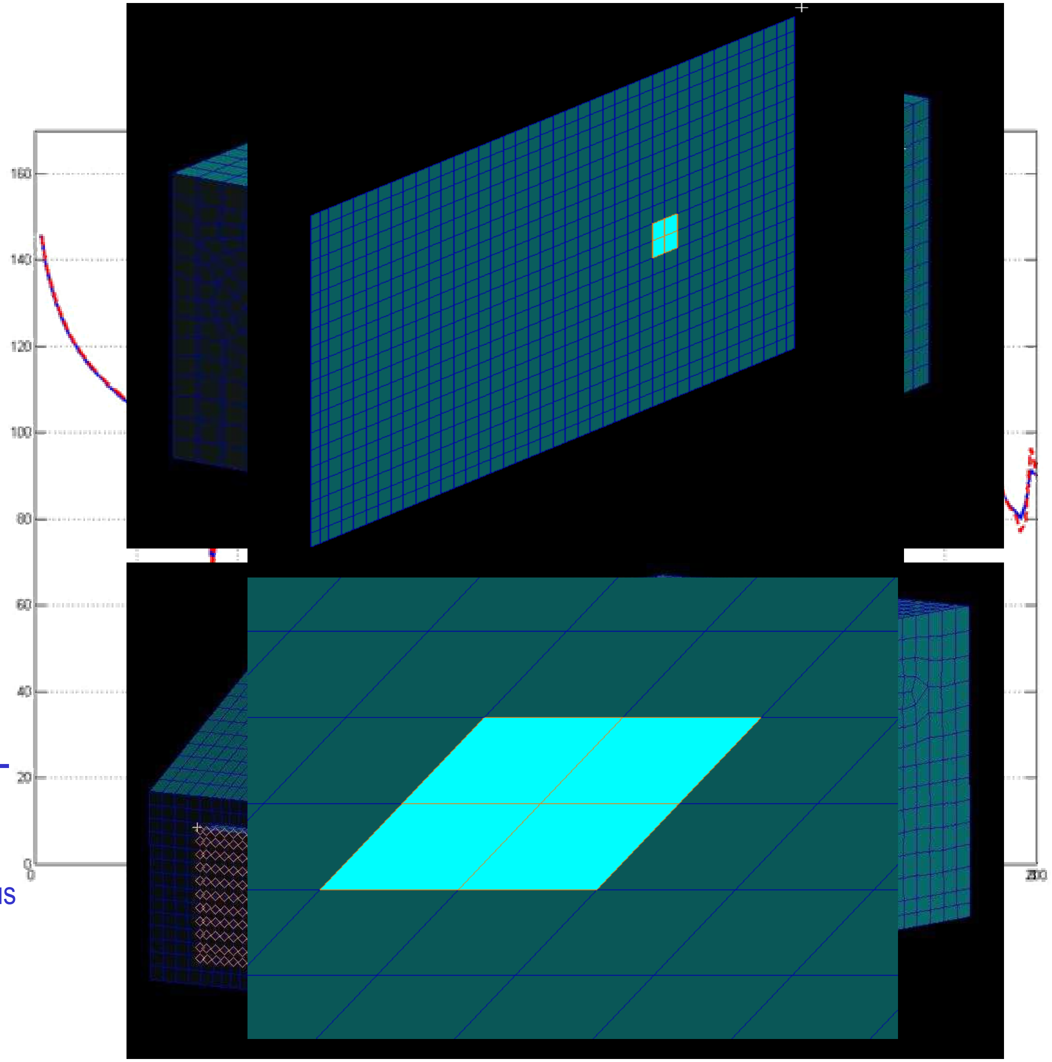
Acoustic domain
25498 HEXA8 elements

Firewall
800 QUAD4 elements

Piezoelectric patches
Dynamic description: laminate material property
Electrical/Electro-mechanic features:
implemented via MatLab© scripts operating on firewall's .BDF entry files

Numerical simulation tool
Reduced State Space fully coupled electro-vibro-acoustic model

NOTE: all the topics hereby listed have been the topic of previous presentations of the author whose content is disclosed and available on request to the members of the research network



Premise on Smart Structures design

What is it for ?

Conventional design doesn't take into account control dynamics, which are processed separately, after structural design choices have been already done

What is the goal ?

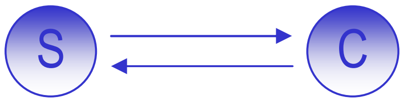
Control dynamics in design phase broaden the scenario of optimal design solutions. Excluding this contribution from designing may provide sub-optimal solutions to the problem

Scope of this presentation

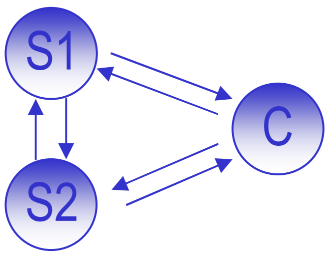
Show the capabilities of concurrent mechatronic (Smart Structures) design through simple cases discussion on the influence of structural and control variables

Premise on Smart Structures design

As a matter of principle…
when a structure and a control are taken into consideration, they influence each other for as regards the global behaviour of the Smart Structure



If COUPLED DYNAMIC SYSTEMS are taken into account…
then the number of interactions increases, and their mutual implication may turn to be not straightforward and counterintuitive



This design problem has to be solved using accurate, powerful but yet quick numerical tools, but can't exempt the engineer from being aware of the nature and the importance of each very aspect of its.

Plate Thickness Variation

Plate's thickness variation brings changing in dynamic behaviour

…hence…

Plate's variation of dynamic behaviour changes fluid -structure coupling condition

…hence…

Coupling condition determines the SPL @ given target point for given path

Passive performance estimation for three cases:

Steel firewall, 895x545xt mm3

t1 = 1 mm

t2 = 1.5 mm

t3 = 2 mm

Plate Thickness Variation

Case t1 = 1mm

SPL rms = **82.41** dB

- Reduced stiffness causes high density of structural modes at lower frequencies

Case t2 = 1.5 mm

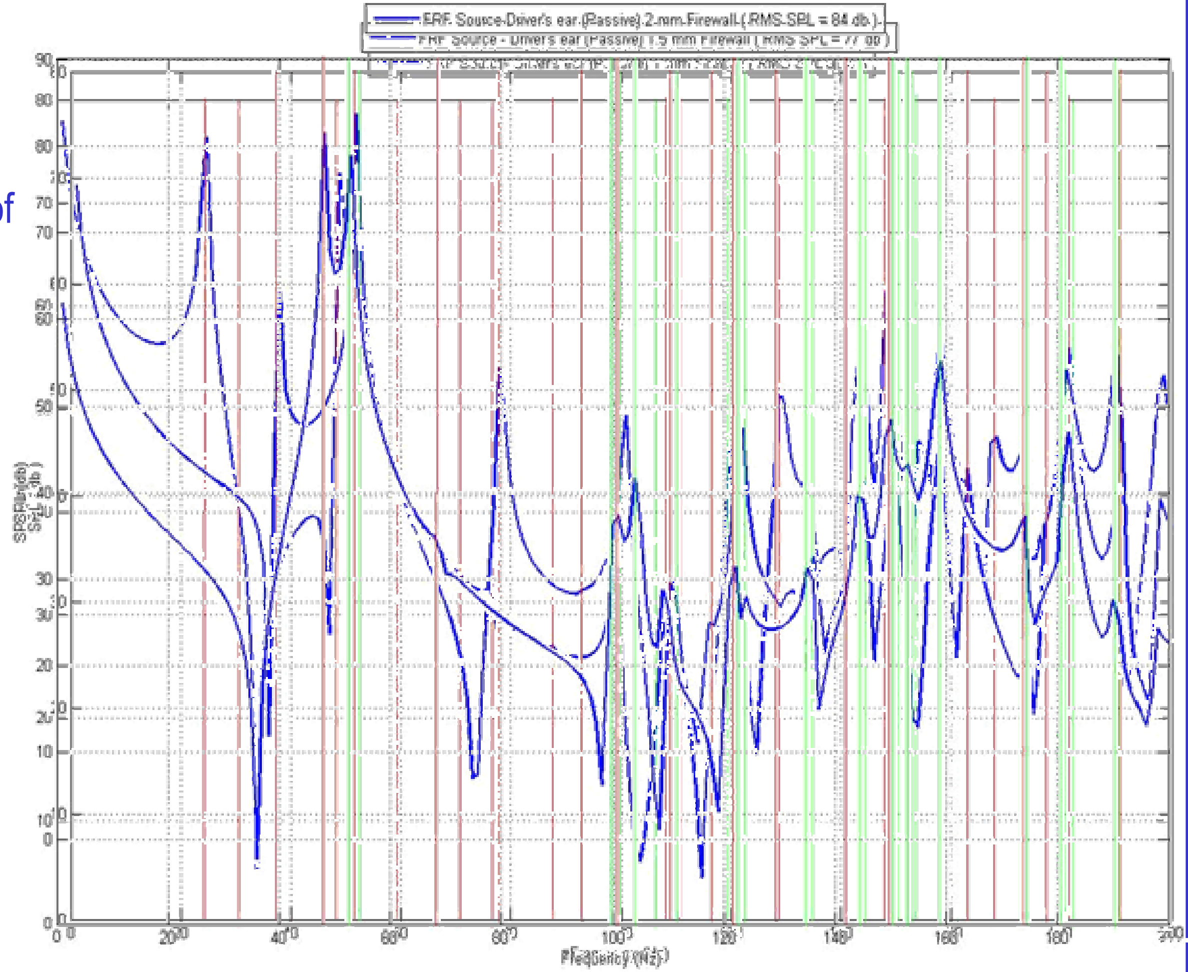
SPL rms = **77.25** dB

- Poor vibro-acoustic coupling makes SPL overall value decrease significantly

Case t3 = 2 mm

SPL rms = **84.03** dB

- Reduced number of modes in the bandwidth of interest is compensated by strong coupling condition



Piezoelectric SA layout

Piezoelectric patches positioning

Choice that influence the global dynamics of the system

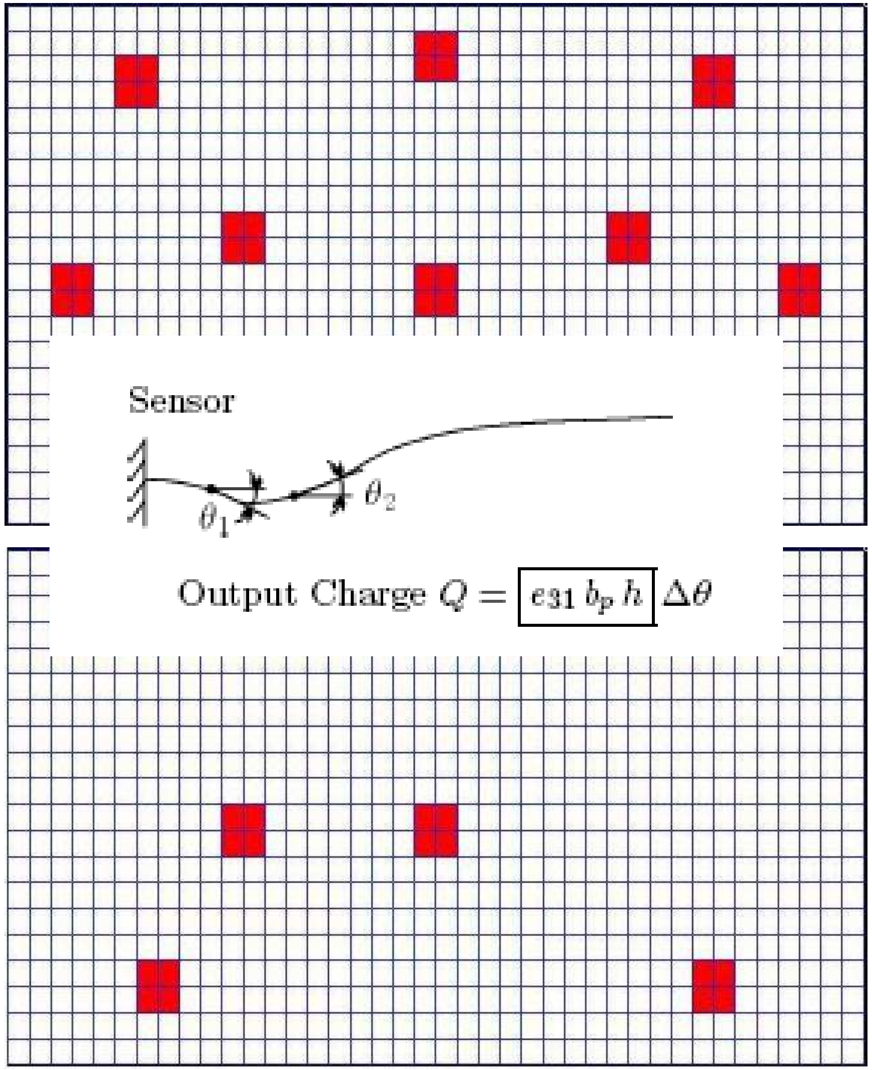
Piezoelectric behaviour

Actuation is proportional to its correspondent co-located sensor output

Piezoelectric direct effect (sensing) is proportional to the difference of rotation at its extremes

Purpose

Evaluate a SA arrangement capabilities on narrow band (around resonance) and broad band SPL reduction performance



Piezoelectric SA layout

STUDY CASE

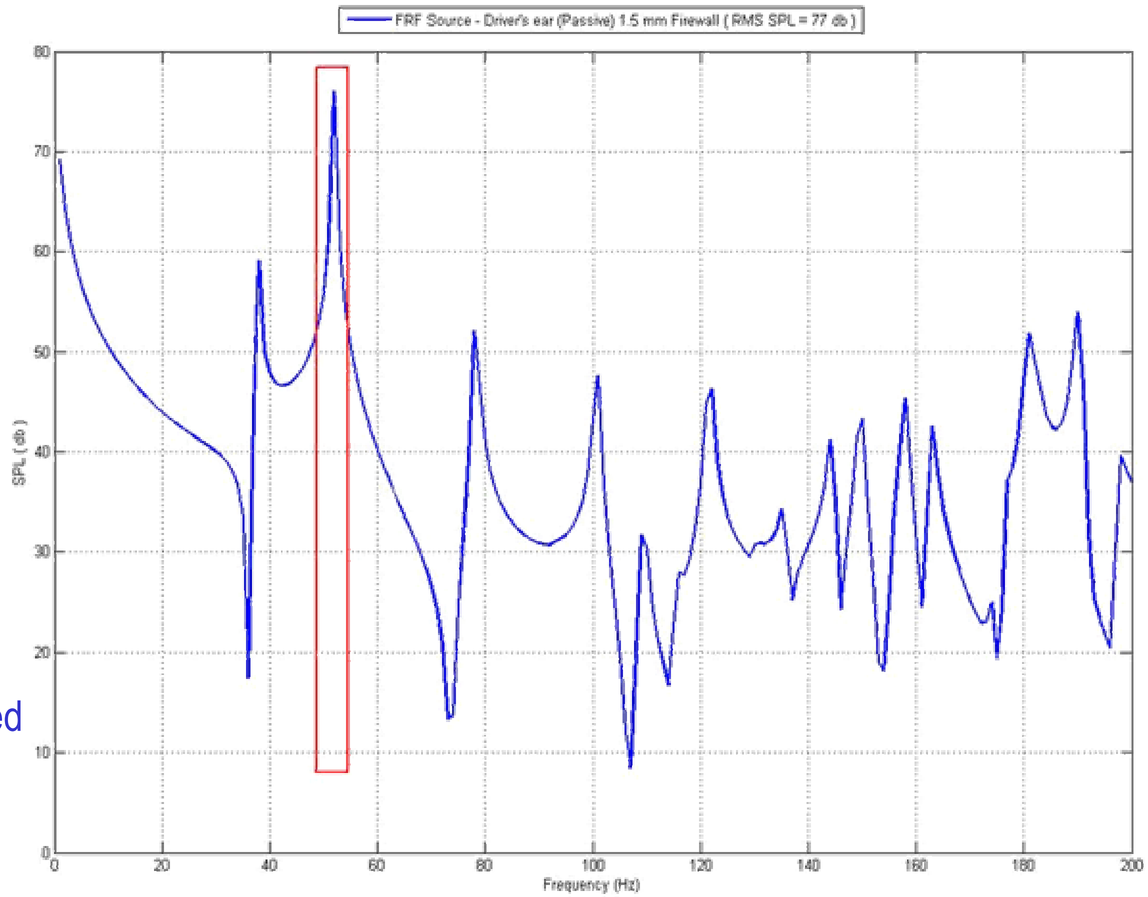
Firewall t2 = 1.5 mm
SPL @ mode 2 = 76dB
SPL 0-200 Hz =77.25 dB

Peculiarity of dynamic behaviour:
High participation of mode 2
(COUPLED:1st acoustic, 2nd structural)

Target
Mode 2 SPL reduction

Strategy
Deployment of 8 sensor/actuator co-located pairs in feedback control

Additional Data
Piezo patch thickness = 0.5 mm
d31 coupling factor = - 180e-12 C/N



Piezoelectric SA layout

Trial Configuration: DGC (double Greek cross)

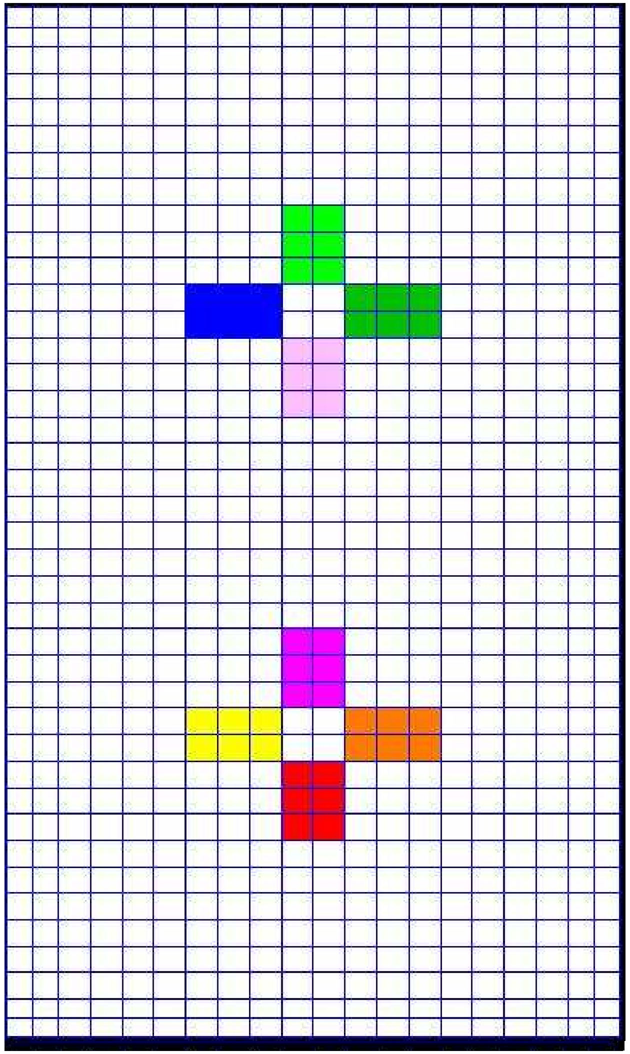
Proposed implementation
varying the distance between cross extremities

DGC-L (Large)
DGC-M (Middle)
DGC-T (Tight)

Rationale
Given a patch of determined size acting as a rotational constrainer:

Close to the border: favourable actuator position

Around mode shape extreme: favourable sensor position



Piezoelectric SA layout

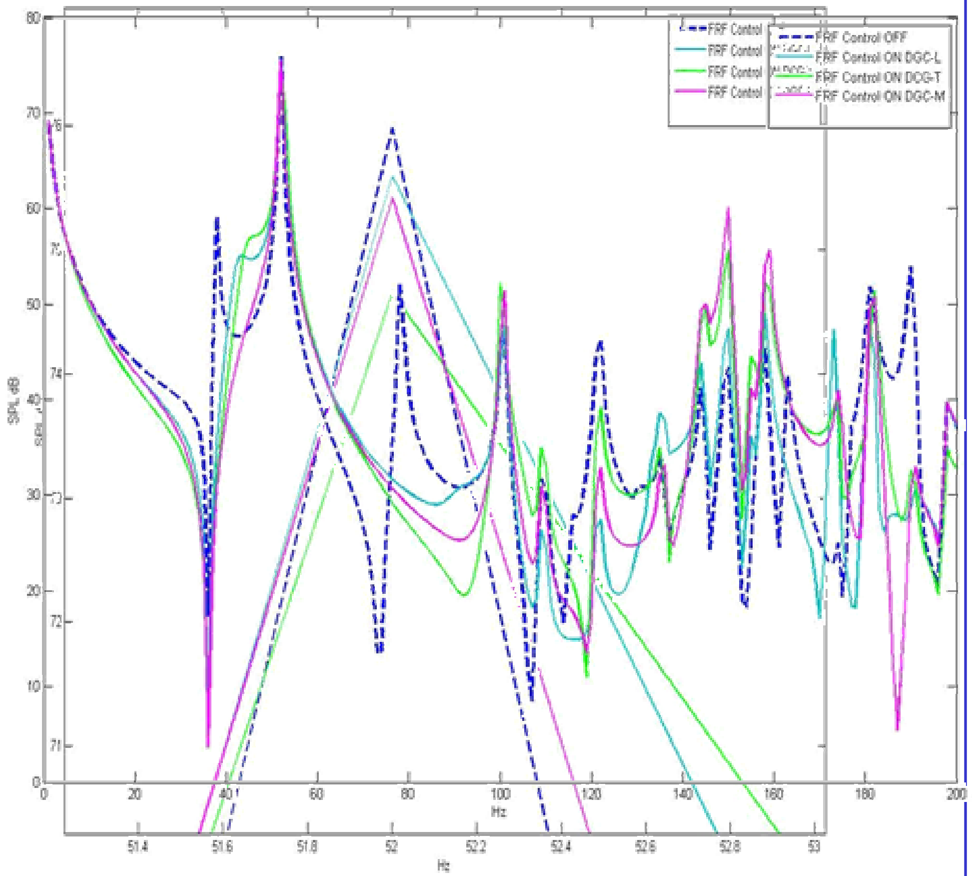
RESULTS DISCUSSION

@Resonance frequency f = 52 Hz
DGC-L = - 0.4 dB
DGC-M = - 0.6 dB
DGC-T = - 1.2 dB

DGC-T acts as a patch of double length on the direction of the longest side, getting the most from curvature difference and acting far enough from maximum displacement to achieve significant performance

Broadband performance
DGC-L = + 0.5 dB
DGC-M = 0 dB
DGC-T = + 0.3 dB
No effect

A narrow band solution is unrelated, or may have a negative influence on the broadband behaviour of the plate



Piezoelectric SA layout

Alternative: Cross Configuration (CCo)

@Resonance frequency f = 52 Hz

ΔSPL = - 4.2 dB

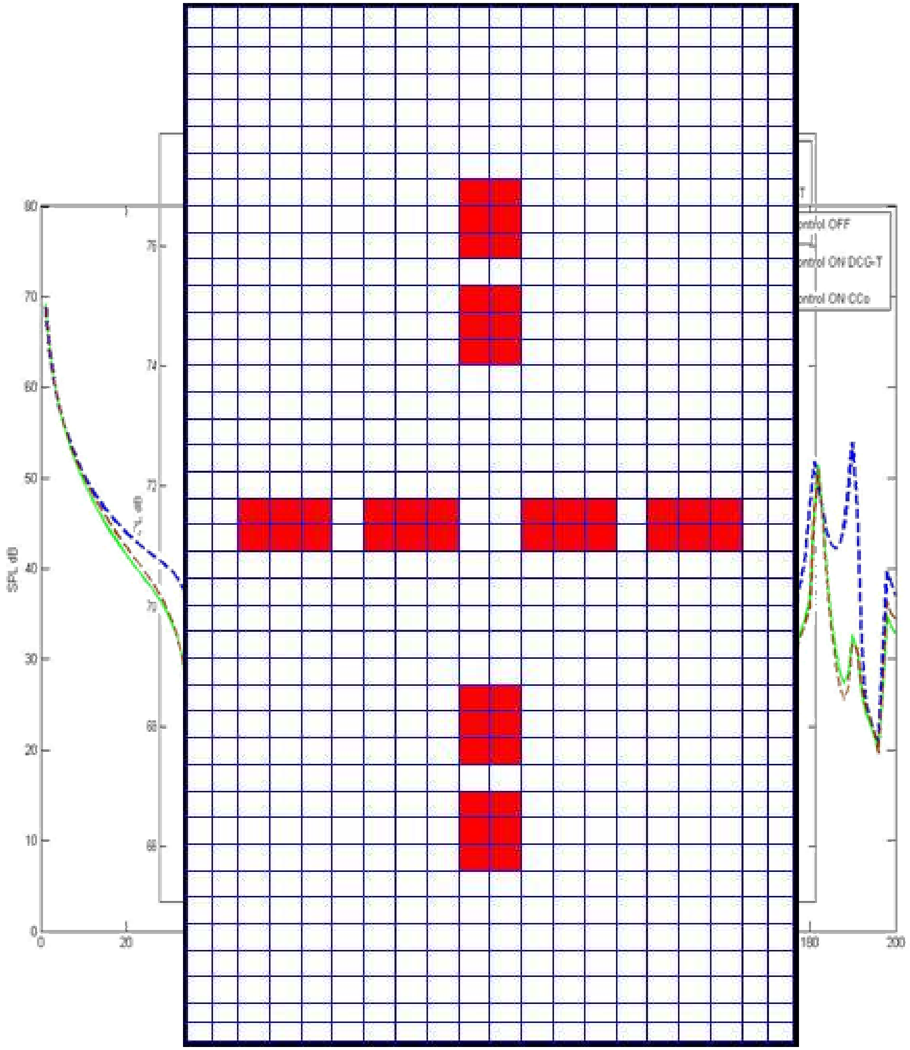
Broadband (0-200Hz)

ΔSPL = - 2.1 dB

Advantages of CCo

Patches are close, thus positive effect in previous T subcase is achieved

CCo configuration covering a wide span of eigenvectors for both even and odd mode shapes



Smart Structures

Amplification Gain Influence

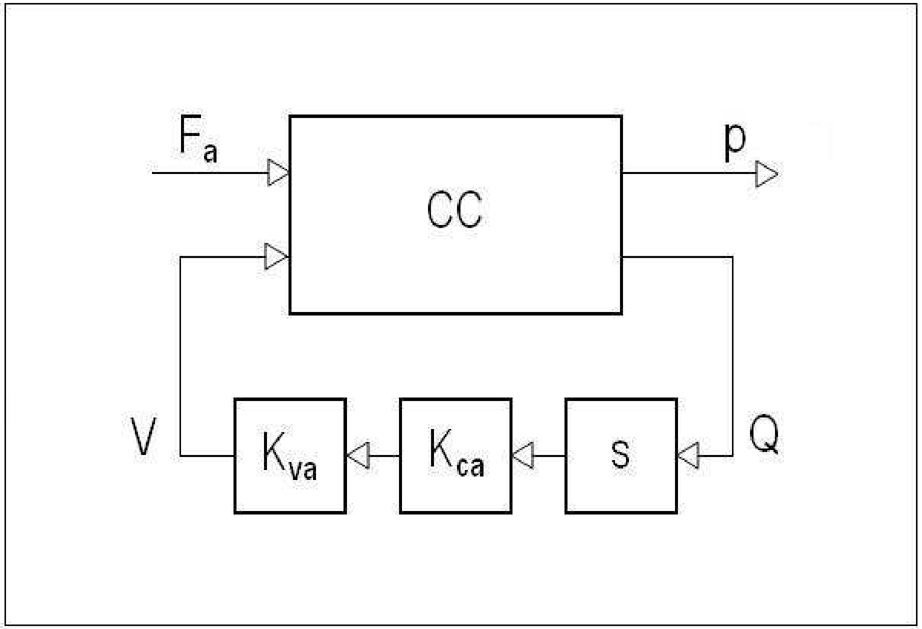
OUTLINE

Velocity feedback control on 8 piezoelectric patches

- Current Amplifier (K_{ca})
- Voltage Amplifier (K_{va})

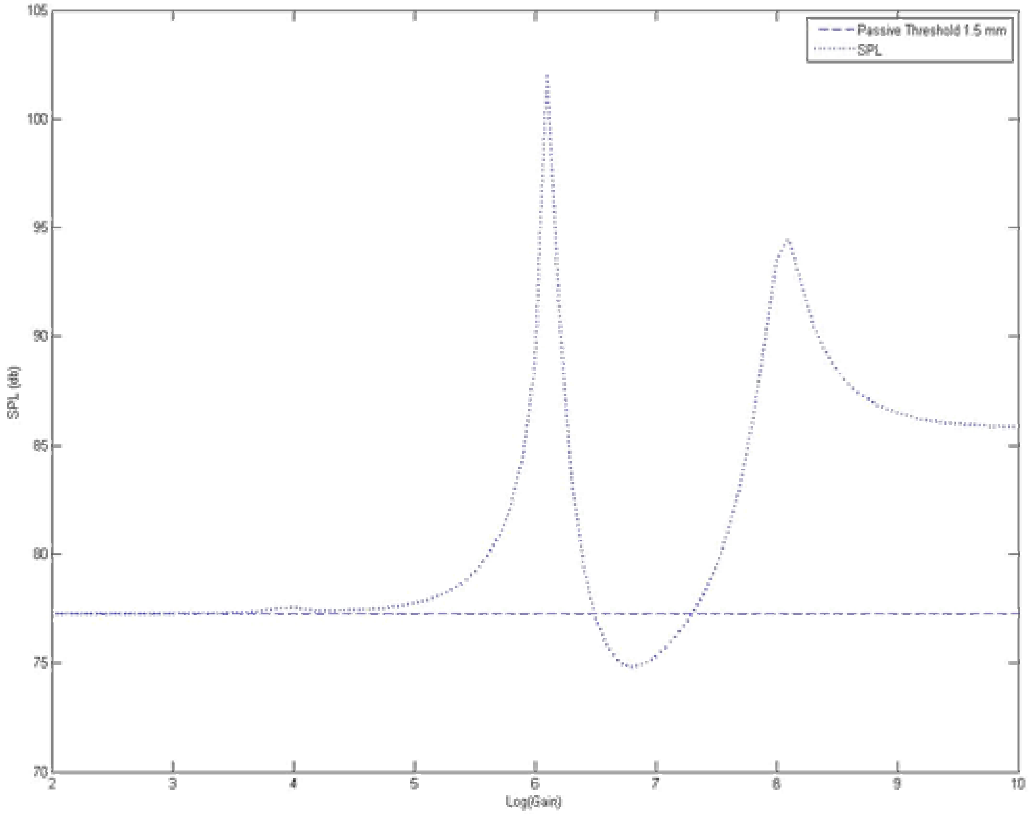
Gain is defined as the overall gain of the amplifiers

Control stability is granted by the co-located configuration



Amplification Gain Influence

Increasing of gain brings point of minimum/optimal for noise transmission reduction providing a crucial design information…



Amplification Gain Influence

Constrain in Gain value

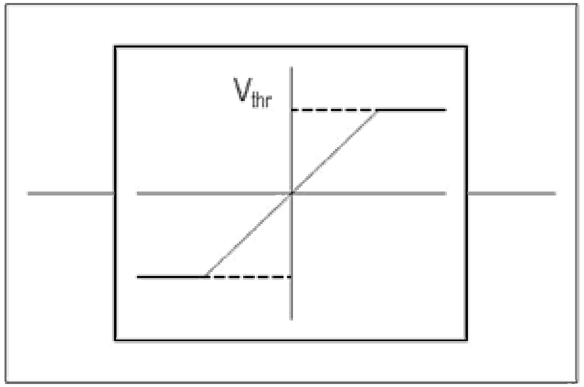
Piezoelectric actuators CAN'T WITHSTAND VOLTAGES ABOVE A GIVEN VALUE DEPENDING ON THEIR MATERIAL PROPERTIES

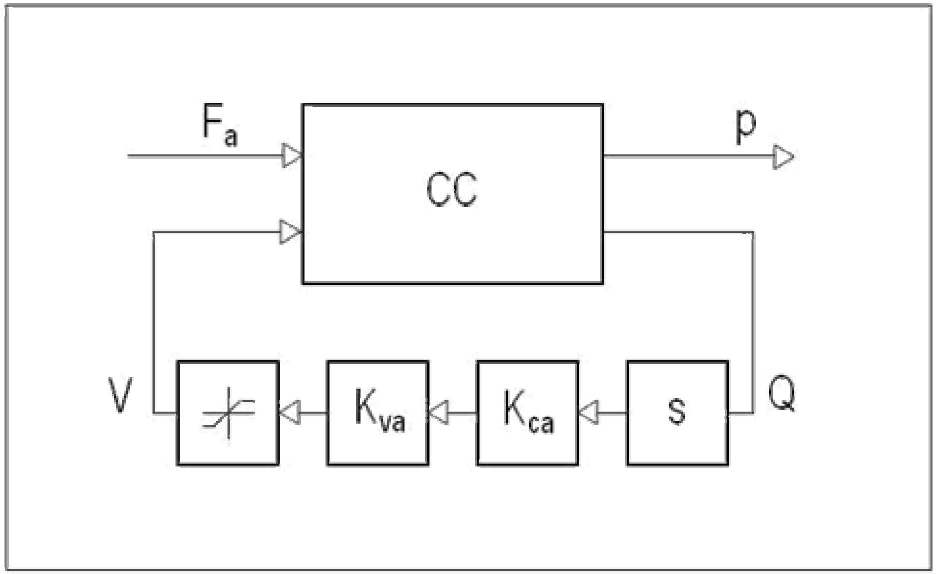
GENERAL STATIC THRESHOLD: 2000 V/mm

A Cut-off block is modelled to impose a safety voltage threshold of 500 V

Implications related to this aspect are still being investigated

- Non linear behaviour of Cut off block
- Voltage limit in dynamic case





Amplification Gain Influence

SPL values curves with Cut-Off

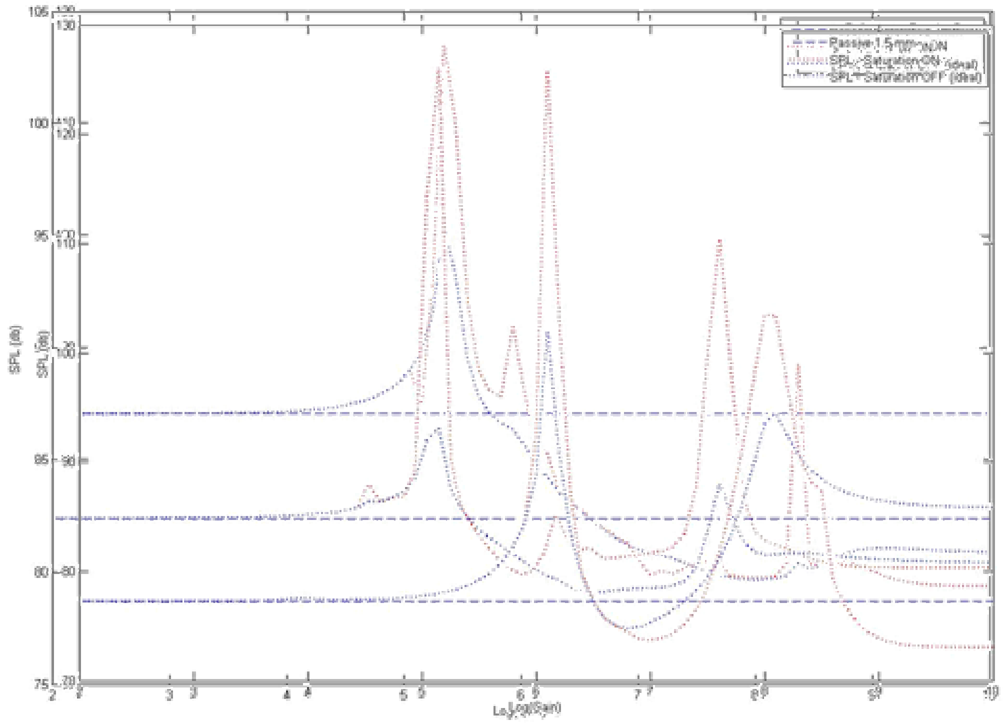
- SA Configuration: CCo

- Graphs obtained for firewall thicknesses t1 t2 t3

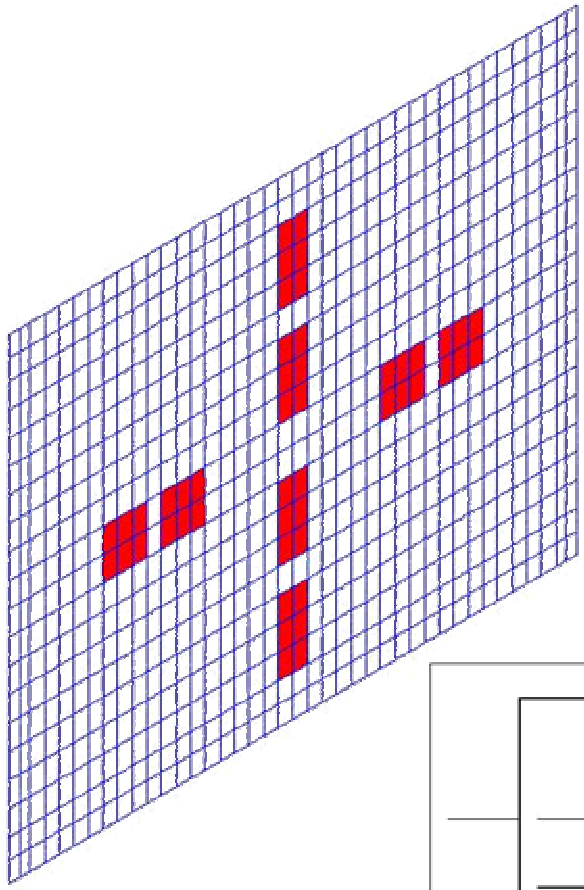
In the area of interest, below the passive SPL, cut-off block provides two possible scenarios; with respect to the configuration without saturation

- Lower SPL reduction @ the same gain value

- Equal performance @ higher gain values



Overall Result

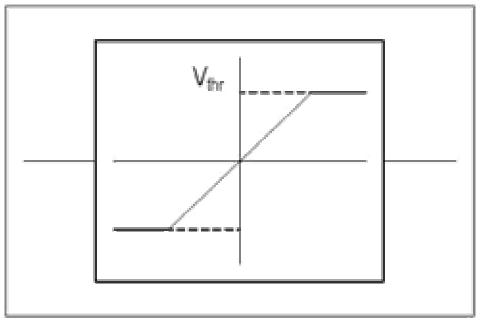


Best performance for CC ASAC controller

- Transducer no: 8 SA co-located pairs
- Configuration: CCo
- Cut-off block

VARIABLES

- Firewall thickness t1 t2 t3
- Feedback gain value



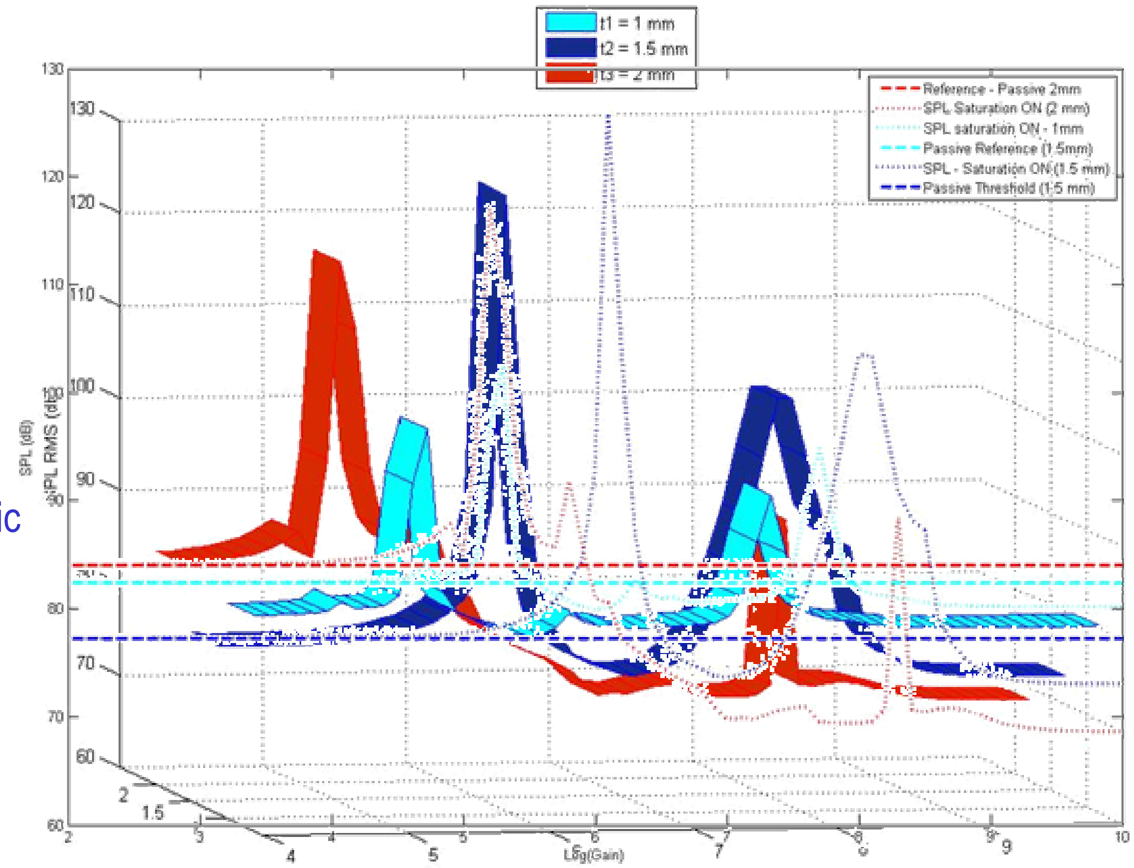
Overall Results

INTERPRETATION OF RESULTS

OPTIMAL SPL REDUCTION VALUE:
t3 = 2 mm

ΔSPL = - 14.8 dB

- t3 firewall had the worst passive ranking
- As previously outlined, strong vibro-acoustic coupling is the key of high performance
- Optimal SPL reduction value obtained at higher gain values, due to the highest mechanical stiffness of t3



Conclusions

In coupled structural-acoustic problems, coupling itself, more than the peculiarities of its components, brings understanding about how the system will behave under a specific control strategy

Spotlighting the mechanisms governing vibro-acoustic coupling alternatively / alongside with parameters defining both the structural and acoustic domain, may bring a new, interesting perspective in methodologies for design/optimization of smart systems

Importance of a concurrent mechatronic design approach has demonstrated how different optimal scenarios may appear considering control variables in design phase

Acknowledgments

Topic of concurrent mechatronic design on the Concrete Car has been previously and extensively studied by Dr. Leopoldo De Oliveira and Dr. Maira Da Silva.

The author (…largely relieved by the fact of having, so far, paralleled their results and conclusions implementing his piezoelectric SA based control…) would like to credit the contribution of his former colleagues, and thank them for the inspiration their work has blown in his

Je vous remercie

pour votre attention