ProSPADD: a guiding tool to optimise and attenuate the vibro-acoustic response of structures

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The main issues induced by the propagation of vibrations and acoustic waves along a structure, such as a car, are the increase in unscrewing and debonding risks, in fatigue stress and in noise level. Theses amplifications, real signature of the structures resonant modes, appear enhanced at their resonance frequency on the vibration transfer diagram. But the basic strategy of separation between excitation and resonance frequencies is rapidly limited from the only parameters mass and stiffness, whilst damping is arbitrary sustained.

The damping technology SPADD® and its methodology offer new perspectives by adding damping without mass nor stiffness leading to highly competitive solutions with regard to the excitation spectrum and the technical-economic constraints of (weight / performances / cost), and easily integrate the design process of the car industry either at a curing or at a preventive stage.

This paper presents the technology and methodology through the application on a real case of the automotive industry.

1 Introduction

As Artec aerospace first used his SPADD® technology in the field of satellites, it clearly proved that the concept was mature enough for application. Marmonier, a specialised supplier in thermic and vibro-acoustic solutions for the automotive industry, had the gamble of introducing this technology into cars.

Even if many things can be and are simulated, we must admit that in most of engineering projects of complex structures (such as vehicles), vibro-acoustic issues generally only appear on real structures, it means at the last stages of design, when most of the design parameters cannot be changed drastically, and when it has become anyway too late to do major changes.

At such design stages, one generally has to completely change the modal contents of a part, or at least cancel one or two modes, but:

- With very few space (because of the interaction of the part with a high number of parts belonging to the same sub-system and to other vehicle sub-systems),
- Without adding weight (which is directly related to the energy consumption of the vehicle and to environmental standards),
- Sometimes even without adding stiffness (which is related to the overall behaviour of the vehicle: changing the stiffness of one single part changes the stiffness of the sub-system it belongs to, and hence can impact the whole vehicle, especially in term of durability),
- With few time to find a solution (because the time to market cannot be changed for marketing purposes and due to the fact that vehicle development planning are always more compressed),
- And of course, without any additional cost (since at this stage, all development budgets have already been consumed).

The purpose of the SPADD® technology is to add damping “without” mass or stiffness.

2 Principle

The underlying principle used in the SPADD® technology is very simple: the purpose is to redirect the energy contents of cumbersome modes in parallel of the structure, where it will be dissipated. This mechanical energy is converted into heat in small “patches structures” called SPADD®. A SPADD® device consists of viscoelastic damping materials constrained or unconstrained and embedded in a mechanical structure. The geometry of a SPADD® device has to be optimised for each problem, but can be found as patches (2D), small 3D structures or struts.

Considering the equation of dynamics, the damping is generally not considered as a dimensioning parameter of this equation, which is a mistake, because it introduces at strong limitation of possibilities.

The addition of SPADD® devices to a system changes its mass, stiffness and damping. Thus efforts are made to avoid re-solution to determine an optimum design. This is achieved by using a perturbation method. In this case, as in all structural dynamic perturbation methods, changes in modal properties like eigenvalues and eigenvectors due to modification can be expressed directly in terms of eigenproperties of the original unmodified system and changes in mass and stiffness matrices...

Comparisons of results obtained by the perturbation method with results obtained by re-solution (updating the modal basis) show that the perturbation method is accurate and computationally efficient.

It is important to use complex values since the dynamic properties of viscoelastic systems are represented under harmonic vibration conditions by complex moduli, which is due to the phase difference between stress $\sigma$ and strain $\varepsilon$ (we do not
indicate stress or strain direction, it is true for any
direction, hence for principal or shear direction):
\[ \sigma_{ij} = E_1 + i E_2 \] (with \( i \) the complex unit),
and \( E_1/E_2 = \eta \) is referred to as the loss factor of the
material.
Viscoelastic material properties can be determined
experimentally using an Oberst apparatus for
example, and generally depend on both temperature
and frequency.

Hence, a standard eigensolver can be used for
finding the complex eigenvalues which give the
natural frequencies and modal loss factors. Modal
summation is then used to compute the response to
excitation.

3 Presentation of the tool and methodology

ProSPADD is a software developed on the
theoretical considerations recalled in the previous
section.
The software is based on Mathlab and related finite
elements tools, and the interface is already done
with Nastran, while universal files will soon be
included in the input file formats.

The aim of this software is to offer designers a very
simple tool to find, without discretizing any device,
the best damping which can be added to the
structure.
The geometrical modelling of the SPADD® device is
replaced by updating the matrix system: the
designer only has to indicate the area where the
optimisation can be performed, and eventually the
kind of technology to be used (unconstrained
material, constrained material, strut...).

The methodology is as follows:

0. start from an existing model in Nastran
1. perform a modal analysis of the system in
Nastran: at this stage, the designer
generally face a problem, because one of
the modal frequency is in a high energy
range of the excitation. In this case, launch
ProSPADD
2. import the FEM model
3. define the type of treatment among available
SPADD® technology
4. define the area of treatment, and eventually
some parameters (maximal dimension,
geometry, materials...)
5. define the mode(s) to be damped or the
vibration level to be attenuate (FRF)
6. launch the analysis
7. analyse the results:
ProSPADD will propose the designer the following
results:
- the best positioning of SPADD® devices
within the chosen area (topological
optimisation)
- the maximum reachable damping according
to the entered constraints (technology,
dimensions...), the others parameters
remaining design parameters
- the damping added to all modal base
- the attenuation of frequency response level
- the export of the FEM of the treated
structure (which can be used for re-solution,
for example, in Nastran)

It is important to understand that this methodology
allows the designer to really consider the damping
as a dimensioning parameter. Until then, it has
generally been applied at the end of the design,
when a problem is encountered (for example a
cumbersome mode), in a curative way. But, as soon
as designers understand the potential of having a
new design parameter, they can start using it in a
predictive way, at the very first stage of the design.
In this case, damping can really be added even
through mass and stiffness can be spared.

4 Academic study of a cantilever beam

In this section, we propose to add damping to the
bending modes (1, 2 and 4, mode 3 being a
torsional mode) of a cantilever beam using different
kind of SPADD® shapes.

We recall the modes 1 to 4 of a cantilever beam:

Experimental validation and presentation of
SPADD® devices:

T-shape, U-shape and
surfacic SPADD®
respectively

Many configurations have been simulated and
tested (different shapes, different geometrical
constraints...), they all have been compared in
terms of FRF and added damping

Results:
The flow charts below shows the results for modes 1
to 3 in term of damping for 3 different materials (A, B
and C), and 3 geometries (P1, P2 and P3):
The following table illustrate correlation between simulation and experimentation.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Freq (Hz)</th>
<th>Damping (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ProSPADD</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>4.26</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>3.24</td>
</tr>
<tr>
<td>4</td>
<td>112</td>
<td>4.15</td>
</tr>
</tbody>
</table>

5 Industrial applications

In this section, we present some industrial applications by keeping industrial confidentiality: we do not mention the customer, the vehicle, and we briefly present the problem and the validated solution.

Curative study of an automotive rail side near a hole – SPADD® T shape

Study constraints:
- The treatment is only possible near the considered hole. Hence, the designer starts by selecting the area (grayed zone):
- The kind of SPADD® technology retained is a T-shape SPADD®, with a maximal height of 1mm:

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Solution:
- ProSPADD displays the optimisation evolution during the computation in terms of potential damping added versus frequency:
- ProSPADD proposes the best area definition and the following solution:
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Curative study of an engine bracket – SPADD® strut

Study constraints:
- Motor interface (static and crash behaviour)
- Stiffness constraint (decoupling modes 2 and 4)
- Curative study: no change on the part, but add a damping device
- SPADD® technology: strut
- Limitation of felt resonances by the motor bracket

Structure:

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Solution:
- Additional potential damping: 5%
- Geometry with the strut:
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Re-design using SPADD®

The previous study has been extended taking into account the following constraints:
- new design including SPADD®
- mass reduction

With this final version, we have:
- new geometry:
  - simplified sizing and manufacturing process (pressed steel)
  - mass reduction: around 60% gain
  - cost reduction: around 50% gain
  - Impact on FRF: gain = 20dB

Optimization of a roof – Surfacic SPADD®

Study constraints:
- Optimise the mass of IFF used to damp a car’s roof

Impact on the FRF: gain = 15 dB

Solution:
- Impact on FRF: gain = 15dB (more than IFF)
- Mass reduction: 30% gain compared to IFF

As a conclusion of the industrial projects, we can say that the SPADD® technology has already be used by several car manufacturers and validated by them. Since SPADD® devices have shown their ability of solving some real problems encountered by car manufacturers, they are not used, at this time, as serial parts, but the technology is validated to be part of the technologies to be included in future cars.

6 Conclusion

In this short paper, we briefly presented the SPADD® technology and methodology and the related software ProSPADD. These tools have been validated by car manufacturers and will probably be used as serial solution in a near future.

Some selected problems have been briefly presented to demonstrate the SPADD® capacity in term of damping.

The main point is that the damping can really be considered as a dimensioning parameter in the equation of dynamics, even if for practical use, it is necessary to have the knowledge of both the geometry of the dedicated device and the characteristics of the constitutive materials.

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