# Innovative products for limitation of surface radiated noise from exhaust systems of vehicles

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## Introduction

These days, the trend of engineering from exhaust systems leads to changes in designs from round, stiff, acoustically advantageous structures to flat, acoustically unfavorable parts which are used due to restrictions in design space. Double layer technologies of mufflers which had been used for noise damping in the past are shifted to single layer materials with reduced wall thickness due to costs and manufacturing processes. Cast iron, which is used for manifolds, is replaced by thin metal sheets because of thermal and light-weight reasons. These actions mean regular increasing noise radiation. New technologies are requested to ensure the sound quality.

This paper outlines the physical phenomena of multiple layered metal sheets and their acoustic behavior as well as innovative low cost solutions with high performance to reduce acoustical radiation. A surface damping element is presented and topography optimizer tools, like OptiStruct® from Altair Engineering®, are shown. The investigations are based on exhaust system parts from vehicles, but the solutions can also be used in other areas of engineering where expenses, thermal or hygienic reasons restrict the use of damping materials.

### Basics

In most cases, structure borne eigenfrequencies of *single* components dominate the direct radiated noise of exhaust systems with frequencies above 250 Hz for passenger cars. Also airborne resonances can appear. The aim of an acoustical development is to decrease the amplitudes, which can be cost efficiently reached by shifting these resonances out of the dominating excitation range. For air borne resonances changes of the interior are required, for structure borne it means to stiffen it. Additional damping or insulation is regular avoided because of expenses.

The following schematic transfer function of a single mass system shows that increasing stiffness as well as increasing damping decreases the amplitudes of the movement. In addition, stiffness causes a frequency shift:

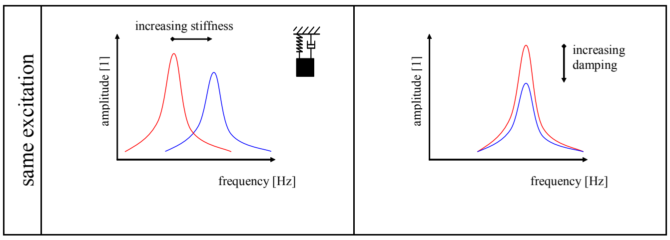



Figure 1: a) general influence of stiffness shift; b) general influence of damping

The amplitudes, the area and the frequency of the first eigenfrequencies give the main impact for the radiated noise. Other influence factors to the acoustical acceptance are the frequency dependent sensibility of the human ear on noise and have to be taken into account, e.g. by the A-weighting.

## Eigenfrequency

The first eigenfrequency of a component is shifted outside the dominating excitation frequency by stiffening the structure using CAE [1] to avoid noise radiation:

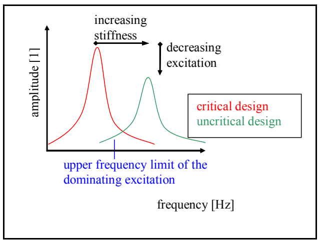



Figure 2: overcritical design of exhaust parts

This can be reached e.g. by:

- Curvature
- Number and position of the baffles
- Connection of the baffle and shell
- Wall thickness

More about the dominating excitation and the movements of exhaust components can be found e.g. in [1], [2].

### Bead pattern optimizer

If the designed exhaust component is fixed in most directions the topography is tuned. Bead pattern is placed onto the structure to increase the stiffness. Tenneco Automotive uses simple geometric forms like circles or rectangles, which are placed in an irregular way over the surface. Optimization tools like OptiStruct® by Altair Engineering® or TOSCA® by FE-Design can give an imagination of the design and where to place them [4]. Typical applications are shown in the following:

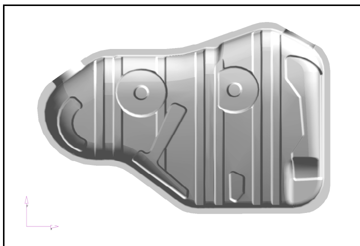


Figure 3: PSA D2X6

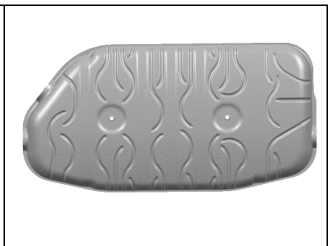


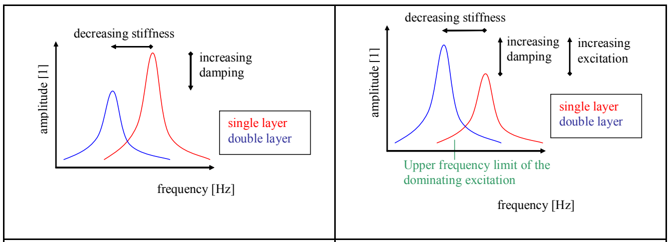
Figure 4: Volvo C1

Frequency shifts are possible from 50 Hz up to 300 Hz and more depending from basic stiffness and free design area.

## Damping by laminated sheets

Over 30 years ago mufflers started to be designed with laminated sheets. The inner sheet is made of stainless steel based on fatigue reasons; the outer sheet is made of aluminized sheets based on costs. Increasing fatigue and optical reasons lead to stainless steel also on the outside.

The disadvantage is a lower eigenfrequency of the laminated part compared to single layered of same thickness. This effect is regularly compensated by higher structural damping from friction between the different layers [1]. A reduction of the overall level up to 4-5 dB is possible (Figure 5a), if the excitation is comparable at the dominating first eigenfrequencies:




| a) same excitation | b) different excitation |
|---|---|

Figure 5: influence of laminated sheets to the eigenfrequency and the amplitude

But: If the use of laminated sheets causes a shift into the dominating excitation range, they can show even higher level than single layered ones (Figure 5b).
Modern exhaust systems use more and more welding techniques, where the technique of double layered sheet is restricted. Laminated sheets explode with the vaporization of leavings from oil which is used for forming between the different layers. Welding seams are sometimes not going through all layers. These and other manufacturing and also costs reasons are advantageously for single layered sheets.
Other components of an exhaust system, e.g. manifolds, are generally single layered or air gap insulated, that means two sheets with an air gap between. Thermal and thermo-mechanical boundary conditions require special acoustical solutions in the manifold region.
New methods of reducing the radiated noise are developed for that. Former designs have neglected that damping is only required, where the main movement takes place. The laminated area can than be often smaller than 10 % of the whole surface. For simple, rounded structures a thin metal ring over a round muffler or catalytic converter [3] had been in use in the past. More flexible is a small and thin metal sheet over the main radiating area. The contact can be reached by point welding, gluing or shrinking. The physical phenomena are damping and insulation. In both cases, it is positive to place the damping element based on the position of the highest movement, which is typically the first mode for exhaust muffler. The area of high amplitudes can be investigated analytically by CAE [1] or experimentally. Figure 6 shows a solution for a manifold with the same wall thickness like the basic part:

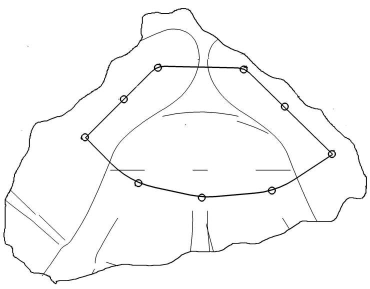


Figure 6: Innovative acoustical solution: surface damping element [5]

The reduction of the radiated noise for the first mode is in average 10 dB and more:

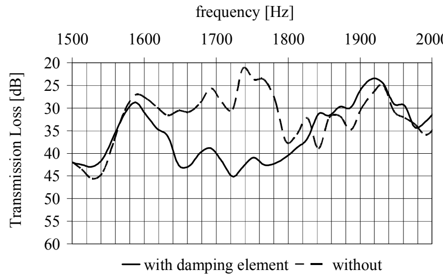



Figure 7: comparison with / without damping element

A thin lamination can already be used as a damping element. The physical phenomenon of damping is than applied. Increasing wall thickness of the lamination increases additionally the insulation. It follows the law of mass insulation, where the radiation can be decreased with 6 dB by double the basic wall thickness.
In these days, a simple metal sheet is in use, which follows the basic structure in form. Variations like micro-perforated metal sheets and the use of other materials are possibly. Layers between the damping element and the basic part will be tested to increase damping and insulation.
This technique can be used for the whole exhaust system, including manifold and tubes. The advantage is given in increasing damping and insulation with less influence to the eigenfrequency of the basic part. The thermal stability of the system remains and the influence to the design space is small [5].

# Conclusions

New demands given, e.g. by increasing steel prices and decreasing design space in the under body of cars, forces changes in the designs of exhaust systems. Therefore new products to increase the acoustical acceptance of exhaust lines are presented, which influence the designs of exhaust systems in the next years. Wall thickness reduction becomes possible and also the replacement of laminated sheets by partial laminated sheets or by single layered ones.

# References

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