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IDENTIFICATION OF THE DAMPING PROVIDED BY A FOAM PLACED ON A METAL PLATE BY AN INVERSE VIBRATION PROBLEM

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ABSTRACT

The reduction of vibration and acoustic levels of structures generally results in solutions with mass addition, which is a problem for products in the transport industry. Some solutions are sometimes studied for only one physical behaviour. This is the case of porous materials that are generally used for thermal insulation and/or sound absorption only. The purpose of this study is to better understand, or even control, the dissipation phenomena on the vibration of structures when porous materials are inserted on them. To experimentally identify the damping added by the foam on a steel structure, a specific test bench is created. It consists of a foam-plate structure where the displacement field of the plate is measured thanks to a scanning laser vibrometer. An inverse method is used to determine locally the structural parameters. The Force Analysis Technique (FAT) and the Corrected Force Analysis Technique (CFAT) are here proposed to determine these structural parameters, such as the equivalent elastic modulus and the loss factor of the assembly. The structure's damping is mainly caused by dissipation: dissipation in the foam skeleton, friction at the interface, viscothermic effects in the cell arrangements. Characterizations of materials properties and finite element models are implemented to understand the influence of these different causes, depending of the foam and the type of contact at the interface.

1. INTRODUCTION

Reduce the environmental impact of vehicles is an issue for the OEM's. In the last 10 years, new types of materials have been used to decrease vehicle's weights, like using soft visco-elastic foam to replace damping pads [1] or lightweight granular materials to damp structural vibration [2]. New structure are designed, like acoustic black hole to focus vibration in an area and use visco-elastic material to damp [3] and composite materials are created to replace carbon steel or cast iron used for the baseline materials [4]. With the emergence of electric motorizations increasing weight, vehicle's lightning has become a necessity / has become a point of concern for car manufacturer. One possible solution could be found in the optimization of NVH comfort. To limit panels vibration, bitumen pads

or viscoelastic treatments are used, as well as absorbing foams to reduce acoustic propagation. Previous studies show that some foam trim used for acoustic absorption, can damp the vibration panels.

A measure bench is created to measure the displacement field on a foam-steel plate structure, with a 1D vibrometer, allowing to estimate the global damping added by the foam. Force Analysis Technique (FAT) [5] [6] and the Corrected Force Analysis Technique (CFAT) [7] [8], are combined to calculate the global stiffness and damping of structure, the displacement field only. Different thickness of foam are tested to observe the influence on the foam damping.

2. THE INVERSE METHOD THEORY

The inverse method is based on the motion equation of a plate

$$D \left(\frac{\partial^4 w}{\partial x^4} + \frac{\partial^4 w}{\partial y^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} \right) - \rho h \omega^2 w = F(x, y, \omega), \quad (1)$$

where D is the bending stiffness, ρ the density, h the thickness, ω the angular frequency, $w(x, y)$ the transverse displacement field and $F(x, y, \omega)$ the distribution of the external forces exerted on the plate. The flexural rigidity

$$D = \frac{E(1 + j\eta)h^3}{12(1 - \nu^2)}, \quad (2)$$

introduces the Poisson coefficient ν and the complex Young's modulus $E(1 + j\eta)$ with η the loss factor, which is the damping factor of the system. The equation of motion (1) is local, since it is valid at any point of the structures and independent of the boundary conditions. Considering an area where no force is applied, the (1) becomes

$$\frac{D}{\rho h} \left(\frac{\partial^4 w}{\partial x^4} + \frac{\partial^4 w}{\partial y^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} \right) = \omega^2 w. \quad (3)$$

The CFAT method regularizes the inverse resolution using the natural filter of discretization by finite differences in the motion equation. This method consists in introducing correction coefficients into the motion equation, in order to benefit from the filtering effect of the finite difference schemes while correcting the bias it introduces into

the inverse resolution. The advantage of the CFAT method is the automatic regularization done during the inverse resolution. It is not necessary to calibrate a regularization parameter, unlike the FAT method. However, the method is not suitable at low frequencies, where the filtering effect of the finite difference schemes is not efficient enough to avoid noise amplification. To identify the characteristics of the plate over the entire frequency range, the FAT method is combined to the CFAT in the low frequency range.

The FAT method is used to regularize errors due to noise using a low-pass filter in wavenumber. First, it is necessary to window the vibration field to remove discontinuities at the limits and avoid unwanted effects of the filter near boundaries (Gibbs phenomenon). This is done using a 2D Tukey window also known as the cosine-tapered window. The filter, which removes high wavenumber components, is weighted by a Hanning window to keep the local aspect of the method. This filter eliminates the amplification of errors associated with the inverse problem.

In our case, the combination of the FAT method with the CFAT method avoids using a regularization parameter.

3. EXPERIMENTAL VALIDATION

The global damping of the foam-plate structure is studied. This damping considers the friction damping, the viscoelastic and the skeleton damping of the foam. The measurement is made on a structure composed of a steel plate (500x400x1 mm) suspended at the four ends by cables, to approach free boundary conditions and a foam plate (400x300 mm) simply placed on top of the plate. A scanning laser vibrometer is used to measure the displacement field in the area of interest (400x300 mm). The vibrometer is located 132 cm below the steel plate. The excitation is a pseudo-random signal applied using a mini-shaker with an amplitude of 2 N and repeated 6 times for each measurement point. The mini-shaker is placed outside the measurement area. Fig. 1 shows a schematic of the experimental set-up.

Fig. 2 shows the stiffness (normalized by the surface density) and the loss factor identified by the inverse method in 3 different configurations.

Two thicknesses of foam are tested, 11 mm and 8 mm, to study the impact of the weight and the thickness on the loss factor. The stiffness is equivalent for all tests, the weight of the foam having no significant influence on it. However, the loss factor increases for the foam, between 300 – 500 Hz for the two thicknesses, compared to the bare plate. The thickness influences the damping, this might be due to the viscothermal interaction, the skeleton in the foam, or the weight of the foam. At high frequency the foam has no effect on the result, the stiffness and the loss factor being equal for all measurements.

4. CONCLUSIONS

The FAT and CFAT are applied to calculate the global stiffness and damping of a foam-steel plate structure. The combination of this two methods increases the frequency band-

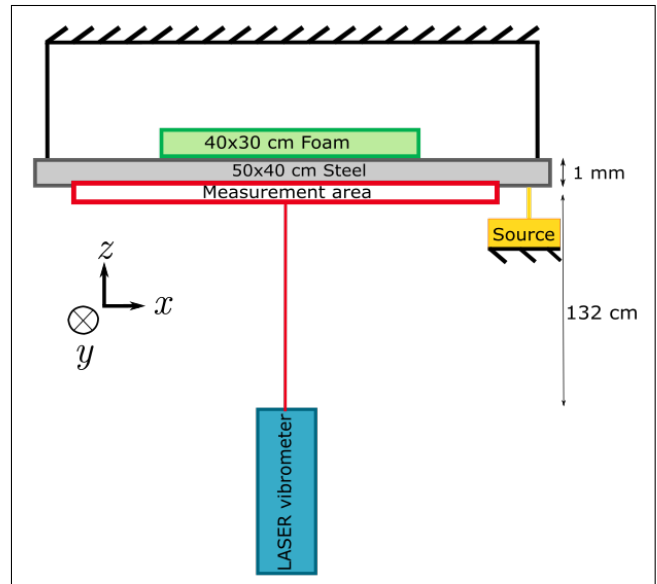


Figure 1. Experimental set-up used to measure the displacement field of the foam steel plate.

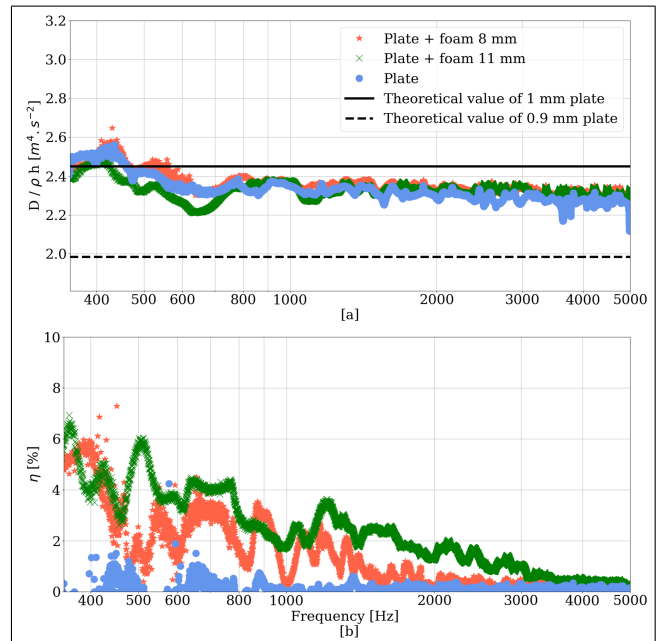


Figure 2. Parallel between measurement with and without foam on the plate depending on frequency with the stiffness (D) divided by the density (ρ) and the thickness (h) of the global structure [a] and loss factor (η) [b]

width of the inverse method. The low cut-off frequency is due to the experimental area measured by the 1D vibrometer and the high cut-off frequency is limited by the CFAT method. With additional calculation, it is possible to differentiate the part of the damping due to the skeleton or viscothermal effect of the foam. The complete interpretation of the damping allows to classify the physical mechanism, like contact damping or material damping.

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