EFFECTS OF POROUS ABSORBING MATERIAL ON THE COUPLING OF MODE SHAPES VIA THE MODAL DAMPING MATRIX OF A FLUID

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INTRODUCTION

In a modal formulation of the underlying equations of motion, the originally uncoupled and diagonal systems of equations are coupled via off-diagonal terms in the fluid-structure coupling matrix. In the presence of an absorption material inside the cavity, additional fluid mode coupling is introduced by a non-diagonal modal fluid damping matrix [1].

The structure of the modal fluid damping matrix reflects the geometric interaction between the fluid mode shapes. Typical patterns can be identified and correlated with the properties of the fluid modes.

This will be illustrated by two examples, each of them calculated using measured absorption data of acoustic trim material, which is typically used in the automotive industry.

THEORETICAL BACKGROUND

Generally, there is no explicit modelling of damping mechanisms for the determination of a damping matrix. Either proportional damping is applied or modal damping is chosen as a fraction of critical damping. Both approaches lead to diagonal modal damping matrices.

By the introduction of a new finite element for a porous absorber [2], it is possible to model the physical damping matrix explicitly. The resulting modal fluid damping matrices are generally non-diagonal.

The FE-model characterises a material not only by its normal impedance but also takes into account lateral effects by introducing a bulk reacting coefficient [3].

The modal fluid damping matrix can be written as:

$$D = \frac{1}{Z} \Phi_F{}^T \int_S N^T N dS \, \Phi_F - \frac{B}{Z} \Phi_F{}^T \int_S \nabla_S{}^T N \nabla_S N dS \, \Phi_F ,$$

with Z: normal impedance

B: bulk reacting coefficient
N: shape functions of the fluid finite elements
S: area of the absorber
Φ_F : undamped fluid modes

The damping matrix is divided in a normal and a bulk part. The structure of both parts of the damping matrix, reflecting the coupling between the modes, is determined only by the geometric properties of the mode shapes and the absorber location and does not depend on the values of Z and B.

This will be illustrated by two applications.

APPLICATION I: TUBE OF KUNDT

For a first application the tube of Kundt has been selected, because its one-dimensional structure allows an insight in the mechanisms of acoustic effects.

In the first example, a porous absorber is mounted to one end of the tube. Figure 1a shows the absolute value of the normal part of the fluid modal damping matrix, figure 1b the absolute value of the bulk part. In both parts, three regions can be identified with mode indices from 1 to 10, 11 to 34 and 34 to 60.

These regions correspond with the nature of the fluid mode shapes: The first ten modes are purely longitudinal, the 11th mode is the first lateral mode with one nodal plane and the 35th mode is the first lateral mode with two nodal planes.

An investigation of the mode shapes with high coupling contributions leads to an explanation of the characteristic structures of the modal fluid damping matrix:

The coupling between fluid modes via a porous absorber will be the more intensive the more the topologies of the mode shapes match each other at the area of the absorber. A longitudinal mode, which has a uniform pressure distribution over the whole absorbing

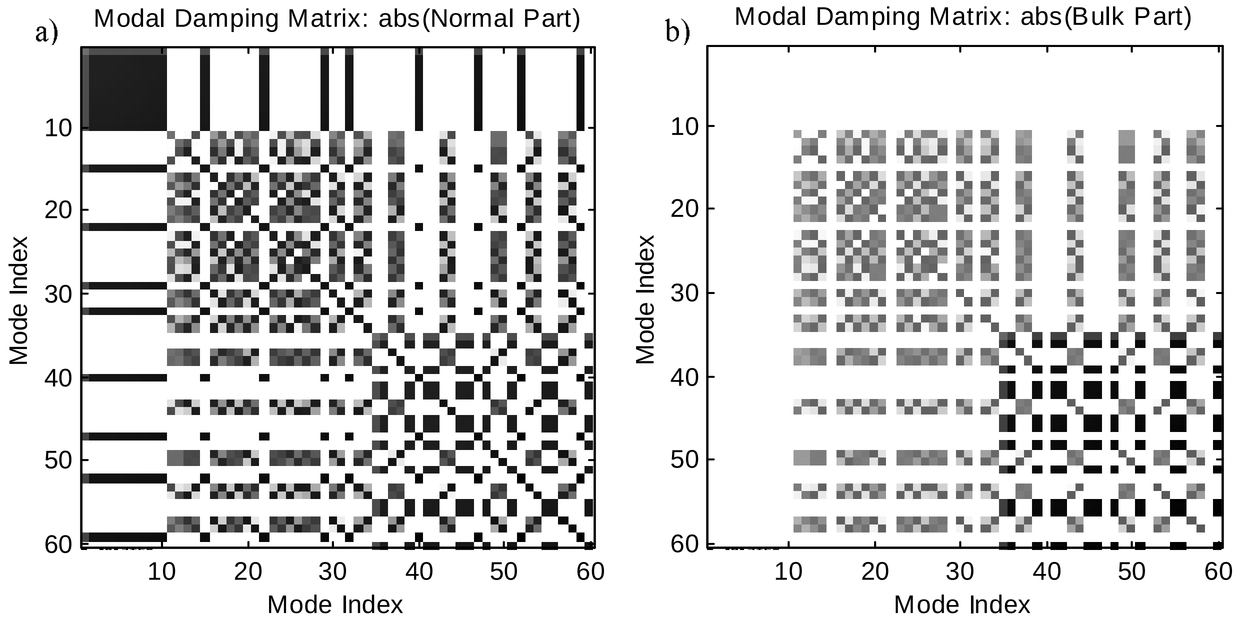
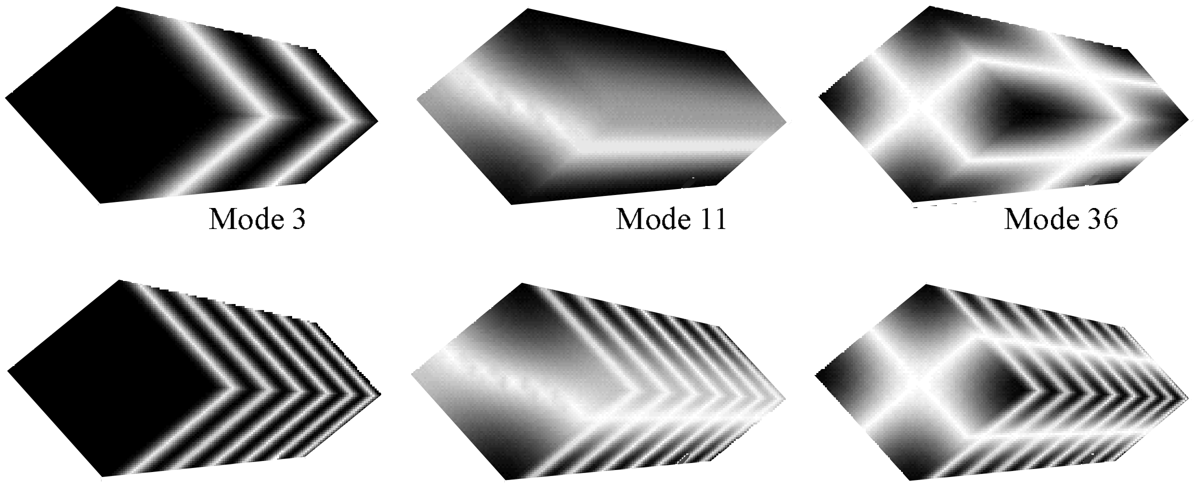


Fig. 1: a) absolute value of the modal fluid damping matrix (Normal Part)
b) absolute value of the modal fluid damping matrix (Bulk Part)



Mode 3 Mode 11 Mode 36

Mode 7 Mode 27 Mode 51

Fig. 2: Pairs of fluid modes with similar pressure distribution across the absorber area (applied to the square in the foreground)

area, only couples to a longitudinal mode, a diagonal mode only to a diagonal mode and so on.

Figure 2 shows three examples of pairs of mode shapes, which exhibit high coupling contributions. One can see, that indeed these mode pairs look the same at the end of the tube.

The bulk part of the modal damping matrix shows basically the same structure as the normal part, but with one difference: The strength of the coupling via the bulk damping mechanism is depending on the gradient of the pressure across the absorber. For the longitudinal modes, there is no pressure gradient along the absorber, therefore the bulk part for these modes is zero. There is a contribution for the diagonal modes and an even greater contribution for the modes with two nodal planes, where the gradient of the

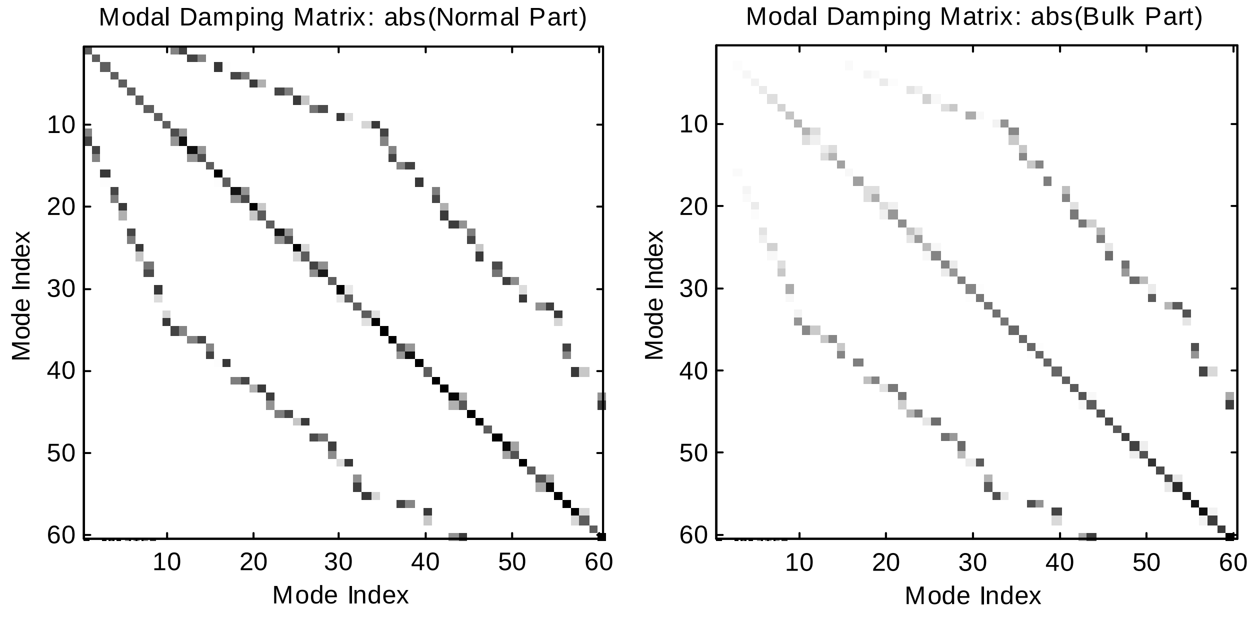


Fig. 3: a) absolute value of the modal fluid damping matrix (Normal Part)
b) absolute value of the modal fluid damping matrix (Bulk Part)

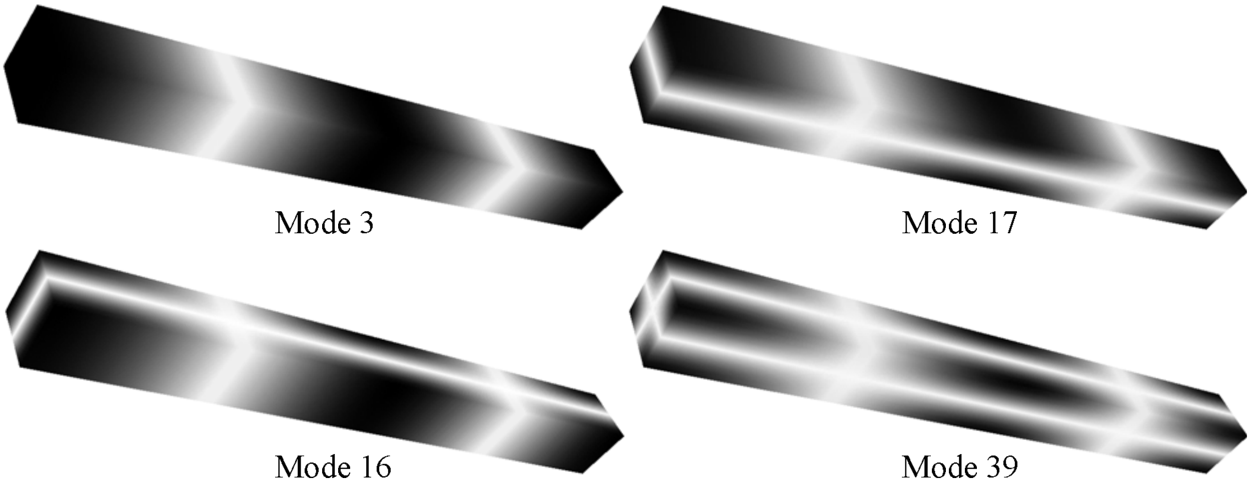

Mode 3
Mode 17
Mode 16
Mode 39

Fig. 4: Pairs of fluid modes with similar pressure distribution across the absorber area (applied to the long side in the foreground)

pressure along the absorber also is higher.

In the second example, the same porous absorbing material is mounted along one long side of the tube. The two parts of the modal damping matrix in figure 3 show a completely different structure than in the first example, but underlie the same mechanisms. Those modes will couple, which have a similar pressure distribution across the area of the absorber. In this example, there is a smaller number of mode shapes that fulfil this condition.

Two pairs of modes with a high contribution in the normal part of the modal damping matrix are shown in figure 4.

In this configuration, the bulk part continuously increases, because even for the lowest coupling modes there is a pressure gradient along the long side of the tube.

In figure 5 the mode participation is shown for an excitation at one end of the tube.

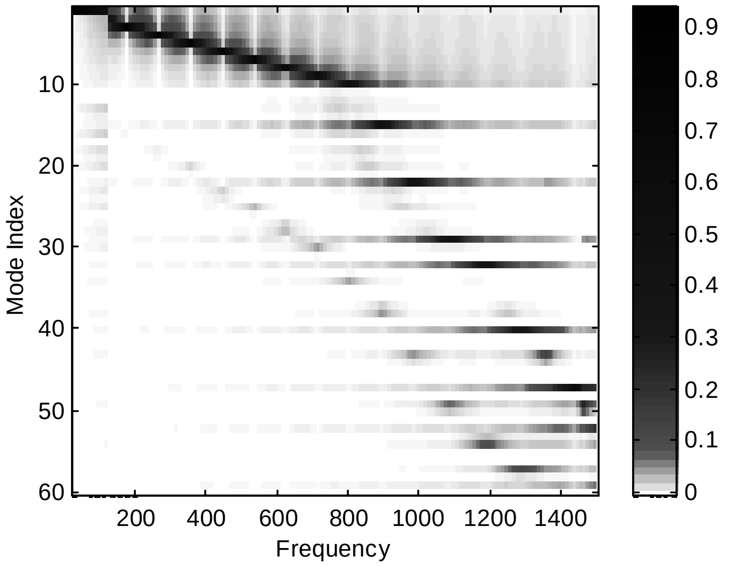


Fig. 5: Mode participation in presence of a porous absorber applied to a long side of the tube of Kundt

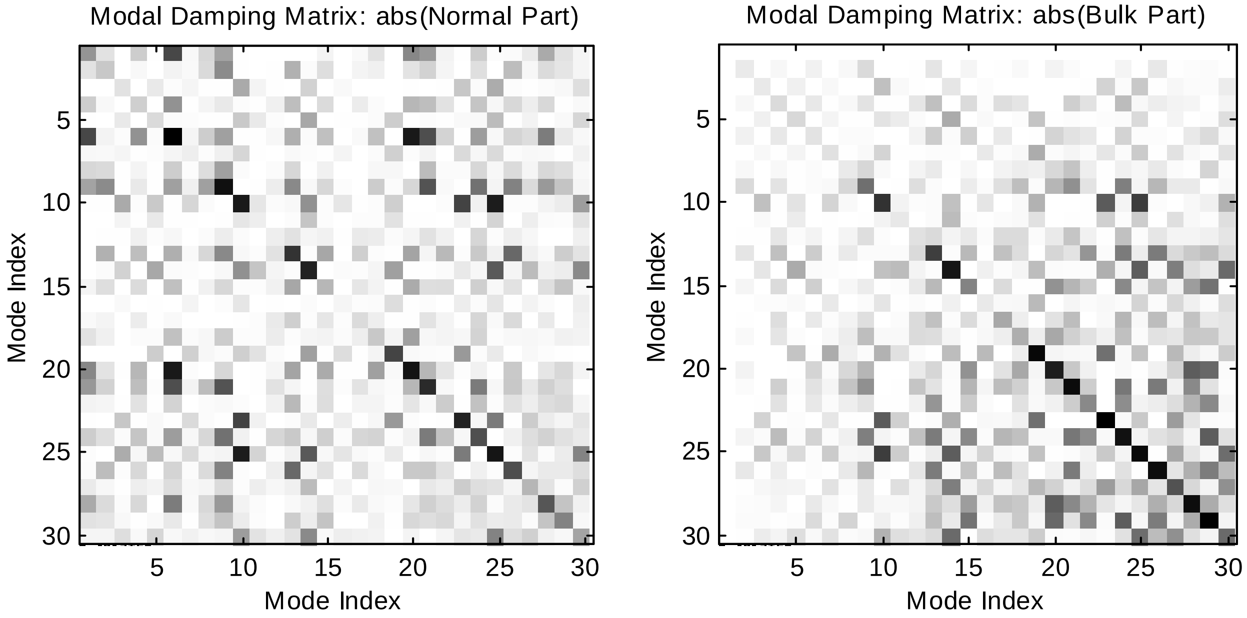


Fig. 6: a) absolute value of the modal fluid damping matrix (Normal Part)
b) absolute value of the modal fluid damping matrix (Bulk Part)

The effect of mode coupling via the modal damping matrix is clearly visible: Additional higher modes are excited during operation.

APPLICATION II: CAR INTERIOR

The second application is the fluid FE-Model of a car interior. A damping pad is attached to the roof of the car.

In figure 6 again the absolute values of the normal and the bulk part of the fluid modal damping matrix are shown. In this real life application the modal damping matrix does not show so striking patterns like in the case of the tube of Kundt. Nevertheless a comparison of two mode shapes with a high contribution to the modal damping matrix (figure 7) shows, that for this car model the coupling mechanism is the same as in the first application.