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Simulation of vibro-acoustic response by Fast BEM and FEM coupling

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Acoustic fluid-structure interaction is a common issue in various engineering applications. The vibro-acoustic behaviour of a structure surrounding or surrounded by a fluid hereby represents a multi-field problem. This contribution explains several phenomena of acoustic fluid-structure interaction and shows how to efficiently model and simulate the two-field problem. In general, heavy fluids such as water, oil, fuel or brake fluid influence the structural field and vice versa. Moreover, strong coupling is observed if acoustic fluids interact with thin or slender structures. Important fluid-structure interaction phenomena in practical applications are for example a shift of natural frequencies, a change of wave number and fluid wave speed, pressure-induced vibrations and sound radiation. The mentioned phenomena are present in automotive and ship applications such as fluid-filled brake/fuel pipes, exhaust systems or partly immersed ship hulls. To predict the hydro- and vibro-acoustic behaviour of these industrial examples, the finite element and the boundary element method are applied using models including full coupling of the two-field problem.

In general, two types of structure-acoustic problems can be distinguished. The interior acoustic problem is characterized by an acoustic fluid which is surrounded by a flexible structure. A typical exterior acoustic problem is the sound radiation of vibrating structures in the exterior acoustic field. It is particularly important to account for flexural vibrations, which are predominantly responsible for noise, vibration and harshness (NVH). Simulation methods for both problems are briefly described in the following.

The finite element method (FEM) is considered as the appropriate discretisation method to investigate the dynamics of the interior vibro-acoustic problem since only a finite volume has to be discretised. However, large-scale examples require model reduction techniques to accelerate the computation times. The application of the Craig-Bampton method to the vibro-acoustic problem including an additional reduction of the remaining interface degrees of freedom leads to a considerable model reduction. Dynamic substructuring techniques [5] are particularly efficient for systems with repeating substructures, since the corresponding component system matrices and the reduction basis has to be computed only once. The simulation technique is applied to fluid-filled automotive piping systems.

The boundary element method (BEM) is well-suited for the solution of exterior acoustic problems since the Sommerfeld radiation condition is intrinsically fulfilled. Another advantage of the BEM is that only the boundary of the structure has to be discretised, which reduces the effort of mesh generation. To overcome the drawback of high memory consumption due to fully populated system matrices, fast BE methods are used, such as the fast multilevel multipole BEM [2] as well as the concept of hierarchical matrices. FE-BE coupling schemes [1],[3] are developed for ship applications, where the ship hull is influenced by the surrounding water and vice versa. Due to the large fluid-structure interface, the reduction of interface degrees of freedom is an important step to obtain moderate computation times [4].

Fast BE methods are also used to compute the sound radiation of automotive structures such as a rear muffler of an exhaust system. Here, both an interior and an exterior acoustic problem have to be solved. The feedback of the exterior acoustic pressure on the vibrating structure may be neglected as long as the impedance mismatch between the two fields is large enough (e.g. stiffened structures surrounded by air).

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