When Is It Worth Using Design Exploration in Practice?

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Abstract

The early design phase of technical products is marked by many inherent uncertainties such as loads, geometric parameters and material properties. For a better classification of the influence of the input parameters on the system response behaviour, numerical experiments can be used to find a more convenient design. This is particularly important in the case of a non-linear relationship between input and output variables.

As the number of input variables increases, the number of possible parameter combinations increases exponentially. A prominent example are laminates in which the layer thicknesses and ply angles can be varied. In practice, there are often requirements, such as symmetry, discrete values for angles and layer thicknesses and a balanced layer structure. Although these limitations reduce the dimension of the design space, there are still too many variation possibilities that require the use of special methods such as Latin Hypercube.

This article aims to show applications in which the use of DOE methods can be useful. These can be tasks in which optimization methods cannot be used because target functions or constraints are not available or derivatives according to design variables do not exist, e.g. non-smooth behaviour in contact problems, eigenvalue and eigenvector derivatives in case of multiple eigenvalues. The collected result data of the sampling procedure can be used to generate response surfaces that allow subsequent optimization. Moreover, the importance of the input variables can be analyzed and judged. At the end of a DOE, a deeper insight in the behaviour of the underlying system is usually available.

Various applications from the fields of acoustics (transmission loss), contact and dynamics (stability of a brake system), buckling of structures and composite materials (laminates) are intended to underpin the meaningful use of DOEs. The structure of the DOE model with regard to the necessary data input is supported by its own wizard within VisPER. All computations are carried out in PERMAS, whereas postprocessing is done in VisPER. Additional evaluations such as response surfaces are conducted using Python scripts. PERMAS specific keywords are denoted by capital letters and a preceding dollar sign in the subsequent text.

1. Introduction

The reduction of noise emissions is an important factor in the design of silencers. Reactive mufflers are based on the reflection of sound from suitable geometrical shapes and resonators, whereas dissipative silencers attenuate sound by absorbing materials such as wool and foams. Both types have been extensively investigated [13,14,18]. Active noise techniques permit a high reduction of observer perceived noise. However, this kind of control struggles with other issues like cost and reliability [15].

Recently, some progress has been made in optimization techniques for acoustic problems. Azevedo [2] proposed an acoustic muffler design procedure based on finite element models and a bi-directional evolutionary acoustic topology optimization. Lee [7] used an acoustical topology optimization to maximize the transmission loss at target frequencies by optimizing partition layouts inside a muffler chamber. Airaksinen [1] considered a multi-objective shape optimization of acoustic mufflers. The shape parameters of the muffler were varied to maximize the transmission loss at two frequency ranges simultaneously. Yeh [17] used simulated annealing and a genetic algorithm to find the optimal design of a double chamber muffler.

If the objective function is smooth and gradient information is reliable, then gradient based optimization algorithms present an extremely powerful collection of tools for solving the problem [3]. The shape optimization of a highspeed energy storage flywheel is considered in [8]. In [9] an axial compressor blade subjected to pressure loads is optimized with respect to the maximum equivalent stress. If gradient information is unavailable, unreliable or difficult to compute, one might use a design exploration. This approach is pursued here. PERMAS [20] offers a so-called SAMPLING procedure (i.e. DOE process) for this purpose. It is a repeated analysis with modified discrete values for all design variables. One possible application of SAMPLING is the improvement and validation of parts and assemblies by targeted parameter variation. Different kind of parameters, e.g. node coordinates as in shape and position optimization, element properties and material parameters as in parameter optimization and even applied loads are accessible in SAMPLING. Metamodeling techniques [6,10,15,18] are used in to find the optimal design of a stiffened plate [4]. Here, we focus on an application from acoustics.

2. Acoustics

The acoustic field in a rigid-wall chamber is obtained by solution of the homogeneous 3-D Helmholtz equation in Cartesian coordinates given by

$$(\nabla^2 + k^2)\, p = 0, \qquad \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\,,$$

where $p=p(x, y, z)$ represents the acoustic pressure field, $k = \omega/c_0$ is the excitation wavenumber and c_0 denotes the speed of sound. In this work the muffler model will use three different boundary conditions, rigid wall condition, imposed particle velocity and imposed impedance, respectively.

3. Examples

The first example is taken from [13]. The finite element model is depicted in Fig. 2. The model consists of two disconnected parts. 158024 FLTET4 elements are used for the fluid mesh. So-called FSINTA elements are used to impose the harmonic excitation at the inlet. Enquist Majda elements (RBCEM1A3) elements are used for the anechoic boundary condition at the outer surface of the outlet. The outlet itself can be moved along the surface of the chamber in global x- and y-direction by a rigid-body movement. Fig. 1 illustrates two different positions of the outlet – one position is displayed transparently. A possible mesh distortion during mesh morphing is avoided by independent meshes for the chamber and outlet, respectively.

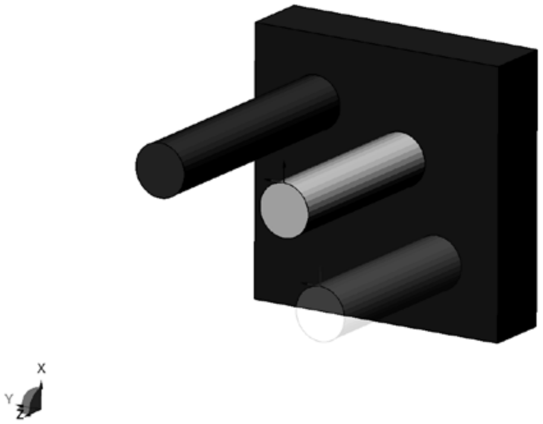

Figure 1: Two different positions of the outlet

The coupling of the pressure degrees of freedom between the outlet and chamber is achieved by incompatible multipoint constraints ($MPC ISURFACE DPDOFS = 1 DOFTYPE = PRES). The shape basis vectors are illustrated by blue and red arrows in Fig. 2. In contrast, a conventional variant analysis would require the time-consuming creation of a new CAD model and subsequently a re-meshing of the underlying geometry. But this also means an increased effort in data management. At this point we benefit from the shape and position optimization fully integrated in PERMAS. Thus, we need one single finite element model to realize the different positions of the inlet/outlet relative to the chamber.

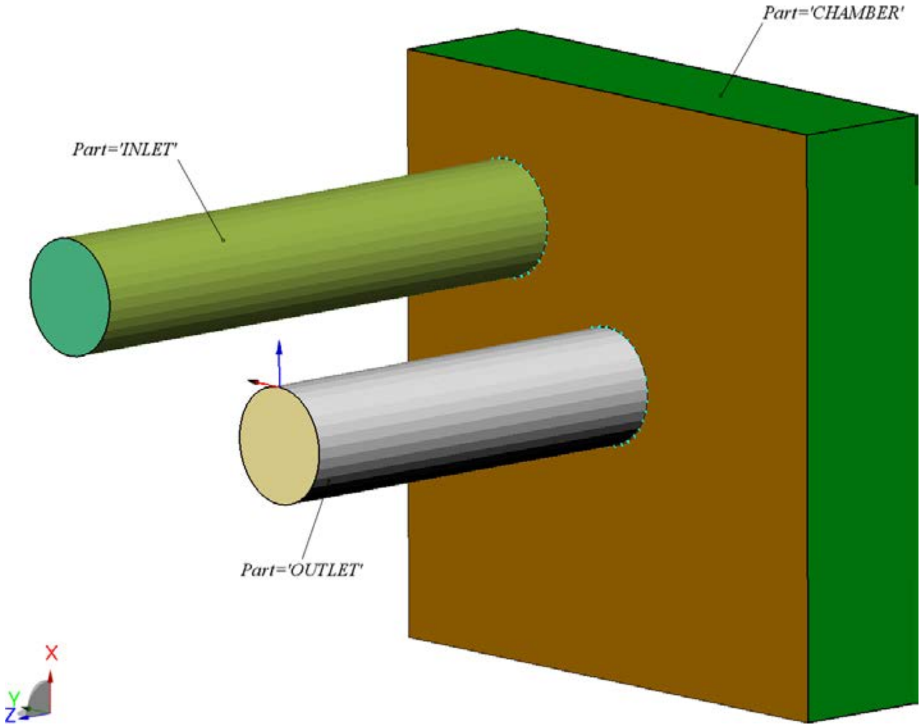

Figure 2: Finite element model of the rectangular expansion chamber

Fig. 3 illustrates the transmission loss for six different positions of the outlet. A regular grid [-20,0] x [-20,0] is used for the position changes with an increment of 10 [mm] in *x*- and *y*-direction. It can be clearly seen that the changes in position affect both the position and height of the peaks as well as the number of peaks in a certain frequency interval. This helps to find suitable geometries in a design-driven development process at an early stage.

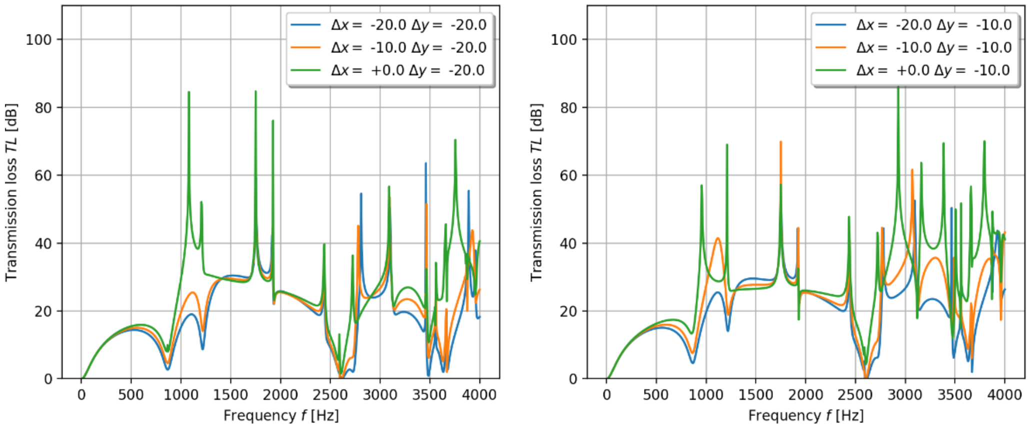

Figure 3: Transmission loss of different positions of inlet/outlet

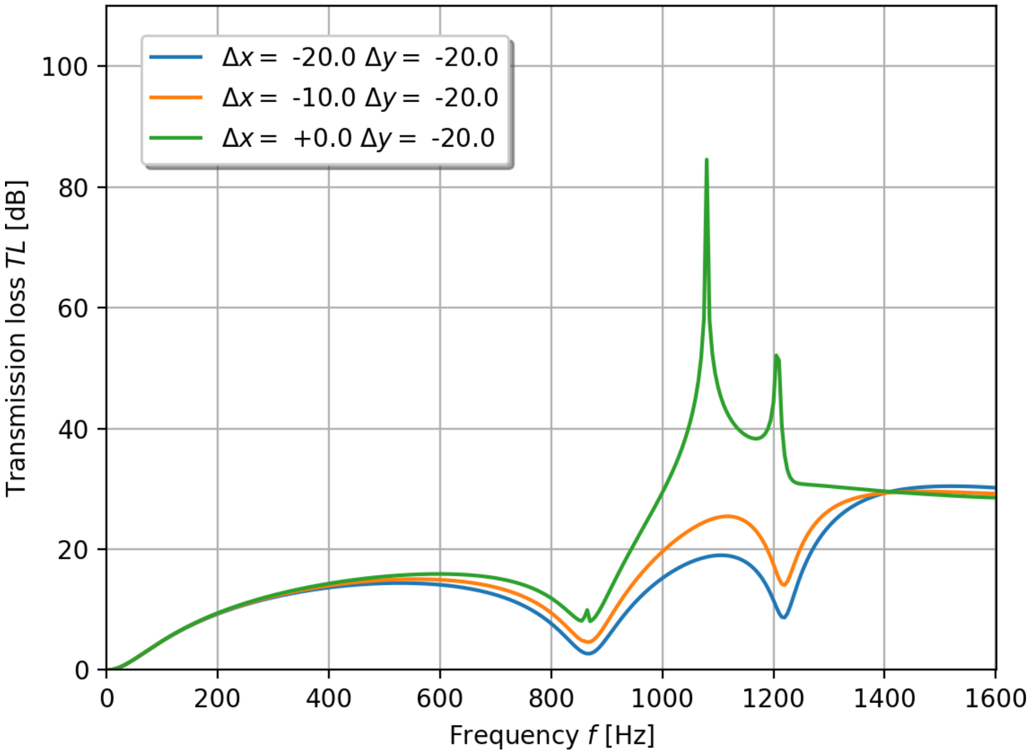

Figure 4: Transmission loss in the frequency range [0,1600] Hz

The goal of the sampling procedure is to detect a configuration where the transmission loss in a certain frequency range, e.g. [0, 1400] Hz is larger compared to all other configurations, (i.e. the configuration corresponding to Δx=0, Δy = -20 mm) in Fig. 4 is the best candidate.

The second example (Fig. 5) is taken from [12]. The goal is to study the influence of the horizontal position of the baffle on the transmission loss. The Shape Wizard in VisPER [21] is used to setup the mesh morphing. Additional restraints such as $DERESTRAINT BOUND and $DESYMM TYPE = AXI are needed to ensure that the outer contour of the muffler is not altered. The configuration for Δx = 20 [mm] is depicted in Fig. 6. Symmetry of the transmission loss for negative and positive coordinate modifications x ± Δx can be observed (Fig. 7).

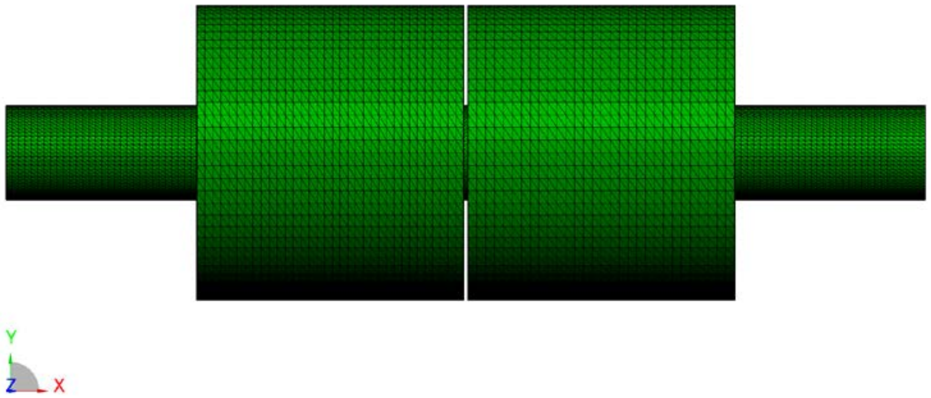

Figure 5: Finite element model of the muffler

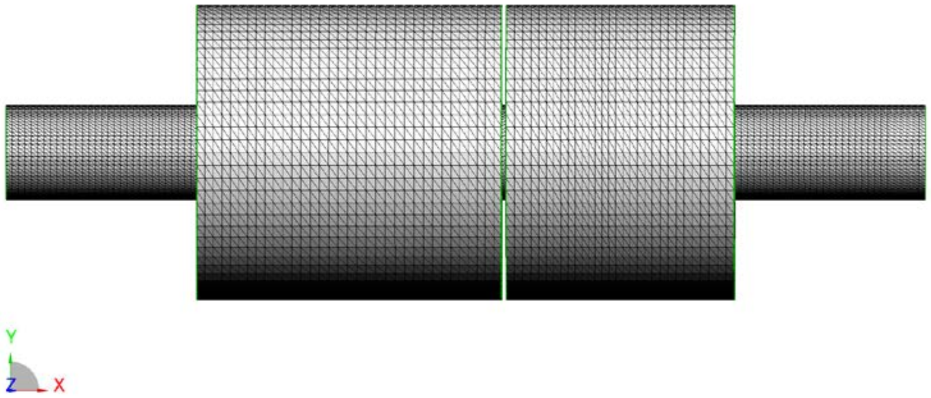

Figure 6: Modified shape of the muffler $\Delta x = 20$ [mm]

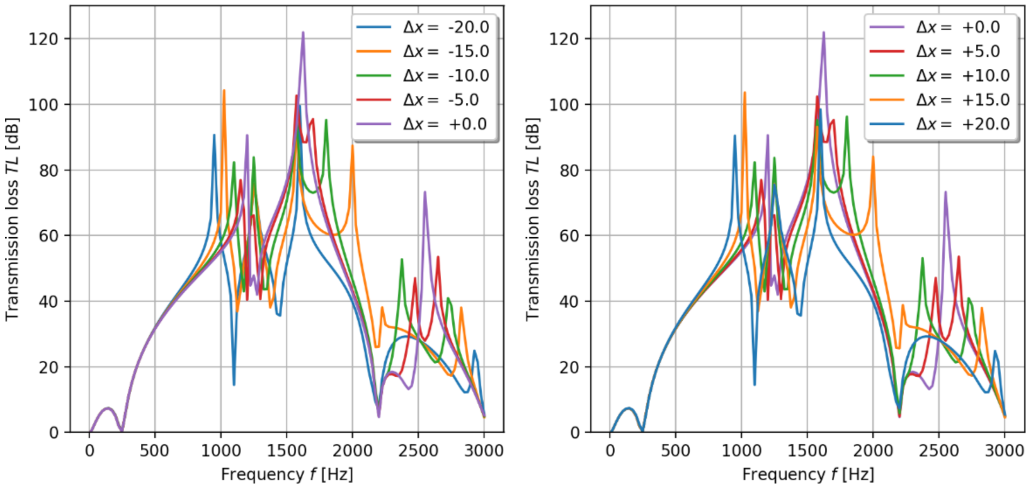

Figure 7: Transmission loss for different configurations of the baffle position

4. Summary and Outlook

A sampling procedure is suggested to accelerate the design driven design of silencers with respect to the optimal transmission loss in a certain frequency range. Shape modifications of the silencers are easily introduced by the optimization capabilities of PERMAS. Thus, only a single finite element model is sufficient to conduct the DOE. The comparability of the results is ensured by the identical topology of the model, which is usually not the case with a new mesh. Time consuming and cost-intensive remeshing is avoided. This also reduces the effort required for data storage of model variants. Further application examples will be provided during the conference.

5. References

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