

# A New Approach for Vibro-Acoustic Optimization Using Discrete and Continuous Shape Variables Applied to a Car Body

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**Abstract** The vehicle development process demands quick evaluation of new designs. CAE and CAD tools are essential in order to perform these assessments in a very narrow time frame. New design variants with desired criteria should be quickly created and analyzed. Geometry based topology and shape optimization can accelerate such a process when changes in body structure are automatically updated. FE mesh generation during topology and shape optimization runs should not require any kind of user intervention. The above mentioned requirements are fulfilled by *SFE CONCEPT<sup>TM</sup>*. This paper describes the feasibility of a vehicle development process where geometry modifications lead to a reduction for the interior noise of a full-trimmed car body model. In order to demonstrate this, a vibro-acoustic optimization is carried out for types of bead patterns in the BIW.

**Keywords** Acoustics · Optimization · Parametric design · Bead pattern · Discrete design variables

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F2012-E03-059

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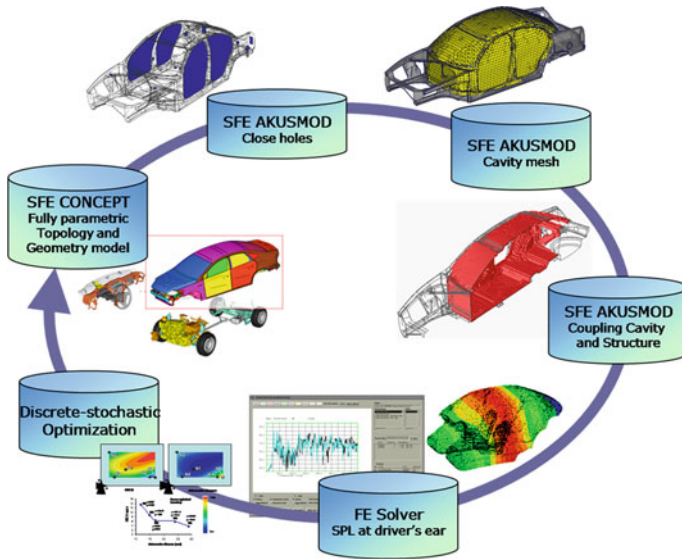


Fig. 1 Vibro-acoustic optimization

## 1 Introduction

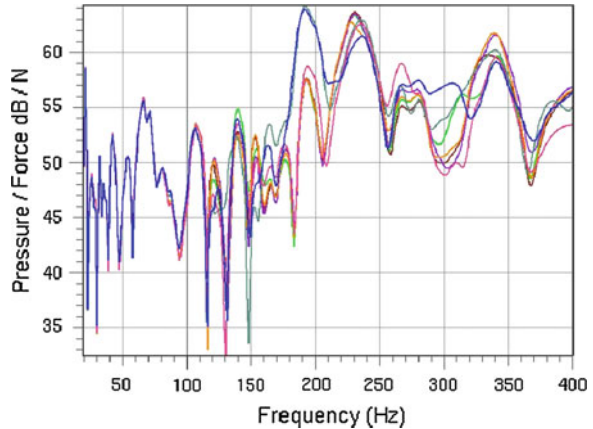
In the car body structure development process *SFE CONCEPT<sup>TM</sup>* [1–7] has become an efficient tool to accelerate the workflow. Figure 1 presents a process for a vibro-acoustic optimization of a full-trimmed car body, including an implicitly parameterized geometry generation using *SFE CONCEPT<sup>TM</sup>* [8], an acoustic analysis using *SFE AKUSMOD* [9, 10] and a new discrete-stochastic implemented optimization algorithm. [7].

Based on the design variable definition on implicitly parameterized geometry model the optimization algorithm modifies the topology and shape using standard ASCII interfaces in *SFE CONCEPT<sup>TM</sup>*. These interfaces include two different kinds of design variables. The first group of design variables are discrete ones like topology changes. The second group are continuous design variables used in well known shape optimization. The parametrical structure allows an automatic consideration of both types in an optimization loop.

After modifying the geometry, the FE-representation of the car body structure is generated. The FE mesh includes all connector elements such as spot welds, laser seams and adhesives. During the optimization loop FE meshes with connections like welds and adhesives and fulfilling the solver quality criteria are generated by a built-in finite element mesh generator in *SFE CONCEPT<sup>TM</sup>*.

*SFE AKUSMOD* provides the data files for an execution of the vibro-acoustic analysis. The steps are closing the holes, generation of the cavity mesh and coupling the cavity mesh and the structure.

**Fig. 2** Two high peaks in frequency responses at driver's ear



The FE-solver calculates the Sound Pressure Level (SPL) at driver's ear for the objective function for the optimization method and a new value set of design variables is generated. Iterations involving automated geometry update, FE (structure) mesh generation, cavity mesh generation, coupling and analysis are done in a batch loop until the optimization criteria for objective and constraints are fulfilled.

## 2 Problem Identification

For a new car development a vibro-acoustic analysis is done in order to reduce the SPL at driver's ear. Particularly a reduction is required for two high peaks excited by one critical load case (Fig. 2).

The part of the structure responsible for the peaks was identified at the lower dash region (Figs. 3 and 4). The narrow distance between excitation point and the lower dash leads to a vibration dynamics characterized by enforced motion. The dynamic load is directly transferred to the lower dash via the relatively inflexible longitudinal rail. Changing the connection of the lower dash to the longitudinal rail or the dynamic stiffness of the dash has a relevant impact on the resonances of frequency response.

In former investigations parameters of the structure were changed manually. The results showed that a reduction is achieved either for the resonance at first peak frequency or for the second peak frequency. It was very difficult to get an improvement good for both resonances. A manual trial and error approach was too time consuming and didn't lead to a good design solution for the frequency range of interest. This required a smart optimization procedure to try out wide range of design parameters and find the rare combination of these parameters in an automated process which leads to the desired reduction in both resonances.

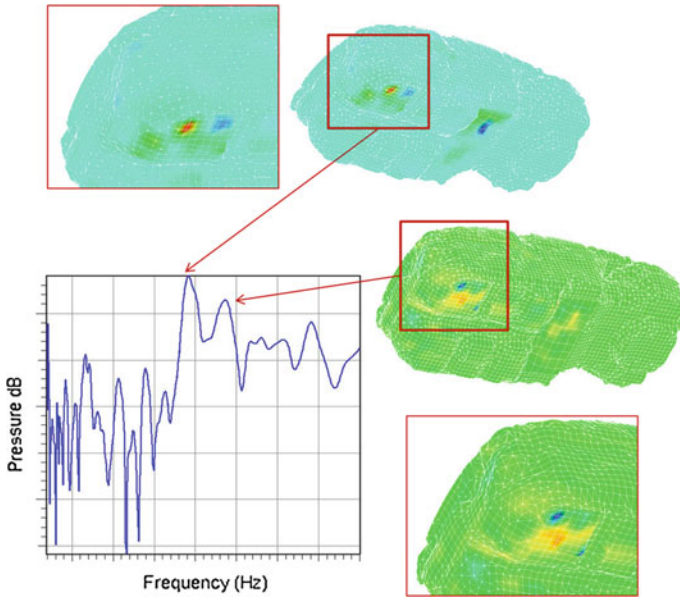


Fig. 3 Section of interest

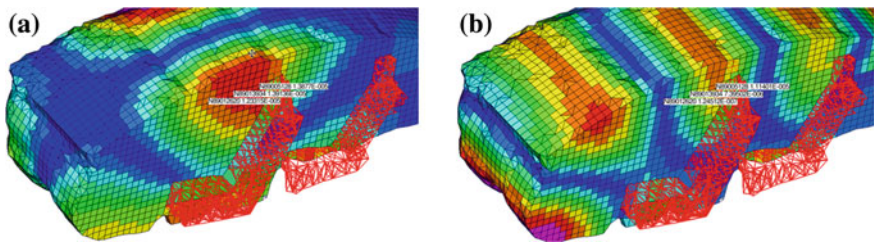


Fig. 4 Dominant fluid modes for the resonances at first peak (a) and second peak (b)

Preferred modifications were the type and location of bead patterns in the lower dash region. Considering the phase of vehicle development and cost involved these were the only allowable changes. A very new and unique approach described below was taken to solve the issue.

Due to higher computation time for the vibro-acoustic analysis the use of full trimmed car body model in the optimization loop is not desirable. The reduced model considers the excitation mechanism. While an influence of the other structure parts cannot be excluded the full trimmed model is used to validate promising results of the optimization.

### 3 Automated Generation of Structure Models

The original bead patterns are removed from the regions of interest and are replaced by the new bead patterns automatically. The model for the vibro-acoustic analysis is divided in a substructure (implicitly parameterized *SFE CONCEPT<sup>TM</sup>* model) providing the geometrical modifications and a substructure (carryover FE-mesh) unchanged during the optimization procedure. The geometry model is controlled by implicit geometrical parameters and is a FE-mesh with all bead patterns for the vibro-acoustic analysis is automatically generated. All this is done while maintaining and redefining connections (wherever necessary) between the FE-meshes of dash model and the carryover substructure. This is a fully automated procedure in *SFE CONCEPT<sup>TM</sup>*.

### 4 Vibro-Acoustic Analysis

*SFE CONCEPT<sup>TM</sup>* deals with parametric modifications of the structure part in the vibro-acoustic analysis. Besides the structure FE-mesh for the analysis in addition a cavity mesh is also required. An automated generation of such a cavity mesh is done by *SFE AKUSMOD*. While generating the cavity mesh cut outs are automatically closed and a fixed microphone position is considered.

In this investigation the volume mesh for the cavity including volume absorber for the seats is unchanged during optimization procedure. The participation features of *SFE AKUSMOD* identify important structure and fluid modes as well as dominating structure parts (panel or grid based). Figure 4 shows the fluid modes dominating the transfer function from excitation to SPL at driver's ear. These modes are characterized by high amplitudes simultaneous at driver's ear and in the lower dash region.

The cavity mesh needs to be coupled to the structure mesh. During optimization the cavity structure coupling needs to be done automatically for each geometric change in structure. For the calculation of the SPL at driver's ear the coupling is transferred via binary data file to the NASTRAN solver. *SFE AKUSMOD* provides the cavity and coupling data file in batch mode.

### 5 Optimization Procedure

Figure 5 shows the flowchart for the vibro-acoustic optimization. The procedure is driven by a integrated-function and combines the automated generation of structure model and the vibro-acoustic analysis. The FE-mesh of the lower dash for a given set of design variables is created by *SFE CONCEPT*. The auto-generated

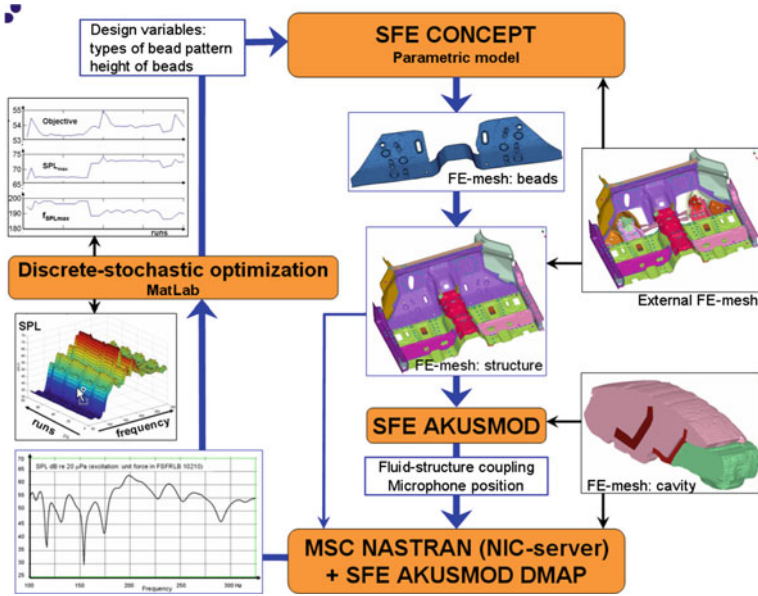


Fig. 5 Vibro-acoustic optimization loop

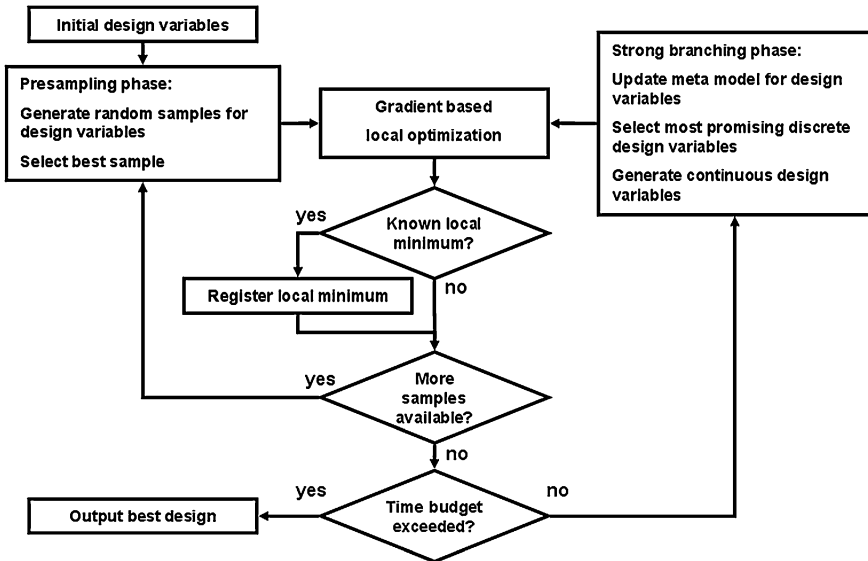


Fig. 6 Flow chart of discrete-stochastic optimization [7]

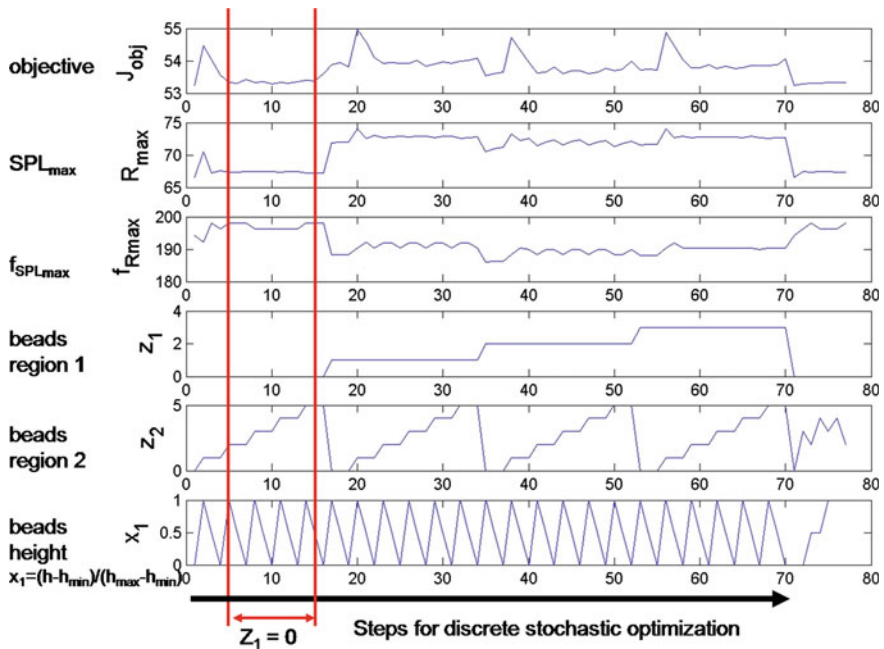


Fig. 7 History: objective, types of bead pattern in region 1 and 2 and bead height

FE-mesh and the constant part of the structure are combined to the structure model. Considering the external volume mesh for the cavity SFE AKUSMOD provides the fluid–structure definition for the FE-analysis. The FE-analysis calculates the frequency responses of the SPL at driver’s ear and provides these responses to the objective function of the optimization algorithm. In order to assess the optimization results in the user-defined frequency range frequency responses are stored for all optimization steps.

An overview of the optimization algorithm [7] is given in Fig. 6. The algorithm consists of a presampling and a strong branching phase. The presampling phase maintains a user-defined number of samples for the design variables. The algorithm evaluates the samples and starts from the best one a local, gradient-based optimization using a sequential nonlinear programming method with trust region globalization. After the provided samples are exhausted, new ones are created essentially randomly.

For the strong branching phase a meta model of the discrete designs is constructed. Based on the model, the discrete design with largest expected improvement is selected for starting the next local optimization, whereby the values for the continuous design are generated randomly.

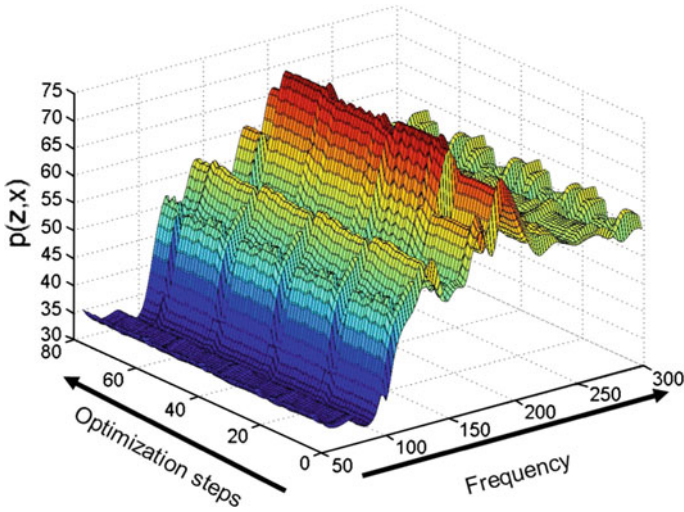


Fig. 8 History: frequency responses of sound pressure at driver’s ear

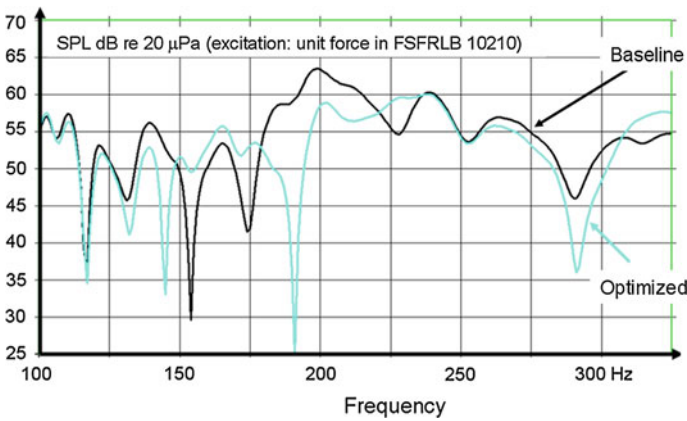


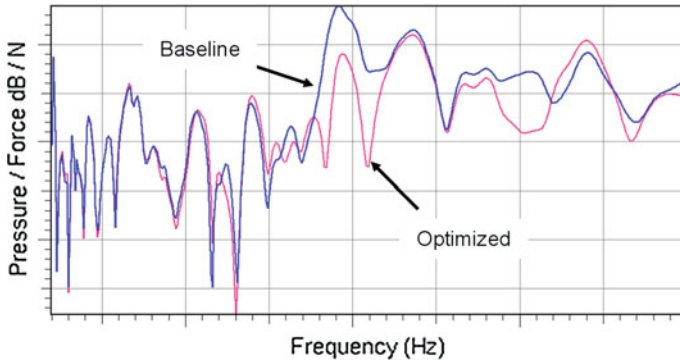
Fig. 9 SPL for bead patterns from base line model and from optimization results validation using the full-trimmed body model

## 6 Design Model and Optimization Results

The design model consists of discrete and continuous design variables. The design variables are provided by *SFE CONCEPT<sup>TM</sup>* and described in Sect. 4.

Figure 7 shows the history of the objective, the maximum of SPL, the frequency for the maximum, and the discrete and continuous design variables. As a first step the optimization starts a DOE regarding a full-factorial design with many variants. The marked section in the history shows the section without beads in





**Fig. 10** Numerical validation results using for the full-trimmed model

region 1. Obviously a noise reduction can be stated in this area. The minimum for this optimization is the reference state without beads.

In order to control the vibro-acoustic analysis for every optimization step the frequency response is shown in Fig. 8. The main influence on the frequency responses is given by changing the discrete design variables. Figure 9 compares the frequency response of SPL at driver's ear for the reference model with a model without beads in region 1. The optimization results can be summarized in the following statements:

- SPL is influenced by type and location of bead patterns,
- smaller independent beads tend to yield better results,
- in this particular case and in the frequency range of interest no beads in region 1 results in a lower SPL.

The numerical validation was done using the full trim body model and sub-structures shown in Fig. 10.

## 7 Conclusions

In this paper a new optimization procedure has been presented that enables the improvement of the vibro-acoustic behavior of body structures efficiently. With the use of *SFE CONCEPT<sup>TM</sup>* it is possible to generate a realistic representation of a structure using implicitly parameterized geometry for the vibro-acoustic simulation. The essential structural elements such as beads and spot welds could be considered without user action in the optimization loop.

The new discrete-stochastic optimization algorithm promises to reduce the expense of a vibro-acoustic optimization significantly because discrete design variables are directly integrated in the design model.

In this particular case the achievement was not only to lower the two critical peaks at desired frequencies but also to maintain the SPL below a certain level over the entire frequency range of interest.

A combination of powerful toolset *SFE CONCEPT<sup>TM</sup>*, *SFE AKUSMOD* and a discrete continuous optimization technique was used to solve vibro-acoustic problems on localized areas and results are scalable on a global scale.

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