

FE-OPTIM and MSC/NASTRAN for a Frequency Response Optimization

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Abstract:

FE-OPTIM, a software tool developed by P+Z Engineering GmbH, supports the MSC/NASTRAN optimization (Solution 200) in all its key features. The use and the benefits of FE-OPTIM, combined with MSC/NASTRAN SOL 200, is demonstrated on an example of an AUDI project.

Introduction

With Solution 200 MSC/NASTRAN offers a tool for structure optimization. The scope of use of Solution 200 ranges from static and dynamic problems up to frequency response analysis. The basic procedure is always the same no matter which calculation method is used. A design objective, for example the total weight, is to be minimized or maximized. For this, several design variables are defined with a lower and upper limit to their range of values. The structural behavior must obey certain constraints during the optimization. The optimizer now tries in single optimization steps to fulfill all conditions under consideration of a design objective.

The design variables, the responses and all constraints are defined through NASTRAN entries. MSC/NASTRAN provides the optimization results in the F06-, OP2- and in the Punch-File.

The pre-processing, that is the generation of all NASTRAN entries, has become time-consuming, complicated and above all error-prone, due to the data format. For each property which is to be taken into account for the optimization, a design variable must be defined stating an upper and a lower limit. Constraints, in the case of a static optimization, for example maximum or minimum displacements at selected nodes, must also arduously be generated individually through NASTRAN entries. While a static optimization has relatively few constraints, a frequency response optimization may have many thousands.

From experience it is known that the efficiency of SOL200 is far beyond its abilities in daily use. One reason for this is the complicated and therefore error-prone definition of the NASTRAN entries. Also post-processing tools are missing which show all results of an optimization in 2 or 3 dimensional format.

It is these weaknesses in the effective use of MSC/NASTRAN SOL200 that the tool FE-OPTIM remedies. The user can simply define all NASTRAN entries necessary for an optimization and generate a complete NASTRAN Deck. In the post-processing area all results are shown in 2 and 3 dimensional format.

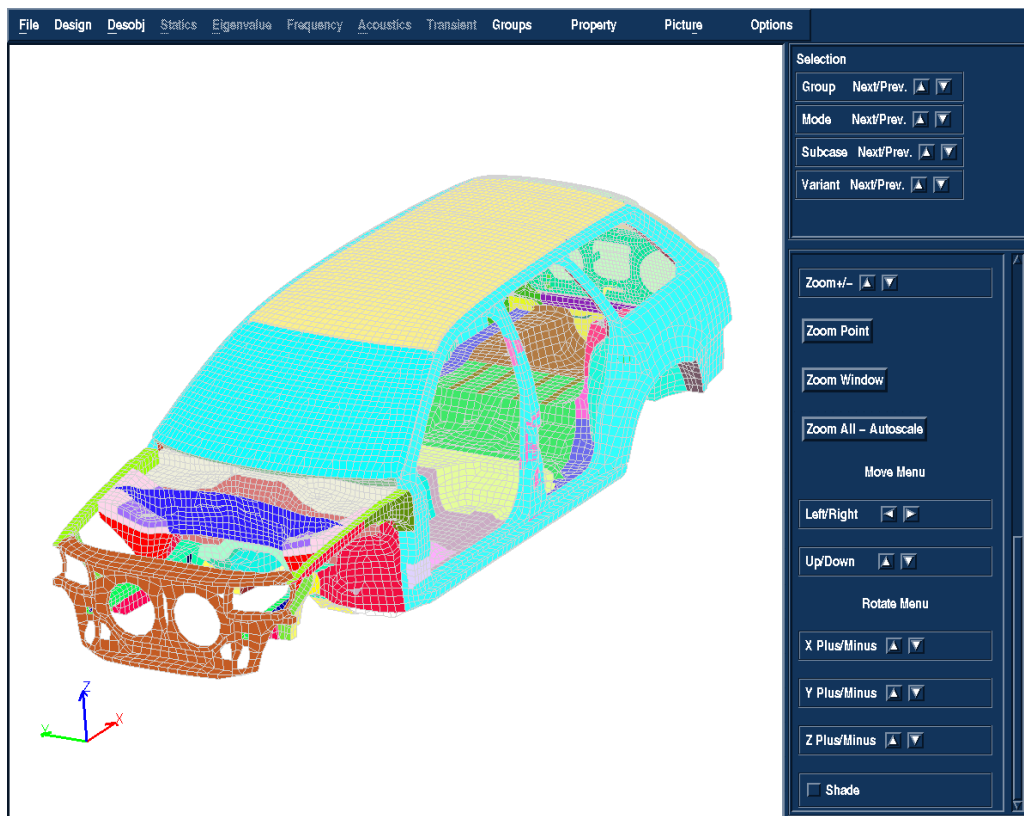
This presentation describes the functions and abilities of FE-OPTIM as pre- and post-processors in the field of parameter optimization with MSC/NASTRAN SOL200. It demonstrates how to use the software for the example of a frequency response optimization of the AUDI B5 Avant. In this connection the use of the BETA Method is also described as an example.

Key functions of FE-OPTIM

The main objective of FE-OPTIM is to offer the calculation engineer a powerful tool for the easy and effective generation of optimization models (NASTRAN Design Optimization Model) and simple graphical visualization of the optimization results. The calculation engineer can therefore use the structure optimization economically and can give the development engineer key information at very short notice.

The software includes the following optimization related basic features:

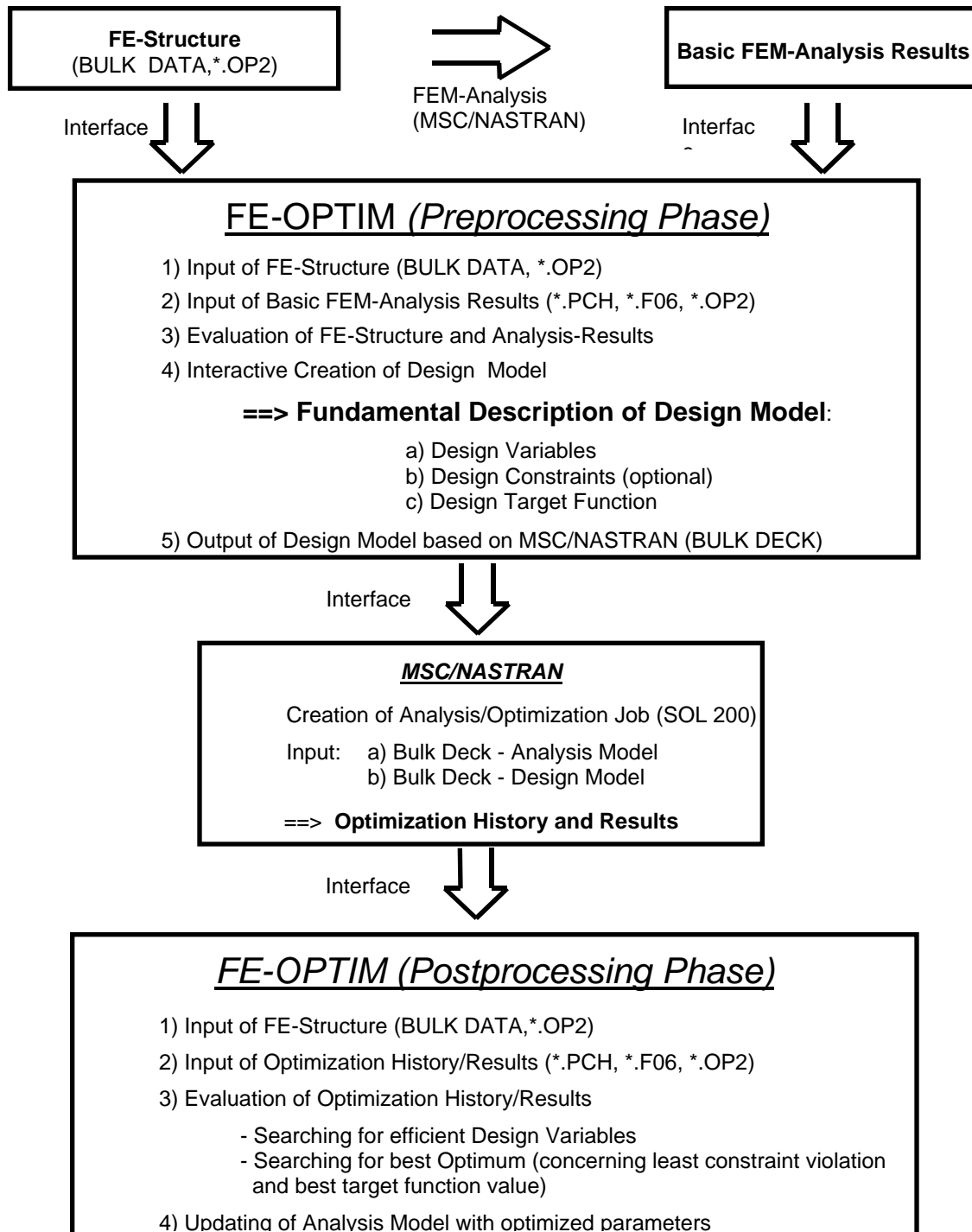
- User friendly graphic interface (GUI)
- Powerful 3D-display visualizing analysis/design model
- Fast input/output data interfaces to major CAE-programs (MSC/NASTRAN, MSC/PATRAN, SDRC/I-DEAS, DEBIS/MEDINA, etc.)
- Fast and efficient handling of large FE-models
- Visualizing pre-/postprocessing data of structure optimization
- Creation of design models in MSC/NASTRAN data format.
- Updating of analysis structure with optimized parameters



Picture 1: FE-OPTIM graphic user interface
Audi B5 Avant

Pre- and Post-processing with FE-OPTIM

Picture 2 shows the coupling of FE-OPTIM with MSC/NASTRAN for pre- and post-processing.



Picture 2: Coupling of FE-OPTIM with MSC/NASTRAN, SOL200

Pre-processing with FE-OPTIM

FE-OPTIM is based on an analysis in which the user has calculated the original state of the structure. The NASTRAN Start Deck of this basic analysis, consisting of File Management, Executive Control, Case Control and Bulk Data Section is read directly into FE-OPTIM. The results of the basic analysis can be read in the form of an OP2- or Punch.File.

With a 3D OPEN/GL graphic the FE model can be shown 3 dimensionally in the graphic display (Picture 1). Dynamic functions like ROTATE, MOVE, ZOOM or display of single groups are also available. A weight analysis supplies the masses of the individual components in the form of a list. Each property can be selected graphically in order to show or modify its values.

For the generation of a design model for optimization the procedure is as follows (see also picture 2).

1. Definition of Design Variables

Properties for which design variables are to be generated can be selected in the form of lists or through graphical selection. When lists are used, the properties can be selected via certain ranges of numbers or via search strings. Design variables can be defined individually or in groups. DESVAR and DVPREL cards are generated which FE-OPTIM with its defined values can show in a 3 dimensional graphic of the structure.

2. Definition of Responses and Constraints

Responses and constraints are either defined via lists or via graphic selection according to their respective area of use. The responses are allocated to individual subcases which must first be read in and then be selected. Values that have already been calculated in the basic analysis are displayed to the user. FE-OPTIM generates DRESP1, DRESP2, DEQUAT, DTABLE and DCONST cards. The following responses can be generated according to the subcase:

Statics

Responses for displacement and stress
Use of the Beta Method

Dynamics

Responses for natural frequencies

Frequency Response

Responses for displacement, velocity, acceleration or mobility
Use of the Beta Method

3. Definition of a Design Objective Function

The design objective is generated automatically through the selection of up to 2 menu points. Optimization parameters (DOPTPRM) can also be entered directly into FE-OPTIM.

4. Creation of a NASTRAN Input File

Via the FE-OPTIM interface the design deck for optimization is generated in the Case Control Section with all selected subcases as well as all necessary entries. The user can choose whether only the NASTRAN entries relevant for the optimization, or all NASTRAN entries including the complete structure, are written.

Post-processing with FE-OPTIM

After finishing the analysis/optimization job (MSC/NASTRAN – SOL200), the user has the problem of controlling the large amount of data (optimization history/result data), which the job will produce. FE-OPTIM reads and stores data in an object related database and is managing the data interactively by a graphical display user interface. To control and evaluate the data, FE-OPTIM is able to visualize selected optimization parameters as list charts, bar/column charts and graph charts. To reduce the large amount of data in a efficient way, FE-OPTIM offers several sorting criteria (e.g. max. component weight, max. shell thickness, etc.).

Moreover, the design variables can be shown graphically in colors on the structures. All diagrams and presentations can be stored as Postscript File or can be printed directly.

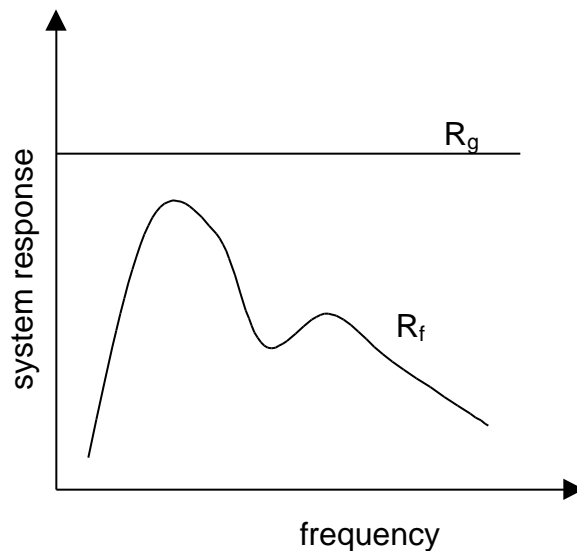
After the user has optimized his structure with the help of MSC/NASTRAN and FE-OPTIM, he can round the optimized properties to standard values and write these rounded values in the Bulk Data Format. Such an example is different shell thicknesses which are only produced in certain sizes.



The BETA Method in FE-OPTIM

FE-OPTIM supports the BETA Method in static optimization and in frequency response optimization.

Picture 3 shows an example of a system response of a degree of freedom from any input in relation to the frequency. The optimization objective is to reduce the maximum amplitude.



Picture 3: The basic principle of the BETA Method

A usual procedure is to minimize the area under the response curve. This, however, does not mean that the maximum amplitude is thus reduced as well. Besides, currently MSC/NASTRAN SOL200 cannot take several subcases into account for such an optimization.

The BETA Method does not have these disadvantages. For frequency response optimization FE-OPTIM is able to take several subcases into account in one optimization run due to the BETA Method. In the following paragraphs the Beta Method for a frequency response optimization will be described.

When the BETA method is used, a limit curve (R_g) is defined first which is used for the normalization of the frequency response (R_f) (picture 3). With the help of the additionally introduced design variable β , whose starting value is usually one, the following constraint is described:

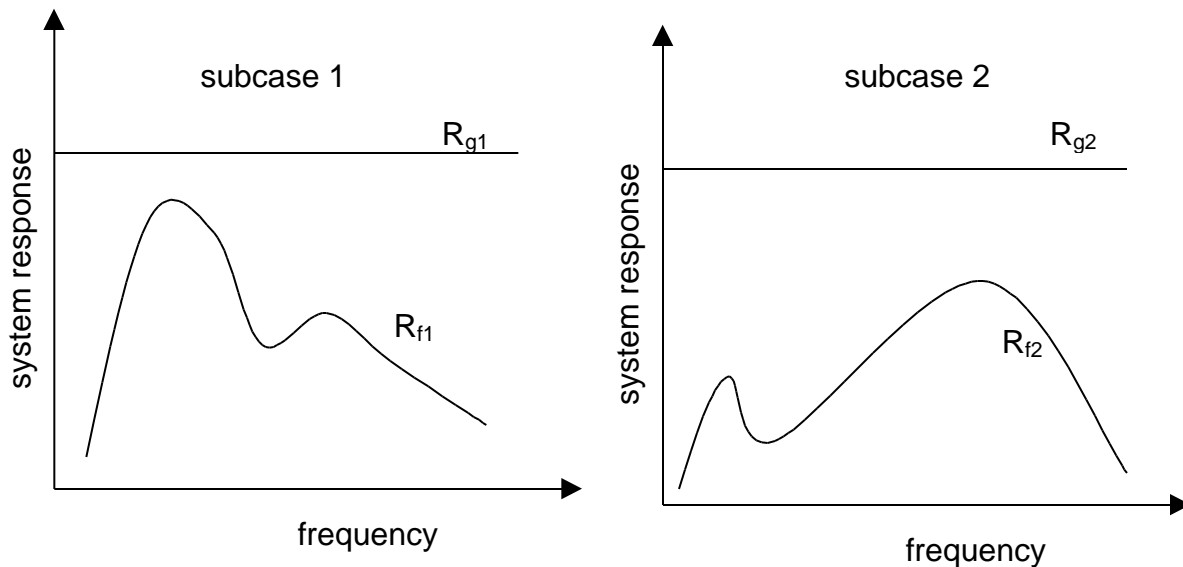
$$\frac{R_f}{R_g} - \beta + 1 \leq 1 \quad (1)$$

With $\beta = 1$ and the curves shown in picture 3 this constraint is fulfilled thus far. For the design objective Z with the constant factor f_1 the following is defined for example:

$$Z = f_1 \cdot R_{f1} \quad (2)$$

Additionally, the design objective is a function of the design variable β . Equation (2) makes immediately clear that a minimization of Z can only be achieved through a minimization of R_{f1} ($f_1 = \text{const}$). From equation (1) follows that for $\beta = 1$ the quotient R_f/R_g must be smaller or equal to 1. If β becomes smaller, the quotient R_f/R_g must also become smaller. If e.g. $\beta = 0.5$, equation (1) is valid and since R_g is constant, this means that a minimization of β results in a minimization of R_f .

An important point is that with the Beta Method several subcases can be optimized at the same time. This is shown in picture 4 in the case where two subcases are to be taken into account. For these applications 2 design variables β_1 and β_2 as well as 2 additional limit curves R_{g1} and R_{g2} are defined. FE-OPTIM defines constraints, which are addressed separately to the individual subcases via the DESSUB card in the Case Control Section (picture 4).



$$\frac{R_{f1}}{R_{g1}} - \beta_1 + 1 \leq 1 \quad \frac{R_{f2}}{R_{g2}} - \beta_2 + 1 \leq 1 \quad (3)$$

$$Z = f_1 \cdot \beta_1 + f_2 \cdot \beta_2 \quad (4)$$

Picture 4: Use of the Beta Method for 2 subcases

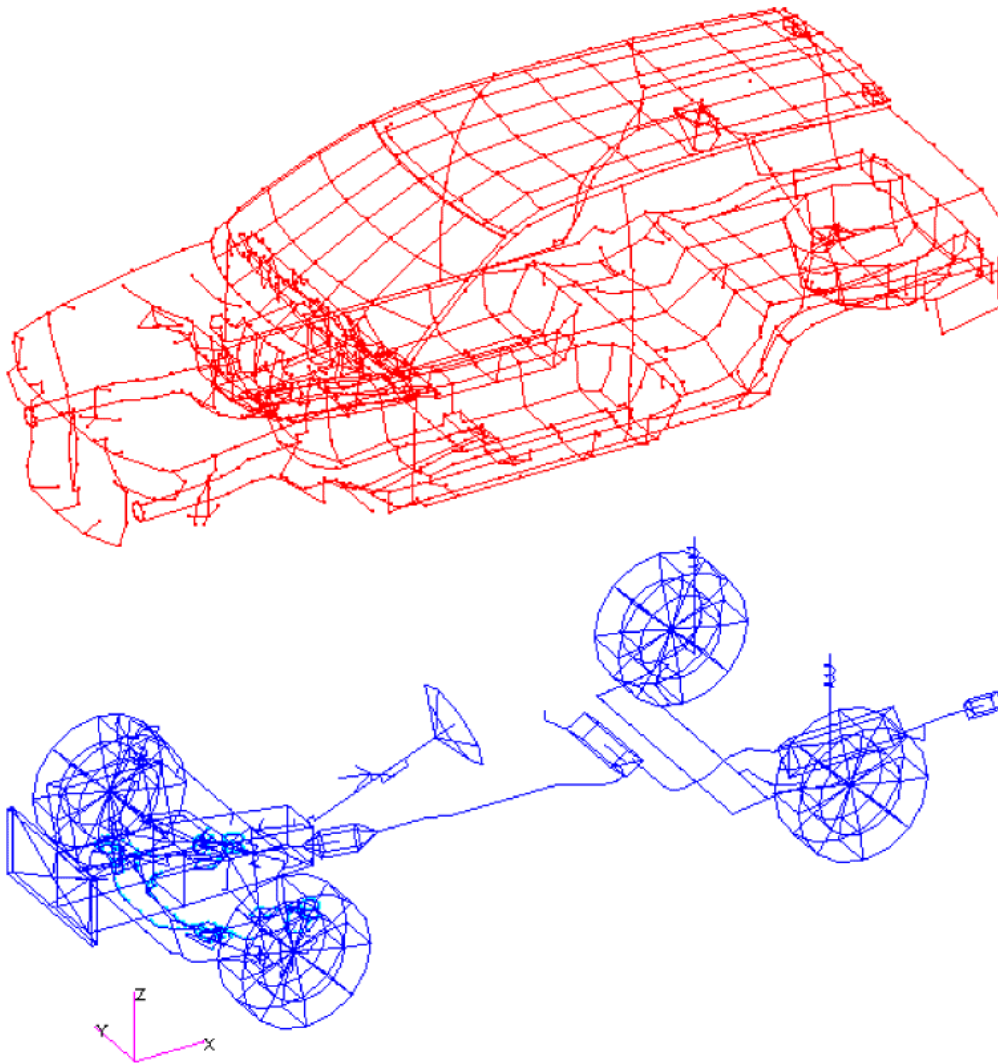
The design objective Z is now a function of the design variable x_1 and x_2 (equation 4), whereby a weighting can be made via the constant factors f_1 and f_2 . Of course it is possible to put the design objective in relation to a design variable e.g. the weight. All NASTRAN Bulk Data entries with all their dependencies for an optimization with the BETA Method are generated automatically by FE-OPTIM during the pre-processing. The limit curve R_g can be defined graphically or through individual sustainers. The number of subcases is unlimited.



Example

Frequency response optimization of the AUDI B5 AVANT with the BETA method

Picture 5 shows a simplified car model of the AUDI B5 Avant. The optimization objective was an improvement of the car behavior as to steering wheel vibrations. These vibrations derive from vertical and horizontal vibrations of the steering wheel which occur with high speed. The stimulation in the simulation can be made via the rear and front axle.



Picture 5: FE model used for the AUDI B5 Avant

Design variables are the pad stiffness of selected rubber pads. A total of 18 independent design variables were used, allowing the pad stiffness to differ from the starting value by a maximum of 40%. In the example 2 subcases were taken into account.

Subcase 1:

Two wheel unbalances at the rear axle vibrate in-phase

Subcase 2:

Two wheel unbalances at the rear axle vibrate in anti-phase

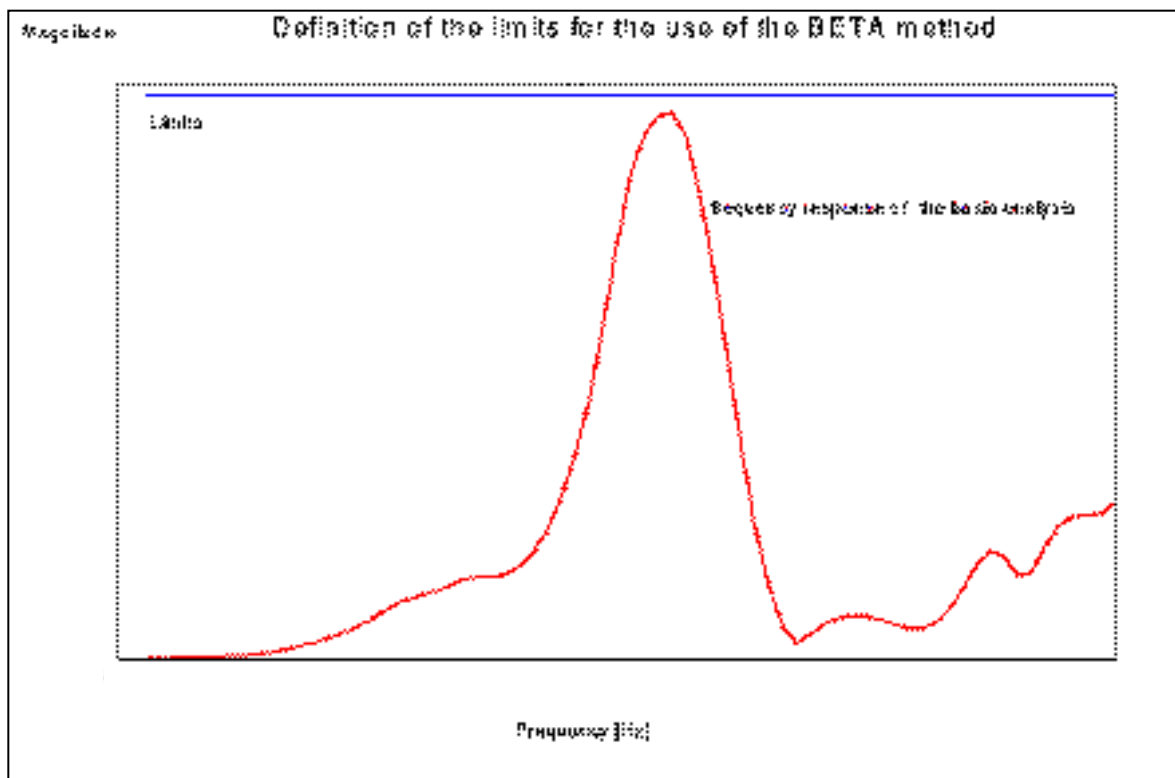
The optimization runs A and B were made and differ as follows:

Optimization A:

Frequency response optimization (SOL200) for subcase 1 with the use of the BETA Method for subcase 1 only. Subcase 2 is taken into account but is not optimized

Optimization B:

Frequency response optimization for subcase 1 and subcase 2 by using the BETA Method for both subcases.



Picture 6: Frequency response curve and the limit curve generated with FE-OPTIM

Picture 6 shows the acceleration at the steering wheel for a degree of freedom within the frequency area that is to be optimized for subcase 1. This curve is the result of a MSC/NASTRAN calculation SOL111. The limit curve generated with FE-OPTIM is also shown. In FEOPTIM this limit curve must only be defined once for a degree of freedom. FE-OPTIM then generates the DESVAR (for the BETA Method), DEQATN, DRESP1, DRESP2, DCONST, DEQUAT and DTABLE entries automatically for all selected degrees of freedom and subcases.

FE-OPTIM generated approximately 1200 NASTRAN entries in the case of optimization A and approximately 2000 NASTRAN entries in the case of optimization B with the frequency range for the optimization being relatively small.

The pictures 7 to 10 show the results of optimization A and B. All pictures have the same scale. Each picture shows the value of acceleration at the steering wheel for the starting state and the last iteration step. Due to the fewer numbers of constraints (BETA Method only for subcase 1) optimization A only needed 3 optimization steps, optimization B (BETA Method for 2 subcases) needed 5 optimization steps. MSC/NASTRAN V70.5 was used.

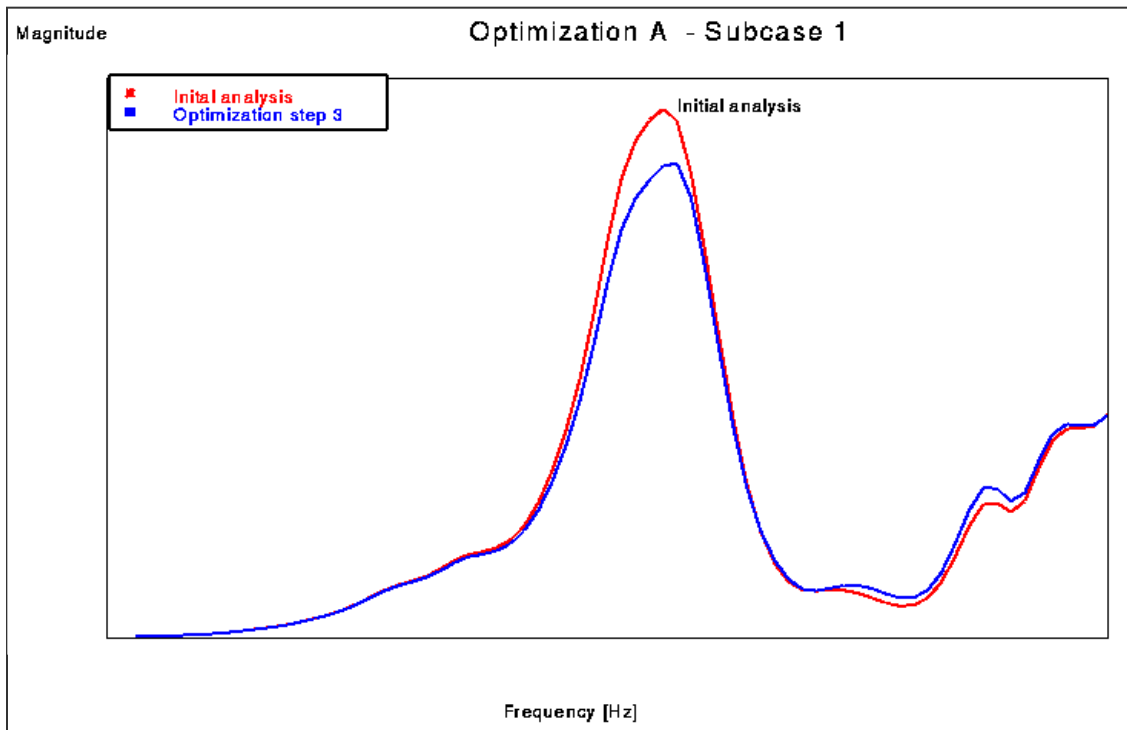
Picture 7 (optimization A) and picture 9 (optimization B) show a very similar course of the frequency response for the last iteration step for subcase 1 since for both subcases the BETA Method was used. There are considerable differences to be seen in picture 8 (optimization A) and picture 10 (optimization B), which show the frequency response for the second subcase. While there are only slight differences between the starting state and the optimized values for the second subcase in optimization A, in the case of optimization B a reduction of the amplitude is clearly to be seen. This is also a characteristic feature of the BETA Method. It tries above all to reduce the maximum amplitudes.

Conclusion

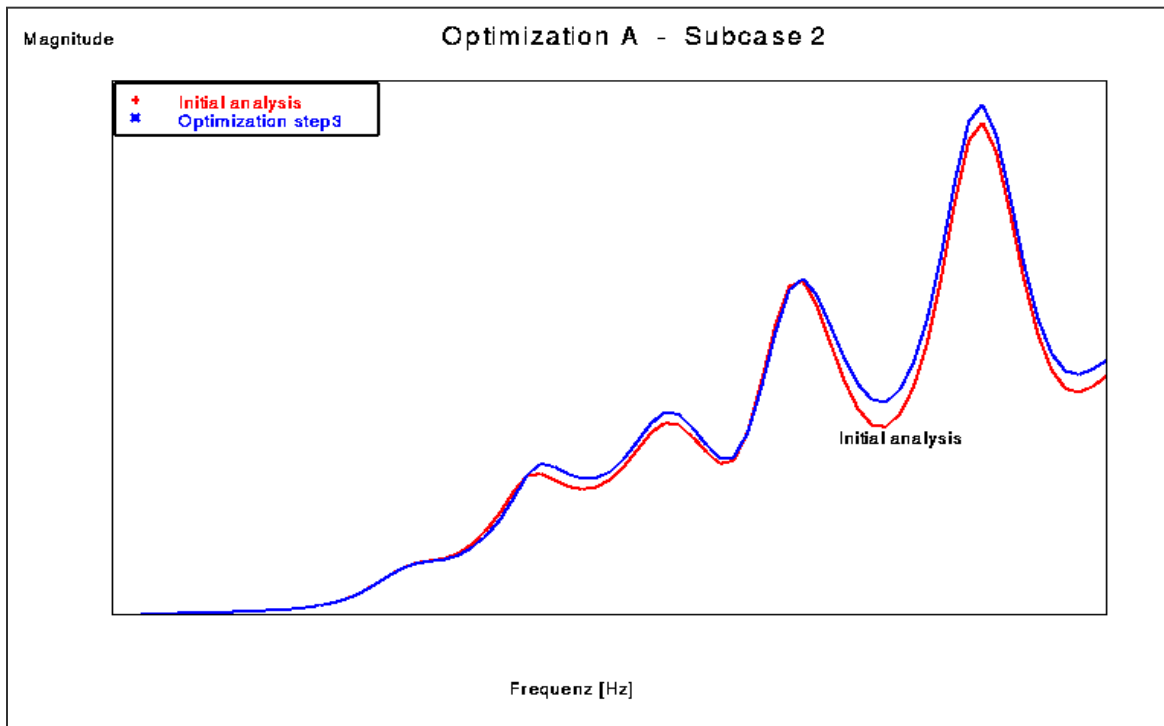
FE-OPTIM is a tool also users with less experience can use to optimize structures with MSC/NASTRAN SOL200. The use of the tool is easy and clear due to the graphic interface. The partly complicated dependencies of the individual NASTRAN entries for the optimization need not necessarily be known to the user.

The evaluation of the optimization results is also made via the graphic interface in the form of list charts, column and graph charts. Thereby errors can be found quickly and easily and the optimization results can be presented clearly.

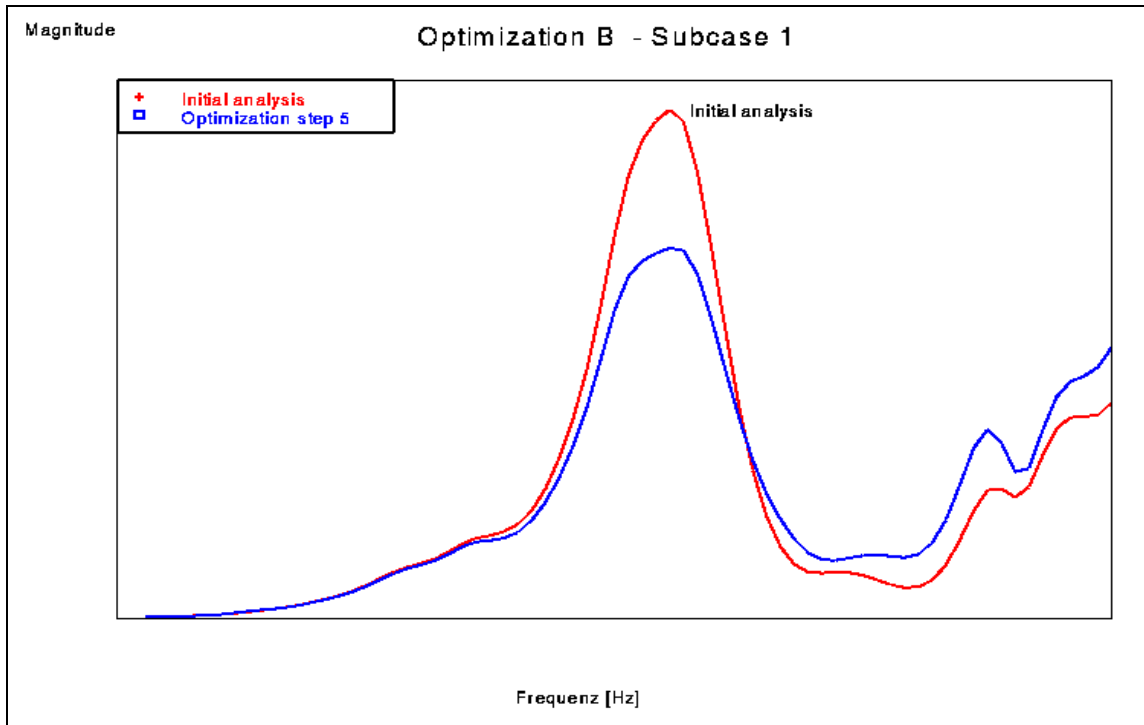
The presented example of the AUDI B5 Avant shows the use of the BETA Method. In the opinion of the authors this procedure is of special interest for the optimization of the vibration comfort of a car, since, if necessary, objective conflicts resulting from different disciplines can be recorded. In the most general case the frequency responses of different degrees of freedom (seat guide rail, steering wheel, ...) are examined for different weights.



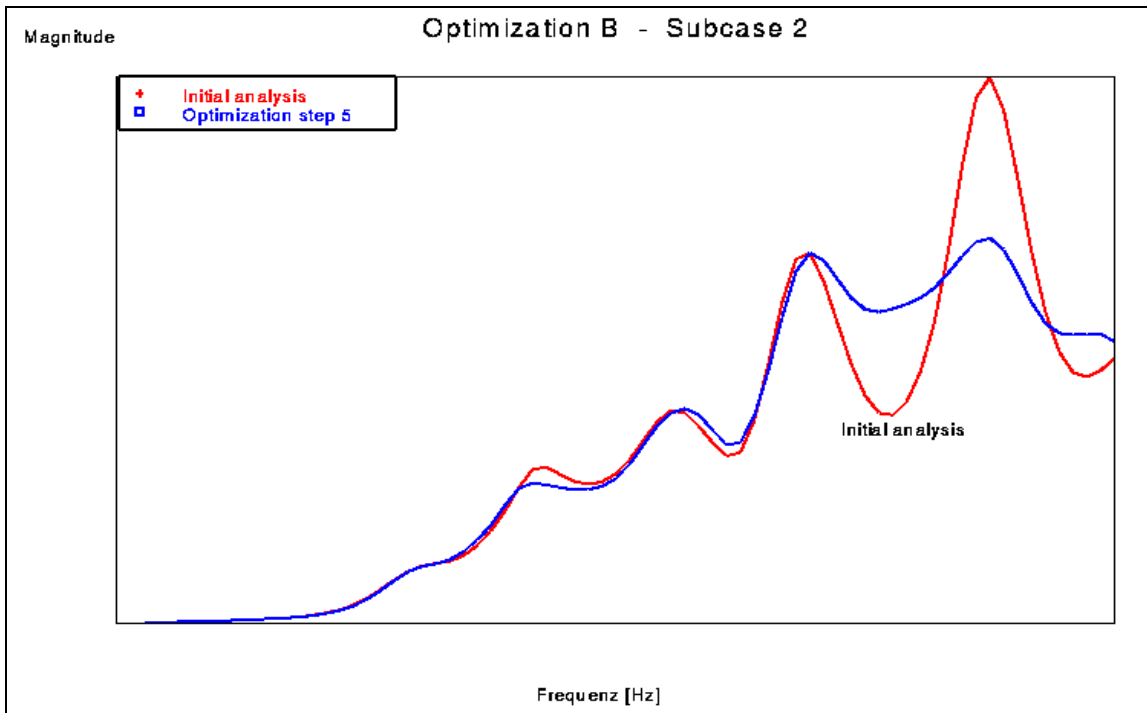
Picture 7: Optimization A – subcase 2
BETA-Method only for subcase 1



Picture 8: Optimization A – subcase 2
BETA-Method only for subcase 1



Picture 9: Optimization B – subcase 1
 BETA-Method for subcase 1 and subcase 2



Picture 10: Optimization B – subcase 2
 BETA-Method for subcase 1 and subcase 2