dynamic software & engineering

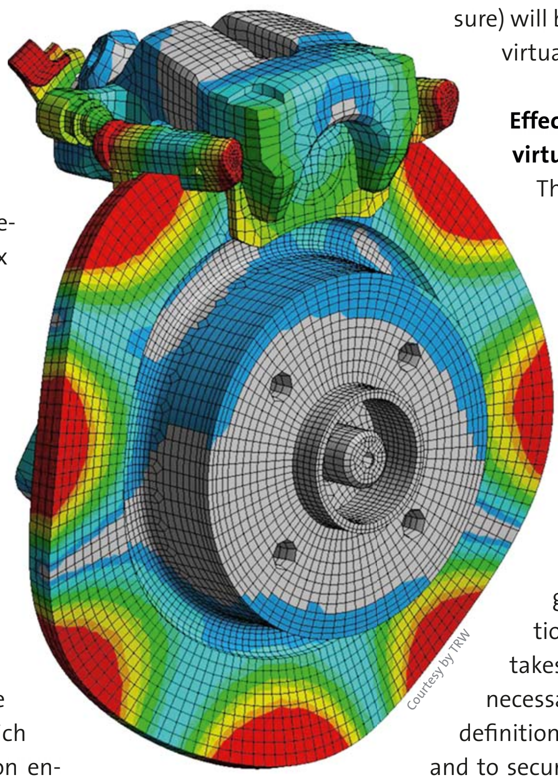
VIRTUAL ROBUSTNESS EVALUATION OF BRAKE SYSTEMS

CAE-based Robust Design Optimization with optiSLang minimizes brake noise and secures product quality already at an early stage of virtual prototyping.

Optimization Task

Brakes are one of the most important safety and performance components in automobiles. Furthermore, aesthetic and environmental concerns focus on the refinement of vehicle acoustics and comfort including brake noise behavior. As a consequence, not only braking power but also the minimization of noise excitation levels becomes an important goal of virtual product development.

Brake noise occurs as a result of instability problems at different frequencies. In order to model brake noise, usually the finite element method based on Complex Eigenvalue Analysis (CEA) is applied. This method is based on the modeling of a friction contact between brake lining and brake disc in vertical and tangential directions providing a coupling with the asymmetric stiffness matrix. Thus, the instability problem can be evaluated based on stable and unstable vibration in the brake system. In case of instability, a positive real eigenvalue is calculated with the related damping coefficient which indicates the amount of excitation energy for the instability.



The general avoidance of brake noise over the whole frequency range is very difficult. Often, design modifications, which are beneficial to avoid one brake noise phenomena, cause an increase of other instability frequencies. Therefore, the minimization of critical damping coefficients over the whole frequency range will be the final goal of optimized product development.

Solution Methodology

Because multiple different noise phenomena at multiple frequencies, as well as scatter of geometry and material, are affecting the brake noise sensitivity, deterministic design load cases ensuring enough safety distances are difficult or even impossible to derive. Alternatively, a direct investigation of brake design robustness can be conducted focusing on the input variation as a result of scattering, material parameter or geometric tolerances. Here, CAD-based robustness evaluation using stochastic analysis at different environmental conditions (friction, pressure) will become a very important part of the virtual design evaluation.

Effective use of stochastic analysis in virtual robustness evaluation

The basic idea of virtual robustness evaluation is the creation and evaluation of a set of possible design realizations representing a scan of the robustness space which is defined by all important scattering input variables. Therefore, the main focus of CAE-based robustness evaluation is estimating the variation of important response variables as a result of scattering material, geometry or environmental conditions. Because every design evaluation takes a significant amount of time, it is necessary to keep a balance between the definition and discretization of uncertainties and to secure the choice of the best stochastic analysis methodology using measurements with a maximum reliability of variation and correlation.

Example of a robustness evaluation*

In case of a robustness evaluation of brake systems, it is known that the scatter of materials represents one of the main sources of uncertainty. Especially the pad material shows a high amount of this phenomena. Therefore, investigations often start with an introduction of scatter according to Young's modulus to different brake parts. Based on the measurements and experience, truncated normal distribution ranging from +/- 5% at 2 Sigma level for steel parts and up to 50% for the brake pad material is used for the estimation of the stiffness scatter. The monitoring of instabilities is carried out for critical frequencies using two frequency windows around 2 kHz and 6 kHz. The CAE process using NASTRAN NX was introduced into optiSLang and the robustness analysis was carried out using a Latin Hypercube sampling of 100 designs. After the NASTRAN calculation was conducted, optiSLang was used to perform statistical evaluation and correlation analysis to get a precise idea of the response scatter of parameter resulting from the scatter of design parameters.

Fig. 1 shows the most influential scattering input parameters and how they influence the responses at 2kHz. It indicates that Pad G33 (stiffness of pad in out of plane direction) is the most important scattering parameter and that it has a high linear correlation with the response. The value of pair wise linear Coefficient of Determination (CoD) indicates how many percent of the response variation can be explained by the variation of the input parameters. In this case, the coefficient of pair wise linear determination is 84%, which is quite high. To find out which is the most important input parameter, correlation analysis using different measurements of importance was used.

As it can be seen in Fig. 2, only one scattering variable dominates the variation in the response values at 6kHz, but the correlation is highly nonlinear and could not be identified with classic correlation analysis using linear, quadratic or monotonic nonlinear (Spearman) correlation assumptions. Due to the high nonlinearities between the response and input variables, only optiSLang's Coefficient of Prognosis (CoP) identified and quantified the main correlation properly. The correlation of Pad G33 to the damping coefficient is complex in the case of 6 kHz. At the mean value of Pad G33, a high variation can be observed. Increase or decrease of Pad G33 from mean value yields lower real eigenvalue.

The robustness analysis stated that the scattering part stiffness of the brake system has a huge influence on the response. In this example, the scatter of the brake pad stiffness in the out of plane direction plays the dominant role in both the 2kHz and 6kHz case.

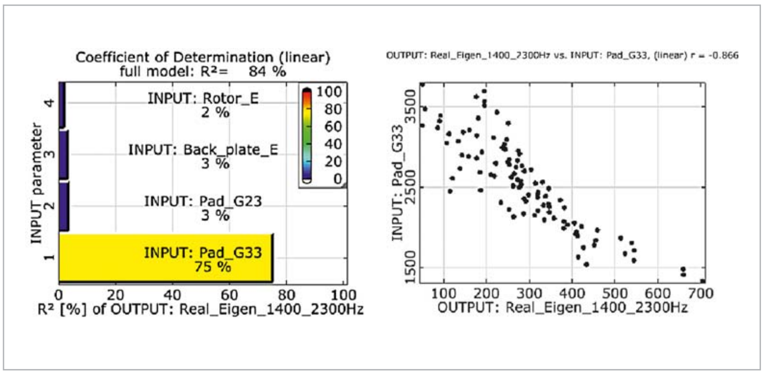


Fig. 1: Most important scattering parameter (left) and correlation between pad G33 and real Eigenvalue (right) at 2 kHz

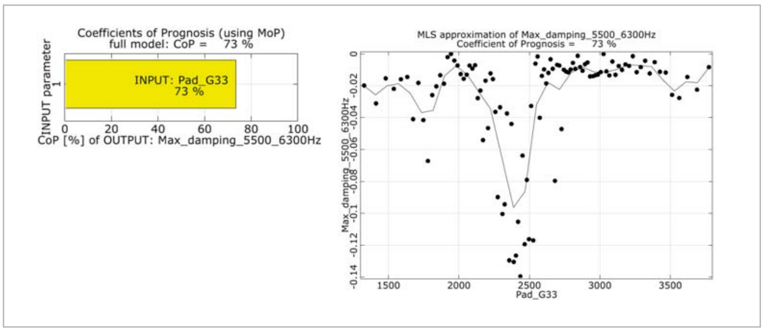
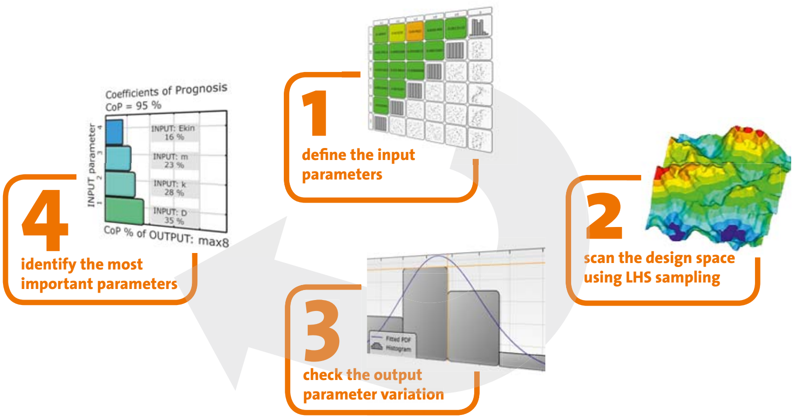


Fig.2: Most important scattering parameter (left) and correlation between pad G33 and max damping ratio (right) at 6 kHz



The flow of robustness evaluation procedure

Customer Benefits

CAE-based robustness evaluation using stochastic analysis offers a new approach to optimize product properties as a part of the virtual design process. The main result of a robustness evaluation is the estimation of variation windows which can be used to check and proof robustness of the designs. In addition, the sensitivities of material and geometry scatter towards brake noise phenomena are investigated. In case of critical material or geometry scatter, the methodology can be applied to minimize the sensitivities. Furthermore, quality control can be optimized towards sensitive material parameters or tolerances while decreasing related costs concerning insensitive parameters.

* Contribution of the 6th Weimar Optimization and Stochastic Days 2009: "Robustness Evaluation of brake systems concerned to squeal noise problem", Ronaldo F. Nunes (Daimler AG, Sindelfingen), Johannes Will, Veit Bayer (Dynardo GmbH), Karthik Chittepu (CADFEM GmbH)

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