Opel implements Hybrid FRF-Based Substructuring (FBS)

ENGINEERING INNOVATION

Compressed development cycles and increased customer expectations in relation to the Noise, Vibration & Harshness (NVH) comfort of a car pressure automotive manufacturers to further extend the capability and efficiency of their NVH engineering process. To be able to meet these demands, Opel introduced FRF-Based Substructuring (FBS) and validated the practical use of this hybrid simulation method.

The FBS method enables Opel engineers to create assembly models based on the structural and vibro-acoustic FRFs of its constituting components. By taking the FRFs of existing components from predecessor vehicles and calculating the FRFs of new components, FBS enables to effectively evaluate design alternatives at earlier stages in the development process. This approach represents a key step in Opel's strategy to implement innovative simulation methods that further increase the quality and performance of its vehicle NVH development process.

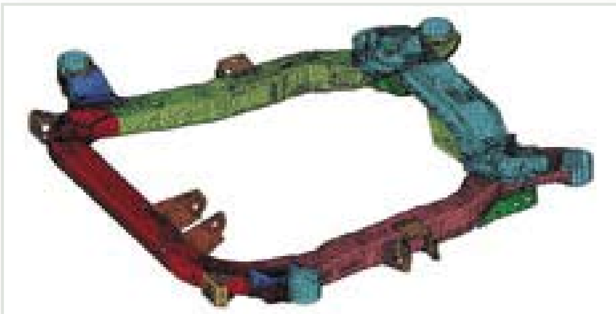
Search for more efficient synthesis solutions

The engineering of vehicles with superior NVH performance is becoming more challenging than ever, especially since development times keep shrinking. Manufacturers are well aware that NVH engineering requires a component-level approach, especially since a higher number of components is developed by different suppliers. As part of its continuous search for innovative solutions, Opel took the initiative to explore and validate the FBS method. FBS is a fast hybrid simulation method that offers the capability to reliably combine FRF-based component models, regardless whether they originate from FE models or from measurements on prototypes or predecessor vehicles.

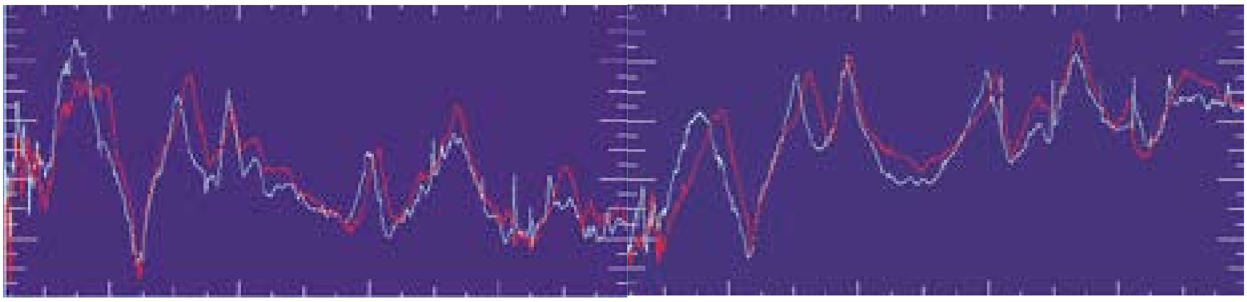
FBS allows engineering teams to flexibly combine test-based FRF models of existing components with calculated FRFs of new non-existing components. With this approach, it is possible to overcome the decreased prediction accuracy for vibro-acoustic FRFs at higher frequencies and the significant modeling efforts required to obtain large pure FE-based models. FBS is particularly suited for simulations in the mid-frequency range, as long as high accuracy standards for the integrated FE models can be guaranteed. By offering the possibility to perform Transfer Path Analysis (TPA) simulations, FBS models enable a detailed investigation of the noise as well as the vibration performance of the complete assembly.

Arnold Böhm, responsible for the implementation of FBS at Opel's NVH Engineering Department, underlines the benefits of FBS as a hybrid simulation method, "The FBS method enables to flexibly choose between test-based and analytical models, offering the potential to dramatically improve the accuracy and speed of NVH predictions performed in the early design stages. This results in decreased testing work and a reduced need for prototypes in later stages of the development process. In order to evaluate the accuracy and usability of the FBS method, we applied it on an existing car, and after successfully evaluating the method, we gradually implemented it in our development process."

To validate the FBS simulation approach, Opel engineers characterized the body and subframe individually through FRF measurements, and compared the predicted vibroacoustic responses of the experimental FBS model with responses measured directly on the assembly.



In a second step, they replaced the measured subframe FRFs with simulated FRFs obtained through FE modeling. Its ability to combine experimental and simulated FRF component models allows FBS to perform vibro-acoustic simulations early in the development.



Sum over all microphone (left) and accelerometer (right) values for a reference point on the modified subframe design, as measured (red) and predicted through FBS (blue).

Applying and verifying the essentials of FBS

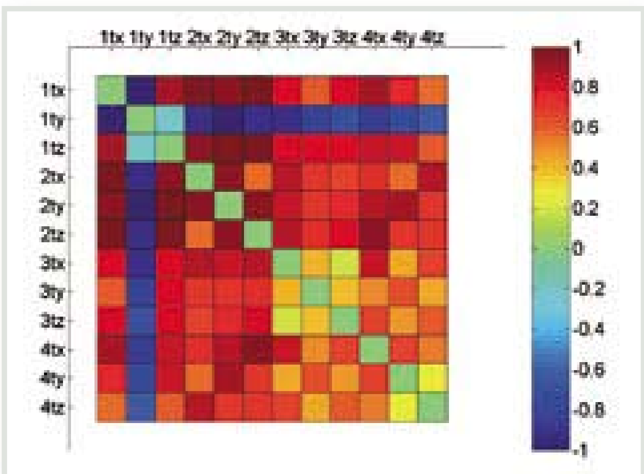
A dedicated project was defined to validate the FBS approach on a practically relevant example – the assembly consisting of a subframe and a fully trimmed car body. In a first phase, pure experimental representations of both components were used in order to exclude the influence of potential FE model inaccuracies. After successfully passing this phase, the test-based subframe model was replaced by its FE counterpart. To shorten the implementation time of the first phase, Opel decided to work with LMS Engineering Services to introduce best practices and to provide specific measurement guidelines.

During the first phase of the project, the structural and vibro-acoustic FRFs of the subframe and the trimmed body were measured in order to build up the test-based representations of the two components. To investigate the prediction accuracy of subframe modifications, two subframe variants were chosen: the original subframe and a significantly stiffened version. In addition, two different types of coupling conditions were foreseen: rigid and flexible couplings. This was realized by replacing the elastic mounts by rigid mounts. All measurements were performed using LMS SCADAS III testing hardware and LMS CADA-X software, the latter containing the LMS FBS module.

Accurate and consistent component modeling

Key requirements to obtain reliable FBS predictions are accurate and consistent representations of the components. To reduce systematic errors in the measurement setups, state-of-the-art techniques were applied. To identify and remove small inaccuracies in the measurement data, dedicated consistency checks were performed. For this purpose, LMS Engineering Services developed an innovative approach based on Frequency Response Assurance Criterion (FRAC) and Phase Assurance Criterion (PAC), which describe the correlation for amplitudes and phases between two nominally reciprocal FRF. By arranging these values into FRAC and PAC matrices, it is possible to assess the overall consistency of a measurement at a glance. These matrices allow identifying insufficient reciprocity due to an unsuitable measurement setup as well as phase errors resulting from incorrect labeling.

After completing the experimental characterization of individual components, Opel and LMS engineers combined the component models and performed the FBS simulations for different configurations, including elastic and rigid attachments of the original and modified subframe to the trimmed body. The predicted vibro-acoustic FRFs were immediately validated against directly-measured FRFs and showed good correlation.



A PAC matrix represents the phase correlation between two nominally reciprocal FRFs - in this particular case clearly indicating incorrect labeling.

FBS and its powerful hybrid simulation capabilities

Before making the switch to hybrid FBS simulations, the measured and calculated FRF representations were compared, showing an acceptable match in both amplitude and phase. Following this approach, hybrid FBS simulations were performed on a system that combines an experimental body and an analytical subframe using flexible couplings. Arnold Böhm commented on the outcome of the project, “The hybrid FBS simulations turned out to correlate well with the FBS system simulations retrieved earlier on in this project. These findings confirm that FBS is a proven simulation tool, capable of reliably predicting tendencies for larger system modifications. FBS is a very practical solution, as it allows evaluating a design modification only by updating the definition of the modified structure. This way of working is much easier and less time-consuming than having to update and re-calculate the complete system model.”

Dr. Eike Brechlin, Project Manager at LMS Engineering Services, added that the success of introducing a hybrid simulation approach depends on a combination of factors. “In over 20 years, LMS Engineering Services built up an impressive track record of executing technology transfer projects together with innovative customers like Opel. We learned that the accuracy of predictive hybrid methods strongly depends on an optimal combination of engineering skills, a significant degree of experience and complementary testing know-how.”

“The validation of the FBS method represents a key success factor for the gradual introduction of the hybrid method in the development process at Opel”, Arnold Böhm commented. “The capability of the FBS method to combine test-based and analytical FRFs enables Opel to flexibly use and combine appropriate component models of choice during each stage of the development process.”

By deploying hybrid simulation in the concept stage, it becomes possible to efficiently assess a high number of design variants, in support of cascading NVH targets of the full vehicle down to the subassembly and component level. This enables engineering teams to more efficiently determine the components that need modification and to identify the most promising design variants. And when considering increased development responsibilities distributed over different suppliers, FBS allows Opel to more efficiently share targets, models and loads, without giving away detailed product model information, consequently protecting its own proprietary engineering know-how. ■

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