Siemens Digital Industries Software

Component-based transfer path analysis

Guidelines to predict component NVH performance before the first vehicle prototype is built

Executive summary

Transfer path analysis (TPA) is a methodology for mathematically evaluating noise contributions from the source to the receiver. Component-based TPA is a relatively new approach that allows characterization of a noise source component independently from the receiver structure and predicts its behavior when coupled to different receivers. This methodology enables quick assessment of a large number of design variants and permanent proactive control of the noise and vibration (N&V) performance. It allows early detection of potential N&V issues and system optimization at the early design stage.

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1 Introduction

Mechanical systems are becoming more and more demanding in terms of noise and vibration (N&V) performance, in particular given the current trend towards electric and hybrid propulsion. If we take the automotive industry for example, the more the combustion noise is reduced, the more secondary noises like drivetrain, auxiliary systems, road and wind noise become of relevance in terms of vehicle noise comfort. In addition, a major challenge for the mechanical industry is to develop advanced techniques capable of predicting the noise contribution of components early in the development process as a result of shortening of the development cycle, increased number of variants and more complex products. To avoid costly and time-consuming design iterations, OEMs are looking for technologies that enable target assembly noise predictions from individual component models that are derived from simulation or test bench measurements. Historically, tools like frequency-based substructuring and modal coupling allowed for the assembly of various "passive" components that do not have any powered components like electric motors or hydraulic actuators. These active components should be seen as source components in terms of their N&V behavior. In recent years, however, a new technology has emerged which uses the concept of blocked forces as a means to characterize these active components independently of their integrated system application. Component-based TPA explicitly uses this concept to allow the assembly of active and passive components and analyze the noise contributions from active components in the whole system.

2 What is component-based TPA?

Component-based TPA is a TPA approach that allows characterization of a noise source component independently from the receiver structure and enables prediction of its behavior when coupled to different receivers. Figure 1 schematically shows the concept behind component-based TPA. This modular approach enables frontloading of the development process and considerably increases flexibility during the design process. The method allows component suppliers to characterize their product before it is integrated into the final system and to predict the interface interaction with the receiving structure and its contribution to the noise comfort of the final assembly. The characterized components can be combined with test-based or simulation-based components for simulated assembly performance predictions during every milestone of the product development cycle.

3 How can component-based TPA improve product development?

In the development of complex products involving many subassemblies (such as cars, trucks, excavators, helicopters, aircraft, satellites and white goods), N&V problems are unfortunately often only discovered late in the design process. The vibro-acoustic response is hard to simulate because of the difficulty in modeling the complex interactions between the different components (mechanical, electrical, etc.) once they are integrated into the full system. Component-based TPA is a technique that can help to overcome these challenges and provide an alternative in the early-phase N&V development.

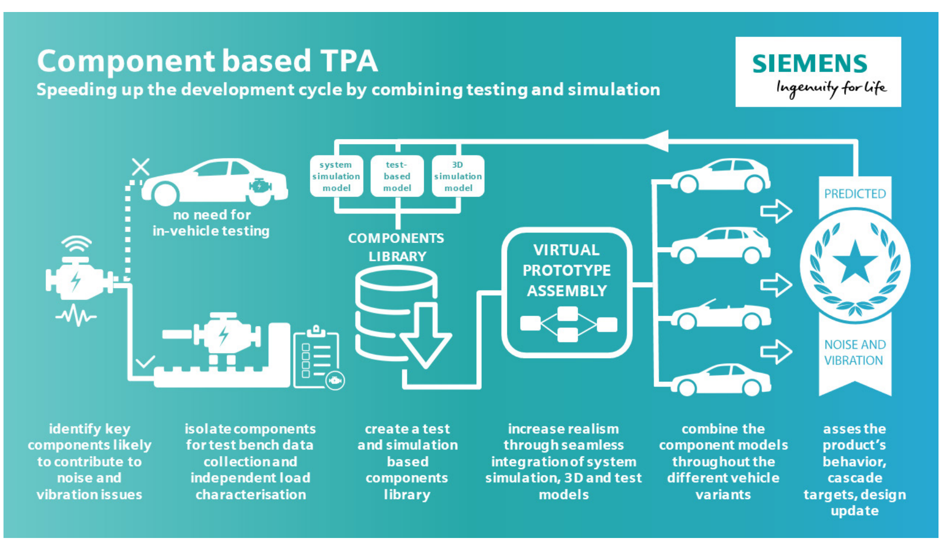

Figure 1: Schematic representation of component-based TPA concept

3.1 Frontloading system-level component noise and vibration testing

For system integrators, the large number of product variants that must be developed challenges engineers in terms of testing work, availability of prototypes and meeting development deadlines. Therefore, they are investigating solutions that can help them meet the N&V design targets for all the variants while keeping development time and cost under control. Component-based TPA is considered a very promising technique for front-loading full vehicle-level system validation throughout the development process. This concept of virtual prototyping, shown in figure 2 for vehicle engineering, enables quick assessment of large numbers of design variants and permanent proactive control of N&V performance. It allows early detection of potential issues and system optimization at a stage where the impact and cost of making modifications are still acceptable.

3.2 Realistic component target setting

Having good design targets is important for maintaining control of the N&V performance of the end product, avoiding costly changes and eliminating many discussions with component suppliers at the end of the development phase. Setting good design targets is not easy, especially when dealing with new components and system architectures. Using independent loads for design target specifications of components can be a way to keep control of N&V performance. Component suppliers will be able to validate sources against receiver-independent targets and OEMs can get an independent load description from suppliers to run target assembly simulations on any variant of the end product and for any scenario.

Further on, during the realization phase of the product lifecycle, quality assurance departments can use these independent load target levels. Where classic operational response spectral levels provide coarse data, dependent on the measurement setup boundary conditions and background effects, the use of calibrated transfer functions (frequency response functions - FRFs) and independent loads can reduce these measurement uncertainties. This allows engineers to reduce the guard band that is basically a safety factor between the acceptance limit and the tolerance limit, influencing the conformance decision risk.

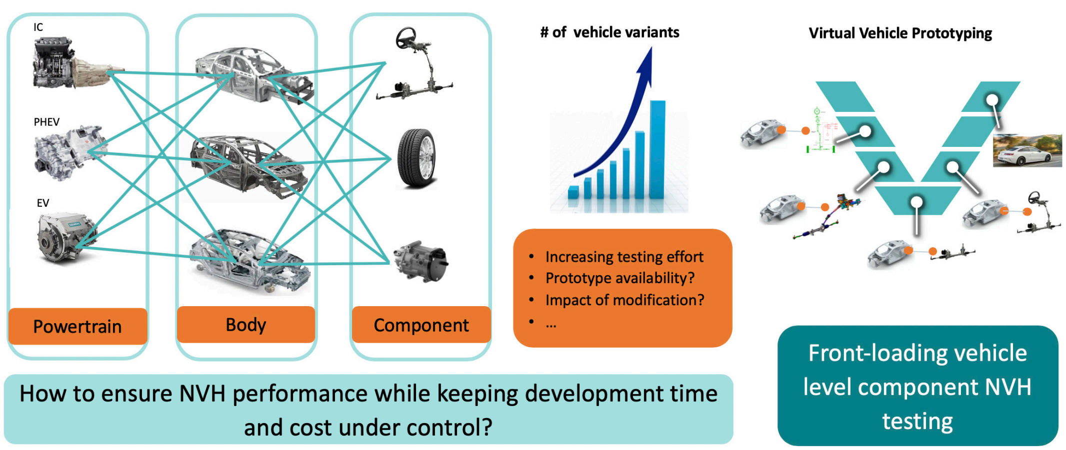

Figure 2: Virtual prototyping concept for vehicle engineering

4 Classical TPA versus component-based TPA

Classical TPA identifies the contact forces that are transmitted between the source and the receiver.[1, 2, 3] Contact forces are dependent on the assembled system and can in general not be transferred to different receivers, since the contact force depends on both the source and the receiver (full assembled system). Therefore contact forces cannot be used for predictive engineering analysis, especially in cases of strongly coupled systems.[32]

Component-based TPA on the other hand describes the source independently from a specific receiver via an independent source description: e.g. blocked forces.[5, 8, 9, 22] These are allowed to be transfered to another receiver for predicitive analysis. This is illustrated in figure 3 with an example. Assume a supplier using classical TPA for contact force identification of an electric motor on a component test rig and exchanging them with an OEM for target assembly prediction.

The predicted target response deviates significantly from the real measured target because in general contact forces are receiver-dependent and will be different when the component is mounted in a different receiver. On the other hand, when the source is characterized independently (e.g. by means of blocked forces or free velocities) it enables more realistic assembly response predictions, together with the information on the connection point impedances of the source and receiver system.

5 Component-based TPA process

Component-based TPA is a relatively new TPA technique that enables engineers to characterize a source component independently from the receiver structure by a set of blocked forces and to predict its behavior when coupled to different receivers, allowing the building of virtual target assemblies.[10, 11, 12, 13, 21] The different steps are depicted in figure 4 and will be discussed in detail.

5.1 Independent source charcterization

Quantities that independently characterize sources of structure-borne sound and vibration are the free velocity and the blocked force. Three possible methodologies to obtain the independent source description will be discussed. The methods below assume that the internal source mechanism (e.g. an idealized imposed force or displacement source) is unaffected by any modification to the receiver.

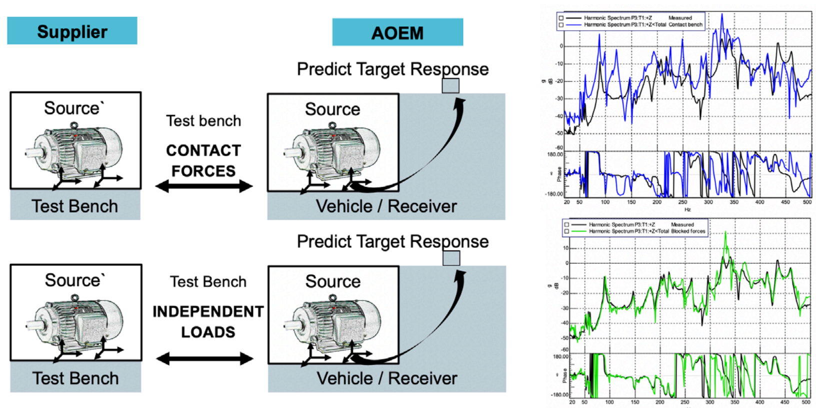

Figure 3: Comparison of measured and predicted target response using contact forces and blocked forces

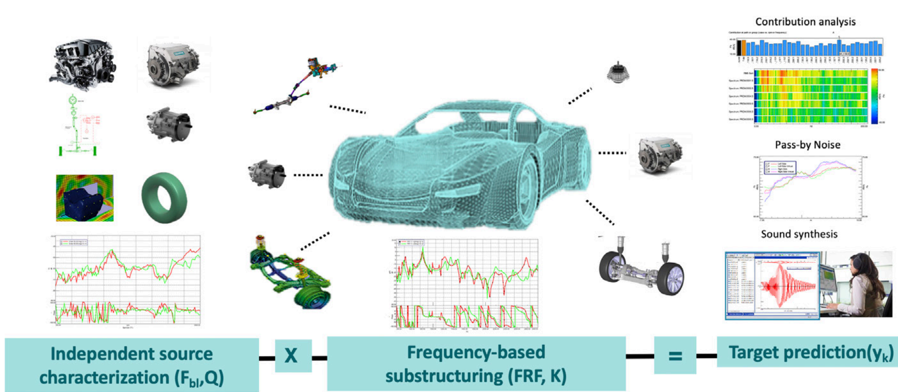

Figure 4: Steps for building virtual target assemblies

Blocked force method

The first method is the direct measurement of the blocked forces. The interface contact points of the component must be clamped or blocked as shown in figure 5. This is done by connecting the source to an infinitely rigid boundary that has no resonances in the frequency band of interest. In practice, however, measuring operating forces from a source in a rigid boundary condition can be challenging or even impossible.

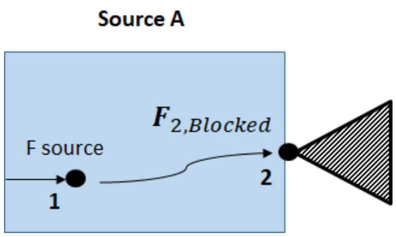

Figure 5: Direct measurement of blocked forces

Free velocity blocked force method

An alternative way to independently characterize the source is using free velocities as described in literature [7, 26] and shown in figure 6. The free velocity represents the interface connections motion of the source component during operating conditions and suspended in free space. In practice, this source characterization cannot be generally applied to all the source components. It can be experimentally achieved with relatively small source components such as an electrical steering motor or with heavy sources that can be mounted resiliently such as a combustion engine resting on its engine mounts, which have the effect of isolating the engine vibration completely from the support structure above a certain (low) frequency.

Blocked forces can be derived from free velocities knowing the free mobility matrix of the uncoupled source component (H_{22}^{A}), as in equation 1:

$$F_{2,Blocked} = [H_{22}^{A}]^{-1} \cdot u_{2\,free} \qquad [1]$$

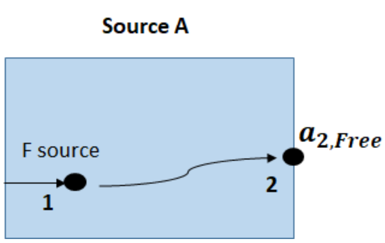

Figure 6: Source contact interface points can freely move

In-situ TPA blocked force method

For applications in which it is not feasible to characterize the source separately from a receiver, the "in-situ" TPA method can be applied. [23, 24, 25] This method can be applied with the source installed on a test rig or in-situ in a particular assembly.

Assume a system composed of two components: a source A and a receiver B, as schematically shown in figure 7. The blocked force is estimated in an indirect way using matrix inversion. Indicator accelerometers are installed on the receiving structure for operational and FRF measurements. The blocked forces identified at the interface connections between the two components can then be calculated using equation 2:

$$F_{2,Blocked} = [H_{j2}^{AB}]^{-1} \cdot u_j \qquad [2]$$

Where H_{j2}^{AB} is the FRF matrix of the coupled system between all the interface connection and any indicator point j on the receiver component receiver B.

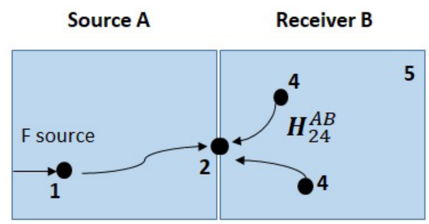

Figure 7: Schematic representation of a source-receiver assembly system

Note the difference with classical TPA where contact forces are identified and the required FRF data is measured with the source disconnected from the receiver. The contact forces $(F_{3,c})$ identified at the connection between the two components can be calculated using equation 3:

$$F_{3,c} = [H_{j3}^{B}]^{-1} \cdot u_j \quad [3]$$

Where H_{j3}^{B} is the FRF matrix of the uncoupled receiver between the connection and any point j on the receiver component B.

5.2 Target assembly

The identified blocked forces, combined with coupled FRFs, allow prediction of the final total contribution in the full assembled system without having to physically integrate the source and the receivers. Coupled FRFs can be experimentally measured if the assembly is physically available. Alternatively, when only the single components are available, or even only partially available, frequency-based substructuring (FBS) is applied to calculate the FRFs of the coupled setup starting from the FRFs of the uncoupled source and receiver. In essence, FBS combines the FRF from the different components (source and receiver) into a new assembled FRF set of the assembled structure. These FRFs can be obtained experimentally or from numerical models.[4, 18, 19]

The coupling of individual components A and B into an assembly AB requires that each component can be described by means of its FRFs system matrix measured in free-free conditions, since the FBS theory assumes the components to be fully decoupled. When components A and B are rigidly coupled into assembly AB, the FRFs of the coupled structure can be calculated using the dual assembly formulation/Lagrange multiplier FBS, equation 4: [4,6]

$$H^{AB} = \begin{bmatrix} H^A_{11} & H^A_{12} & 0 \\ H^A_{21} & H^A_{22} & 0 \\ 0 & 0 & H^B_{44} \end{bmatrix} - \begin{bmatrix} H^A_{12} \\ H^A_{22} \\ -H^B_{43} \end{bmatrix} \cdot [H^A_{22} + H^B_{33}]^{-1} \cdot \begin{bmatrix} H^A_{12} \\ H^A_{22} \\ -H^B_{43} \end{bmatrix}^T \quad [4]$$

Assembling experimentally measured FRFs from individual components is quite a challenging process. This approach puts high demands on data quality during the component characterization to ensure free-free conditions and linear behavior at the boundaries. Errors in the substructure FRFs can be dramatically amplified, especially if the conditioning of the FRF matrices is bad: if a structure is lightly damped, then the FRF matrices will be nearly rank one in the vicinity of each resonance. As a result, small measurement errors will generate large errors in the estimation of the stiffness coefficients on the interface.[14, 29] One of the measures that can be taken to mitigate the effect of these errors is to weaken the interface compatibility. Also symmetrization or modal fitting are often applied as a counter measure. [30, 31]

5.3 Target prediction

Once identified, the blocked forces at the interface connection of the source considering equation 1 or equation 2, the response at any target point in the receiver structure (u_r) can be predicted combining the blocked forces with the FBS equation, as in equation 5:

$$u_T = H^{AB}_{T2} . F_{2,Blocked}$$
$$u_T = [H^B_{T3} \cdot [H^A_{22} + H^B_{33} + K^{-1}]^{-1} \cdot H^A_{22}] \cdot F_{2,Blocked} \quad [5]$$

By combining equations 3 and 5, the relation between blocked forces and contact forces is derived, as shown in equation 6:

$$F_{3,c} = [H^A_{22} + H^B_{33} + K^{-1}]^{-1} \cdot H^A_{22} \cdot F_{2,Blocked} \quad [6]$$

In case the source is characterized using free velocities, by substituting equation 1 in equation 6, contact forces can be derived as follows in equation 7:

$$F_{3,c} = [H^A_{22} + H^B_{33}]^{-1} \cdot u_{2\,free} \quad [7]$$

An alternative way of determining the contact forces is described in ISO/CD 21955.[27] It describes how the contact forces of the source on the test bench ($F_{3,Bench}$) can be used to determine the expected contact forces of the source in the final target assembly ($F_{3,c}$) using equation 8. It requires the decoupled inertance matrices of each component (including the test bench) together with the mount stiffness characteristics on the bench and target assembly.

$$F_{3,c} = \left[H^A_{22} + H^B_{33} + K_{\square}^{-1}\right]^{-1} \cdot \left[H^A_{22} + H^{Bench}_{33} + K^{-1}_{Bench}\right] \cdot F_{3,Bench} \quad [8]$$

6 ISO standards

In response to the demand of the industry to have standardized procedures for independent load identification, several standards are available as shown in figure 8.

Choosing which standard to follow is strictly dependent on the application case. The Siemens component-based TPA technology is developed to support all three mentioned stardards. Recent publications in the field of component based TPA and substructuring have proven the experimental applicability of these technologies for predictive engineering analysis starting from component invariant loads [8, 9]. Next the different standards for structure-borne source characterization will be briefly discussed.

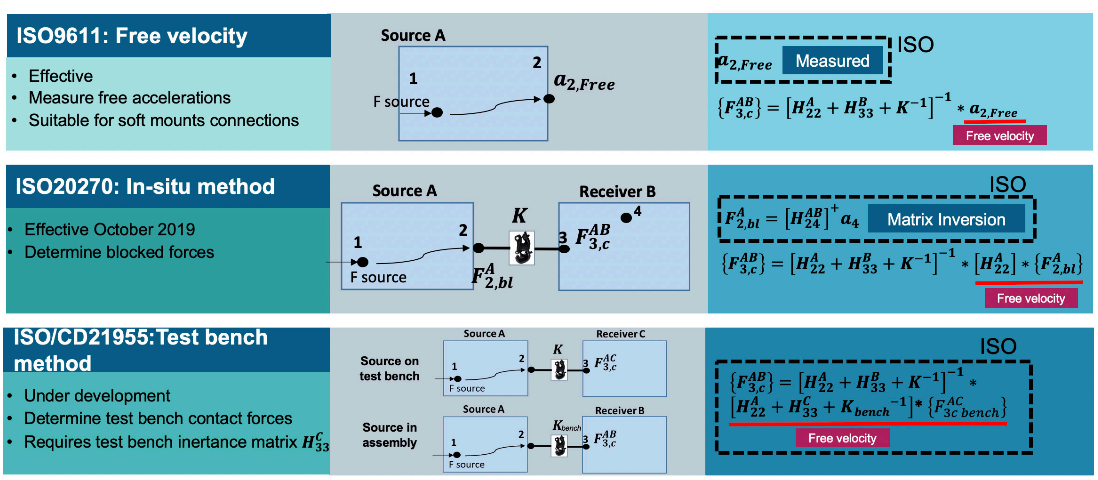

Figure 8: ISO standards

6.1 ISO 9611: Measurement of velocity at the contact points of machinery when resiliently mounted

The ISO 9611:1996 standard defines the experimental measurement procedures to characterize structure-borne noise sources of machines that are mounted on resilient isolators.[26] The methodology uses free velocity measured at the machine connection as a source descriptor. This approach is valid for machines mounted on sufficiently soft isolators that ensure decoupling between the source and the foundation in the frequency of interest.

6.2 ISO 20270: Indirect measurement of blocked forces

Recently the ISO 20270:2019 has been developed as an alternative way to perform source characterization.[28] The standard describes an indirect method for characterizing the source by a set of blocked forces using an inverse method. As decribed in 5.1, the indirect method can be carried out with the source attached to any receiver structure (in-situ). Therefore the receiving structure can be part of a real system, such as a full vehicle, but can also be a designed test bench ensuring that a representative dynamic loading for the source can be performed.

6.3 ISO/CD 21955: Experimental method for transposition of dynamic forces generated by an active component from a test bench to a vehicle

These above mentioned standards describe two alternative ways of characterizing the source, but prediction of sound and vibration in a new assembly is not specifically mentioned in the normative part of these standards. In this context, the French community is developping the ISO/CD 21955.[27] This standard specifies experimental methods to transpose the dynamic forces generated by an active component mounted on a test bench into dynamic forces transmitted to another receiving structure. This standard provides guidelines and recommendations on how to carry out the methods experimentally.

7 Virtual point transformation (VPT)

For correct coupling of individual components using FBS and for correct blocked forces calculations, FRF data is required at exact connection center locations and for completeness both the translational and rotational FRFs need to be considered. In practice however it is not always feasible to measure this data because certain input and output degrees of freedoms (DOFs) cannot be accessed or because of the nonexistence of the physical location.

Virtual point transformation, also called geometrical reduction, can help overcome these limitations. VPT allows transformation of the measured forces, accelerations and FRFs to any geometrical point that fulfills the local rigidity assumption and it provides translational and rotational FRFs.[9, 13, 15, 16, 17] Assuming local rigidity means that the structure between the measured locations and the target ruction location acts as a rigid structure, i.e. there is no local deformation between these points. Since the resulting transformed FRFs only contain the local rigid deformation modes, using these in substructuring context can be advantageous. The remainder of the interface behavior that cannot be described by the local rigid body motion around the connection point will not be assembled: this will weaken the interface compatibility.[29] Lessening the interface compatibility can improve the substructuring results as explained earlier in 5.2.

7.1 Example VPT use cases

In figure 9, simulation data is used to demonstrate the error that can be made in the calculation of blocked forces by means of in-situ TPA when incorrect FRF data is used. In-situ TPA requires the source to be kept in place, preventing exact force excitation at the connection centers. This means that the structure needs to be excited at some distance from the exact position. A comparison between the correct blocked force (in red) and the blocked force calculated with the incorrect FRF data (in blue) shows that the error can be significant. To overcome this, VPT makes it possible to recalculate the off-center FRF data to the correct FRF data at the centerlines of the connections.

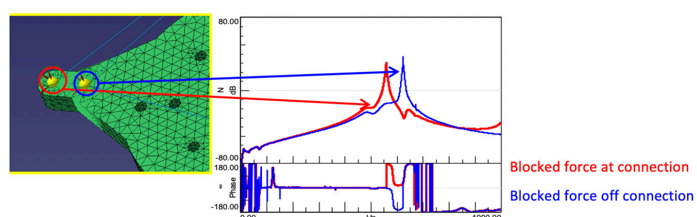

Figure 9: Error in the calculation of blocked forces by means of in-situ TPA when incorrect FRF data is used

Another typical application of VPT is in the context of road-noise analysis for identification of blocked spindle forces and moments and for coupling a wheel-tire system with the suspension using FBS for in-vehicle noise prediction.[8]

For analysis of the wheel spindle forces, VPT is applied to get FRF data with rim center force and moments inputs out of FRFs with input on different locations around the wheel center as shown in figure 10.

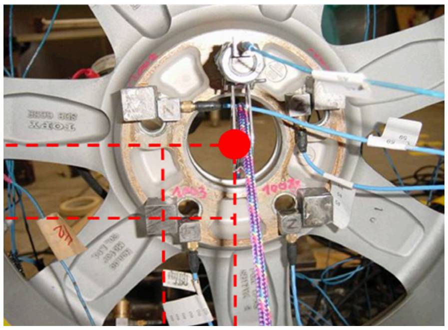

Figure 10: VPT to get FRF data with input at the center of the wheel to identify blocked spindle forces and moments

For FBS, VPT is applied to get FRF data at the exact coupling points of the two assemblies. For the tire the FRF data is reduced to a virtual point at the center of the wheel and for the suspension to the spindle location.

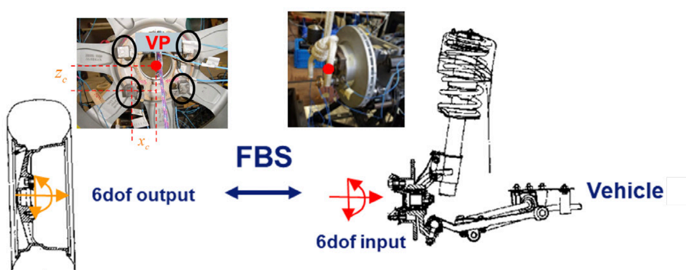

Figure 11: VPT to get FRF data at wheel center and spindle location for FBS

8 Measurement challenges

Measurement of FRFs is a critical element in transfer path analysis and frequency-based substructuring, as solving the equations comes back to inverting FRFs' system matrices as explained above. Small errors and noise on the data tends to be amplified after inversion. Furthermore, when going to higher frequencies including the phase in the overall TPA processing becomes an issue. The spectra become noisy and the coherence of the FRFs low.

8.1 Data accuracy

Several sources of uncertainty contribute to the total measurement uncertainty. One often overlooked source of uncertainty is related to the excitation side of the transfer function acquisition. Alignment of the excitation as well as minimal coupling between exciter and test object are essential during the FRF acquisition.

To ensure high-quality FRF measurements, dedicated electro-dynamic shakers have been developed for TPA applications. The Simcenter™ Qsources range consists of state-of-the-art shakers (figure 12), the specific design of which help ensure:

- easy access to hard to reach locations
- correct shaker angle and position accuracy
- improved repeatability and signal-to-noise ratio
- good excitation levels in relevant frequency range of interest

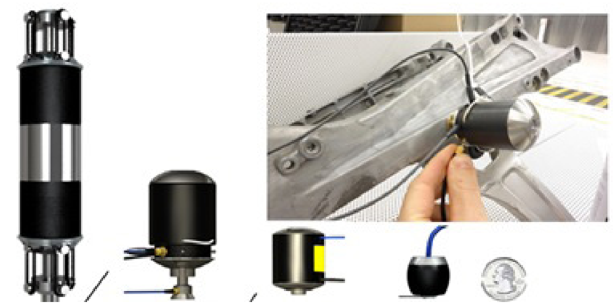

Figure 12: Simcenter Qsources shakers family

8.2 Data validation

TPA models can quickly become very large with thousands of FRF data. Verifying the quality of all these FRFs is almost impossible and certain errors are even harder to detect, such as direction errors. In order to quickly asses the quality of the FRF data, dedicated displays have been developed such as the matrix heatmap shown in figure 13. Dragging and dropping the FRF data in such a display enables instant identification of possible anomalies such as misalignment errors, mass loading effects, reciprocity issues, driving point behavior and nonlinearities.

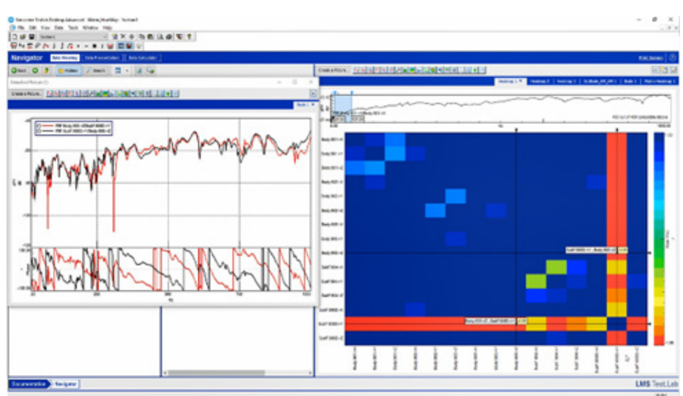

Figure 13: Matrix heatmap display quickly assesses quality of FRF data

9 Experimental case

In this chapter the different steps of the component-based TPA process will be illustrated for a wiper e-motor application case. The different steps of the process are schematically illustrated in figure 14.

In an intial step, independent source characterization is conducted in agreement with:

- ISO 20270: indirect measurement of blocked forces
- ISO 9611: measurement of free velocities

In a second step the identified blocked forces are combined with corresponding FRFs of the new source-receiver target assembly "Engine+SupA".

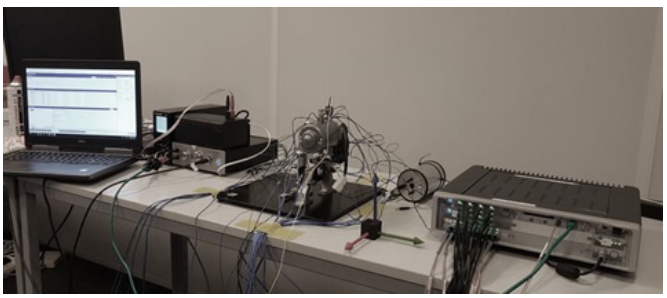

Figure 14: Experimental setup

Finally the target response is predicted to assess the performance of the engine component in the new assembly using:

- Blocked forces
- Free velocities
- ISO/CD 21955

9.1 Experimental setup

The experimental setup is shown in figure 15. The necessary FRFs and noise transfer functions (NTFs) data have been measured with Simcenter™ Testlab™ MIMO FRF testing using a QSource High-frequency Shaker (Q-HSH). The shaker enables structural/vibro-acoustic FRF measurements in the high frequency range (300Hz-10kHz) which is very useful for electrical components or electrified powertrains. The shaker can be installed in any angle without the need for external support and generate a broadband uni-axial force spectrum. For operational measurements, engine run-ups from 300 rpm to 3,000 rpm have been measured using Simcenter Testlab signature acquisition and Simcenter SCADAS hardware.

Two different test setups for the e-motor will be used, shown in figure 16: original assembly "e-motor + test bench " and target assembly "e-motor + receiver". The wiper e-motor is considered as active vibration source. The source has 3 rigid connections points described by 3 translational DOFs (x,y,z). A set of indicators and targets (t1 and t2) accelerometers are placed on the receivers for FRF and operational measurements.

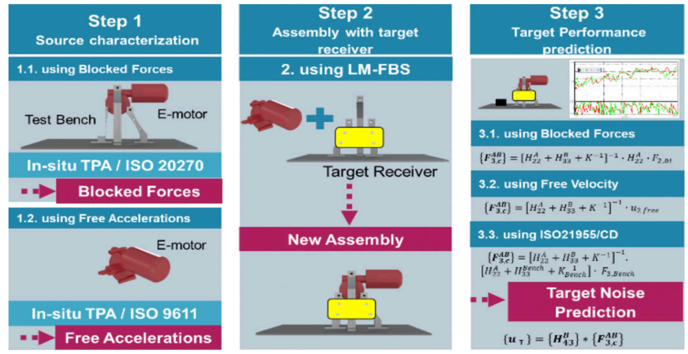

Figure 15: Steps of component TPA process for a wiper e-motor application

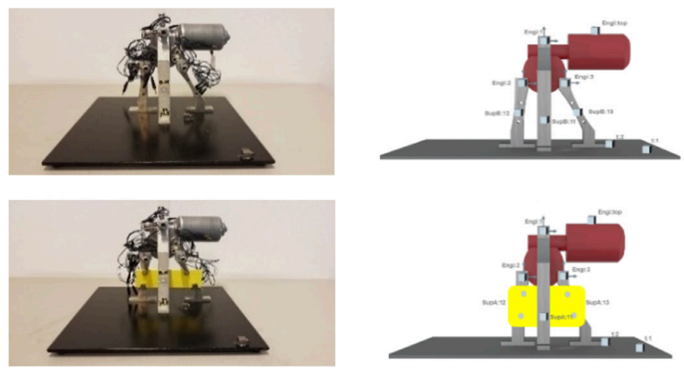

Figure 16: Setups for original and target assemblies

9.2 Source characterization

Blocked forces: cross validation (on-board validation)

The first validation consists of using the in-situ blocked force procedure as described in ISO/DIS 20270 on the original assembly. The blocked forces are calculated using in-situ TPA matrix inversion according to equation 2 and then used to predict the response on the same structure and on targets that were not used for the inversion. Figure 17 shows a very good match between the measured and predicted order spectra over the entire rpm range. This validation can give an idea of the quality of the blocked forces calculation for the considered assembly.

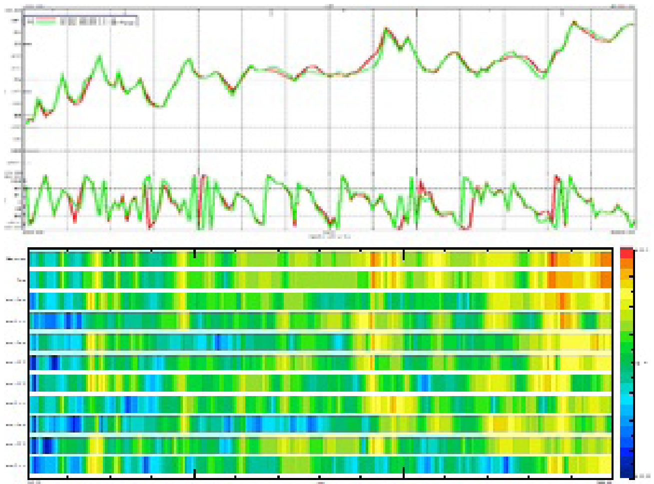

Figure 17: On-board validation in target t1 for order 90.
Top: Comparison of measured target (red) and predicted target (green) using blocked forces determined in-situ from the original assembly.
Bottom: predicted contributions

Blocked forces: transferability validation

As a next step, the identified blocked forces in the original assembly (e-motor + test bench) will be used to predict the response in the target assembly (e-motor + receiver) using measured coupled FRFs of the target assembly. Figure 18 shows a good match between the measured and predicted target over the entire RPM range.

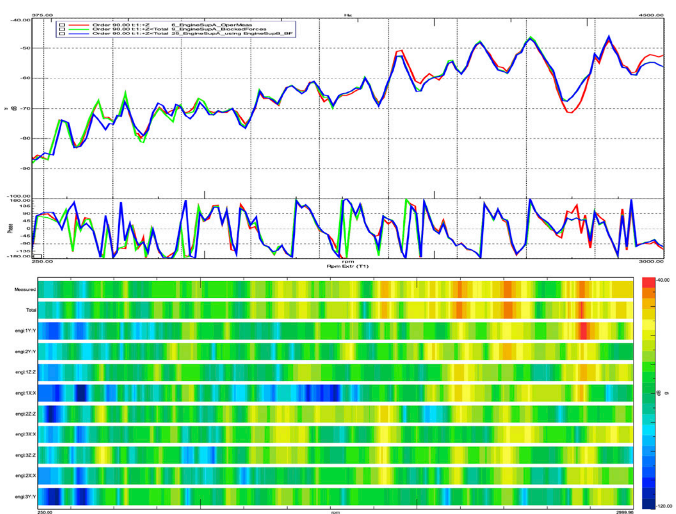

Figure 18: Transferability validation in target t1 for order 90.
Top: Comparison between measured target (red), predicted target using blocked forces in-situ determined on target assembly (green), and predicted target using blocked forces determined in-situ from original assembly (blue). Bottom: predicted contributions

Free velocity characterization

Free velocity measurements of the motor have been conducted as described in ISO 9611. The motor is placed on a resilient surface and operational measurements have been taken at all connection points as shown in figure 19.

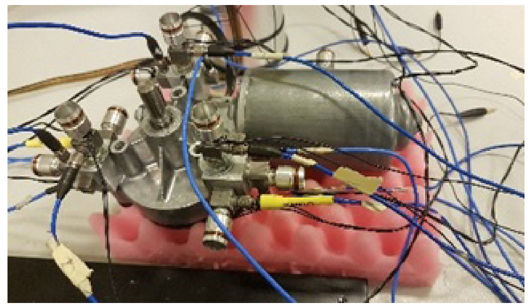

Figure 19: Setup used for free velocity measurements

Figure 20 shows a comparison of the measured and predicted order spectra when applying the free velocities to the target assembly. Although the predicted curve follows the trend of the measured one it can be noticed that the fit is better in the higher rpm range. The use of FBS in the calculations could explain some of the larger deviations of the prediction from the measured target.

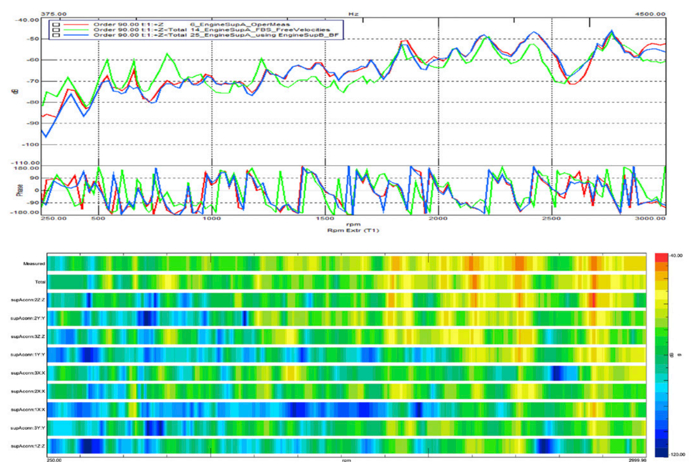

Figure 20: Validation in target t1 of target assembly (engine + SupA) using free velocities. Top: comparison of measured (red) with predicted using free velocities (green) and using blocked forces in-situ determined on original assembly (blue). Bottom: predicted contribution

9.3 Assembly with target receiver

FBS: FRFs comparison

A first direct approach for FBS validation is a comparison of the measured coupled and calculated assembly FRF.

The dual assembly formulation/Lagrange multiplier FBS described in equation 4 is used to determine the target assembly FRF. A comparison with the measured one is shown in figure 21 for target t1 and excitation in x direction in one of the connections.

FBS: contact forces

A second approach to validate the FBS is based on the contact forces comparison. Contact forces obtained from classical TPA are compared with those calculated using blocked forces and FBS as described in equation 6.

Figure 21 and figure 22 again show a relatively good match between the different approaches giving confidence that the components are experimentally well-characterized.

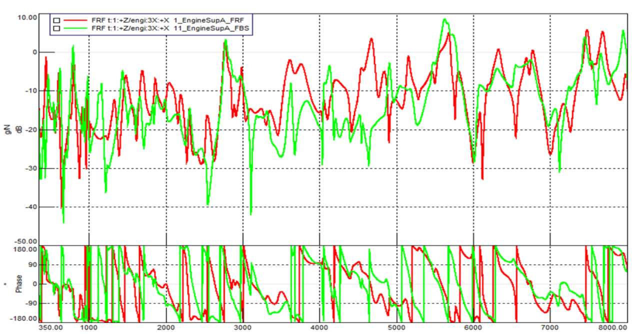

Figure 21: Comparison of measured (red) and calculated (green) coupled FRFs

Figure 22: Comparison of measured (red) and calculated (green) contact forces

9.4 Target performance prediction

FBS and blocked forces

Target prediction can be done by combining the calculated blocked forces with the calculated coupled FRFs of the target assembly from FBS. The target response is predicted with equation 5 and compared with the measured response as shown in figure 23.

ISO/CD 21955 using testbench contact forces

An alternative method for target prediction is based on combining testbench contact forces, testbench inertance, source inertance and target host inertance. Equation 8 is used to convert the test bench contact forces into target assembly contact forces. Figure 24 compares a measured target response with predicted reponses using respectively test bench contact forces and blocked forces.

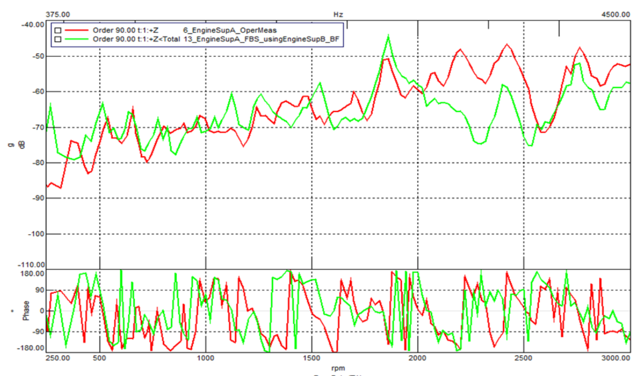

Figure 23: Comparison of measured (red) and predicted (green) target response using blocked forces

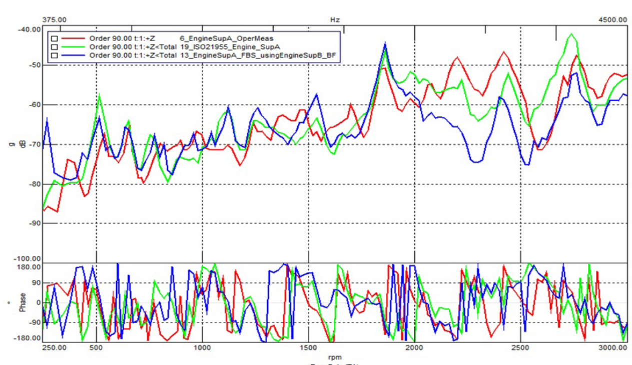

Figure 24: Comparison of measured target (red), predicted using testbench contact forces (red) and predicted target using blocked forces (blue)

9.5 Time domain prediction: auralization

The target predictions can also be performed in time domain. The time domain blocked forces are determined from response time data by converting the FRFs to finite impulse response (FIR) filters. These time domain blocked forces are then used to synthesize time domain target responses in the target assembly for auralization. This way of processing the data not only allows objective evaluation using metrics but also actual listening to the expected noise response.

Figure 25 shows time domain prediction results using Simcenter Testlab time domain TPA. For validation purposes the same processing was applied on the measured target response time trace. The colormaps look very similar.

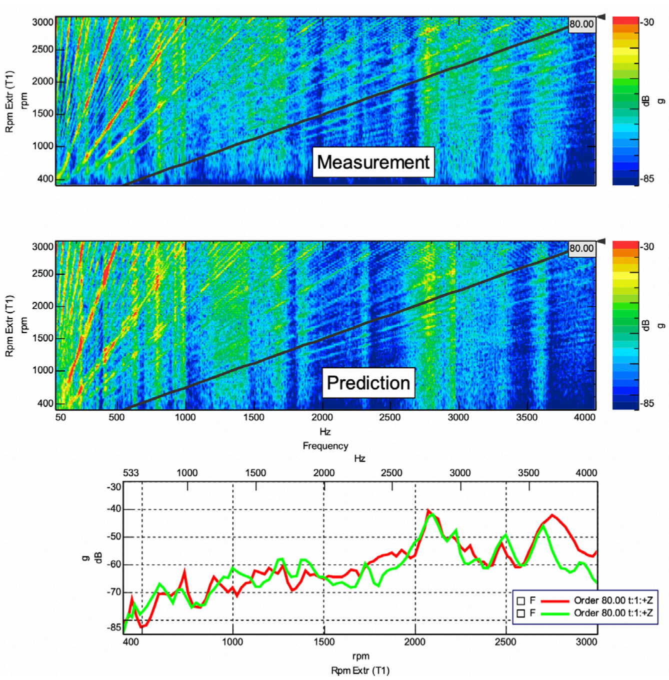

Figure 25: Measured and predicted time domain assembly responses

9.6 Hybrid modification prediction

As discussed, the component-based TPA method allows advanced what-if studies. For example, using finite element modeling techniques in Simcenter™ 3D software, a simulation model of a new target receiver (e.g. an optimized design of the structure) can be generated (see figure 26).

The optimized receiver model can then be combined with the source description of the e-motor to create a hybrid environment enabling early evaluation of a modified design. After creating the assembly with the new target receiver, the invariant loads can be applied on the new coupled structure to predict the N&V response, thanks to their transferability capability.

In this way, fast evaluations can be performed for each design iteration and the N&V performance can be consistently monitored during these design steps. This process also supports the user in setting realistic design targets for each component in the assembly.

To unlock the full potential of this approach, however, the data exchange between simulation and test teams and supplier and integration engineers needs to be facilitated. Dedicated model data management systems are set up to support this exchange. They guide the users through the process of supplying the compatible component models and generating assemblies in an automatic way for noise prediction and target cascading purposes.

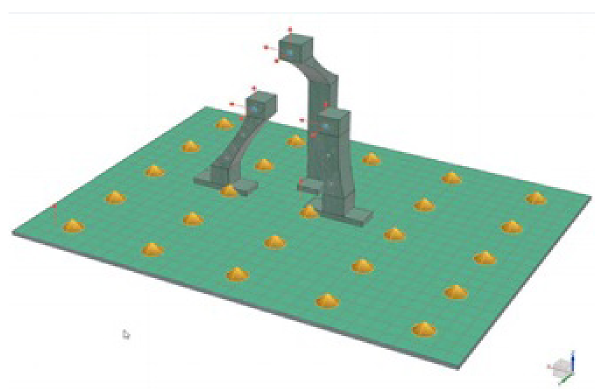

Figure 26: A target receiver structure FE model can be combined with e-motor source description for hybrid target predictions

Summary

Component-based transfer path analysis is a relatively new approach that allows evaluation of the source component contributions from dedicated test rig measurements early in the product development process. The objective of component-based TPA is to identify the independent source loads from test rig data, and combine these with a receiving structure using FRF-based substructuring methods or measured noise transfer function to predict its N&V performance in the virtually assembled configuration.

This concept of virtual prototyping enables quick assessment of a large number of design variants and permanent proactive control of the N&V performance. It allows early detection of potential N&V issues and system optimization at a stage where the impact and cost of making modifications are still limited.

Using the e-motor application case, the potential of component-based TPA process has been demonstrated. In a first step the e-motor was characterized independently using different techniques (e.g. blocked force and free velocities). In a second step assembly predictions were made using substructuring techniques that can help accelerate engineering decisions.

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Siemens Digital Industries Software

Headquarters
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas
Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe
Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific
Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

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