CUSTOMER STORY // AUTOMOTIVE ENGINEERING

MULTI-BODY SIMULATION OF TRUCK MOUNTINGS ON ROUGH ROAD CONDITIONS

optiSLang enables a simulation of loads based on fast and cost-effective measurable signals for an efficient assessment of changes to the drivetrain configuration without the repetition of expensive driving tests.

Introduction

In the simulation of large mechanical systems such as full vehicle models, you have to retain the behavior of the interaction of multiple moving parts and also the behavior of complex force elements as simply as possible. In general, there are limits due to time and cost constraints, but above all, by the necessary parameterization of the many individual components of a system. One of the main difficulties in modelling is the reduction of the complex behavior of an individual component to its fundamental behavior without changing the overall behavior. The over-simplification of the force coupling elements leads to poor results of the simulation. The consequent necessary assessment and verification of the simulation results can be done via the comparison of the measured and simulated data.

The investigated MBS model is neglecting the elasticity of the supporting frame as well as the elasticity of all components of the drivetrain and it is reproduced by means of rigid bodies, which are connected by ideal joints and force elements. It is important to represent the properties of the main force coupling elements in sufficient detail, which is why the modelling of elastomeric bushings plays a special role. Due to its material properties, the elastomeric bushing characteristics show a high scattering. Thus, they are ideal leverage points for a possible fine tuning in order to compensate previous model assumptions. Through careful selection of individual bushing model parameters and the use of nonlinear stiffness and damping characteristics, insufficient assumptions are partially compensated. In practice, parameter identification tools can take over the very time-consuming data input of the force coupling elements and optimize the result to a given target. In this context, the data input is now defined by means of comparison between the results of simulated and measured data as an optimization problem. The parameter identification of an MBS-submodel for the gearbox elastomer bushing enables the automated and optimized adjustment of the simulation with the measurement results. For this purpose, the elastomeric bushings of the engine and the gearbox are dynamically measured on a hydro-pulse test bench and these parameters are used as initial values in the process loop with the optimization software optiSLang and the multi-body simulation software Simpack. A frequency and amplitude-dependent elastomeric bushing model in Simpack is the necessary prerequisite for the examination of the dynamic behavior.

Optimization process

In drive tests on rough roads, accelerations at individual points of the frame and the drivetrain are measured. From the measured accelerations, frame motion is calculated back to its rigid body motion in order to obtain real excitation signals for the frame in the simulation. In the multi-body simulation, this frame is specified as a motion function of time to finally obtain the simulated time behavior of the bushing forces and acceleration signals from the drivetrain.

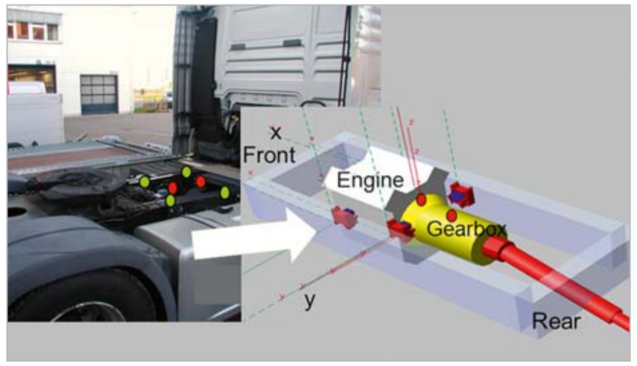

Fig. 1: MBS modelling | Green dots – acceleration sensors on the frame for calculation of the rigid excitation (input data for MBS simulation) | red dots – acceleration sensors for verification process (output data for MBS simulation)

To assess the quality of the simulated bushing forces, the model is verified by comparing the additionally measured acceleration signals on the engine and the gearbox from the driving test and the corresponding accelerations from the simulation.

By using suitable optimization software, you can automatize the process of 'manual' parameter search for the best possible correlation between measurement and simulation. In this case, the algorithm compares the results of the simulation with the detected rough road acceleration signals of the drivetrain and determines the deviation of the defined target function. To minimize the objective function, optiSLang differentiates between gradient method, response surface optimization (response surface methods) and stochastic search strategies.

The used algorithm 'Adaptive Response Surface Method' (ARSM) optimizes on the response surface of an approximation of the objective function. Pre-investigations have already shown that the parameter identification of elastomeric bushings for the complete test drive generates no satisfactory results. The challenging task is therefore to derive an optimization strategy that allows a separate consideration of the individual parts of the track for the extraction of individual parameters and characteristics. So, linear parameters have to be separated from nonlinear parameters through careful selection of individual maneuvers.

After completion of parameter identification, there must be a quantitative evaluation of the optimized result of the simulation with the measured values of the driving test. For this purpose, statistical methods are used. The calculation of the damage has proven to be a sensitive rating scale to represent a quantitative comparison of two curves. It is a pseudo-damage which is determined by assuming a 'virtual' fatigue life curve, so that the damage values allow relative comparisons.

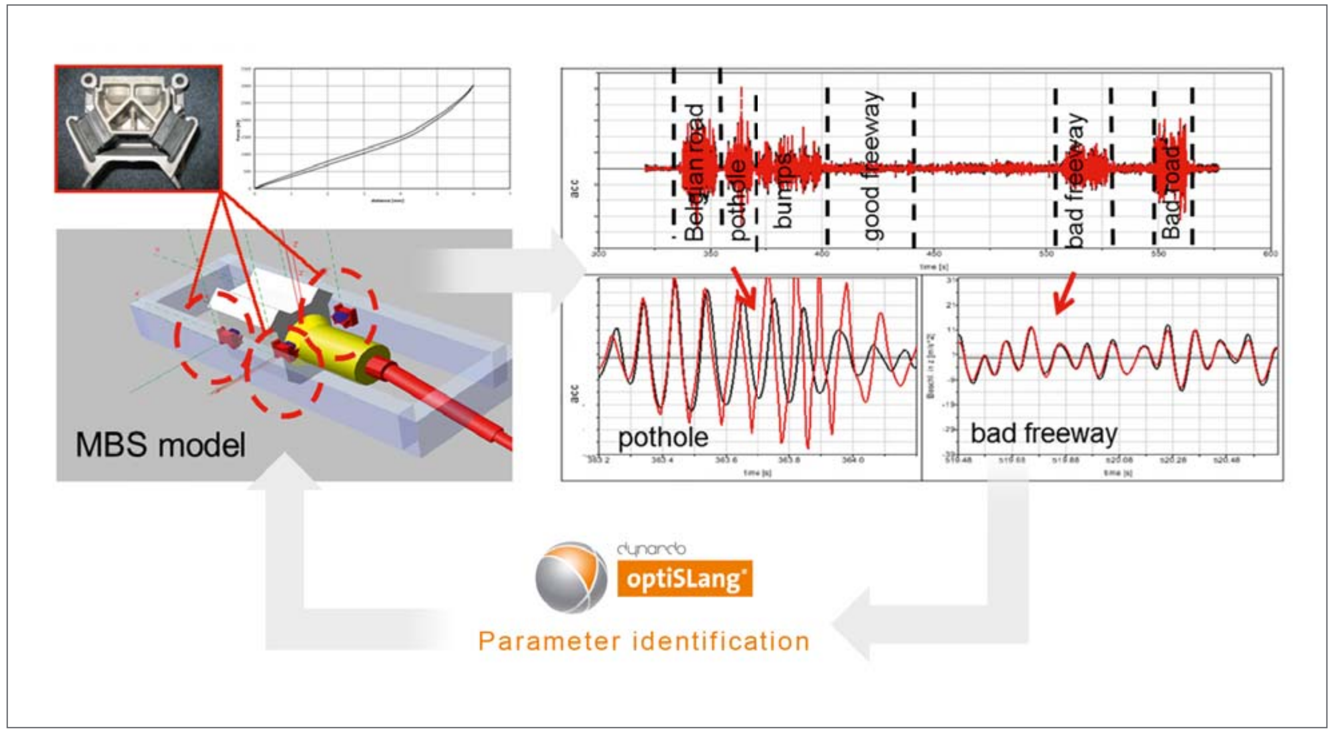

Fig. 2: Process loop of the identification process | black curves – measured accelaration signals = optimization target | red curves – simulation result of current optimization loop

Derivation of the optimization strategy

The determination of good start design values is very important for the optimization process. Therefore, dynamically measured characteristics from a hydro-pulse test bench of engine and gearbox mounts were used. At the beginning, optimization experiments were started emanating from arbitrary start design values. Also, the attempt of the simultaneous identification of engine and gearbox mounts parameters did not yield a satisfactory result. Thus, the engine mount parameters were finally kept constant with the data input from the hydro-pulse measurement. Overall, many different variants of starting parameters (different stiffness model parameters, damping sizes, other model control variables, etc.) were tried out in order to identify early trends of positive result impacts.

In this context, the use of different optimization targets had a very large influence on the result. The method used at the beginning of the study of 'Euclidean norm' turned out to be ineffective in this case. Finally, the maximum and minimum ordinate, within predefined time ranges, so called slots, was used. Thus, the absolute values of the extreme value differences between simulation and measurement were added in the respective directions of the bushings and the optimization target was the minimization of the total value. Also, the use of two locally separated acceleration values on the

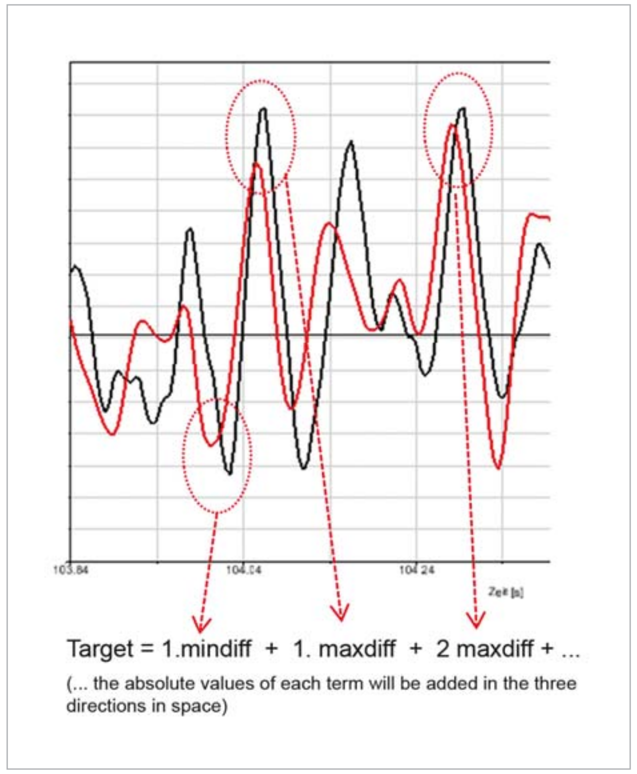

Fig. 3: Process loop of the identification process

drivetrain within the target size calculation was an important detail. Otherwise, the rigid body rotation of the drivetrain would not have been properly recognized. First, the bushing parameters of the three spatial directions could be identified, each separated from one another. At the end, the optimization was done in all three spatial directions together with reduced parameter limits.

The essential idea of the developed optimization strategy

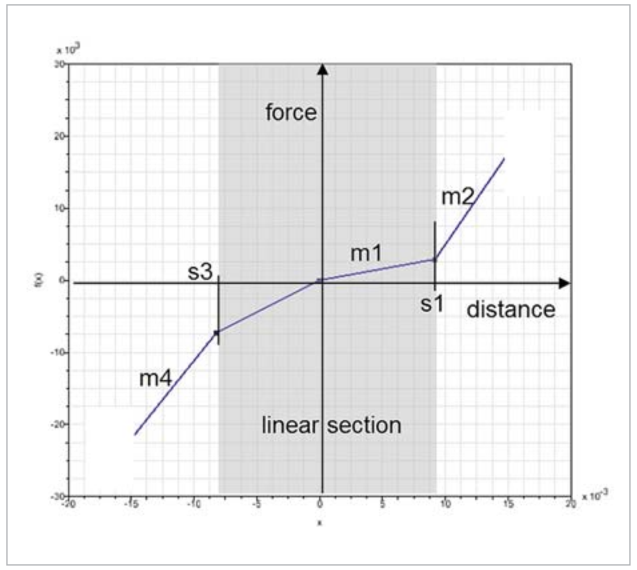

Fig. 4: Identification of stiffness characteristics

rested then on the assumption that there were sections of the complete track where only linear parts of the stiffness characteristics of the elastomeric bushings were loaded. Also, equal sections of the track were present where the

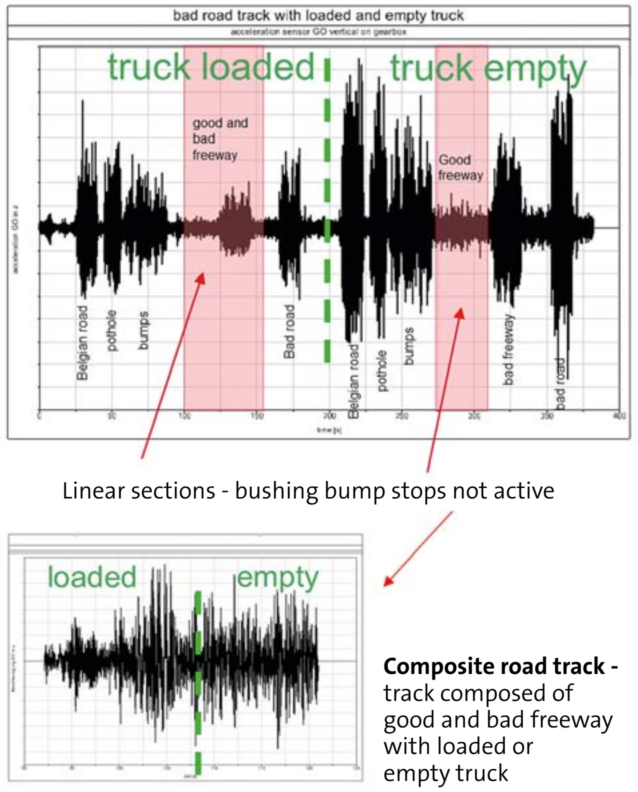

Fig. 5: Composition of linear sections

Automotive Engineering

mounts operated in the nonlinear region of the stiffness characteristics. Such a process would be a response of the bump stops, which is implemented through the input of nonlinear stiffness characteristics. Creating such stiffness, a characteristics was achieved by identifying four parameters, which were respectively identified by the algorithm.

Sections that addressed only linear regions of the stiffness characteristics were considered as 'good' and 'bad' freeway. Here, the bump stops were not active. They were composed for the loaded and empty truck to a total 'linear section' of about 30 seconds duration.

The same procedure was applied to the areas where the bushings operated in the nonlinear regions of the stiffness characteristics, such as Belgian road and pothole track. Here, the largest amplitudes could be seen. The composed parts of the track had a time span of 15s.

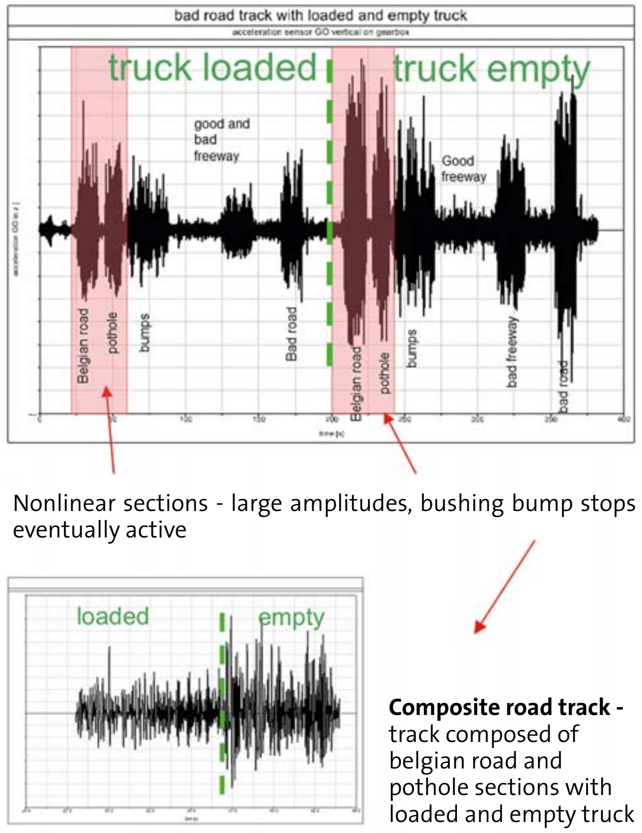

Fig. 6: Composition of nonlinear sections

During the identification process of the non-linear parts of the bushing characteristics, the previously identified linear parameters of the bushing model were kept constant, so the individual identification loops were built on one another. A complete run of such an identification process took about 38 hours, with about 2700 calls of the MBS simulation. In order to keep the total time small, the duration of the composite sections for the MBS simulation should be kept as short as possible. During the total 8 process runs, the bushing parameters for the three spatial directions were first identified individually, then together and third also regarding the breakdown in linear and non-linear sections.

Results

After the application of the derived optimization strategy in the separated identification process, the recalculation of the total track with the identified parameter from the linear and nonlinear sections was conducted. The diagram below shows the acceleration values of the sensor GO (gearbox above) in the three spatial directions (x, y horizontal lateral and z vertical).

The measured rough road accelerations were compared with the accelerations obtained from simulation.

- measured rough road accelerations (black)
- calculated accelerations (green) with the unchanged bushing values from the hydro-pulse (MBS simulation without parameter optimization)

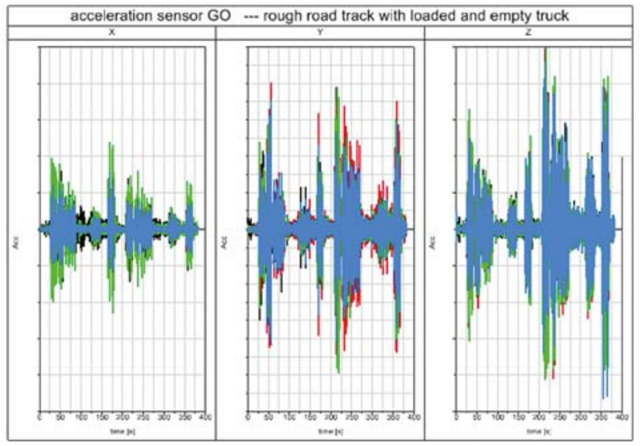

Fig. 7: Time history of acceleration data | black - measured data, green - simulated accelarations with dynamic measurements of the mounts, red - simulated accelarations after first optimization, blue - simulated accelarations after second optimization

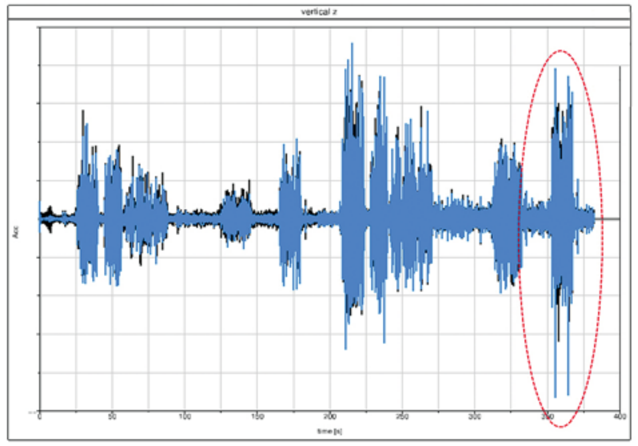

Fig. 8: Time history of vertical acceleration data | black - measured data, blue - simulated accelarations after second optimization

- accelerations of the optimized simulations after identification of linear parts (red)
- accelerations of the optimized simulations after identification of nonlinear parts (blue).

The diagram of the measured and simulated vertical accelerations shows the very good fitting for medium and small amplitudes. Especially for large amplitudes, the result quality was significantly improved by incorporating the nonlinearity in the stiffness characteristic. The largest deviations existed in the track section "bad national road" for the empty truck (framed in red area), because this section was not taken into account in the identification loop of the nonlinear bushing characteristics. In retrospect, especially for the identification of nonlinear characteristics, all relevant road sections had to be considered in order to achieve quantitatively good results.

The representation in time domain, as shown above, can offer a rough overview, but a significant comparison criterion is missing. Classification methods, such as level crossing count (diagram below), allows a better evaluation of the quantitative comparison. The level crossing counting shows the important information regarding the number and the level of amplitudes. Only in the identification of the linear parts of the mount characteristics did the rare extreme amplitudes still show large deviations (red curve). However, the improvement in the adaptation of large amplitudes due to the identification of the nonlinear bump stops is clearly shown in the diagram below.

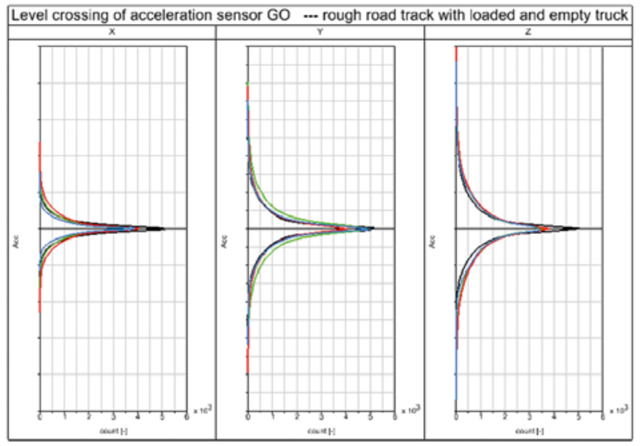

Fig. 9: Level crossing count | black - measured data, green - simulated accelarations with dynamic measurements of the mounts, red - simulated accelarations after first optimization, blue - simulated accelarations after second optimization

A good correlation of the maximum amplitudes concerning amount and number was, of course, extremely relevant for the durability calculations. Amplitudes which were smaller than 20% of the maximum amplitudes had a minor influence on durability.

A further contemplation was the calculation of the damage. The calculation of the damage provided a criterion that allowed the quantitative assessment and comparison of curves with a single value. The damage calculation was done by assuming a 'virtual' fatigue life curve, so the damage values allowed a relative comparison.

The damage calculation of the measured and the simulated accelerations showed the efficient improvement of the optimization process carried out. The existing deviations were due to the unconsidered sections of the track and, of course, due to the assumptions made during model building.

Overall, there was a positive development of the calculated damage for each spatial direction. The efficiency of the developed optimization process was obvious. The variances in the damage could be qualified by the fact that even within several measured accelerations from rough road track, a deviation of 30% in the damage could be detected.

		pseudo damage	normalized damage
GO in X		1.38E-15	1.00
GO in X		8.30E-15	6.04
GO in X		2.97E-15	2.16
GO in X		4.03E-16	0.29
GO in Y		3.49E-14	1.00
GO in Y		9.65E-14	2.77
GO in Y		1.38E-13	3.96
GO in Y		3.90E-14	1.12
GO in Z		8.07E-14	1.00
GO in Z		3.62E-13	4.49
GO in Z		2.58E-13	3.20
GO in Z		1.44E-13	1.78

Fig. 10: Table of pseudo damage | black - measured data from rough road track, green - simulated accelarations with dynamic measurements of the mounts, red-simulated accelarations after first optimization (linear section), blue - simulated accelarations after second optimization (non-linear section)

Conclusion

The optimization strategy derived from this study utilized the fact that in some track sections the mounts acted exclusively in the linear parts of the stiffness characteristics. On the other hand, there were sections of the track where the mounts operated in the nonlinear part of the bushing characteristics. Only through targeted splitting of the complete track and the adaptation of an individual optimization strategy on the identification process, could a very good fitting for medium and smaller amplitudes be achieved. The high damage potential of large load amplitudes required a high correlation with the measurement. This balance must be considered by the incorporation of nonlinearity in the stiffness characteristic during the identification process. The largest deviation occurred in the section 'bad road' of the empty truck, because this section was not taken into account in the identification process of the nonlinear bushing characteristics. It was recommended that during the identification process, all sections with large amplitudes should have been considered in order to obtain quantitatively good results.

Overall, the methodology of automated parameter identification played an important part in the alternative load determination process for gearbox housings. For this purpose, it was necessary to derive a problem dependent, individually tailored optimization strategy in order to achieve the desired result. Only after the successful development of such a suitable process was it possible to generate quantitatively useful results for the calculation of durability. However, if the presented methodology shall be used for identifying load spectra for the component testing of gearbox housings, the results have to be robust and safe. Due to this and also for the generation of meaningful simulation models, parameters have to be scattered within their possible physical limits. The influence of scatter on the result must be exactly assessed.

In this way, reliable load limits for the design can be derived and defined. This next step can also be reached with the used optimization software in the existing process loop.

Author // A. Rasch (ZF Friedrichshafen AG)
Source // www.dynardo.de/en/library

Automotive Engineering