Optimization strategy for the identification of elastomer parameters of truck mountings for the improved adjustment of Multi-Body Simulation data with measured values on rough road conditions

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Abstract

With a simple multi-body simulation model of a truck drivetrain mounted in its frame, loads are calculated on the gearbox housing. The presented alternative process to calculate loads based on fast and cost-effective measurable signals should enable the efficient assessment of changes to the drivetrain configuration, without the required costly repetitions of driving tests on rough roads with complex measurement and sensor technology. It is also preferable to avoid the complex model building of complete vehicles in the simulation, including the often expensive tire models and road data. One of the main difficulties in building an appropriate, simple simulation model is the reduction of the complex behaviour of individual components to their essential behaviour without changing the overall behaviour. The over-simplification of the force coupling elements leads to poor results of the overall simulation. Therefore, there's a need for monitoring the calculated results. The necessary assessment and verification of the simulation results is done via the comparison of the measured and simulated accelerations of the drivetrain. A parameter identification of the MBS submodel for the truck mount is used for the tuning of the simulation to match with the measurement results. The time-consuming manual data input of the force coupling elements, here the elastomeric bushing, is done by a parameter identification tool that automatically optimizes the result to a specified target, namely the successful adjustment of the simulation and the given measurement. Finally, the aim is the implementation and development of the identification process presented as an important component in this alternative load determination process.

Keywords: measurement, multi-body simulation, drivetrain, bushing

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1 Motivation

In the simulation of large mechanical systems, such as full vehicle models, you have to retain the behaviour of the interaction of multiple moving parts and also the behaviour of complex force elements as simple 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 behaviour of an individual component to its fundamental behaviour without changing the overall behaviour. 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. So 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 a 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 behaviour.

2 Optimization process

In drive tests on rough road, 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 behaviour of the bushing forces and acceleration signals from drivetrain.

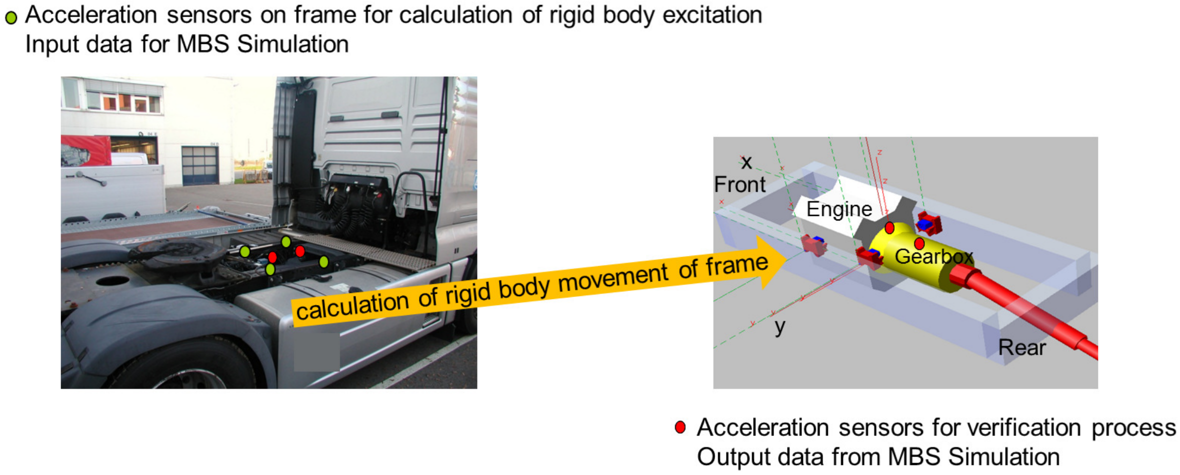

Figure 1: MBS modelling

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 driving test and the corresponding accelerations from 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 drive train 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.

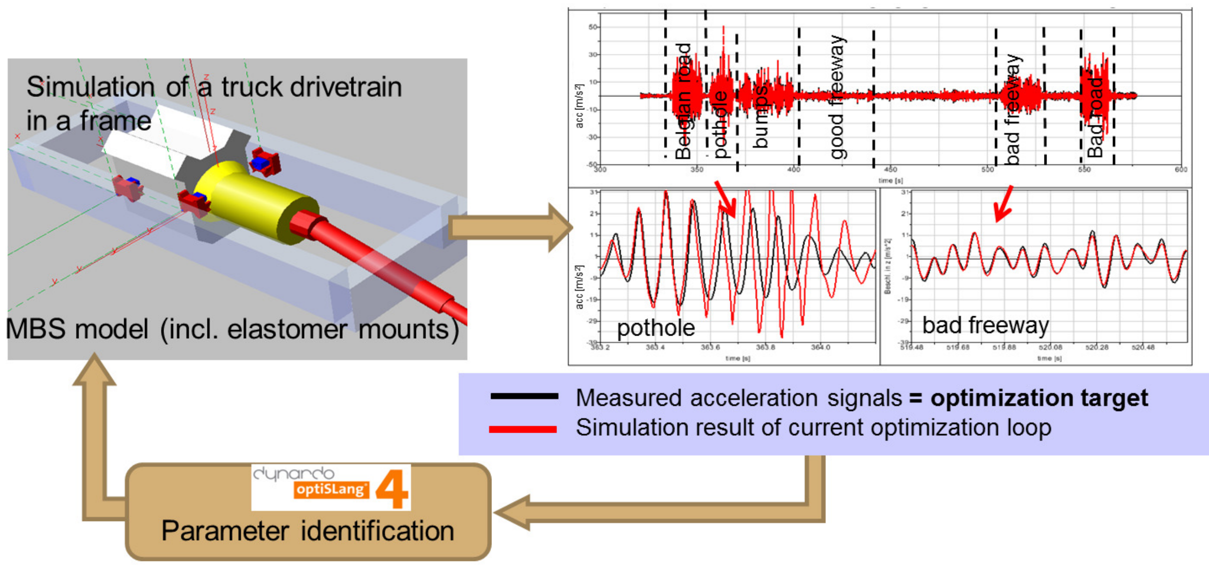

Figure 2: Process loop of the identification process

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 for the extraction of individual parameters and characteristics by a separate consideration of the individual parts of the track. So, linear parameters have to be separated from nonlinear parameters through careful selection of individual manoeuvres.
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.

3 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 are used. At the beginning, optimization experiments were started emanating from arbitrary start design values. Also the attempt by the simultaneous identification of engine and gearbox mounts parameters did not yield a satisfactory result, so that 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 are added in the respective directions of the bushings and the optimization target is the minimization of the total value.

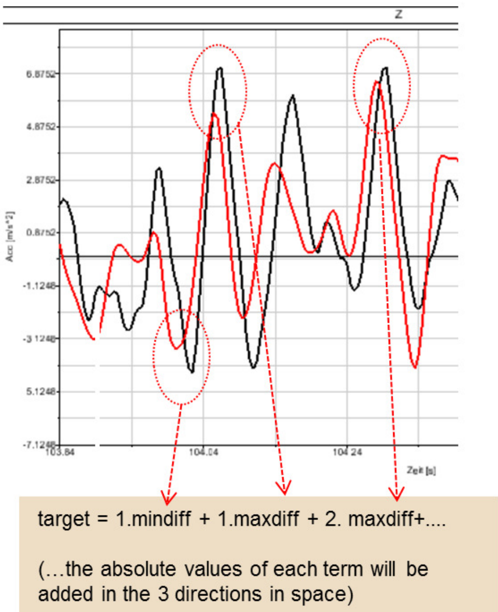

Figure 3: Process loop of the identification process
Also the use of two locally separated acceleration values on the drivetrain within the target size calculation is an important detail, since otherwise the rigid body rotation of the drivetrain

is not properly recognized. First, the bushing parameters of the three spatial directions can be identified, each separated from one another, while at the end, the optimization is done in all three spatial directions together with reduced parameter limits.
The essential idea of the developed optimization strategy rests now on the assumption, that there are sections of the complete track, where only linear parts of the stiffness characteristics of the elastomeric bushings are loaded and that equal sections of the track are present, where the mounts operate in the nonlinear region of the stiffness characteristics. A response of the bump stops is such a process, which is implemented through the input of nonlinear stiffness characteristics. Creating such stiffness characteristics is achieved by identifying four parameters, which are respectively identified by the algorithm.

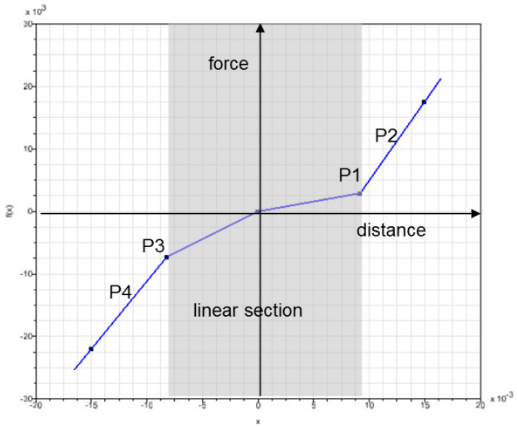

Figure 4: identification of stiffness characteristics

Sections that address only linear regions of the stiffness characteristics are 'good' and 'bad' freeway. Here the bump stops are not active. They are composed for the loaded and empty truck to a total ‘linear section’ of about 30 seconds duration.

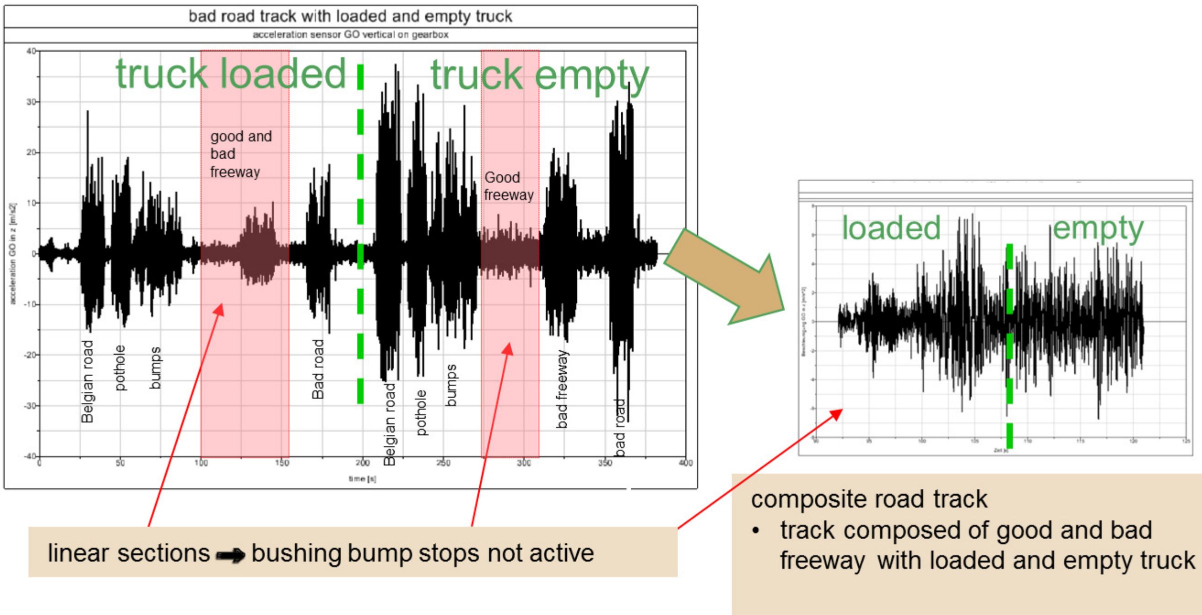

Figure 5: composition of linear sections

The same procedure is applied to the areas where the bushings operates in the nonlinear regions of the stiffness characteristics, such as Belgian road and pothole track. Here are the largest amplitudes visible. The composed parts of the track have a time span of 15s.

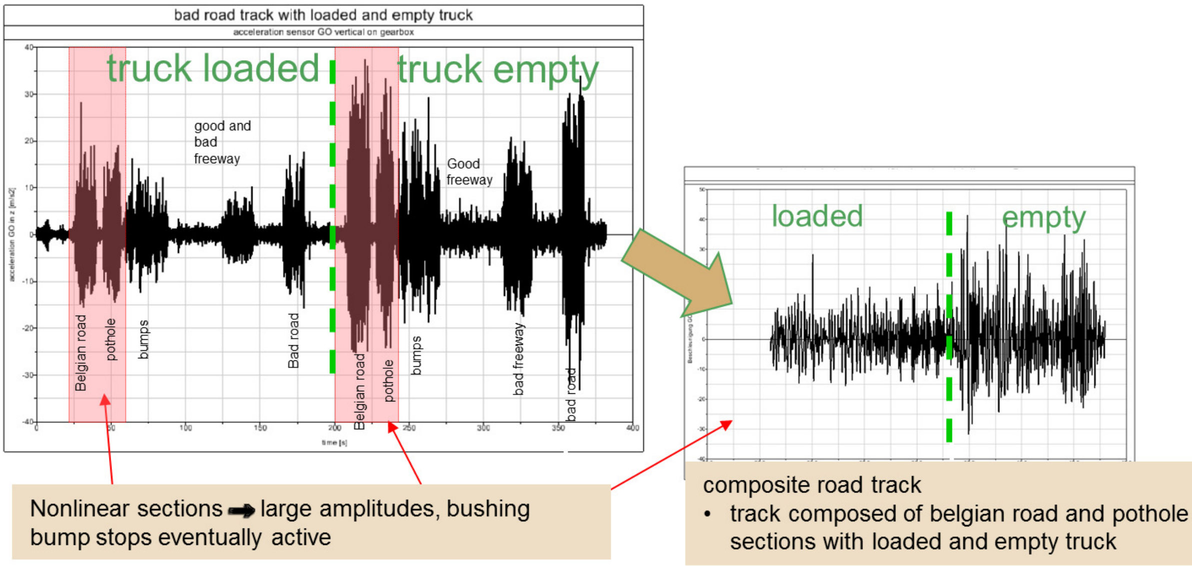

Figure 5: composition of nonlinear sections

During the identification process of the non-linear parts of the bushing characteristics the previously identified linear parameters of the bushing model are kept constant, so that the individual identification loops are built on one another. A complete run of such an identification process takes 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 8 process runs in total, the bushing parameters for the three spatial directions are first identified individually, then together and also regarding the breakdown in linear and non-linear sections,.

4 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 is conducted. The diagram below shows the acceleration values of the sensor GO (gearbox above) in the three spatial directions (horizontal x, y lateral and z vertical).

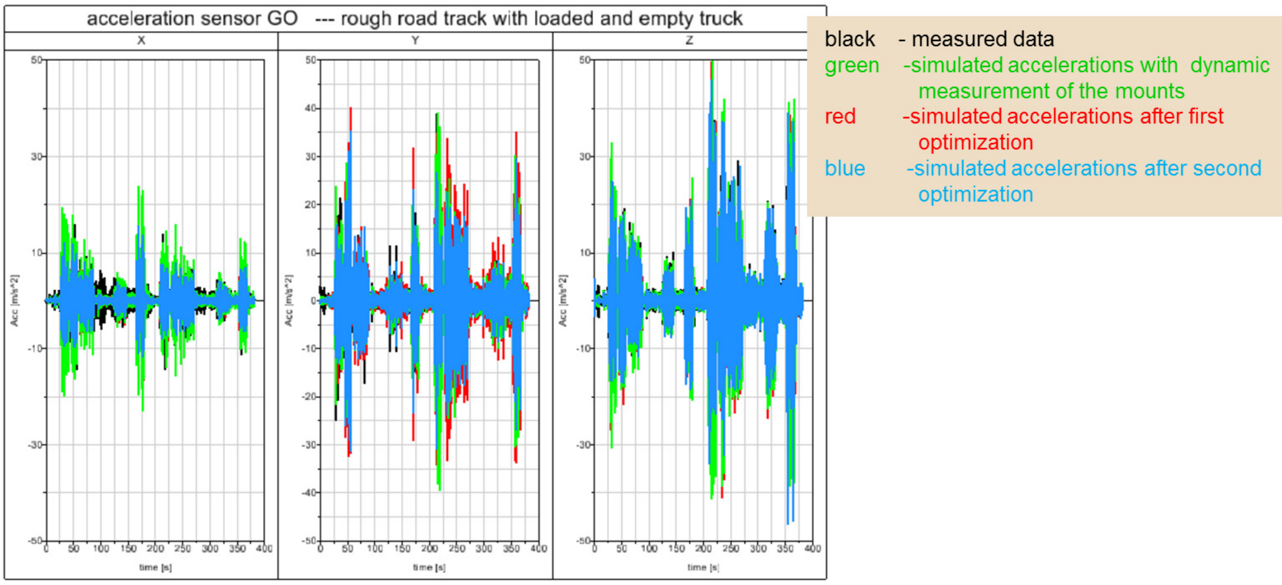

Figure 7: time history of acceleration data

The measured rough road accelerations are 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)
- accelerations of the optimized simulations after identification of linear parts (red)
- accelerations of the optimized simulations after identification of nonlinear parts (blue).

A closer look at the vertical direction is presented in the following diagram.

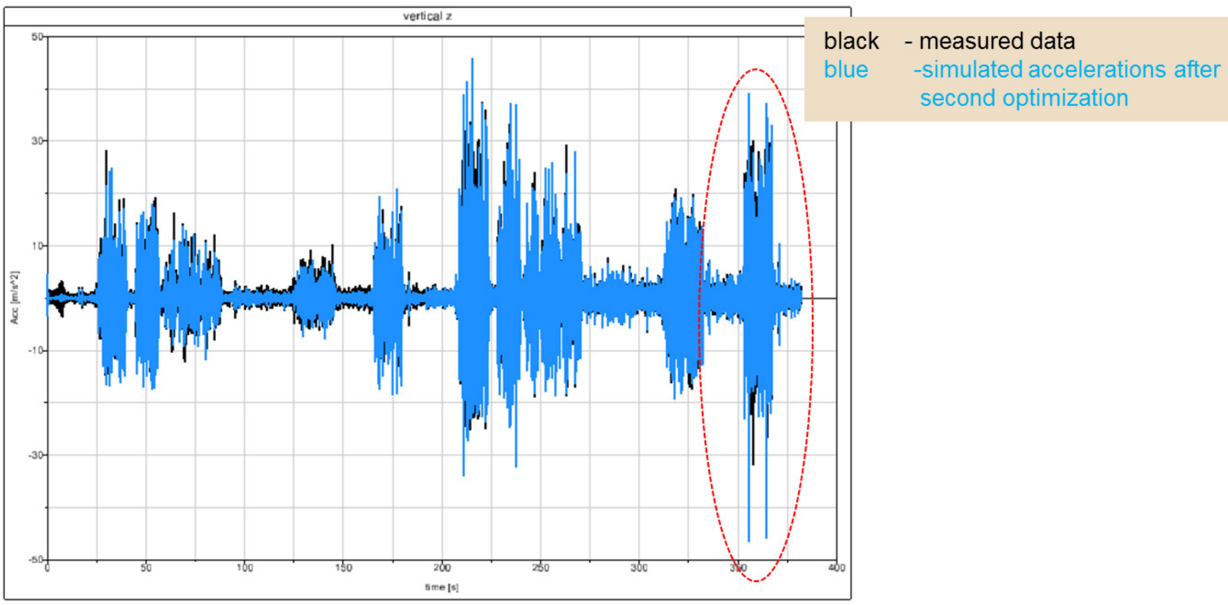

Figure 8: time history of vertical acceleration data

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 exist 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 have 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, 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.

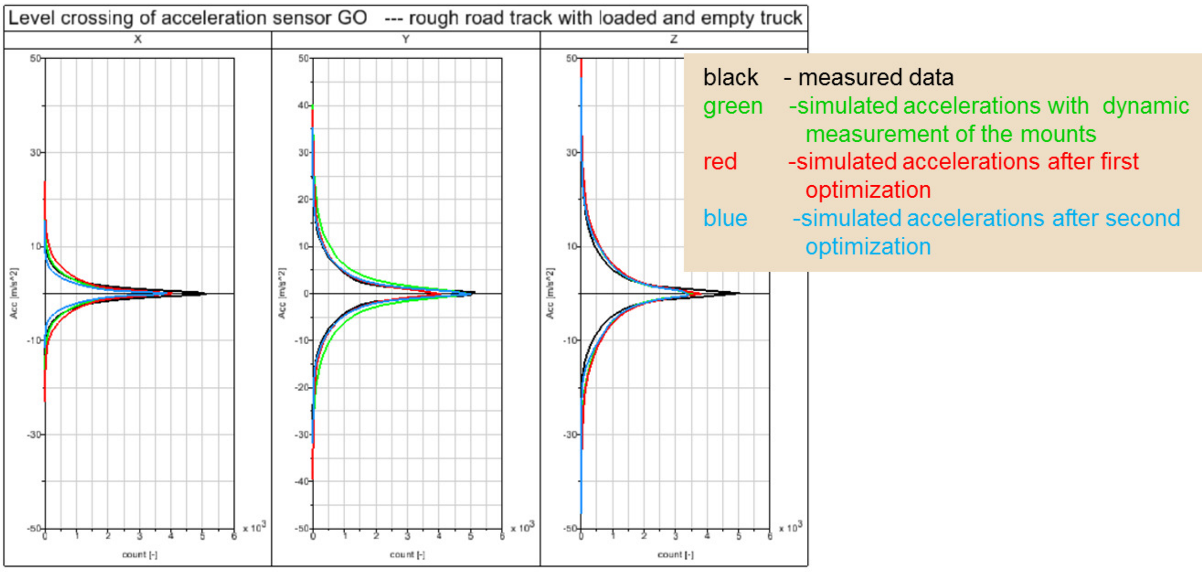

Figure 9: level crossing count

A good correlation of the maximum amplitudes concerning amount and number is of course extremely relevant for the durability calculations. Amplitudes which are smaller than 20% of the maximum amplitudes have minor influence on durability.
A further contemplation is the calculation of the damage. The calculation of the damage provides a criterion that allows the quantitative assessment and comparison of curves with a single value. The damage calculation is done by assuming a 'virtual' fatigue life curve, so that the damage values allow for relative comparisons.

		Pseudo damage	normalized damage
GO in X	measured data from rough road track	1.38E-15	1.00
GO in X	simulated accelerations with dynamic measurement of the mounts	8.30E-15	6.04
GO in X	simulated accelerations after first optimization (linear sections)	2.97E-15	2.16
GO in X	simulated accelerations after second optimization (nonlinear sections)	4.03E-16	0.29
GO in Y	measured data from rough road track	3.49E-14	1.00
GO in Y	simulated accelerations with dynamic measurement of the mounts	9.65E-14	2.77
GO in Y	simulated accelerations after first optimization (linear sections)	1.38E-13	3.96
GO in Y	simulated accelerations after second optimization (nonlinear sections)	3.90E-14	1.12
GO in Z	measured data from rough road track	8.07E-14	1.00
GO in Z	simulated accelerations with dynamic measurement of the mounts	3.62E-13	4.49
GO in Z	simulated accelerations after first optimization (linear sections)	2.58E-13	3.20
GO in Z	simulated accelerations after second optimization (nonlinear sections)	1.44E-13	1.78

Figure 10: table of pseudo damage

The damage calculation of the measured and the simulated accelerations shows the efficient improvement of the optimization process carried out. The existing deviations are due to the not considered sections of the track and, of course, due to the assumptions made during model building.

Overall, there's a positive development of the calculated damage for each spatial direction, the efficiency of the developed optimization process is obvious. The variances in the damage can 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.

5 Conclusion

The optimization strategy derived in the study uses the fact that there are sections of the track, where the mounts act exclusively in the linear parts of the stiffness characteristics and on the other hand that there are sections of the track where the mounts operate 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, very good fitting for medium and smaller amplitudes could be achieved. The high damage potential of large load amplitudes requires a very good correlation with the measurement. This balance must be considered by the incorporation of nonlinearity in the stiffness characteristic by the identification process. The largest deviation occurs 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 is recommended, that during identification process, all sections with large amplitudes have to be considered in order to obtain quantitatively good results.
Overall, the methodology of an automated parameter identification is an important part of the alternative load determination process for gearbox housings. For this purpose, it is necessary to derive a problem dependent, individually tailored optimization strategy in order to achieve the desired result. But after the successful development of such a suitable process, it is 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 on the safe side. Due to this and also for the generation of meaningful simulation models, parameters have to be scattered within their possible physical limits and the influence on the result must be assessed exactly.
In this way, reliable load limits for the design can be derived and defined. This next step can also be realized with the used optimization software in the existing process loop.