

Automated model improvement in dynamic simulation based on road load data measurements

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ABSTRACT: Dynamic simulation results depend mainly on used excitation data and model accuracy. Assumed that the excitation is well known the model parameters play a significant role to get adequate results. Model parameters are often inaccurate, estimated or uncertain. A manual modification of parameters requires a lot of effort and depends on the experience of the engineers. This article presents an automated process to optimize model parameters based on road load data with reasonable run-times. An example of a full vehicle shows the capability of the method where the damper characteristic is optimized to realize an excellent correlation to measurement.

KEY WORDS: vehicle development, computer aided engineering, model optimization

1. INTRODUCTION

A typical dynamic simulation requires a model and its excitation. Based on these two inputs, the goal is often to achieve results which correlate with measured signals, so called road load data (RLD).

If the excitation is known, the model quality is responsible for the simulation accuracy. Important parameters of a dynamic model using multiple body structures (MBS) are mass, mass moment of inertia, locations of center of gravity or stiffness characteristics of the connection elements which are usually inaccurate due to difficulties in definition, identification, modelling type or based on insufficient supplier values. Some other parameters like damper characteristics can change their behavior during life time or often show different behavior between left or right side of suspension.

Such model parameters can be modified manually based on simulation results but this process is usually complex, requires a lot of effort and is not always successful depending on the experience of the engineers.

This article presents an automatic process to optimize model parameters based on RLD, i.e. measurements at the structure. An example of a full vehicle is presented where the damper characteristics is optimized to result in an excellent correlation between simulation and measurement.

2. MODEL IMPROVEMENT

2.1. Approach

The excitation of a dynamic model, typically a multiple body structure (MBS), is usually defined (stochastic road, standard

load cases), measured (forces, WFT signals, digital road) or can be computed based on measured signals at the structure (e.g. virtual iteration process^{(1),(2)}).

The simulation leads to different outputs which can be used for further investigations or can be compared with measured signals. If such a correlation to measurement differs a lot from the real behavior, the model must be analyzed in details for modifications to get a better comparability.

This manual process of parameter modification during the simulation is a typical step in the work flow of a project. This process can be very complex and time-consuming. Therefore an automated process called model improvement (mi) was implemented in the software FEMFAT Lab⁽³⁾. This process allows to improve model parameters of a MSC.ADAMS model automatically based on RLD. Typical used signals of road load data in such a process are:

- Accelerations, one or three axial
- Displacements or angles
- Strain gauges
- Load cells
- WFT - wheel force transducer

Strains reflect the load flow in the structures and are very powerful for this reason. A strain can be used directly or calibrated to a force. If its value is used, a flexible body has to be included in the MBS model for measuring the length of 2 points at the structure. If a strain gauge is calibrated to a force, the force can be used in the MBS model without including a flexible structure. It is often difficult to define exactly the location and

orientation of a strain. The advantage of calibrated forces is that this information is not necessary.

Following MBS parameters can be improved automatically in the new process to achieve a better correlation in measured signals:

- Mass
- Mass moment of inertia: one direction, several directions or one factor on several direction
- Center of gravity: one direction, several directions or one factor on several directions
- SForce element:
 - Translational or rotational
 - Stiffness and/or damping
 - By a value or nonlinear spline
- VForce, GForce or Field (bushing) element:
 - One direction, several directions or one factor on several direction
 - Translational and/or rotational
 - Stiffness and/or damping
 - By a value or nonlinear spline

The improvement can be applied on one element (single, left or right), symmetrical elements (left and right) or on a group of elements.

Summarized, after a dynamic simulation where channels are compared between simulation and measurement and some of these channels do not correlate well, the model improvement can be applied to improve parameters in a way that these channels also correlate with higher accuracy.

For this process all parameters must be defined in the model and will be updated. The excitation is defined and will be not changed during the improvement procedure.

Additionally a diagnose tool is provided by the software which helps the engineer to find out worse defined parameter.

An important issue in the process is the assessment of the accuracy, it is evaluated by a norm and it can be chosen between the relative damage value and the well known root means square value (RMS). The relative damage value reflects the damage content of one signal divided by the damage content of another signal. Therefore the target value is one and this means that both signals have the same damage content accordingly. In the damage a rainflow classification is used and the miner elementary algorithm computes the damage values consequentially. The inclination of the underlying S/N curve in the analysis is fixed and typically defined by five.

The described process will be sketched in the following by the new module model improvement of FEMFAT Lab.

Model improvement requires the MBS model, excitation and the measurement data, the excitation can be included in the measurement data file certainly. The ADAMS model has to be exported in form of adm file and the solver command call must be defined which is usually used for simulations with the external solver at the command line.

The software should be processed step by step during the following sequence, see Fig.1:

1. *Input and output definition*

The measurement data and the channels which should be used will be defined, i.e. not all channels of the measured data must be selected. If the excitation is not already in the adm file included it can be applied to the model from a time series data file (different data formats will be accepted). The selected measured signals have also to be defined by requests for using them in the simulation.

2. *Parameter selection*

All parameters of the model are listed in one row or can be shown by filtering of type, see Fig.1:

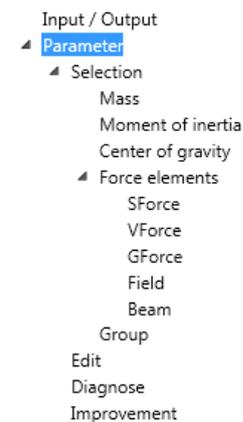


Fig.1 Sequence of process

The parameters which should be investigated have to be selected and can be used afterwards for the diagnose or improvement process.

3. *Edit*

Detailed settings can be defined for each parameter. Typical examples are selection of directions, linear or nonlinear usage of parameter, stiffness or damping selection.

4. *Diagnose*

All selected parameters will be modified by defined variation and simulated. The effect of this variation compared to the original model is displayed by the relative damage value for each channel. A high deviation indicates that the varied parameter has influence to a channel, on the other hand a value close to one indicates that a modification

of this parameter has less impact to the considered channel. From a resulting table (parameter vs. channels) usually the responsible parameter for the inaccuracy can be derived and selected in the dialog *Edit* for the improvement process.

5. *Improvement*

The improvement process requires different settings, one issue is that the target must be defined, it is usually a free definable combination of the channels assessed by relative damage or RMS value. When the improvement process will be started, several an ADAMS simulation runs and each successful improvement step will be displayed by a time plot showing measured and simulated signals. Additionally a convergence plot will be displayed to see the improvement by the defined target. The improvement is finished when the stop criteria is reached, therefore 3 different stop criteria can be selected separated or in a combination:

- Maximal improvement steps
- Minimum difference between 2 improvement steps
- Absolute end time

The resulting new parameter will be saved in a new adm file and can be used for subsequent investigations.

3. FULL VEHICLE EXAMPLE

The simulation was performed by using virtual iteration. Virtual iteration is based on determination of the excitation of a model in the time domain using dynamic simulation (usually multi-body simulation)^{(1),(2)}. The iteration process allows to adjust external loadings applied on a structure with non-linear behavior in such a way that internal measurements, i.e. proper load flow, can be reproduced with desired accuracy (solution of a non-linear inverse problem). The procedure is similar to the iteration process in the laboratory of real test rigs.

The process of automatic model improvement will be applied to this full vehicle example with the iterated excitation where the correlation between resulting simulated and measured damper forces is insufficient.

3.1. Model

The MSC.ADAMS/Car model in Fig.2 was built up including all relevant parts regarding fatigue issues based on road induced loads.

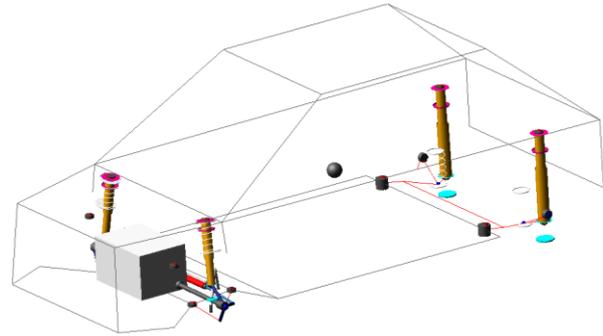


Fig.2 ADAMS model

The excitation was applied at the wheel centers and consists of a GForce element for FX, FY, TX and TZ and a Motion element for vertical displacement (see Fig.3). The GForces and Motions were excited by splines whereby the Motions were computed by virtual iteration in a way that the relative displacements and vertical hub accelerations at the suspensions were achieved (see 3.1.3).

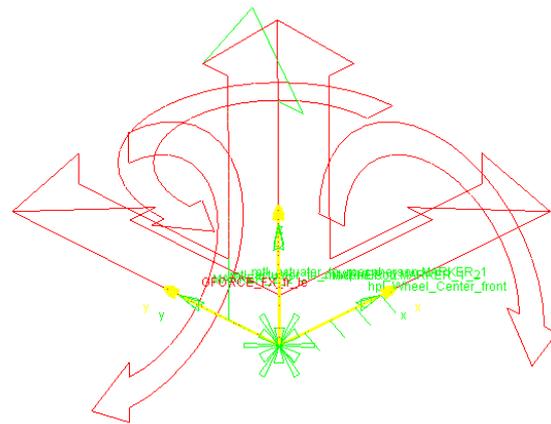


Fig.3 Excitation at each wheel center, GForce element (red) and Motion element (green)

3.2. RLD

The measurement was carried out on different test tracks. For model check, trimming and first simulations usually a maneuver with high amplitudes and high frequency content is used, therefore a part of rough road maneuver was cut and taken for the investigations, see Fig.4. After this first track, all other ones could be simulated with the identified settings and modified model.

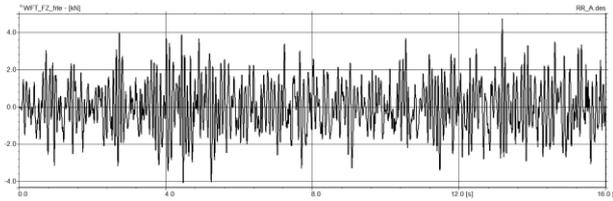


Fig.4 Rough road maneuver for MBS simulation, vertical WFT signal front right



Fig.5 Damper force measurement based on strains



Fig.6 Wheel force transducer

Many channels were measured and for these investigations the following signals were used:

- Spring displacements
- Vertical wheel center accelerations
- Damper forces, Fig.5
- Vertical body accelerations
- WFT (wheel force transducer) signals, Fig.6

3.3. Virtual iteration

The vertical displacements (Motions) at the wheel centers were computed to get the measured spring displacements and vertical wheel center accelerations.

Additionally the measured WFT signals were applied for the remaining directions (no driving torque was applied)

- Longitudinal force
- Lateral force
- Camber torque
- Steering torque

Furthermore the simulated vertical WFT forces, damper forces and vertical body accelerations were compared to measured signals, i.e. these signals were just compared but not used for computation of the vertical motion.

The spring displacements, wheel center accelerations and vertical WFT forces show well correlation, the damper forces and vertical body accelerations differ a lot from measurement at the front suspension, the accuracy at the rear suspension is accurate enough, time signals are shown in Fig.7 and Fig.8, the resulting values are listed in Fig.9.

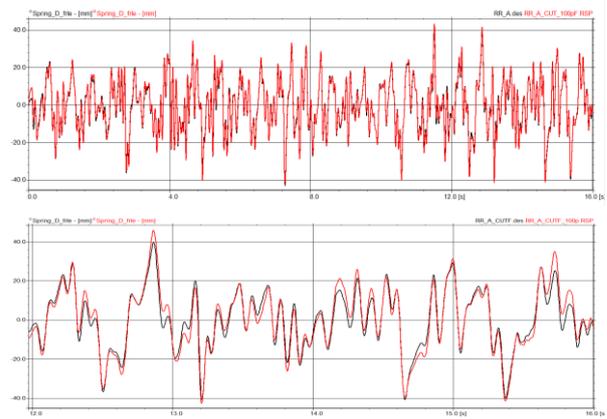


Fig.7 Spring displacement front left, full signal (top) and interval of 4 seconds (bottom)

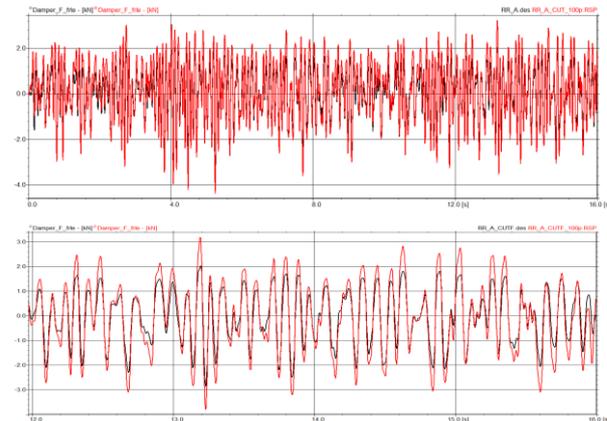


Fig.8 Damper force front left, full signal (top) and interval of 4 seconds (bottom)

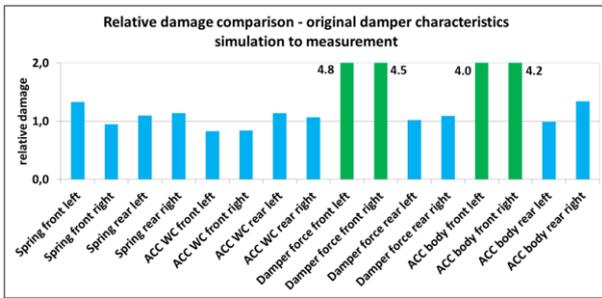


Fig.9 Relative damage values of all channels

3.4. Model improvement

The result of the simulation was not acceptable for the damper forces, therefore the model had to be modified to get a better correlation to measurement of the rough road maneuver.

3.4.1. Damper

In the full vehicle example, the damper forces were inaccurate, therefore the parameter to improve was known and no diagnose study had to be performed. Only the SForce element damper front was selected (symmetrically, i.e. left and right side was improved in the same way). The target of the improvement process was defined as sum of the RMS values of the two front damper forces. Generally a wide range of possibilities can be used for the target definition by an extensive formula editor (see Fig.10). Such targets can be a combination of different channels or channels can be weighted and many other possibilities.

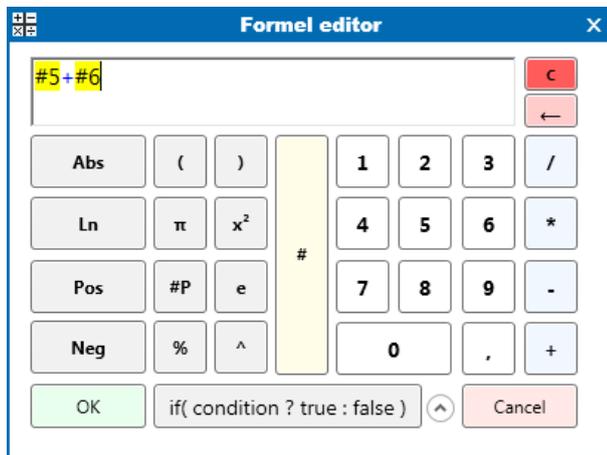


Fig.10 Defining objective function,

the sum of the 2 channels no. 5 (damper force front left) and no. 6 (damper force front right)

The process should stop when the difference in the parameter value between two successive improvement steps was smaller than 5%.

Generally there are two possibilities to modify the damper or bushing characteristics. The existing characteristics can be

modified by applying a factor, i.e. the full curve will be stretched or compressed. The second way is to modify the characteristic nonlinearly, i.e. the curve can change also its qualities like different inclinations and curvatures.

The second method was used for the damper characteristics in this project. Therefore a special GUI (see Fig.11) supports to define parameters of the characteristics. The red points show the values of the original damper spline in the ADAMS model, by pressing the *Fit* button, the blue curve was interpolated and the coefficients defining this curve were the basis for the improvement process. These 6 coefficients are shown in Fig.11 and Fig.12, whereby only SC, SM, VM and ST can be used for an improvement process, Ec and Et will be used for defining the curvature of the characteristics and will be fixed during improvement process.

The 6 coefficients define:

- *ST* – stiffness of tension
- *SC* – stiffness of compression
- *SM* – stiffness in middle section
- *VM* – velocity at edge of the stiffness of tension
- *Et* – curvature of tension characteristics
- *Ec* – curvature of compression characteristics

The values are displayed after pressing the Fit button. Afterwards these values can be still modified and the resulting curve will be shown. If the *Fit* button is not used, the values can be also defined and modified manually. Each coefficients can be deactivated and will be not changed during improvement process consequently.

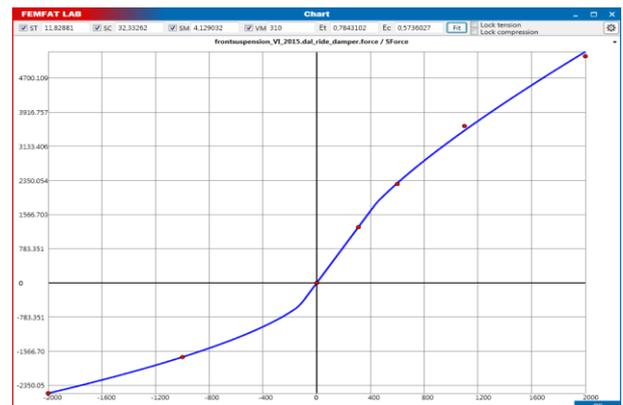


Fig.11 GUI of defining the damper characteristics using 6 coefficients shown at the top of the GUI

Only the 2 coefficients SC and ST were chosen for this improvement because these coefficients are responsible for high amplitudes of the rough road maneuvers, of course also the other 2 parameters SM and VM could be used.

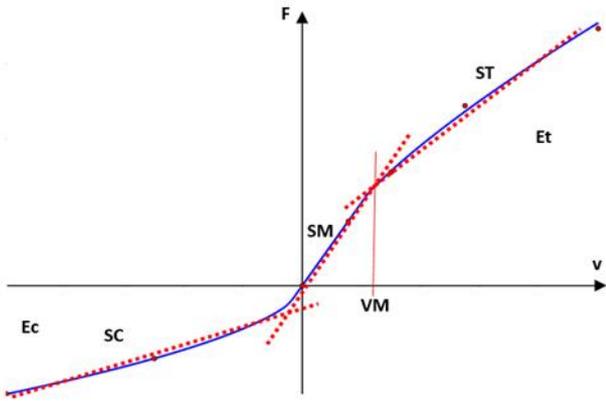


Fig. 12 Description of the 6 coefficient which define the curve

The improvement process was started and stopped automatically when results were not improved more than 5% between 2 consecutive steps anymore. After each improvement step, the GUI of the damper characteristics was updated by the curve in green shown in Fig.13 after first improvement step and in Fig.15 after final step.

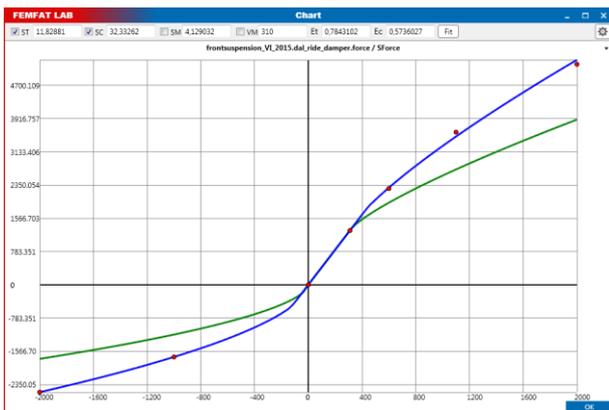


Fig. 13 Original damper characteristics (blue) and improved characteristics after first improvement step (green)

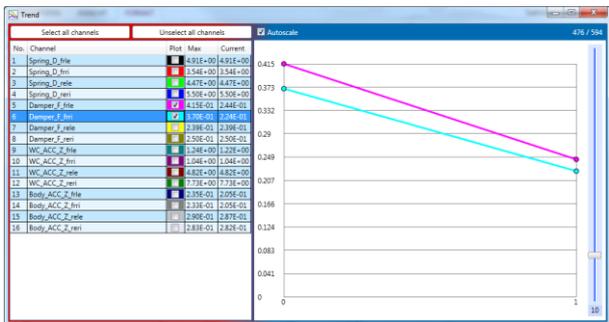


Fig. 14 Convergence behavior of damper forces front, RMS values was reduced with first improvement step

Also the convergence behavior in the selected norm was shown and updated after each improvement step, see Fig.14 and Fig.16. In this example the RMS value was used as norm to assess the accuracy.

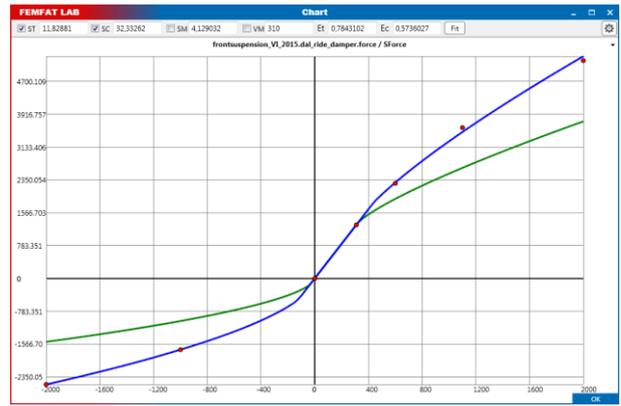


Fig.15 Original damper characteristics (blue) and improved characteristics after finished improvement (green)

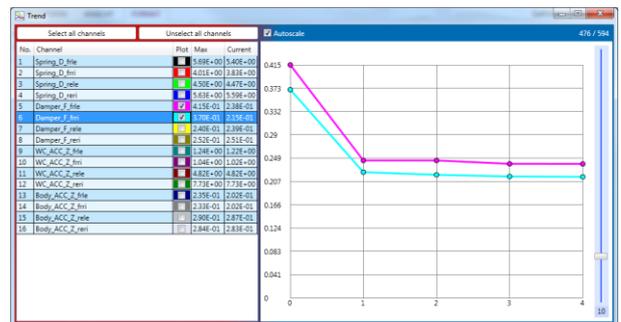


Fig. 16 Convergence behavior of damper forces front, RMS values

Additionally also the resulting damper forces were plotted. In Fig.17 the damper force front left is shown, where the measured signal is black, the simulated force with original damper characteristics in red and the resulting force with improved characteristics in green.

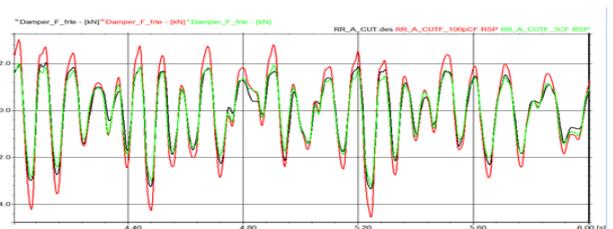


Fig. 17 Short interval of measured and simulated damper force front left, black...measured, red...original characteristics, green...improved characteristics

The damper forces were achieved accurately and the resulting relative damage values are shown in Fig.18, also for a comparison with the original values in Fig. 9.

Overall 14 ADAMS simulations were required until the improvement process stopped.

A new adm file was generated where the updated damper characteristic was included and could be used for the further investigations.

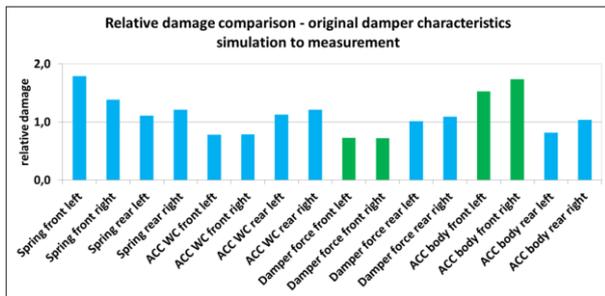


Fig.17 Relative damage values of the improved model compared with measurement

4. CONCLUSION

Model optimization is always a big issue during MBS projects. If measurement data is available, model can be modified in a way that the correlation between simulation and measurement will be increased. Usually this process will be done manually and takes a lot of time. A new process is presented where this modification will be done automatically for a wide range of parameters in an ADAMS model. The presented example shows the capability of this method, specially also applied on nonlinear characteristics. The damper curve could be modified regarding better correlation between simulated and measured damper forces. The method is included in the software FEMFAT Lab and the process is automated for a convenient usage.

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