Full vehicle simulation using virtual iteration to ensure an excellent correlation between measurement and simulation

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ABSTRACT: Dynamic simulation results depend strongly on the used excitation data. Input signals from test track or test rig are often not yet available, extremely expensive or cannot be measured. The method of virtual iteration represents a well-rounded solution to handle this problem. Vertical displacements at the wheel centers or at the tire contact patches can be computed in such a way that measured internal signals can be reproduced and small model parameter deviations can be compensated. Available measured wheel forces can be easily applied additionally for achieving an excellent convergence between measurement and simulation.

KEY WORDS: **vehicle development, computer aided engineering, load simulation,** virtual iteration (B2)

1. INTRODUCTION

Dynamic simulation is an integrated part in the developing process of vehicles to achieve high quality of components and sub-systems. A challenge for dynamic simulations is to get an accurate excitation of the model. Measured data can be used as input directly or the excitation will be computed from measured signals. This article describes the approach of virtual iteration to generate excitation signals in a way that measured internal signals can be reproduced accurately.

Another issue is that for a new developed vehicle, e.g. succeeding model, at the time of simulations, no physical prototype exists and therefore no road load data (RLD) can be measured. One approach is to compute invariant signals with virtual iteration (VI), i.e. signals which do not differ significantly between different vehicles and can be transferred from one model to another one. In case of full vehicle simulations, the road surface is an invariant signal for the vertical direction. If the new model is similar to the existing vehicle, i.e. suspension types do not change and other parameters are similar, additionally to the vertical excitation measured WFT signals can be applied for investigations of all relevant force and torque directions.

2. VIRTUAL ITERATION

2.1. Approach

Virtual iteration is based on determination of the excitation of a model in the time domain using dynamic simulation (usually multi-body simulation). 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 workflow of virtual iteration is described with the following 5 steps:

1. Generation of a noise signal u_{Noise} to determine the transfer function of the model.
2. Simulation of the MBS model with noise signals applied on all inputs and the system response will be the output y_{Noise}.
3. Calculation of the inverse transfer function of the MBS model, i.e. transfer function between input and output channels, see formula (1)

$$F = \frac{y_{Noise}}{u_{Noise}} \tag{1}$$

4. The inverse transfer function will be applied to the measured signals, the so called desired. The first input results by formula (2)

$$u_0 = F^{-1} \cdot y_{Desired} \tag{2}$$

5. Several iteration steps can be performed automatically by formula (3)

$$u_{n+1} = u_n + F^{-1} \cdot (y_{Desired} - y_n) \tag{3}$$

The iteration will be finished as soon as a desired accuracy is achieved. Usually the signals of simulation and measurement will be compared in time domain, additionally sometimes in frequency domain and to access the accuracy by a value, the relative damage comparison is recommended, see also 3.3.2.

2.2. Measurement signals

Typical measurement signal used for VI are:

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

Strains are very powerful and can be used directly or calibrated to forces. If strains are used, a flexible body has to be included in the MBS model for measuring strains on 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 exactly define the location and orientation of a strain gauge. The advantage of calibrated forces is that this information is not necessary.

3. FULL VEHICLE INVESTIGATIONS

The investigations were split in two section:

- Existing vehicle
- New vehicle (succeeding model)

3.1. Existing vehicle

The first step was to analyze the existing vehicle with corresponding RLD.

3.1.1. Model

The MSC.ADAMS/Car model in Fig.1 was built up including all relevant parts regarding fatigue issues.

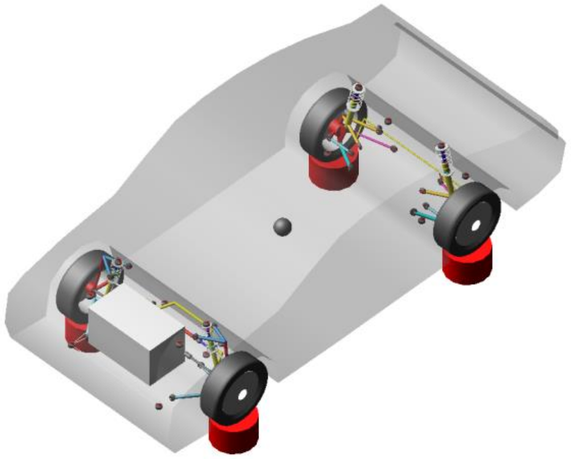

Fig.1 ADAMS model of the existing vehicle including 4-poster

The tires were represented as mass and radial tire stiffness which was important for vertical behavior. Posters were modelled under the tires which could only move vertically, see Fig.1 and Fig.2. The motions were excited by splines. The values of the splines were computed by the virtual iteration in a way that the measured signal were achieved.

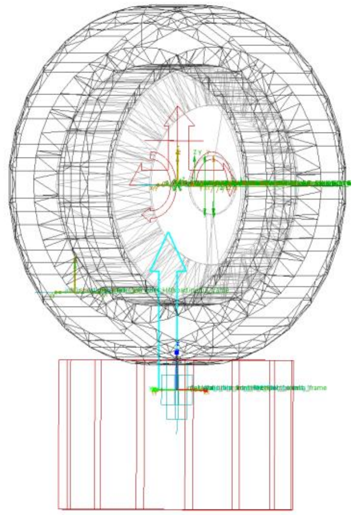

Fig.2 Poster (red part), motion of poster (blue arrow) and tire with radial stiffness (red force element)

3.1.2. RLD

The measurement was carried out on different test tracks like rough road, belgian block, cobblestones and so on. Fig. 3 shows a WFT signal of one measurement run of different tracks.

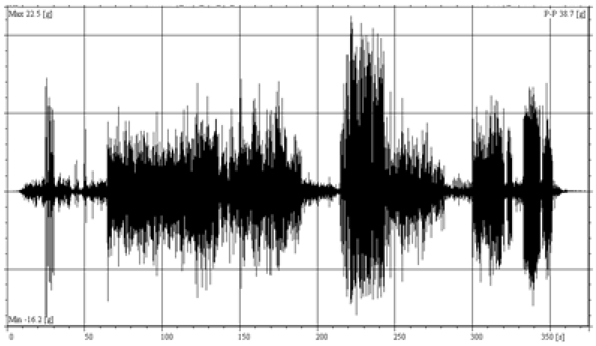

Fig.3 One measurement run

Fig.4 Spring displacement measured by wire based sensor and acceleration sensor

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

- Spring displacements, Fig.4
- Vertical wheel center accelerations, Fig.4
- WFT (wheel force transducer) signals, Fig.5

Fig.5 Wheel force transducer

3.1.3. Virtual iteration

The goal of the first step was to find the poster displacements (road surface) which led to same spring displacements and wheel center accelerations of the measured track.

The iteration process is shown for a rough road maneuver. A noise signal consisting of 4 poster displacements was generated and applied to the ADAMS model and simulated. After simulation, the response of noise signal was converted from the ADAMS requests. With the noise and its response, the inverse transfer function was computed (shown in Fig.6) and used to compute the first drive from the measured signals. The transfer function shows the transfer path between the 4 input channels (poster displacements) and the 8 output channels which are used for iteration (4 spring displacements and 4 wheel center accelerations).

The first drive was applied on the MBS model and its response was computed by an ADAMS simulation. Because the results did not correlate with desired accuracy, several further iterations were done additionally. After 8 iterations the results were accurate enough and time plots showed a correlation with high quality in all channels, the results in time domain are represented in Fig.7 – Fig.9 for full track (upper signal) and for a short interval (lower signal).

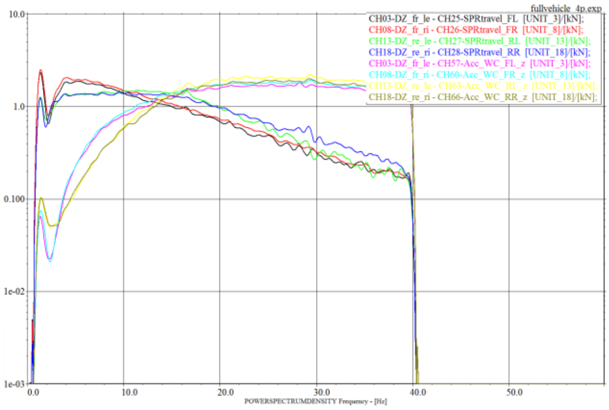

Fig.6 Inverse transfer function

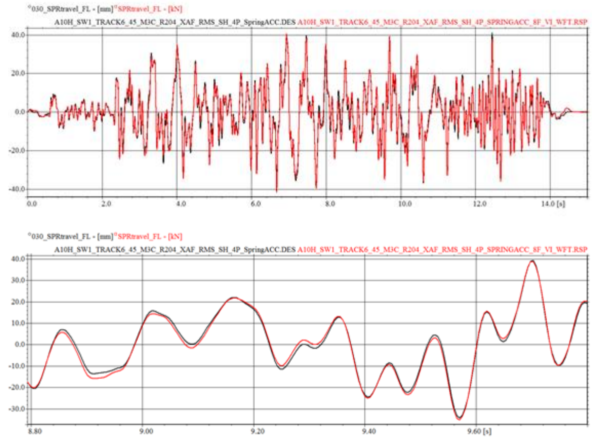

Fig.7 Overlay plot of spring displacements front left, black measurement, red simulation

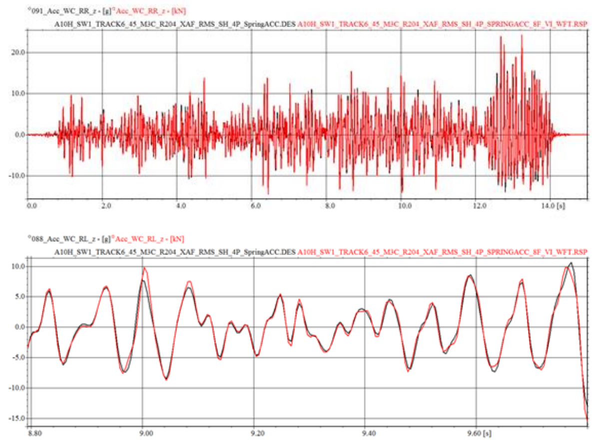

Fig.8 Overlay plot of wheel center acceleration rear left, black measurement, red simulation

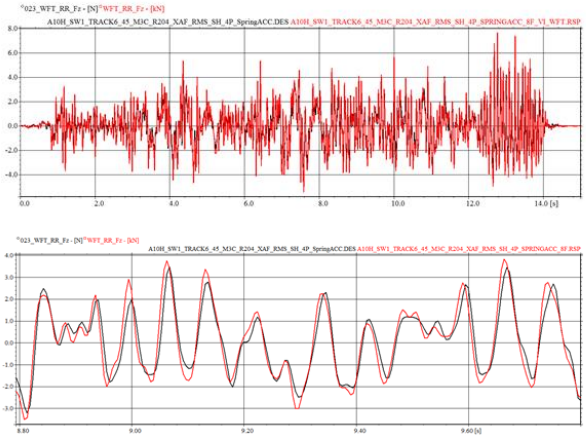

Fig.9 Overlay plot of vertical wheel force rear right, black measurement, red simulation

Summarized the measured signals were achieved in a satisfying way. With an accurate MBS model the resulting poster displacements reflected the road surface (see Fig.10) and this one could be used for similar models.

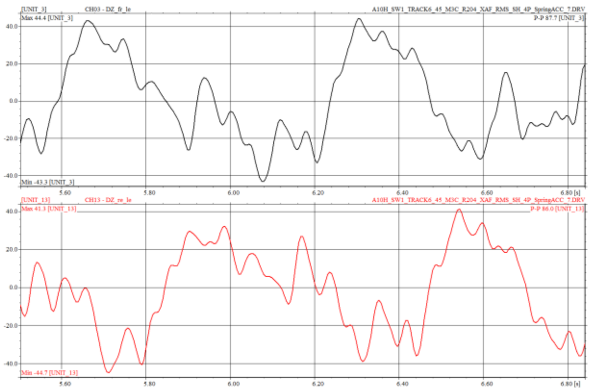

Fig.10 Short interval of poster displacements left side, front (up) and rear (low)

The resulting road surface cannot be seen as the exact real road surface, e.g. scanned road, because the tire itself has influence on it. But at least for similar vehicles with same or similar tires, this approach should be accurate. (1) shows such a comparison between scanned road and computed road surface by VI.

3.2. New vehicle

No physical prototype existed from succeeding model and therefore no RLD measurement was possible. A virtual prototype was built up in MSC.ADAMS/Car and the results of the simulation of existing vehicle were used for investigations of new model.

3.2.1. Model

The MBS model of the existing vehicle was modified by following changes, see also Fig.11:

- Full vehicle mass was increased by 10 per cent
- Spring rate was increased by 10 per cent, front and rear
- Damper and bushing characteristics were adjusted to new suspension stiffness
- Wheel base was increased by 100 mm
- Center of gravity was adapted

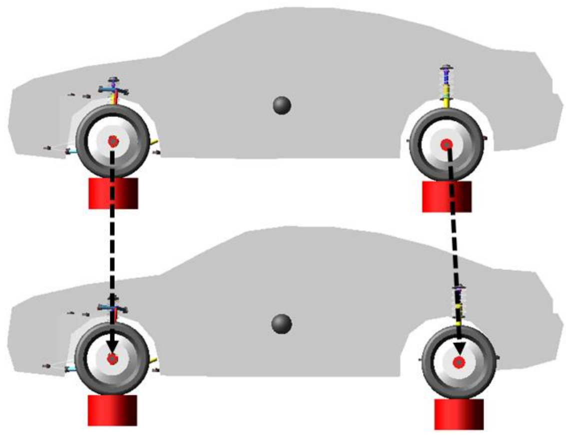

Fig.11 Difference between new and old model, e.g. wheel base and position of center of gravity

All other parameters were unchanged and therefore the presented approach seemed to be accurate respectively led to accurate results regarding durability in terms of absolute damage.

3.2.2. Excitation

The road surface computed by the existing vehicle using RLD could be used for the new vehicle. Because the wheel base was increased, the real axle signals were shifted backwards regarding this modification, the shift can be seen in Fig.12.

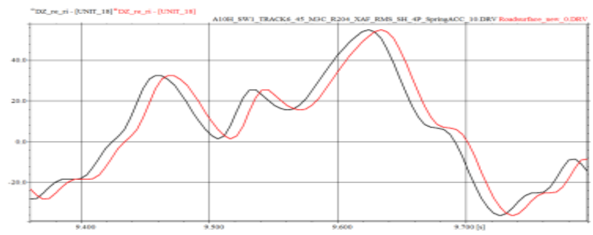

Fig.12 Poster displacement rear right, black of existing vehicle, red of new vehicle

Additionally the measured WFT signals were applied for the remaining directions

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

The torque about lateral axis was applied only for braking maneuvers, i.e. braking torque. No driving torque was applied. The signals were scaled regarding new wheel loads, because of changed full vehicle mass and center of gravity, these values changed for the new vehicle. The rear axle forces also time-shifted backwards according new wheel base, same procedure as described before for vertical displacements.

3.2.3. Simulation

The simulation was performed with the described input channels for a rough road maneuver. The usual output of such simulations based on RLD are internal forces for fatigue analysis e.g. with FEMFAT MAX (2). Because the simulations were based on RLD and the measured signals could be reproduced with desired accuracy, the durability results could be used for an absolute fatigue assessment, assumed the models (MBS and FEM for durability) were accurate enough.

Specially for the comparison in 3.3. the interface forces of the body were computed.

3.3. Comparison of VI- with WFT-approach

VI approach is based on computation of invariant signals, the road surface. The WFT-approach is to use the measured WFT signals also in vertical direction. In this chapters these two methods were analyzed using the new vehicle model.

3.3.1. WFT-approach

Because no RLD measurement was available for the new vehicle, the RLD from existing vehicle was used for the new model, but the forces were scaled by new wheel loads, see also 3.2.2.

The MBS model in Fig.13 was equal to the one used before but no posters and tires were modelled because in vertical direction the measured wheel forces were used. Weak springs acting between “ground” and wheel hub were included in the GFORCE element in vertical direction for stabilizing the model, see Fig.14. Otherwise the model could be instable because of small differences between physical and virtual vehicle and using measured signals. These weak springs have nearly no influence on the applied forces but maybe on the vertical movement behavior.

The new vehicle was simulated with these modified measured signals and the internal forces for the body were computed.

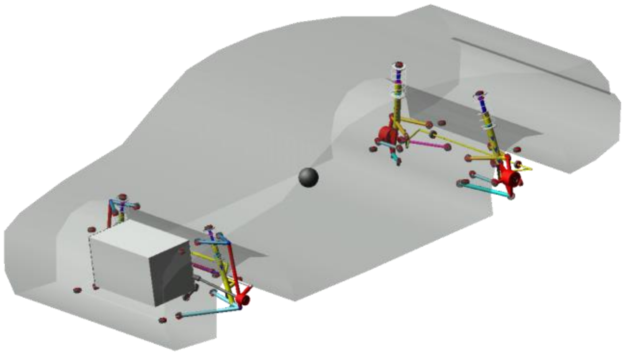

Fig.13 Model using WFT signal as excitation

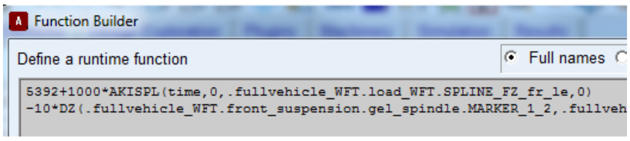

Fig.14 Model using WFT signal as excitation

3.3.2. Comparison

Interface forces of body were computed for both methods. These forces were compared in terms of relative damage. The relative damage is a norm to assess signals in time domain. This damage value has no relation to a damage of a structure, it just describes the damage content of a signal for a fixed S/N curve. The damage values is based on a rain flow classification of the signal and calculation of the damage based on Miner elementar method using a fictive S/N curve with inclination of 5.

The relative damage just represents the damage value of a signal divided by the damage value of a corresponding signal, i.e. value one means that two signals have same damage content but could be completely different in their time domain behavior. Therefore an automatic stop criteria for the VI process based on the relative damage value makes no sense, because the signals should have similar characteristics in time domain and additionally the relative damage value should be close to one.

For the comparison in Fig.15, the channels with high amplitudes respectively important locations were selected. The resulting relative damage values are shown in Fig.15 where the WFT approach is compared to VI approach.

The vertical forces show higher deviation because different input signals were used. VI computed vertical displacements with the goal that measured wheel center accelerations and spring displacements were reproduced accurately. On the other hand the vertical wheel forces were less accurate. The WFT approach just applied the measured vertical forces with no option to increase correlation of spring displacements which are closer to the body interface points. The difference of the two methods is shown in Fig.15 and specially at the damper dome locations which are often critical regarding durability, the different loading had influence. The other directions fit better because same signals were applied in both methods, the differences came mainly from vertical direction.

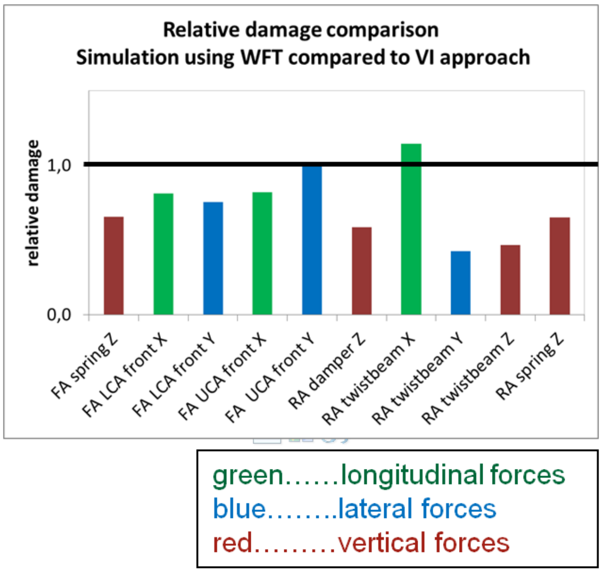

Fig.15 Relative damage comparison, WFT approach with VI

4. CONCLUSION

Full vehicle simulations based on RLD can be done with different procedures, some are very simple, others need more effort. Which method should be used depends also on parts of interest. Parts which are located far away from the excitation point, e.g. the body or sub-frame, should be simulated using signals close to their location and it is important to reproduce these measured signals even though signals far away are less accurate, e.g. vertical wheel forces. In this paper the difference can be seen for body forces. Maybe the difference seems not that high, but with superposition of all signals, e.g. for durability investigations, the result can differ.

The results are shown for a short rough road maneuver but the results have similar behavior also for other typical durability tracks.

The VI can be used to compute external excitation in a way to get internal measured signals and to achieve an excellent convergence between measured and simulated signals somewhere at the structure, close or far away from parts of interest.

Additionally the VI method can compute absolute vertical displacements which cannot be measured but are preferred because no additional stabilization is required.

In many cases VI helps improving the model quality, e.g. if some signals like spring displacements fit well but other signals show a bad correlation, inaccurate parameters can be identified and should be checked or modified otherwise no satisfying correlation will be achieved.

The method of VI is implemented in the software FEMFAT LAB (3) and is automated for:

- ADAMS
- MOTIONSOLVE
- RECURDYN
- SIMPACK

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