DURABILITY TRANSFER CONCEPT FOR THE MONITORING OF THE LOAD AND STRESS CONDITIONS ON VEHICLES

Andreas Rupp, Alexander Masieri, Thomas Dornbusch

monitoring, durability evaluation, online processing, loads, accelerations, stresses

Abstract

With the Durability Transfer Concept a new methodology is presented, in which the fatigue damage under operational loading conditions in different areas of a vehicle can be determined from the accelerations measured on the suspension. Thus long term measurements can be performed extremely cost efficient with only a 3 axis accelerometer on the suspension and a data logger. The accelerations are online processed, rain flow counted and a damage accumulation is evaluated. The instrumentation of a vehicle and the effort during measurements is reduced to a minimum. Counting into the rainflow matrices allows measurements withot time limit. From the calculated damages of the accelerations the damage evolution of other quantities all over the vehicle can be derived based on the durability transfer functions identified in short term measurements. This concept is especially favourable for investigations on the loading and stress conditions under customer usage conditions on a larger number of vehicles, on specific mission profiles and on usage conditions in different countries.

1 Introduction

With the Durability Transfer Concept a new methodology is presented, in which the fatigue damage under operational loading conditions in different areas of a vehicle can be determined by the accelerations measured on the suspension. For the investigation of the loading and stress conditions on vehicles under defined mission profiles, under country specific usage conditions or in customer usage, cost effective long term measurements of only the suspension accelerations will provide valuable information about loads and stresses in different areas of the vehicle. The signals of the accelerations are measured and recorded by respective data loggers.

In the first step of the methodology short term measurements are performed with a vehicle equipped with accelerometers on the suspension and sensors for quantities of interest, such as wheel force transducers, strain gages in different areas e.g. the chassis or the body. The vehicle is driven under well defined manoeuvres and on selected test tracks. The signals of the accelerometers are processed by band pass filters to virtual accelerations with defined frequency content. Subsequently the virtual accelerations and all signals of the measured quantities are rainflow counted and their damage is evaluated by damage accumulation. The calculated damages of the virtual accelerations and of each load or stress quantity are then correlated to derived respective transfer functions. These durability transfer functions describe the complex load and stress conditions in different areas of a vehicle.

In the second step, during long term measurements on similar vehicles, only the accelerations on the suspension are acquired, processed by the filters and virtual accelerations are rainflow counted. In the final step, the rainflow and calculated damage of the virtual accelerations are processed by the identified durability transfer functions to the calculated damage of each identified quantity.

Effort and cost for the preparation, instrumentation, performance and processing of the long term measurements have been decisively reduced, since only the accelerations on the suspension are recorded, reduced and processed. Still the most valuable information about the damaging content of the load and stress conditions of parts and components in different areas of a vehicle are reliably gained.

Within this paper state of the art data loggers are mentioned, which allow to record load and stress data from respective sensors on a vehicle for long term measurements due to online processing and data reduction by counting algorithms. The new durability transfer concept is presented step by step and its potentials are described on examples of short and long term measurements of different quantities measured on a heavy commercial vehicle. Finally different applications are discussed.

2 Data Logger with online processing and data reduction

In the modern design and development process of innovative vehicles the knowledge of the load and stress conditions of the vehicle with its multiple components and sub systems is of great importance. For a save design of the structures it is most important to acquire such data on many vehicles under real customer usage conditions in different missions, countries and with different drivers. As a state of the art data loggers with online processing and counting of the signals of quantities e.g. loads, stresses, displacements and accelerations are widely used in automotive testing, to gain information about the loading and stress conditions during long term test series – see Fig. 1. For example the Logger Micro II box allows to condition, filter and sample up to 20 signals of strain gages, high voltage signals and additionally digital channels and bus signals. Especially the online rainflow counting allows to derive data about service conditions without a time limit. Level crossing and range pair spectra are provided as well from the rainflow matrices. In view of drive line investigation also the counting method time at level, multi dimensional is of interest, for eg. acquiring the drive torque and the speed. Trigger functions allow an efficient recording of time histories of signals during events of interest.

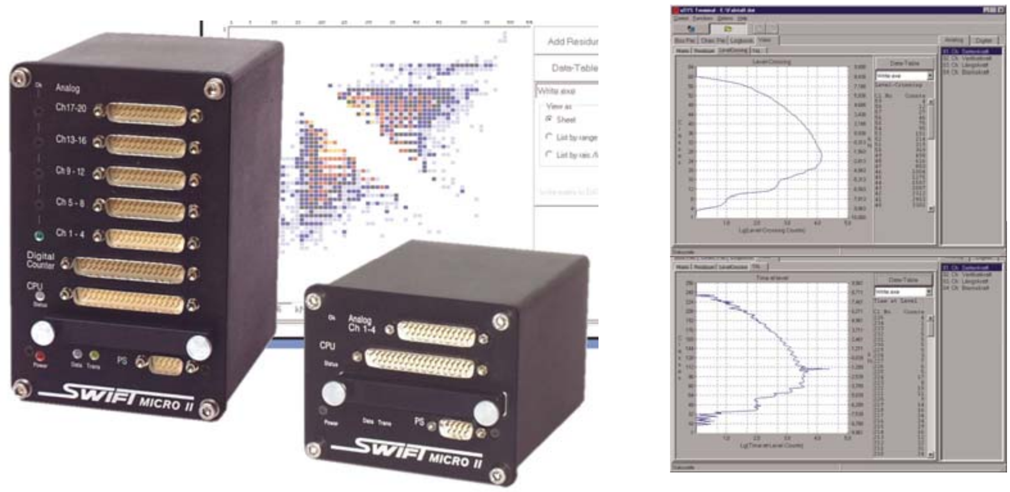

Fig 1: Data Logger with online rainflow, level crossing and time at level etc.

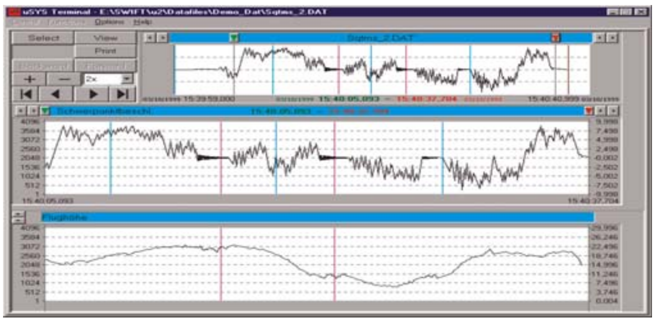

Fig. 2: SQTMS – Sequential Peaks and Troughs with Time and Master/Slave

Additionally the SQTMS (Sequential Peaks and Troughs with Time and Master/Slave) reduces the signals to the most relevant peaks of load and saves them together with their time information. The maxima and minima of selected master channels are recorded together with the values of selected slave channels and the time of maximum or minimum – see Fig. 2. The extreme data reduction by this method already allows long recording times and requires low capacity storage on the logger.

With such data loggers information about the recorded measuring quantities are available for further analysis and evaluation in view of loading conditions and durability.

3 Loads and stresses on vehicles

Measurements on all components and in many locations of a vehicle provide the relevant information about the complex load and stress conditions for the designers. However, due to high effort and costs such road load data acquisition can normally not be performed to a necessary extent.

The new concept allows to obtain the information about the complex stress and load conditions in different areas of a vehicle by an extremely cost-efficient instrumentation on a vehicle, 3 accelerometers on a suspension and a data logger. Such measurements need to be performed in addition to the standard short term measurements on such vehicles during the development and proof out processes.

Stresses, cross sectional loads in between components and loads eg. on the wheels of a vehicle are generated due to the different physical driving and loading situations with their specific intensities. The correlation of the stress / load conditions in different areas of the vehicle to the accelerations on the suspension may be described phenomenologically.

Figure 3 shows the power spectral densities of the vertical and lateral wheel forces of a commercial vehicle on different road types, such as cobble stone test track and 2 public roads of different quality. Exitations of similar frequency content can be observed on the roads however with different intensities. It therefore may be possible, to observe such loads in terms of frequency content and intensity to identify the driving and loading conditions relevant for different roads and service conditions. Further, similar observations can be found not only on quantities such as wheel loads, and component stresses but also on the accelerations on the suspension. Therefore, a correlation between the different quantities is apparent, since they were created by the loading conditions. The correlation between the suspension accelerations and other quantities is of major interest, because such accelerations may be measured with comparably low effort.

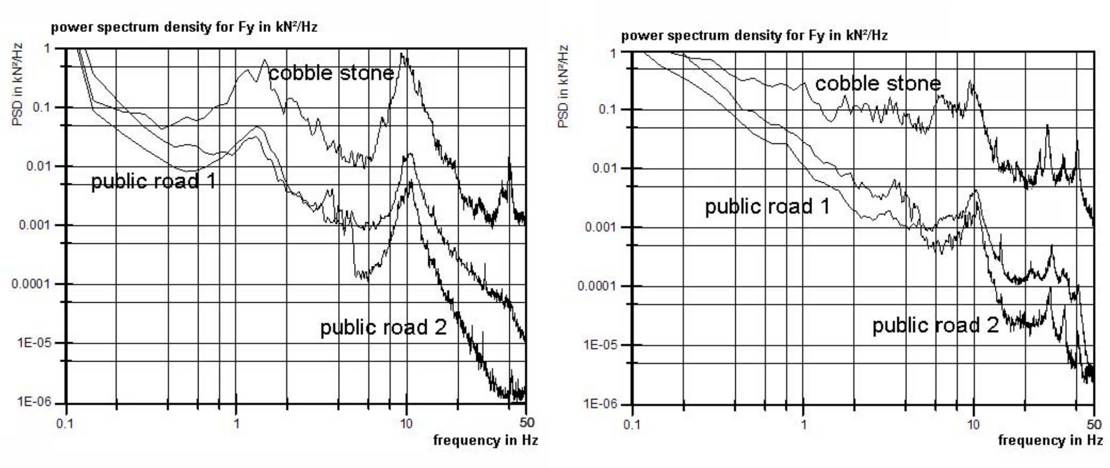

Fig. 3: Power spectral density of wheel loads on different tracks and roads

4 Procedure of durability transfer

The application of the new methodology of the durability transfer consists of three steps: Pre-Processing of short term measurements to identify correlations, long term measurement with Online-System and Post-Processing to apply the initially identified durability transfer functions and evaluate the damage of selected quantities during the measured long term service, even though their signals were not recorded.

4.1 Pre-Processing

For the pre-processing (Fig. 4) a test vehicle needs to be instrumented with a 3 axis accelerometer on the suspension and sensors to acquire quantities of interest, such as wheel force transducers, load cells for suspension component loads or local strain gages.

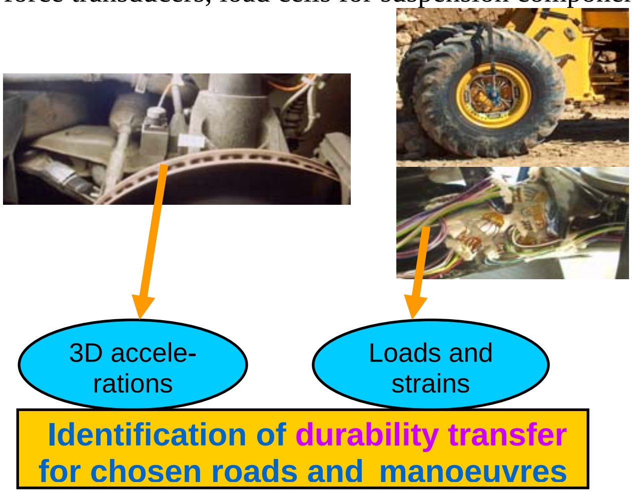

Fig. 4: Pre-processing

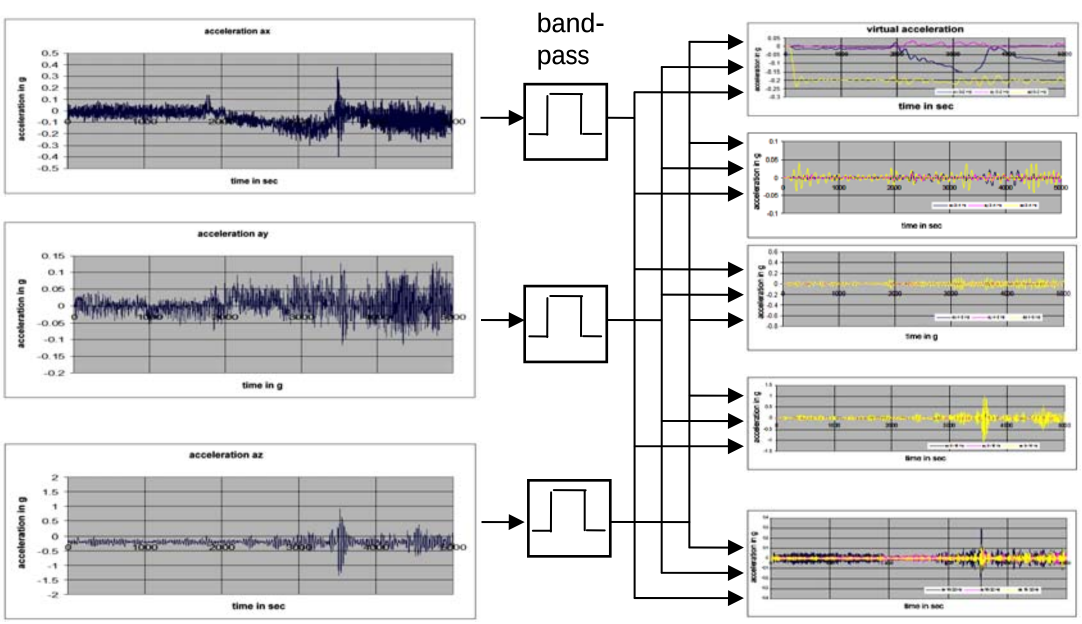

Fig. 5: Virtual accelerations by filtering

Short term measurements are performed with this test vehicle under well defined driving and loading manoeuvres e.g.:

- left, right curves, driving eights, lane change with different velocity;
- braking straight and in curves with different intensities;
- driving over obstacles with varying speeds;

and on selected tracks

- cobblestone with different speeds;
- sinus-track with different speeds.

The manoeuvres and tracks should represent the great variety of loading conditions under normal usage.

From the 3 axis accelerations on the suspension of the test vehicle under the different physical loading conditions, virtual accelerations are created by band pass filtering according to Fig. 5. Thus for 5 frequency bands from 0 Hz to 32Hz 15 virtual acceleration channels describe the characteristic loading of the vehicle and the resulting internal loads and stresses.

Plotting the time histories of the virtual accelerations together with the signals of interest e.g. stresses or loads, it becomes obvious, that a correlation may be quantified. The time history of a selected quantities such as loads or local strains in different areas of a vehicle seem to be a composed by the time histories of the several virtual accelerations of different directions and frequency content. In Fig. 6 the strain time history at the body may be composed by the low frequency longitudinal and lateral accelerations and the medium frequency content of the vertical suspension acceleration.

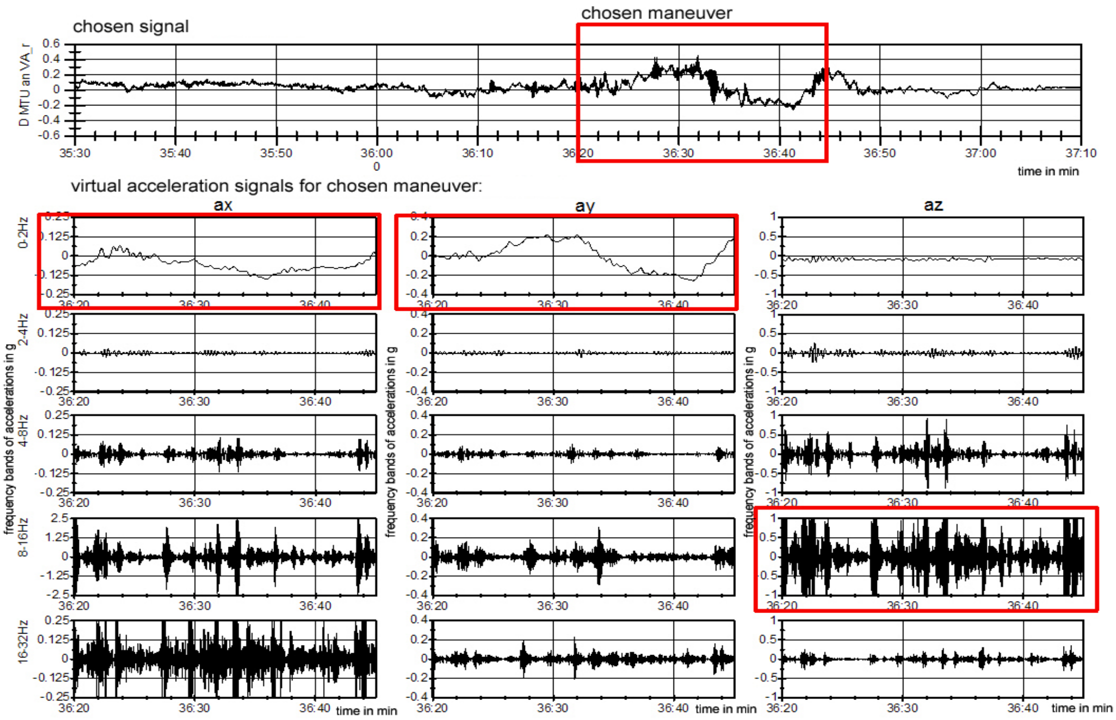

Fig. 6: Strain on the body and virtual accelerations during steering manoeuvres

However, the exact sequence of the quantities cannot be determined from each other due to different transfer distances and dynamic behaviour of the structures. In view of the durability evaluation of the quantities on the vehicle, not the signals themselves are correlated, but their rainflow cycles evaluated by a damage accumulation referred to a reasonable time basis. As a result a calculated damage increment is obtained for each manoeuvre or track from the short term measurements.

A correlation is then identified between the damage increments of all virtual accelerations and one selected quantity of interest for a minimum of 15 different manoeuvres or tracks – see Fig. 7. Straight forward mathematical approaches and in a next development step neuronal nets are used to define these durability transfer functions.

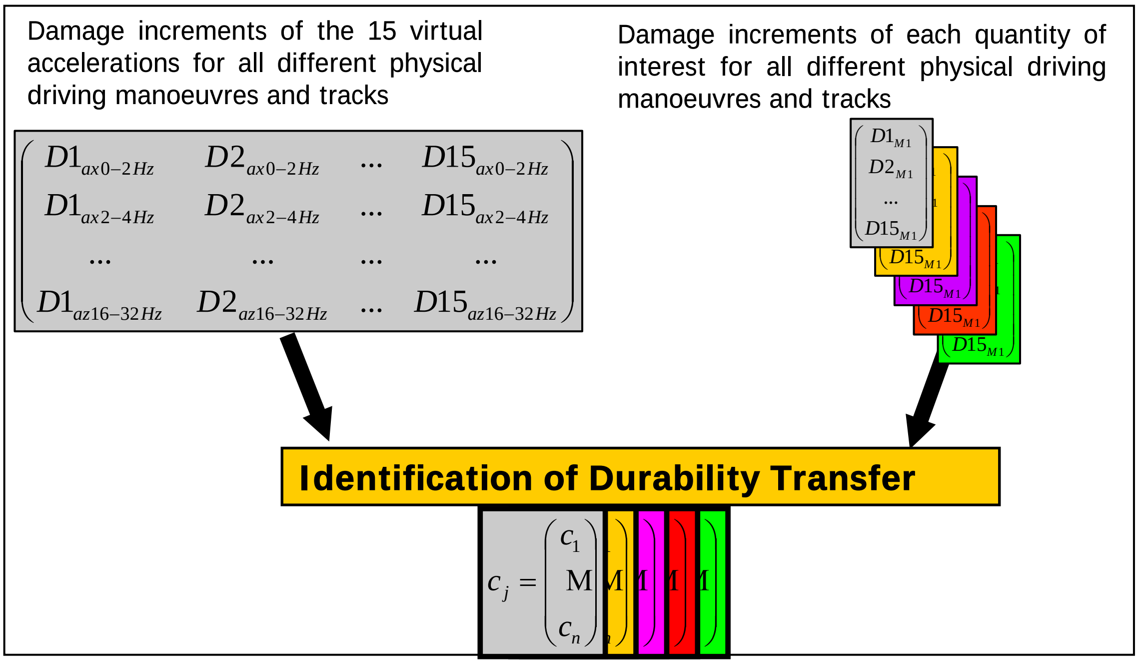

Fig. 7: Identification of durability transfer functions from damage increments

4.2 Long term measurements

Long term measurements can then be performed with the same type of initially identified vehicle with an extremely low effort in instrumentation and personal to handle the equipment. Such kind of measurement may even be controlled only be the driver without any test engineer on board. A 3-axis accelerometer is attached to the suspension and the data logger OCEAN (Online Counting and Evaluation Analysis; Fig. 8).

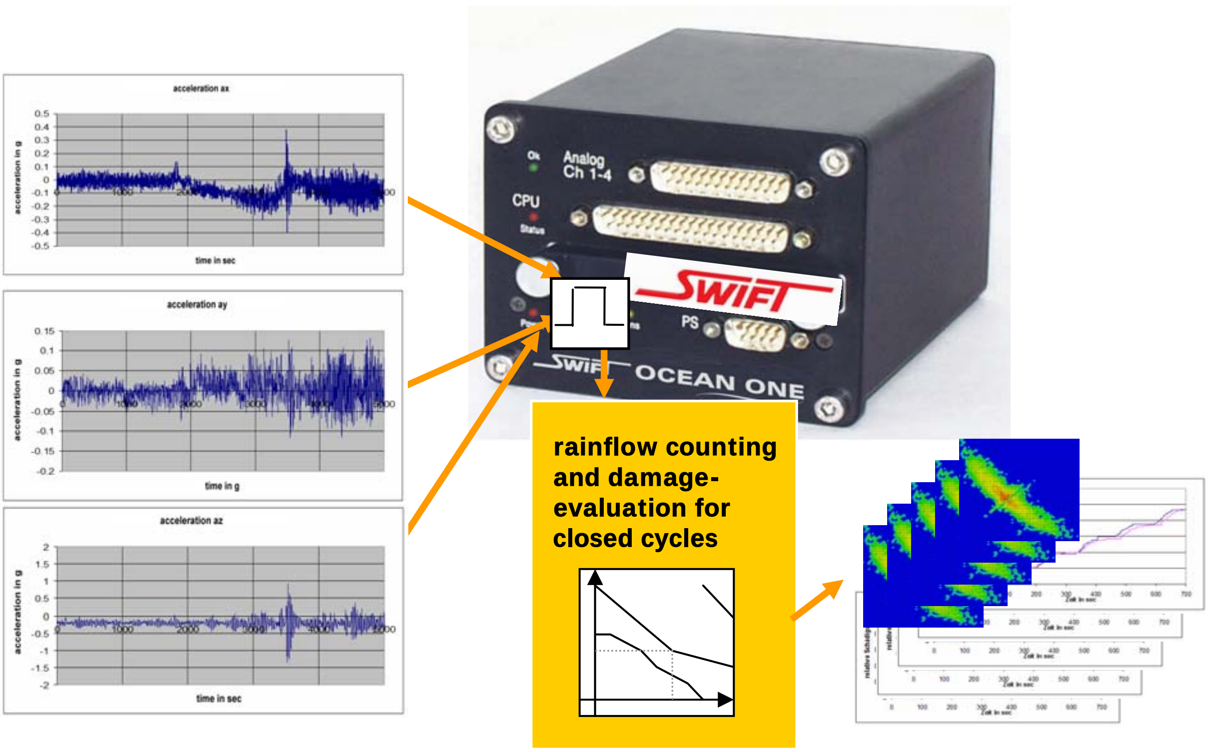

Fig. 8: Online processing and counting unit OCEAN

The data logger OCEAN samples the 3 acceleration signals and creates by band pass filtering 15 virtual accelerations. These virtual signals are online rainflow counted and stored in the rainflow matrices. Optional each closed cycle is directly evaluated by a damage accumulation as a calculated damage increment. The damage increments are stored in a defined time interval e.g. 10s as a sequences of damage evolutions. A minimum of storage capacity for the 15 rainflow matrices of several kByte for measurements over months and even years is required and it does not change with time at all.

After the long term measurements the data are read from the logger via the serial interface to the data management system of post-processing unit. An remote control unit optionally allows to read the measured data via GSM modem from the instrumented vehicle to the home office.

4.3 Post-Processing

In the final step the acquired rainflow matrices and/or damage evolution histories are evaluated for a measurement campaign of identified vehicles with the Post-Processing tool – see fig. 9.

From the matrices or the damage evolution histories the calculated damage for each identified quantity can be derived by the durability transfer functions. As a result the damage evolutions of the quantities of interest are reconstructed under the loading conditions of the long term measurements, even though they were not measured on the vehicle.

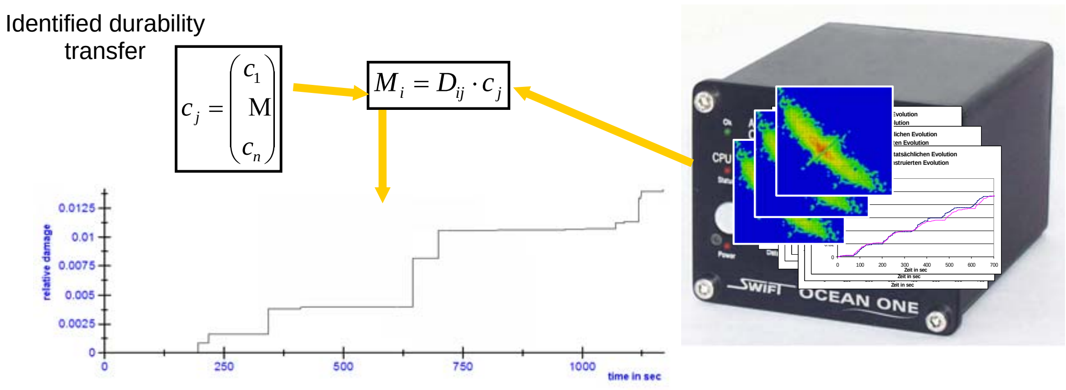

Fig. 9: Reconstruction of damage evolutions of identified quantities

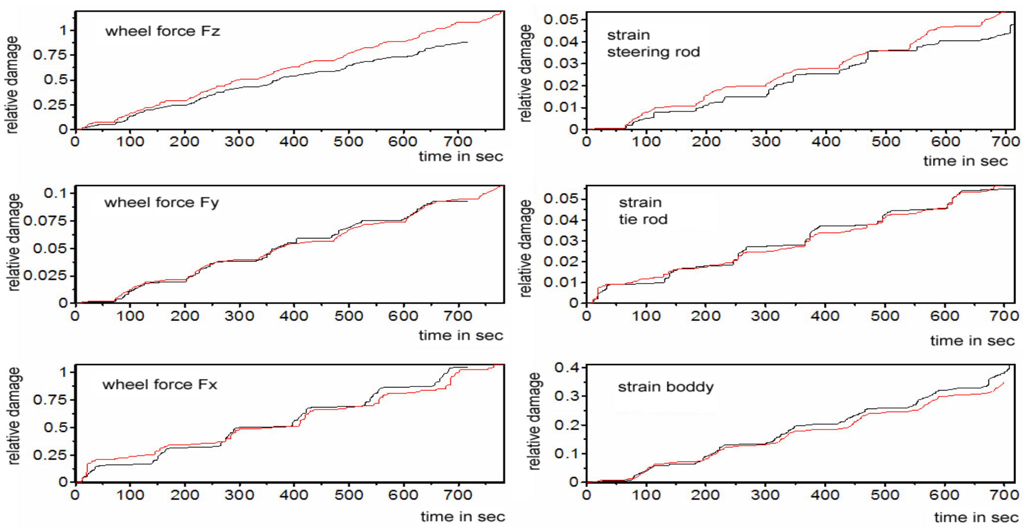

Fig. 10: Reconstructed damage evolutions of identified quantities from signals (black) and with durability transfer from accelerations (red) driving on a test track for about 10km

In Fig. 10 the damage evolutions of measured quantities on a heavy commercial vehicle are presented, derived for 6 laps on a durability test track containing of different cobblestone and rough road segments. In the 3 diagrams on the left the wheel forces, on the right diagrams the damage evolutions of a strains on the steering, the tie rod and in a body location are given. To evaluate the reliability of the durability transfer concept and its potentials, the calculated damage evolution derived from the 3 accelerometers is compared to the damage evolution calculated directly from the measured quantity. The red curves show the damage evolution calculated from the 3 accelerations based on the durability transfer functions; the black curves are derived from the measured quantities themselves. The 2 curves are corresponding extremely well not only for the quantities close to the area where the accelerations were measured like the wheel forces but also for the quantities far away on the steering and even on the body. In Fig. 11 the damage evolutions when driving about 400km in 7.5h on public roads were determined from signals directly (black) and from the accelerations on the suspension (green with neuronal net, and red with matrix calculation). Also here the black and red curves are corresponding very well with the exception of the strain on the tie rod. However the damage increments on the tie rod are smaller by a factor of about 10^5 and therefore the difference may be neglected at all.

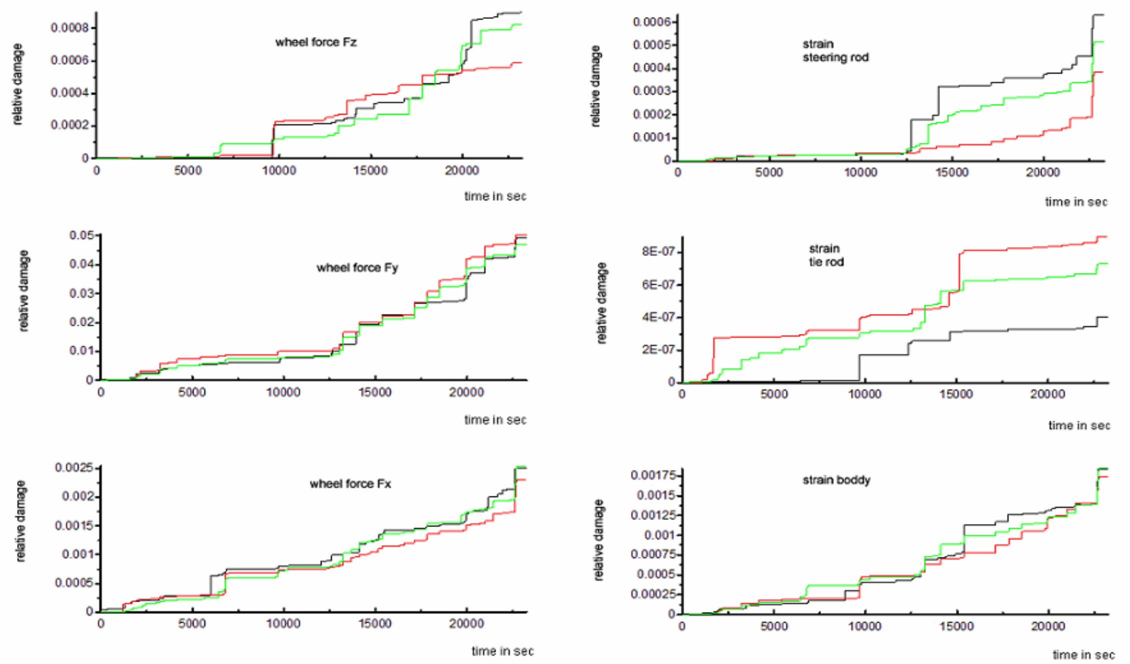

Fig. 11: Reconstructed damage evolutions of about 400km public roads, from quantities directly (black) and from accelerations (red and green)

5 Literatur

[1] Masieri, A: Potenziale neuer Datenreduktionsverfahren für Monitoring-Systeme in Fahrzeugen, Diplomarbeit FH-Kempten, 2004 (not pubished)
[2] Dini, A.; Rupp, A.: Comparison of Procedures for Experimental and Theoretical Durability Approval of a Truck Axle. SAE Paper 982787 (1998)

6 Author information

Andreas Rupp, Dr.-Ing.
Professor
Univ. of Applied Sciences
Bahnhofstr. 61 – 63
87435 Kempten, Germany
+49 173 3511380
andreas.rupp@fh-kempten.de
www.fh-kempten.de

Alexander Masieri, Dipl.-Ing. (FH)
Scientist
O.F.T.
Georg Haindl Str. 15
87447 Waltenhofen, Germany
+49 831 5409823
alexander.masieri@aibf.de

Thomas Dornbusch, Dipl.-Ing.
Manager Development
SWIFT GmbH
Am Dieburger Berg 18
64354 Reinheim, Germany
+49 6162 82086
info@swift-online.de
www.swift-online.de