Simplifying a Chassis Test Bench by Virtual Iteration of Structural Strains with SIMPACK

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Overview

1. Endurance strength verification of the chassis at Mercedes Benz Vans
2. Simplification of the testing of a semi-trailing arm rear suspension of a Mercedes-Benz Viano
3. Test design study and load data generation with SIMPACK
   1. Reproduction of the strain gauge signals in SIMPACK
   2. Virtual iteration with SIMPACK and FEMFAT Lab VI
   3. Damage calculations with FEMFAT MAX for semi-trailing arm
4. Verification and implementation on a physical test bench
5. Summary and Outlook
Endurance strength verification of the chassis from Mercedes-Benz Vans

- Endurance strength verification of the chassis is based on proving ground testing (torture track and maneuver like braking, weaving, ...) in Stuttgart Untertürkheim
- Verified agreement of proving ground testing with customer loads
Endurance strength verification of the chassis from Mercedes-Benz Vans
Axle suspended to rigid
- Physical test bench excitation with all 6 DOF measured wheel forces each side, iterated on vehicle measurements
- SIMPACK Model is excited with measured wheel forces directly
  - Nonlinear characteristic curve for damper force type 04
  - Force elements for rubber bushing force type 43 or 42
  - Bump stoppers with force element type 18
  - Semi trailing arm as an elastic body
- Total model with 14 DOF + 56 DOF of elastic body each side
- Global behavior of such test benches are usually calculated with high accuracy
Test simplification using a rigid spring/damper

Efficiency improvement with a rigid spring/damper
- Cooling damper, elastomer omitted
- Replacement of elastomer omitted

Target: Strain gauge signals unchanged

Excitation: Torture track, braking, weaving

**Executed project:**
- Feasibility study, concept design, concept verification
- Realizable on an existing 12 channels axle test bench at the test area of Mercedes-Benz Vans
- Calculate input signals for physical rigid test bench in advance
Approach to the concept study, validation and implementation

Vehicle measurements
torture track +
maneuver

„Online“
strain calculation
with
SIMPACT

Virtual Iteration of synthetic strains.
Feasibility study, concept design.
Concept verification and
load data generation

Verification
and
implementation

Measurements
wheel forces

accelerations
displacements
strains

SIMPACT Model
of suspended
test bench

Validation,
Optimization

SIMPACT model
of rigid test bench

Physical test bench

forces

FEMFAT LAB vi

gray arrows: model validation

blue: process of the implementation
Measuring points, data acquisition

Wheel forces
Differential displacements
Accelerations
Strains
Modeling of strain gauges in SIMPACK

\[ \varepsilon = \frac{\Delta l}{l_0} \]

[μm/m]

- Measurement of displacements on 2 nodes / markers
- Calculation of \( \Delta l / l_0 \) with function expression
Validation / optimization of strain calculation by means of quasi-static test bench measurements

- Good correlation between simulation and measurement on relevant strain gauges
- Use of an optimized model with regard to precision and CPU time
Validation of strain calculation by means of vehicle measurements, dynamic maneuver weaving

- Vehicle measurement
  - Strain determined with SIMPACK (simplified strain approach)
  - Strain determined with FEMFAT STRAIN (strain calculation with complete FE model)

Generally, $\Delta l/l_0$ approach shows good accuracy in dynamic simulations.

At locations with high strain gradients or close to load introduction, complete strain calculation with FEM is more exact than $\Delta l/l_0$ approach.
• Simulation vs. measured strains are mostly not exactly the same because:
  • Strain gauges are often located at „hot spots“ with high strain gradients. Strains thus highly sensitive on position and orientation errors
  • Simplified strain estimation in SIMPACK
• Therefore „synthetic strains“ (calculated strains instead of measured) are used
• Differences should be compensated because of same FE-model in calculation ① and ②
Why do we need Virtual Iteration?

- Different boundary conditions for test bench: suspended and with rigid rod
- Excitation of both systems with identical loads on wheel hub
- Different strain results inside trailing arm due to changed boundary conditions
- Target: tuning of excitation to gain identical strains inside trailing arm
Virtual Iteration of loads using FEMFAT Lab

1. Pink noise
2. Response of noise
3. Transfer functions
4. Drive signal
5. Response
6. Response = desired

\[
u_{n+1} = u_n + F^{-1} \left( y_{\text{Desired}} - y_n \right)
\]

\[
F = \frac{y_{\text{Noise}}}{u_{\text{Noise}}}
\]

\[
u_0 = F^{-1} y_{\text{Desired}}
\]
Virtual Iteration of loads using FEMFAT Lab

- Excitation/Drive
  - Forces and torques on wheel hub applied via RBE2 to include support effect of bearing
  - Additional constraints during breaking maneuver
  - Lateral torque not applied on wheel hub during driving
- Response/Target/Desired
  - Seven strain gauges on semi-trailing link
Virtual Iteration of loads using FEMFAT Lab

- Complete SIMPACK simulation at each iteration step
- Calculation of damage $D_{\text{Iteration}}$ based on simulated strains using synthetic S-N curve (rigid test bench)
- Comparison of desired damage $D_{\text{desired}}$ (suspended test bench) with damage during iteration
- Good convergence of iterated loads
- Only few iteration loops necessary

\[
\alpha_i = \frac{D_{\text{Iteration}}}{D_{\text{desired}}}
\]

$D \sim e^5$
Virtual Iteration of loads using FEMFAT Lab

- Iteration result:
  Modified time signal for all forces and torques of rigid test bench
- Simulation of strains by application of modified loads on model with rigid rod
- Goal accomplished:
  Same strains in both models
Damage calculation with FEMFAT ChannelMAX

Channel 1

\[ F_V = \]  

Channel 2

\[ F_S = \]  

Channel 3

\[ F_L = \]  

SIMPACK Loads Stress

Specimen Data

Results

- Damage
- Endurance Safety
Damage calculation with FEMFAT ChannelMAX

- Required to assure that hot spots don’t change in location with modified boundary conditions (rigid vs. suspended) and loads.

- Calculation of damage distribution based on simulation results for both models.

- Channels are inertia relief load cases and eigenmodes.

- Comparison: Similar damage distribution with no additional hot spots.
Verification and implementation on physical test bench

Example: strain gauge 2

- Synthetic „desired“ strain on the suspended test bench (representative of vehicle measurements)
- Strains on rigid test bench determined by means of virtual iteration

**Time comparison**

- Vehicle measurement
- Rigid physical test bench, excited by virtually created test bench excitation

**Time comparison**
Summary and Outlook

Summary (1):

- Simplified test concept (for example rigid setting, channel reduction) offers a large efficiency potential in durability testing
  ⇒ Application of virtual processes to derive testing concepts and excitation loads increases efficiency
- In the presented project, a concept for rigid testing of a semi-trailing arm rear suspension was worked out
  - The spring was replaced with a double-sided cardanic supported rod
  - The damper was omitted
- Because of the change of the global movement behavior and force flow, a virtual iteration with respect to component strain is necessary in SIMPACK
- A strain calculation based on relative displacement of neighboring nodes by means of function expression was introduced in SIMPACK
  - Good computer time efficiency in conjunction with good accuracy on locations with moderate strain gradients but with lower accuracy at locations with higher strain gradients
  - Therefore iteration of “synthetic” instead of measured strain in the whole process is more target-oriented
Summary and Outlook

Summary (2):

- Virtual iteration by means of FEMFAT LAB and SIMPACK:
  - „Drive“ wheel loads for rigid testing so iterated that „Target/Desired“ strains were reproduced as good as possible
  - The damage distribution throughout the whole component was positively verified by means of FEMFAT MAX
- Verification/implementation on the physical test bench
  - Test bench excitation with “Drive” wheel loads from virtual iteration
  - Strains agree very well with measured strains in the vehicle

Outlook:

- Reduction of test time through omission
- Further improvement in efficiency through channel reduction
- Derivation of testing loads for the other vehicles with modified damper kinematics and setup