Brake Design for Multi-Axle Vehicles

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Commercial Vehicle Calculation
TPC/PCD
Brake Design for Multi-Axle Vehicles

- Simulation task
- Basics of braking dynamics and calculation methods
- Modeling
- Simulation results
- Summary and outlook
Truck Models for Individual Transportation Tasks

[Images of various truck models]
**Braking Process Dynamics**

- **Adhesion requirement:**
  \[ f_i = \frac{F_{Bi}}{F_{Ni}} \leq \mu \]

- **Braking rate:**
  \[ z = \sum_{i} \frac{F_{Bi}}{(m_f g)} \]

- **Utilized brake force is dependent on the dynamic wheel load and the adhesion coefficient \( \mu \) between the tire and road surface**

- **An overbraked / locked rear axle would lead to unstable, uncontrollable handling**

- **In the case of a 2-axle vehicle, axle kinematics are not necessary for the calculation**
  \[ \Rightarrow \text{simple calculation} \]

- **Calculation equations:**
  \[ F_{N1} = F_{N1\text{stat}} + \frac{h}{E} m_f z \]
  \[ F_{N2} = F_{N2\text{stat}} - \frac{h}{E} m_f z \]
Adhesion Diagram

- In the case of increased braking rate due to dynamic axle load shift from the rear axle to the front axle, the rear axle adhesion curve (f2) is progressive and the front axle adhesion curve (f1) is degressive.
- For stable braking behavior, the f1 curve has to be above the f2 curve.
Standard Truck Models

- Standard model vehicles can be covered by conventional brake design programs, because the dynamic axle loads are "simple" to calculate.
- For special models and vehicle modifications, the dynamic axle loads would have to be generated by laboriously generating the equations of motion.

⇒ Use of SIMPACK expedient
Principle Comparison of Calculation Processes

Calculation with simplified axle kinematics; formula derivation

\[ \Delta F_b = \frac{B_{1,HA} \cdot y \cdot z - B_{2,HA} \cdot (y + g) \cdot \tan \gamma_b - h + f \cdot c \cdot u}{c \cdot u \cdot y + a \cdot v \cdot z} \]

Calculation with SIMPACK

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Definition of the Brake System for Special Models and Vehicle Modifications

To meet customer requirements, vehicles are converted by installing additional axles (2nd front axle (FA), leading axle (VLA), trailing axle (NLA))

The brake system has to be adapted to the changed axle kinematics

Example: 8x2/4

FA  Steel springs
VLA  Air springs
RA/NLA  Steel springs
8x2/4: VLA and RA /NLA Axle Designs

**VLA:**
Can be raised; axle load is regulated via the air spring pressure depending on the rear spring travel

**RA/NLA:**
On braking, the RA/NLA as a whole is dynamically relieved; due to the brake forces, the axle load is shifted from the RA to the NLA
Leading Axle (VLA): CAD Model and Substructure

Steering kinematics available in model
Axle raising via constraint: massless link
Extension of the air spring user routine for the bellows
RA/NLA Axle Assembly: CAD Model and Substructure

Geometry integrated from CATIA solid model
Leaf springs as elastic bodies (BEAM elements)
Leaf springs mounted in one boss and three contact supports
⇒ use of contact elements

Contact elements
Leaf springs as beam elements
Substructure

CAD model
Swing axle rocker
SIMPACK Vehicle Model for 8x2/4 Trucks

SIMPACK vehicle model in substructure technology

Body (rigid)
Steering
FA
VLA
RA/NLA (steel springs as elastic bodies)
Tires
Brakes
Air spring controller link
ALB link
Brake System Components

FA brake cylinder

Service brake valve

RA brake cylinder

ABS/ASR

Retard

Motor

3

1

2

ALB controller

ABS solenoid valve

Source: WABCO
Mercedes-Benz Marketing Academy
Brake System with ABS: Modeling in SIMPACK

Wheel speeds
FA / RA

Brake command
Actuation

Service brake valve

Controller angle

Automatic
Load-dependent
Brake pressure control

Brake system module

Wheel speed

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Brake actuation

Brake cylinder FA

VLA
Air spring pressure

Reduction

Brake cylinder VLA

Brake cylinder RA

Brake cylinder NLA

ABS control module

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p_{\text{ABS FA}}

p_{\text{ABS RA}}

p_{\text{alb}}

BRAKING TORQUES
EU/ECE Brake Regulations (Excerpt)

- Commercial Vehicles > 3.5t GVW (class N2/N3) ⇒ ABS is required
- A braking rate of 5 m/s² is required with an intact brake system on a good road surface which provides good grip.
  
  i.e. indirectly controlled wheels must be lock-free below 5 m/s².
- If the necessary braking rate without locking can only be achieved with intact ABS, ABS failure must be indicated via a red warning instead of a yellow warning (new in ECE R13)
- Lock-free braking > 2.2 m/s² in the event of failure situations on a good road surface which provides good grip (secondary braking)
Locking Behavior of 8x2/4 Vehicles with indirect ABS controlled axles

 Regulation: lock-free braking
> 5 m/s²
To reliably meet this requirement, a braking rate
> 55% is desired at μ=0.8

VLA:
Indirectly controlled via FA.
“Lock-free” can only be ensured with bellows pressure limitation with a 1:1.5 reduction valve.

NLA:
Indirectly controlled via RA.
Adhesion curve f4 runs beneath adhesion curve f3
-> NLA is lock-protected
Locking Behavior on ABS Failure – Warning Concept

ABS failure:
- Lock-free: > 5m/s² yellow warning
- < 5 m/s² red warning

- In operable vehicle states, 62% braking rate is achieved with basic variant and 55% with higher assembly on the RA/NLA.
- The 4-axle chassis status must be avoided. The RA’s adhesion requirements may be reduced by raising the VLA or NLA.

⇒ A yellow warning is sufficient in the event of ABS failure.
## Simulation Variants

<table>
<thead>
<tr>
<th>Loading conditions:</th>
<th>Chassis</th>
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<tbody>
<tr>
<td>Unladen with body (12t)</td>
<td></td>
</tr>
<tr>
<td>Partially loaded (18t)</td>
<td></td>
</tr>
<tr>
<td>Partially loaded (25t)</td>
<td></td>
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<tr>
<td>gross vehicle weight (32t)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Axle conditions:</th>
<th>4 axles</th>
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<tbody>
<tr>
<td>3 axles (VLA raised)</td>
<td></td>
</tr>
<tr>
<td>2 axles (VLA and NLA raised)</td>
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<table>
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<tr>
<th>Brake systems:</th>
<th>Different brake cylinder assemblies</th>
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<tr>
<td></td>
<td>Brake force reductions</td>
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<td>ALB adjustment</td>
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Extensively automated simulation variant processing is required
Simulation Process Step I: Generation of the Loading Conditions

The basic model was modeled in its design position, laden, with 32t permissible gross vehicle weight.

The other loading conditions with even loading were generated using time simulation with "decreasing loading force"

 BATCH calculations under variation num6.File
⇒ Basic system condition for the loading conditions
Chassis (fg)
Unladen with body (leer)
Partially loaded 18t (tb1)
Partially loaded 26t (tb2)
Permissible gross vehicle weight (zGG)
Simulation Process II: Execution of the Variant Calculations

Variant calculations per loading condition via dbi file exchange in batch mode:

Truck_8x2_basis_<bel>_<var>  
Truck_8x2_basis_<bel>_VLA_raised_<var>  

<bel> ∈ { fg, leer, tb1, tb2, zGG }  
<var> ∈ { V1, V2, V3, V4, V5, V6}  

Σ 60 simulation variants

Calculation time per variant approx. 20 minutes

⇒ On distribution amongst several computers, the calculations can be carried out within a matter of hours
Summary and Outlook

- As a tool, SIMPACK is particularly suitable for designing brakes for special vehicle designs with complex axle kinematics
- In the case of standard vehicles, dynamic effects can also be analyzed more precisely than with standard programs
- Integration of electronic brake systems for developing control algorithms
- Option of simulating type approval scenarios (deceleration, stopping distance, ABS, ...)
- For processing "vehicle families", more extensive automation is desired with regard to model generation and evaluation
- The option of code export (axle kinetics) for integration into the standard programs must be checked