Jan van Oosten

SWIFT-Tyre in SIMPACK:
for comfort, ride, durability
and chassis control analysis

TNO Automotive

SIMPACK User Meeting
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Contents

• INTEC - TNO co-operation

• From Magic Formula modelling to comfort, ride, chassis control and durability

• SWIFT-Tyre concept and validation with test data

• Application examples

• SWIFT parameter sets

• SWIFT-Tyre in SIMPACK

• Concluding
INTEC - TNO co-operation

INTEC is reseller of DELFT-TYRE models

Current available models in SIMPACK:

- **MF-Tyre**
  - Standard MF model for all basic handling simulations
  - ± 10 deg camber
  - up to 8 Hz
  - long road wavelength undulations (> 1.5 m)

- **MF-MCTyre**
  - similar to MF-Tyre
  - all basic motorcycle handling simulations
  - up to 60 deg camber
  - applicable for vehicle roll-over
we have three main problem aspects:

- belt dynamics involving natural frequencies of ca. 30, 50, 70 Hz and higher
- road unevennesses: cleats
- short wavelength wheel oscillations


**SWIFT-Tyre concept**

- Rigid Ring for tyre belt vibrations up to 60 Hz
- MF slip force calculation between belt and road
- Contact model for short wavelength slip variations
- Effective inputs for obstacles with short wavelength
Tyre belt natural frequencies
Lateral: Yaw oscillation test

amplitude ratio $F_y/\psi$

amplitude ratio $M_z/\psi$

Experiment  Simulation  $V[\text{km/h}]$
Tyre belt natural frequencies
Rotational: Dynamic braking test

longitudinal force to brake torque

longitudinal force to wheel slip

belt dynamics

slip stiffness

relaxation length

ampl.

phase.

frequency [Hz]

measurement simulation

$V = 25 \text{ km/h}$

$F_{z0} = 4000 \text{ N}$

Tyre belt natural frequencies

Measured and Simulated FRFs

longitudinal force to brake torque

longitudinal force to wheel slip
Tyre belt natural frequencies
Vertical: Cleat excitation

Vertical force
free rolling

Power spectrum

- $V = 25$ km/h
- $V = 39$ km/h
- $V = 59$ km/h

measurement simulation
Tyre enveloping
Rolling over cleats

Flat plank, slow rolling to avoid inertia effects
Tyre enveloping
Rolling over cleats

Vertical force

Vertical force [N]

wheel position [mm]

$F_{z0} = 6000$ N

$F_{z0} = 4000$ N

$F_{z0} = 2000$ N
SWIFT compared to test data
free rolling over cleat

Vertical force
free rolling, trapezoid cleat

Vertical force [N]

-2000 -1500 -1000 -500 0 500 1000 1500 2000

time [s]

0.05 0.10

measurement simulation

V = 25 km/h

V = 39 km/h

V = 59 km/h

30 mm

10 mm

10 mm

30 mm
SWIFT compared to test data
free rolling over cleat

Longitudinal force
free rolling

\[ V = 25 \text{ km/h} \]
\[ V = 39 \text{ km/h} \]
\[ V = 59 \text{ km/h} \]

measurement simulation
SWIFT compared to test data
free rolling over cleat

Rotational rim velocity
free rolling

Wheel velocity [rad/s]

- $V = 25$ km/h
- $V = 39$ km/h
- $V = 59$ km/h

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measurement  simulation
SWIFT compared to test data
rolling over pot hole during braking

Longitudinal force
influence of brake torque

$V = 25 \text{ km/h}$
SWIFT compared to test data
step slip angle input

Lateral force [N] (detail)

$F_z = 3700$ N, $V = 25$ km/h
SWIFT compared to test data
free rolling over a sequence of cleats
SWIFT compared to test data
full vehicle over uneven road

Validation by a SWIFT user:
• Driving over uneven road at 55 mph
• Test vehicle vs. full vehicle model
• vertical axle accelerations
SWIFT compared to test data
full vehicle over uneven road

Vertical axle acceleration model vs. test vehicle data

Power Spectral Density (dB/Hz)

Frequency (Hz)

- Measurement
- SWIFT simulation
Applications of SWIFT-Tyre

- Comfort & Ride, also linearisation and frequency domain calculations are supported
- 4 post rig ride testing
- Chassis control systems (ABS, ESP, VDC, ..)
- Combined dynamic braking, cornering and ride
- Steering system and braking vibrations
- Drive line vibrations
- Shimmy analysis
- Calculation of durability load cases
- ..

Note: Basic handling similar to MF-Tyre
For all kinds of tyres
SWIFT-Datasets

- **SWIFT-Dataset Library**
- **Full estimation of a specific tyre**
  - fast and low cost
  - based upon experience
  - only basic tyre property data required
- **Testing of a specific tyre**
  - Basic steady state tyre testing (MF testing)
  - Loaded and effective rolling radius testing
  - Cleat testing at low speed (Tyre enveloping)
  - Cleat testing at moderate speeds (Tyre belt natural frequencies)

- **Estimation and test protocol free available**
- **Supported by tyre manufacturers**
**SWIFT-Datasets**

**Estimation method**

**Required data:**
- Unloaded tyre radius
- Tyre mass and inertia
- Nominal tyre load
- Lateral relaxation length or non-rolling lateral stiffness
- Longitudinal relaxation length or non-rolling longitudinal stiffness
- Slip or Cornering stiffness
- Tyre F&M data, or MF-coefficients
SWIFT-Datasets

Testing

- Only conventional test equipment required
- Data processing supported by SWIFT-Tool+
- TNO co-operates with tyre manufacturers for ‘in-house’ SWIFT testing
- TNO can support with test facilities
## SWIFT-Datasets

### Tyre Data Requirements (IAVSD tyre model benchmark, draft)

<table>
<thead>
<tr>
<th>Geometry and Material information</th>
<th>Loads</th>
<th>Speed</th>
<th>Other conditions</th>
<th>SWIFT-Tyre</th>
<th>F-Tire</th>
<th>RMOD-K</th>
<th>CD-TIRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size tyre and rim</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free tyre radius</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tyre mass</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polar tyre moment of inertia</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diometrical moment of inertia</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tread height</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tread width</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tread modulus/ShA</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tread stiffness ratio longitudinal/lateral</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tread friction</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belt width, radius, angle &amp; cross section</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belt cord stiffness</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tread and belt mass</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Stationary test data

#### Non-rolling tyre

<table>
<thead>
<tr>
<th>Vertical stiffness on flat surface</th>
<th>0 - 1.3 x Fz ETRTO</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal stiffness on flat surface</td>
<td>0.5, 0.8, 1.1 x Fz ETRTO</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Lateral stiffness on flat surface</td>
<td>0.5, 0.8, 1.1 x Fz ETRTO</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Footprint (paper copy)</td>
<td>0.5, 0.8, 1.1 x Fz ETRTO</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Vertical stiffness on cleat</td>
<td>20x20mm</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

#### Rolling tyre

| Rolling at various speeds (loaded radius testing) | 0.5, 0.8, 1.1 x Fz ETRTO | 0 - 300 Hz, not loaded, fixed rim | x | x | x | x | x | x |
| Steady state F&M testing lateral (MF testing) | TIME test procedure | x | x | x | x | x | x |
| Steady state F&M testing longitudinal (MF testing) | >40% slip | x | x | x | x | x | x |

### Dynamic test data

#### Modal Analysis

| Eigenfrequencies | 0 - 300 Hz, not loaded, fixed rim | x | x | x | x | x | x |
| Modal damping    | 0 - 300 Hz, not loaded, fixed rim | x | x | x | x | x | x |
| Modal shapes     | 0 - 300 Hz, not loaded, fixed rim | x | x | x | x | x | x |

#### Cleat testing

| Rectangular cleat 90 deg with wheel plane | 0.5, 0.8, 1.1 x Fz ETRTO | 0 - 300 Hz, not loaded, fixed rim | x | x | x | x | x | x |

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Often confidential data

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**SWIFT-Tyre in SIMPACK**

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SWIFT-Tool+

Supports efficient tyre data exchange between tyre and vehicle manufacturers and automotive suppliers.

In addition to MF-Tool+ functionality:

- estimation method
  
  SWIFT-Datasets on basic tyre properties

- fitting of test data from cleat testing
  
  - low speed testing (tyre enveloping)
  
  - moderate speed testing (tyre belt stiffness and damping rates)

- supports mixed partly estimation and partly testing

- visualisation of tyre dynamic and enveloping properties
SWIFT-Tyre in SIMPACK

- <to put the avi of bmw in simpack>
Concluding

SWIFT-Tyre:

• **SWIFT-Tyre** is available in SIMPACK
• **is an upgrade of MF-Tyre**
• **can handle tyre 3D behaviour up to 60 Hz, vertical up to 100 Hz, driving over any obstacle/uneven road**
• **required effort for SWIFT-Datasets is low:**
  • library
  • estimation
  • testing
• **process from data/estimation to Datasets supported by SWIFT-Tool+**
• **support of tyre manufacturers**