FTire: Stepping Towards the Real Tire

Modeling Imperfections
Operating Conditions
Misuse Extensions
Temperature
Tread Wear

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Model Imperfections
Operating Conditions
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FTire: Stepping Towards the Real Tire

Agenda

- Model Imperfections
- Operating Conditions
- Misuse Extensions
- Temperature
- Tread Wear
Constant and Harmonic Imperfection Data

- **Ply-Steer**
  
dimensionless quantity, relating to contact length and wheel load

- **Conicity**

  specified by conicity angle

- **Static Imbalance**

  specified by required balance weight and its location

- **Dynamic Imbalance**

  specified by required pair of balance weights and its location
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Zero and First Order Imperfections: Specification
Direction Dependency of Conicity and Ply-Steer Forces/Moments

- Conicity
- Ply-Steer

- Rolling backward
- Rolling forward

- Side force
- Aligning torque
Imbalance Results: $F_z$ and $M_z$ PSDs on Flat Road

**straight rolling**

**static imbalance**

50 g

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>40</th>
<th>80</th>
<th>160</th>
<th>320</th>
</tr>
</thead>
</table>

**dynamic imbalance**

2 x 50 g

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>40</th>
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</thead>
</table>
Imperfection Spline Data, Varying along Circumference

- **Radial non-uniformity** (stiffness variation)
- **Tangential non-uniformity** (stiffness variation)
- **Radius** variation (with automatic static balancing)
- **Tread gauge** variation (along circumference or full 2D)
- **Mass distribution** variation

```
radius_var_vs_angle_spline =
120 0
160 5
200 0
270 0
290 -5
310 0  ! [deg], [%]
```

*piecewise linear* or smooth spline interpolation selectable
**F Tire: Stepping Towards the Real Tire**

Varying Imperfections: Specification
Extreme Radius Variation (for Demonstration Purposes)
→ Model Imperfections
→ **Operating Conditions**
→ Misuse Extensions
→ Temperature
→ Tread Wear
Operating Conditions

might be set or changed arbitrarily during a running simulation

- cold inflation pressure
  (actual pressure depends on temperature and more)

- tread depth
  (if not controlled by wear model)

- environmental temperature

- tire temperature
  (if not controlled by thermal model)
**Inflation Pressure**

- Inflation pressure is an *operating condition* and might arbitrarily vary during a running simulation, without any slow-down of the simulation.

- Pressure forces are applied to belt segments in radial direction.

- Every translational, rotational, and bending *stiffness value* depends on inflation pressure.

- Sudden *pressure loss*, up to run-on-flat simulation is possible.
Inflation Pressure

stiffness: 
\[ c = c(p) \]

pressure forces: 
\[ F_{pressure} = F(p) \cdot n \]
FTire: Stepping Towards the Real Tire Operating Conditions: Specification
Blowout at 180 km/h
→ Model Imperfections
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→ **Misuse Extensions**
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Rim-to-Belt Contact

additional stiff unilateral springs, distributed along rim flanges, between rim and belt inner side

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Misuse Extensions: Rim-to-Belt Contact
Sidewall Contact

'tread' contact elements extended over outer half of sidewalls
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Misuse Extensions: Rim-to-Road Contact

Rim-to-Road Contact

contact force normal to obstacle, nonlinear function of intrusion depth
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Misuse Extensions: Data Specification
Sidewall Contact: Falling Wheel
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Misuse Extensions: Example Curb Impact (1)

hitting and climbing an oblique curb, 20 deg heading angle, 60 km/h
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Misuse Extensions: Example Curb Impact (2)

- rim/belt intrusion
- sidewall intrusion
- rim/road intrusion
Model Imperfections
Operating Conditions
Misuse Extensions
Temperature
Tread Wear
Thermal Model

- tire structure temperature influences inflation pressure via $pV = kT$ (and thus indirectly the tire stiffness)

- distributed tread temperature influences road friction characteristic

Regions with different thermal properties:
- tire structure (side-wall, belt, air volume)
- tread outside contact patch
- contact patch (distributed temperature)
Thermal Model

→ heating due to structural damping and friction in contact patch

→ cooling by convection and radiation in sidewall and tread (depending on rolling speed and ambient temperature)

→ heat transfer between regions determined by heat transfer coefficients

heat transfer coefficients
heat capacities
determined by
steady-state temperatures
heating time constants
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Thermal Model: Data Specification

Thermal Model / Wear Model: How to Activate / Specify
**FTire: Stepping Towards the Real Tire Temperature During Side-Slip Sweep**

- **side-slip angle**: ±10 deg
- **camber angle**: 2 deg
→ Model Imperfections
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Tread Wear Model

for each individual tread block, wear rate is assumed to be a function of friction power and temperature:

\[ \dot{h}_{\text{tread}} = -f_{\text{wear}}(P_{\text{loss}}, T_{\text{tread}}) \]

where

\[ P_{\text{loss}} = F_f \]

each tread block’s height is treated as an additional state variable.
Tread Wear Model

Change in tread depth affects

→ **tread geometry**  
   (and thus ground pressure distribution)
→ **compression stiffness** and damping
→ **shear stiffness** and damping
→ **mass**
→ **heat capacity**
Q & A

*FTire* etc. demo versions, papers, animations, documentation, version updates, and more:

www.cosin.eu