Lecture

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Tire Mechanics
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Tire Design Fundamentals

- Running surface
- Shoulder
- Belt
- Intermediate ply
- Carcass
- Sidewall
- Bead reinforcement
- Bead core
- Interior insulating layer
- Bead
The Tire - A Compromise (1)

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Tire Design Measures</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good damping characteristics</td>
<td>Large volume</td>
<td>Limited high speed capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased substructure loading</td>
</tr>
<tr>
<td>Excellent ride comfort</td>
<td>Low inflation pressure</td>
<td>Reduced service life</td>
</tr>
<tr>
<td></td>
<td>Obtuse cord angle</td>
<td>Increased heat-up</td>
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<tr>
<td></td>
<td></td>
<td>Less sufficient cornering stability</td>
</tr>
<tr>
<td>Low rolling resistance</td>
<td>Increased inflation pressure</td>
<td>Moderate springing characteristics</td>
</tr>
<tr>
<td></td>
<td>Acute cord angle</td>
<td>Bad road surface contact</td>
</tr>
<tr>
<td></td>
<td>Belt type</td>
<td>Minimal service life</td>
</tr>
<tr>
<td>Minimal heat up</td>
<td>Thin sidewall</td>
<td>Marginal sidewall stiffness</td>
</tr>
<tr>
<td></td>
<td>Mixture with marginal damping</td>
<td>Marginal adhesion on wet roads</td>
</tr>
<tr>
<td>Excellent adhesion on wet road surface</td>
<td>Transversely situated tread lugs</td>
<td>Marginal smoothness</td>
</tr>
<tr>
<td></td>
<td>Fine profile</td>
<td>Marginal service life</td>
</tr>
<tr>
<td></td>
<td>Flat, broad running surface</td>
<td>Increased running noise</td>
</tr>
<tr>
<td>Good cornering stability</td>
<td>Higher inflation pressure</td>
<td>Marginal ride comfort</td>
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<tr>
<td></td>
<td>Acute cord angle</td>
<td>Marginal springing characteristics</td>
</tr>
<tr>
<td></td>
<td>Longitudinally orientated profile</td>
<td>Increased shoulder loading</td>
</tr>
<tr>
<td></td>
<td>Low height/width ratio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Broadened rim width</td>
<td></td>
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<tr>
<td>Limited high speed capacity</td>
<td>Increased substructure loading</td>
<td></td>
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<tr>
<td>Reduced service life</td>
<td>Increased heat-up</td>
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<tr>
<td>Less sufficient cornering stability</td>
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<td>Moderate springing characteristics</td>
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<td>Bad road surface contact</td>
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<td>Minimal service life</td>
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<tr>
<td>Marginal sidewall stiffness</td>
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<td>Marginal adhesion on wet roads</td>
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<td>Increased running noise</td>
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<td>Increased shoulder loading</td>
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## The Tire - A Compromise (2)

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Tire Design Measures</th>
<th>Trend</th>
</tr>
</thead>
</table>
| Maximum service life                | Increasing stiffness of running surface  
Uniform surface pressure distribution                                               | Limited high speed capacity  
Increased heat-up  
Marginal ride comfort                 |
| Operational safety at high speed   | High-strength cord types  
Thin sidewalls  
Acute cord angle  
Heat resistant mixture                                                             | Flat spots after prolonged standstill  
Marginal ride comfort                  |
| Rolling noise reduction             | Circumferential-rib tread, no fine tread  
No lateral cutting  
Running surface mixture with high damping                                              | Marginal adhesion when wet, snow and ice  
Increased rolling resistance             |
| Driveability in winter              | Massive bar winter tread profile  
Spikes                                                                                | Increased riding noise  
Decreased service life  
Limited high speed capacity            |
| Off-road capacity                   | Big volume  
Low inflation pressure  
Massive bar tread profile  
Adaptable carcass                                                                     | Increased heat-up  
Limited high speed capacity            |
System ”Wheel/Tire” - Evaluation Criteria

Primary criteria

- Safety
- Economy
- Maximum attainable comfort for driver and load
System “Wheel/Tire” - Tire Characteristics Influencing Safety

Safety criteria

- Mechanical strength
- Tire force fit
- Adhesion on dry, wet and icy road surfaces, when decelerating and accelerating
System “Wheel/Tire” - Tire Characteristics Influencing Economy

Economic criteria

• Service life
• Rolling resistance
• Dimension and weights
• Tire/chain compatibility
Influence of Inflation Pressure and Load on the Service Life of a Tire
Influence of Inflation Pressure on Fuel Consumption of Commercial Vehicles

Results from test vehicles 1996-2002

- Increased fuel consumption (mean values)
- Reduction of inflation pressure

- Vans and light trucks (<7.5 t)
- Heavy trucks (>7.5 t)
System “Wheel/Tire” - Tire Characteristics Influencing Ride Comfort

**Comfort criteria**

- Springing behavior
- Response- and re-aligning behavior
- Uniformity and running noise
- Ease of assembly
Radial Spring Stiffness of a Commercial Vehicle Tire

Tire:
Michelin XZA
11 R 22.5

Spring stiffness

Slip angle $\alpha$

Sturz: 2°
Adhesion between Tire and Road Surface - Scope of Testing

- Influence of surface pressure
- Forces acting on a tire
- Tire on dry road surface
- Free rolling wheel under slip
- Straight-ahead rolling wheel while accelerating and decelerating
- Combination of slip angle and slip
- Tire on wet road surface
- Tire on wintry/icy road surface
Tire Test Truck

Measuring axle
Tire Test Stand
Coefficient of Adhesion in Dependence of Surface Pressure

- Passenger cars
- Commercial vehicles

Dry road surface

Surface pressure $p_m$
# Forces Acting on Tires

<table>
<thead>
<tr>
<th>Dimension Unit</th>
<th>Term</th>
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<tbody>
<tr>
<td>B</td>
<td>kN</td>
</tr>
<tr>
<td>f</td>
<td>mm</td>
</tr>
<tr>
<td>M</td>
<td>Nm</td>
</tr>
<tr>
<td>M&lt;sub&gt;γ&lt;/sub&gt;</td>
<td>Nm</td>
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<tr>
<td>n</td>
<td>mm</td>
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<tr>
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<td>bar</td>
</tr>
<tr>
<td>Q</td>
<td>kN</td>
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<td>mm</td>
</tr>
<tr>
<td>S</td>
<td>kN</td>
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<tr>
<td>v&lt;sub&gt;0&lt;/sub&gt;</td>
<td>km/h</td>
</tr>
<tr>
<td>α</td>
<td>°</td>
</tr>
<tr>
<td>β</td>
<td>°</td>
</tr>
<tr>
<td>γ</td>
<td>°</td>
</tr>
</tbody>
</table>
Tire Characteristics According to Gough

Wheel load $R = 50\, \text{kN}$

Lateral force $S$

Slip angle $\alpha = 2^\circ$

Re-aligning torque $M_R$

Caster $n_s$

Michelin XZA

$11\, R\, 22.5$

$p_i = 7.75\, \text{bar}$

$v_0 = 60\, \text{km/h}$

Dry road surface
Lateral Force/Slip Angle Characteristics

Michelin XZA
11 R 22.5
Inflation pressure = 7.75 bar
Speed = 40 km/h
Dry road surface
Wheel load R = 40 kN

Lateral force, S

Slip angle, \( \alpha \)
Influence of Camber Angle on Lateral Forces

Michelin XZA
11 R 22.5
p_i = 7.75 bar
v_0 = 60 km/h
Dry road surface

Wheel load
R = 40 kN

Lateral force S

Camber angle
0°
5°

Slide angle α

Lateral force S vs. Slip angle α graph with different camber angles and wheel load.
Influence of Tread Conditions on Lateral Forces

Tread condition
- 95%
- 60%
- 30%

Lateral force $S$

Slip angle $\alpha$

Michelin XZA

11 R 22.5
$p_i = 7.75$ bar
$R = 30$ kN
$v_0 = 60$ km/h
Dry road surface
Braking Force/Slip Characteristics

Michelin XZA

Wheel load $R = 40 \text{ kN}$

$\pi = 7.75 \text{ bar}$

$v_0 = 60 \text{ km/h}$

Dry road surface
Influence of Tire Inflation Pressure on Lateral and Braking Forces

**Graphs:**
- **Michelin XZA**
  - 11R 22.5
  - $v_0 = 60$ km/h
  - Dry road surface

**Lateral Force vs. Slip Angle**
- Tire inflation pressure $p_i$:
  - 7.75 bar
  - 6 bar
- Wheel load $R = 30$ kN
- $R = 10$ kN

**Braking Force vs. Slip**
- Tire inflation pressure $p_i$:
  - 7.75 bar
  - 6 bar
- Wheel load $R = 30$ kN
- $R = 10$ kN
Influence of Camber Angle on Braking Forces

Tendency

Camber angle increases
Influence of Slip Angle when Braking

**Michelin XZA**

- 11 R 22.5
- $p_0 = 7.75$ bar
- $R = 40$ kN
- $v_0 = 60$ km/h
- dry road surface

Slip angle increases
The Principle of Cooperation between Circumferential Forces, Lateral Forces, Slip Angle and Slip
Measured Tire Characteristics

Michelin XZA
11 R 22.5
\( p_i = 7.75 \) bar
\( R = 40 \, \text{kN} \)
\( v_0 = 60 \, \text{km/h} \)
dry road surface
Envelope Curves for Maximum Possible Adhesion of a Tire with Wheel Load as Parameter

Michelin XZA

11 R 22.5

$\pi = 7.75 \text{ bar}$

$v_0 = 60 \text{ km/h}$

dry road surface

Wheel load
$R = 40 \text{ kN}$
Contact Area of a Tire on a Wet Road Surface

- Direction of travel
- Water wedge

Contact area for a dry road surface
Contact area for a wet road surface
Influence of Water Depth on Braking Force/Lateral Force - Characteristics

Water depth increases

Braking force (Lateral force)

Slip (Slip angle)

0.2 mm

0.0

2.0 mm

Braking force

Speed

Water depth increases

Water depth increases

Tread depth
Dependence of Adhesion Limits from Water Depth

Lateral force $S$

<table>
<thead>
<tr>
<th>Water depth (mm) increases</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>2.0</td>
</tr>
</tbody>
</table>

Dry road surface

Michelin XZA

11 R 22.5
$R = 40 \text{ kN}$
$v_0 = 80 \text{ km/h}$
Aquaplaning Performance of Tires made by Different Manufacturers

Products A, B, C, D, E, F of certain tire manufacturers

Test Conditions: Water depth 2mm, Speed 100km/h, Wheel load 2kN
Influence of Ice Temperature on Lateral Force Capacities

- Ice surface temperature increases
- Road speed increases