ABOUT THE ROLLING RESISTANCE (RR) TRAILER AND PARAMETERS INFLUENCING RR

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Overview

1. Introduction
2. Trailer measurements
3. Coast down measurements
4. One-third-octave band texture levels
5. Conclusions
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1. Introduction

Rolling resistance (RR) \( \uparrow \)
Energy consumption \( \uparrow \)
\( \text{CO}_2 \) emission \( \uparrow \)

Influence of road surface?

Rolling Resistance Coefficient:
dimensionless ratio of RR force to wheel load
\( C_r = \frac{F_r}{F_z} \)
where the forces \( F_r \) and \( F_z \) are magnitudes and not vectors
1. Introduction

Trailer measurements
- Quarter-car with car suspension
- Tyre load 2000 N
- Force $R$ counteracting rolling of wheel causes backward motion over angle $\theta$
- Sensors:
  - Inclination $\theta$ wheel carrier - frame trailer
  - Inclination $\mu$ frame trailer - horizontal plane
  - Inclination $\alpha$ trailer - towing vehicle static condition
  - Tyre temperature: external infrared sensor at sidewall near shoulder tyre
- Speed
- Acceleration
1. Introduction

Coast down measurements

- Rudimentary measurements
- No specialized measuring equipment
- Each vehicle was coasted with transmission disengaged until standstill
- Distance travelled was measured
- A lot of parameters are still influencing the measurements: e.g. vehicle RR and aerodynamical resistance
1. Introduction

Texture measurements
Dynamic laser profilometer
BRRC:
- 78 kHz sample frequency
- laser beam 0.2 mm diameter
- 40 km/h when measuring in steps of 0.2 mm
- vertical measuring range 64 mm
- 16-bit system
- vertical resolution 1 μm
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2. Trailer measurements

Short time repeatability
- 9 test tracks
- 5 days in between
- Temperature correction:
  \[ C_r(T) = C_r(T_0) \times e^{\left( T_0 - T \right) / T_1} \]
  where \( T_0 = 30 \, ^\circ C \), \( T_1 = 50 \, ^\circ C \) [Descornet]
- All outliers were included in graphs and analyses
- Good repeatability (slope approaches 1)
- Reasonable correlation

\[ y = 0.9160x \]
\[ R^2 = 0.7401 \]
2. Trailer measurements

**Long time repeatability**

- **Part I:**
  - 2 measurement campaigns
  - 10 test sections
  - 2 different groups of researchers
  - 8 – 11 months
- Good repeatability (slope approaches 1)
- Correlation not so good
- Possible reasons:
  - 2 different groups of researchers, communication errors
  - Wear road surface
  - Calibration errors students
2. Trailer measurements

Long time repeatability

- Part II:
  - 2 measurement campaigns
  - other test sections (same as short term repeatability)
  - same group of researchers
  - 3 months
- Repeatability is good (slope of approaches 1)
- Correlation is reasonable

\[ y = 0.9745x \]
\[ R^2 = 0.7108 \]
2. Trailer measurements

Tyre load
- loads: 1285 N, 1416 N, 1547 N, 1678 N, 1809 N and 1939 N
- 2 directions of street: east and west
- influence load on RR force is linear
- \( C_r \) constant and more or less independent of the load
- applying temperature correction yields better correlation
2. Trailer measurements

**Tyre inflation pressure**

- 1.2 bar - 3.2 bar (in steps of 0.5 bar)
- tyre inflation pressure decrease = $C_r$ increase
- 1 bar difference = approx. 0.004 raising or lowering of $C_r$ (15 - 20 %)
- tyre inflation pressure very important factor for RR
- tyre inflation pressure increases with temperature -> good warm-up procedure
2. Trailer measurements

Wind shielding
- removable wooden windscreen
- measurements with old and new tyre at 30, 50 and 70 km/h
- eastern wind during measurements with new tyre
- generally \( C_r \) higher without windscreen
- windscreen absolutely necessary for measurements, but windscreen all around tyre and to ground level would even be better
2. Trailer measurements

**Speed**
- measurements with old and new tyre at 30, 50 and 70 km/h with/without windscreen
- generally $C_r$ increases when speed increases (except for one measurement without windscreen)
- more recent research [MIRIAM]: larger windscreen (encapsulating whole tyre) advisable to eliminate wind influence at higher speed
2. Trailer measurements

Tyre type
- old tyre: slick Michelin SB-15/63-14X, about 30 years old
- new tyre: Michelin Energy Saver 195/70 R14 91T
- C_r values new tyre lower than old tyre
- not only road surface important share on RR, also tyre
- well thought selection of tyre can provide lower CO2 emission
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3. Coast down measurements

- Always same driver, fuel tank filled up before start
- Tyre pressure – cold condition
- At least 10 km to warm up tyres
- Length test sections 100 to 200 m
- Initial speed 20 km/h vehicle A and 25 km/h vehicle B
- Clutch pedal pushed, coasted from start point until standstill, distance measured
- To eliminate influence slope, measurements in 2 directions because of safety on opposite driving lane
- 3 coast down measurements in each direction
- Dry weather conditions and low wind
- Ambient air temperature: 5.6 - 20.5 °C no temperature corrections
3. Coast down measurements

<table>
<thead>
<tr>
<th></th>
<th>Vehicle A</th>
<th>Vehicle B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicle weight</strong></td>
<td>1480 kg</td>
<td>1400 kg</td>
</tr>
<tr>
<td>(driver included)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Picture of vehicle</strong></td>
<td><img src="image1" alt="Vehicle A" /></td>
<td><img src="image2" alt="Vehicle B" /></td>
</tr>
<tr>
<td><strong>Tyre Inflation</strong></td>
<td>2.5 bar</td>
<td>2.4 bar</td>
</tr>
<tr>
<td><strong>Tyre type</strong></td>
<td>Triangle 225/45ZR17</td>
<td>Michelin 205/55R16</td>
</tr>
<tr>
<td><strong>Tread depth tyre</strong></td>
<td>6.0 mm</td>
<td>4.8 mm</td>
</tr>
<tr>
<td><strong>Picture of tyre</strong></td>
<td><img src="image3" alt="Tyre A" /></td>
<td><img src="image4" alt="Tyre B" /></td>
</tr>
</tbody>
</table>
3. Coast down measurements

Correlation between measurements 2 vehicles

**All sections**

- **Direction 1**
  - $y = 0.6077x + 105.65$
  - $R^2 = 0.26$

- **Direction 2**
  - $y = 2.9911x - 115.44$
  - $R^2 = 0.47$

- **Average**
  - $y = -1.0354x + 268.32$
  - $R^2 = 0.28$

**Only sections with homogeneous texture in both directions**

- **Direction 1**
  - $y = 0.501x + 107.33$
  - $R^2 = 0.42$

- **Direction 2**
  - $y = -1.2204x + 275.97$
  - $R^2 = 0.59$

- **Average**
  - $y = 3.9906x - 197.92$
  - $R^2 = 0.50$

Distance vehicle B [m]

Distance vehicle A [m]
3. Coast down measurements

Correlation between coast down and trailer measurements

- 6 test sections in common
- Vehicle B shows good correlation (25 km/h)
- Low correlation vehicle A (20 km/h)
- Explanation:
  - vehicle A less accurate because of lower initial speed?
  - first measurements, operators not yet used to measurement method?
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4. One-third-octave band texture levels

Texture measurements (trailer, De Bie – Hofmans)
4. One-third-octave band texture levels

Texture measurements (coast down, Aerts – Cools)

- Hooiendonkstraat
- Nekkerhal 1
- Nekkerhal 2
- Nekkerhal 3
- Roekstraat
- Steenweg op Heindonk
- Corluylei
- Prinsendreef
- Stijn Streuvelslaan
- Van Den Nestelaan
4. One-third-octave band texture levels

- Low correlations De Bie – Hofmans: change of tyre, new sensors… calibrations issues
- Contact area length of car tyre is 0.15 m; maxima graphs Dotsenko-Helsen and Aerts-Cools (B) are situated around 0.16 m wavelength
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5. Conclusions

- Long and short time repeatability reasonable
- Influence of load on RR force linear; $C_r$ constant and more or less independent of load
- Tyre inflation pressure large influence; 1 bar difference = approx. 0.004 raising or lowering of $C_r$ (15 - 20 %)
- Wind shielding necessary -> more accurate results at higher speeds
5. Conclusions

- $C_r$ increases slightly when speed increases; more research needed larger windscreen
- Selection of tyre – lower CO$_2$ emission
- Calibration very delicate, high influence
- Rudimentary coast down plausible RR results
- Very good correlations RR – megatexture (coast down, Dotsenko-Helsen, Descornet)
Thank you for your attention!