TRUCK TYRE - ROAD CONTACT STRESS MEASUREMENT AND MODELLING

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Topics

- Measuring System
- Finite Element Model of the Truck Tyre
- Tyre Model Contact Stress Distributions
- Contact Stress Distributions Comparison
- Stress Ratio Measured in Contact Patch
- Conclusions
Measuring System

- original equipment designed to measure tri-axial tyre-road stresses
- covering the entire contact patch width
- measuring in real rolling conditions
- designed primarily for truck tyres, also usable for other tyres
- able to measure stresses in various conditions
  - free rolling
  - braking
  - traction
  - rolling with slip angle
Measuring System

- 30 sensing elements placed in a row-type arrangement, each having the upper surface co-planar with the road surface.
- Strain-gauge instrumented elements for measuring tri-orthogonal components of force applied on the upper surface.
- Elements designed to have very small tri-orthogonal displacements, especially on vertical direction, but to ensure adequate sensibility of measurement on each direction.
- Complex transducer temporarily inserted in the road surface; it can also be placed indoor, for more repeatability.
- Measurements performed in real rolling conditions for a wide speed range.
- Stress distribution resolution of 10 mm on lateral direction, but considerably higher resolution on longitudinal direction.
Measuring System

- fixed measuring system with 90 strain-gauge channels
  - distributed forces $F_x$, $F_y$, $F_z$ as a function of time
- mobile measuring system placed in the vehicle
  - vehicle speed and distance as a function of time
- fixed and mobile systems simultaneously started by an optical trigger device, in view of obtaining the distributed forces $F_x$, $F_y$, and $F_z$ as a function of contact patch length
- vehicle trajectory controlled by the driver, using a camera fixed on the vehicle in front of the tested wheel
Finite Element Model of the Truck Tyre

- model geometry obtained from point coordinates measured on 11R22.5 tyres
  - outer coordinates measured on the tyre used for experimental investigations
  - inner coordinates obtained using a section cut from a tyre of the same type
- location of different types of rubber components, position and structure of tyre plies and bead wires obtained using tyre section
- simplification of tread pattern of the modelled tyre consisting mainly of circumferential grooves
  - neglecting the thin transversal sipes located on two ribs
  - considering grooves with constant width along tyre circumference, although the real ones have jagged edges
- the tri-dimensional model of the tyre section, developed using finite element software Abaqus, has been obtained by rotating the bi-dimensional tyre model
Finite Element Model of the Truck Tyre

- solid elements for the rubber components
- surface elements in which the reinforcement layers are defined, considering the properties of wires:
  - section area
  - spacing
  - angle
- mechanical properties of rubber components defined taking into account the hyperelastic behaviour
- steel wire components modelled with linear elastic isotropic properties
- finer mesh in the contact region, for improving resolution in the contact patch, without increasing too much the number of nodes and elements
Finite Element Model of the Truck Tyre

- rim modelled only as a rigid body, to which the corresponding nodes of the tyre model have been constrained
- road modelled as a rigid surface with one translational degree of freedom
- contact defined between road surface and tyre tread elements, with friction coefficient equal to 1.0 and normal force applied between road surface and tyre model
- tyre rolling analyses performed for different values of tyre inflation pressure, normal force, and camber angle
- angular velocity and translational velocity applied simultaneously on the tyre model to obtain free rolling, traction and braking conditions
- the analyses have provided the following distributions of normal, longitudinal and lateral stress, representing the action of the tyre on the road
Tyre Model Contact Stress Distributions

- **normal stress**
  \[ \text{[N/m}^2\text{]} \]

  - 3.2 km/h
  - 20445 N
  - 780 kPa
  - 1° camber
Tyre Model Contact Stress Distributions

• normal stress in the contact patch of the FE model
  • the highest values are located in the contact patch centre, due to moderate vertical load
  • in traction conditions, the highest values are slightly displaced in the rolling direction, while in braking conditions they are slightly displaced in the opposite direction
  • left-right asymmetry of contact patch shape and normal stress distribution due to camber angle
  • fore-aft asymmetry of contact patch shape and normal stress distribution due to torque applied on wheel
Tyre Model Contact Stress Distributions

- **longitudinal stress**
  
  \([\text{N/m}^2]\)

- 3.2 km/h
- 20445 N
- 780 kPa
- 1° camber
Tyre Model Contact Stress Distributions

- longitudinal stress in the contact patch of the FE model
  - in free rolling conditions, the longitudinal stress values are significantly lower than in the two other conditions
  - in traction and braking conditions, the highest values are located near the trailing edge of contact patch
  - differences appear between the longitudinal stress distributions along each rib in traction and braking conditions
Tyre Model Contact Stress Distributions

- **lateral stress**
  \[ \text{[N/m}^2\text{]} \]

- 3.2 km/h
- 20445 N
- 780 kPa
- 1° camber
Tyre Model Contact Stress Distributions

- lateral stress in the contact patch of the FE model
  - the distribution has opposite orientation on each tread rib
  - however the resultant stress is oriented predominantly towards the longitudinal plane
  - the rolling conditions have very small influence on the distribution of lateral stress, visible only near the trailing edge of the contact patch
Contact Stress Distributions Comparison

- free rolling conditions at 14.5 km/h

experimental

FE modelled

rolling direction

[N/m²]
Contact Stress Distributions Comparison

- comparison between stress distributions determined using the tyre model and those obtained experimentally in **free rolling conditions**
  - distributions of normal stress determined using the tyre model show good similarity to those obtained experimentally
  - longitudinal stress values are lower for the tyre model
  - lateral stress values are lower for the tyre model than the experimental ones
Contact Stress Distributions Comparison

- braking conditions at 7.8 km/h

![Comparison of contact stress distributions in normal, longitudinal, and lateral directions for experimental and FE modelled data.](image)

- rolling direction [N/m²]
Contact Stress Distributions Comparison

- comparison between stress distributions determined using the tyre model and those obtained experimentally in braking conditions
  - distributions of normal stress determined using the tyre model show good similarity to those obtained experimentally
  - longitudinal stress distribution in braking conditions is very similar to the measured results
  - lateral stress values are lower for the tyre model than the experimental ones
Stress Ratio Measured in Contact Patch

\[ R_{\text{shear}} = \frac{\sigma_{\text{shear}}}{\sigma_z} \]
\[ \sigma_{\text{shear}} = \sqrt{\sigma_x^2 + \sigma_y^2} \]

free rolling conditions                      braking conditions
Stress Ratio Measured in Contact Patch

- strongly connected to the tyre-road friction coefficient and slip phenomena

- comparison of stress ratio in free rolling and braking conditions
  - stress ratio values are in both cases higher towards the trailing edge of the truck tyre contact patch
  - in braking conditions the shear stresses in this region are almost double with respect to normal stresses
Conclusions

- the original measuring system
  - can be used to measure tri-axial truck tyre-road stresses
  - for tyres in free rolling, traction and braking conditions
  - simultaneously covering the entire contact patch width
- the finite element model of the truck tyre
  - provides distributions of contact stress in free rolling, traction and braking conditions
  - includes the structure of tyre plies and different types of rubber components, circumferential ribs of tyre tread
- comparison between modelling and experiment
  - normal stress determined using the tyre model shows good similarity to those obtained experimentally in both free rolling and braking conditions
  - longitudinal stress distribution of FE model in braking conditions is very similar to the measured results, but is lower in free rolling conditions
  - lateral stress values are lower for the tyre model than the experimental ones
Future Research

• FE model improvement by considering transversal sipes of tread profile
• performing measurements for treadless tyres
• performing measurements in traction and slip angle conditions

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Thank you for your attention!

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