Determination of the pneumatic tire rolling resistance

Laboratory class guide

Exemplary test questions that may be given during the test at the beginning of laboratory class are given below. Answers can be found in a handbook edited by Gent A.N. and Walter J.D.: "The Pneumatic tire"; NHTSA, Washington, D.C., August 2005, on-line link: www.nhtsa.gov/staticfiles/safercar/pdf/PneumaticTire_HS-810-561.pdf

Exemplary questions:

1. **Draw a cross section of a radial pneumatic tire and name the particular components of the tire structure** (handbook, chapter 1., section 3. "Tire components", page 6).
2. **List the materials utilized for tire reinforcement plies. Which of them are typically used as body ply** (handbook, chapter 1., section 3. "Tire components", page 6).
3. **Distinguish the difference between radial and diagonal tires. List the advantages and disadvantages of each type of tire** (handbook, chapter 1., section 2.2. "Tire types", page 3).
4. **What is the main cause for tire rolling resistance** (check the answer for question no. 6., see also handbook, chapter 12, section 1.3., page 480). **Which section of the radial tire is mainly responsible for energy dissipation while tire rolling** (handbook, chapter 12, section 2.1., page 483).
5. **What is the influence of:**
   - **vertical load of the tire,**
   - **inflation pressure of the tire**

   on tire rolling resistance. (handbook, chapter 12, section 2.2.2., page 491). Answer shall be given preferably with use of chart illustrating each relationship (check handbook, page 493).
6. **Explain the phenomena of the pneumatic tire rolling resistance.**
   ANSWER: Rolling resistance is caused by conversion of mechanical energy into heat while the pneumatic tire is being rolled. Thermal energy generation occurs because of following reasons:
   - mechanical hysteresis and viscoelasticity of rubber compound,
   - internal friction between reinforcing plies of a tire (body ply and belt plies),
   - friction between tire bead and rim,
   - friction between tread and road (slippage occurs at least partially within the road – tire contact),
   - aerodynamic drag acting at the tire,

   The most severe energy loss is the hysteretic loss which is due to viscoelastic properties of rubber. Typically 80-95% of rolling resistance is caused by rubber mechanical hysteresis.

   Firstly, hysteretic loss can be explained using energetic approach. The relationship between mean pressure within tire – road contact and tire deflection in case of standstill loading – unloading cycle is as depicted in Fig. 1a. Mean pressure represents also vertical force acting within the contact or, which is even more important, stress within the tire body during load – relaxation cycle. Consequently, area under the loading curve represents energy that shall be applied so as to deform the tire (increasing mean pressure, 0-A-B-C branch). On the other hand area beneath unloading curve (declining mean pressure, C-B'-A'-0) represents the energy that is restored when the tire is released. Contrary to perfectly elastic bodies, e.g. a spring made from steel, in case of a pneumatic tire said areas are not equal. It leads to a conclusion that during a single loading – unloading cycle of a tire a small amount of energy (represented in the Fig. 1a. by dashed area) must be lost in some way. Indeed, this portion of energy is converted into heat, mainly due to internal friction of polymeric chains of rubber compound.

Now, dividing the tire for infinite number of radial cross sections, one can easily see, that as the wheel is being rolled over the road, each cross section of the tire encounters multiple loading – unloading cycles. It means that energy is being continuously dissipated.

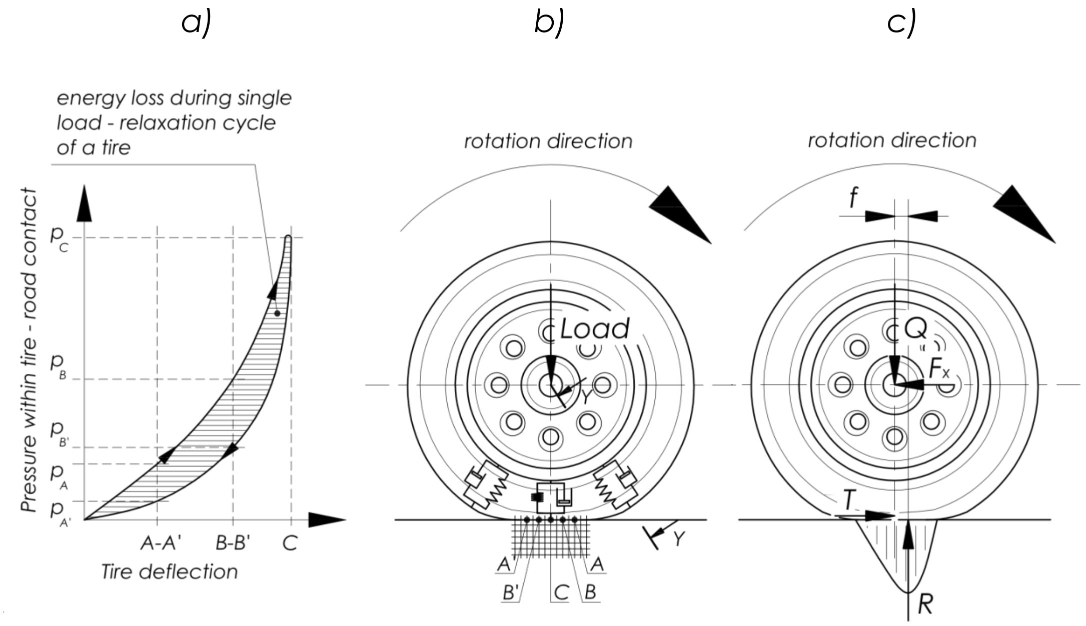

Fig. 1. Viscoelastic/hysteretic mechanism of the pneumatic tire rolling resistance: a) qualitative tire – road mean contact pressure vs. tire deflection relationship for typical pneumatic tire, b) scheme of a pneumatic tire loaded with vertical force causing radial deflection, c) forces acting at loaded pneumatic tire

The rolling resistance deriving from viscoelastic properties of rubber can be also explained using mechanical approach. To do so one shall consider pressure distribution within the tire – road contact.

In case of wheel rolling in direction given in Fig. 1. the cross sections of the tire located on the right hand side with respect to point C (Fig. 1b.) are in loading phase. As a single cross section of the tire reaches point C, its deformation is close to the maximum value. Finally, after passing point C, the tire cross section is being gradually unloaded. Taking an assumption that deformation of the tire is symmetrical with reference to the point C, on the basis of Fig. 1a. one can easily come to the conclusion that pressure within the tire road contact is not symmetrical. In case of given rotation direction unit pressures are higher on the right hand side with respect to point C, where the tire is in loading phase (Fig. 1. $p_A > p_{A'}$, $p_B > p_{B'}$). It means that overall vertical reaction force R is also shifted form point C by a distance of f, as depicted in Fig. 1c. Force R multiplied by f equals the additional torque – rolling resistance torque – that has to be applied in order to keep the wheel rolling, even if F_x force equals 0.

NOTE: For more details, please check handbook, chapter 12, sections 1.1., 1.2., 1.3. and 2.1., respective pages 476, 478, 480, 483.