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Truck and bus tyres — Methods of measuring rolling resistance

Pneumatiques pour camions et autobus — Méthodes de mesure de la résistance au roulement

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9948 was prepared by Technical Committee ISO/TC 31, *Tyres, rims and valves*, Sub-Committee SC 4, *Truck and bus tyres and rims*.

Annex A forms an integral part of this International Standard. Annexes B and C are for information only.

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Truck and bus tyres — Methods of measuring rolling resistance

1 Scope

This International Standard specifies methods for measuring rolling resistance, under controlled laboratory conditions, for new pneumatic tyres designed primarily for use on trucks and buses. The relationship between values obtained and the fuel economy of the vehicle is undetermined, and such values are not intended to be used to indicate levels of performance or quality.

This International Standard applies to all truck and bus tyres.

It enables comparisons to be made between the rolling resistance of new tyres when they are free-rolling straight ahead, in a position perpendicular to the drum outer surface, and in steady-state conditions.

In measuring tyre rolling resistance, it is necessary to measure small forces in the presence of much larger forces. It is, therefore, essential that equipment and instrumentation of appropriate accuracy be used.

2 Definitions

For the purposes of this International Standard, the following definitions apply.

2.1 rolling resistance, F_r: Loss of energy (or energy consumed) per unit of distance.

NOTE 1 The SI unit conventionally used for the rolling resistance is the newton metre per metre (N·m/m).

This is equivalent to the drag force in newtons (N).

2.2 rolling resistance coefficient, C_r: Ratio of the rolling resistance, in newtons, to the load on the tyre, in newtons. This quantity is dimensionless and is derived as follows:

$$C_r = \frac{\text{rolling resistance}}{\text{test load}}$$

2.3 capped inflation: Process of inflating the tyre and allowing the inflation pressure to build up, as the tyre is warmed up while running.

2.4 regulated inflation: Process of inflating the tyre to the required pressure independent of its temperature, and maintaining this inflation pressure while the tyre runs under load. This is most commonly done by using a regulated pressure source attached to the tyre through a rotating union. (See annex B.)

2.5 parasitic loss: Loss of energy (or energy consumed) per unit distance excluding tyre losses, and attributable to aerodynamic loss, bearing friction and other sources of systematic loss which may be inherent in the measurement.

2.6 skim reading: Type of parasitic loss measurement, in which the tyre is kept rolling, without slippage, while reducing the tyre load to a level at which energy loss within the tyre itself is virtually zero.

2.7 machine reading: Type of parasitic loss measurement, involving losses of the test machine, exclusive of losses in the rotating spindle which carries the tyre and rim.

2.8 moment of inertia: (See annex C.)

3 Test methods

The following alternative measurement methods are given in this International Standard. The choice of an individual method is left to the tester. For each method, the test measurements shall be converted to a rolling resistance force acting at the tyre/drum interface.

a) Force method: the reaction force at the tyre spindle.

b) Torque method: the torque input to the test drum.

c) Power method: the power input to the test drum.

d) Deceleration method: the deceleration of the test drum and tyre assembly.

4 Test equipment

4.1 Drum specifications

4.1.1 Diameter

The test dynamometer shall have a cylindrical flywheel (drum) with a diameter of between 1,7 m and 3 m inclusive. It should be noted that the results are different; see 8.3 for drum diameter correction for comparisons, if necessary.

4.1.2 Surface

The surface of the drum shall be smooth steel or textured, and shall be kept clean. For the textured drum surface, see B.4.

4.1.3 Width

The width of the drum test surface shall exceed the width of the test tyre tread.

4.2 Test rim

The tyre shall be mounted on a test rim, as specified in annex A.

4.3 Load, alignment, control and instrumentation accuracies

Measurement of these parameters shall be sufficiently accurate and precise to provide the required test data. The specific and respective values are shown in annex A.

4.4 Thermal environment

4.4.1 Reference conditions

The reference ambient temperature, as measured on the rotational axis of the tyre, 1 m away from the plane touching the nearest tyre sidewall, shall be 25 °C.

4.4.2 Alternative conditions

If the reference temperature cannot be obtained, the rolling resistance measurement shall be corrected to standard temperature conditions in accordance with 8.2.

4.4.3 Drum surface temperature

Care should be taken to ensure that the temperature of the test drum surface is approximately the same as the ambient temperature at the beginning of the test.

5 Test conditions

The test consists of a measurement of rolling resistance in which the tyre is inflated and the inflation pressure allowed to build up (i.e., "capped air").

5.1 Test speeds

5.1.1 Test speed for load index 122 and above

The value shall be obtained at a drum speed of 80 km/h for tyres with speed symbols K to M inclusive and at 60 km/h for speed symbols F to J inclusive.

5.1.2 Test speeds for load index 121 and below

The values shall be obtained at drum speeds of 80 km/h, and if required, 120 km/h.

5.2 Test load

The standard test load shall be computed from 85 % of the maximum single load capacity of the tyre and shall be kept within the tolerance specified in annex A.

5.3 Test inflation pressure

The inflation pressure shall be the inflation pressure, specified by the tyre manufacturer concerned, corresponding to the maximum single tyre load capacity. The inflation pressure shall be capped with the accuracy specified in A.4.1.

5.4 Duration and velocity

When the deceleration method is selected, the following requirements apply:

a) for duration, Δt, the time increments shall not exceed 0,5 s;

b) any variation of the test drum velocity shall not exceed 1 km/h.

5.5 Optional conditions

If the sensitivities of load, inflation or velocity are desired, the additional information given in annex B should be consulted.

6 Test procedure

The test procedure steps described below are to be followed in the sequence given.

6.1 Break-in

To ensure repeatability of measurements, an initial break-in and cooling period is required prior to the start of the test. Such a break-in should be carried out on a vehicle or on a test drum of at least 1,7 m in diameter.

6.2 Thermal conditioning

Place the inflated tyre in the thermal environment of the test location for the time necessary to achieve thermal equilibrium which is generally reached after 6 h.

6.3 Pressure adjustment

After thermal conditioning, the inflation pressure shall be adjusted to the test pressure and verified 10 min after the adjustment was made.

6.4 Warm-up

The tyre shall be run at constant test velocity until reaching a stabilized steady-state value of rolling resistance. Recommendations for warm-up periods are given in annex B.

6.5 Measurement and recording

The following shall be measured and recorded (see figure 1):

a) test velocity, U_n;

b) load on the tyre normal to the drum surface, L_m;

c) test inflation pressure:

1) initial, as defined in 6.3,

2) final, for capped inflation;

d) the driving torque on the drive shaft, T_t, the tyre spindle force, F_t, the input power, $V \times A$, or the deceleration of the test drum/tyre/wheel assembly, $\Delta\omega/\Delta t$, depending on the method;

e) distance, r_L (see 7.2.1);

f) ambient temperature, t_{amb};

g) test drum radius, R;

h) test method chosen;

i) test rim (designation and material).

6.6 Measurement of parasitic losses

Determine parasitic losses by a procedure given in 6.6.1, 6.6.2 or 6.6.3.

6.6.1 Skim reading

a) Reduce the load to maintain the tyre at the test velocity without slippage to, for example, 50 N.

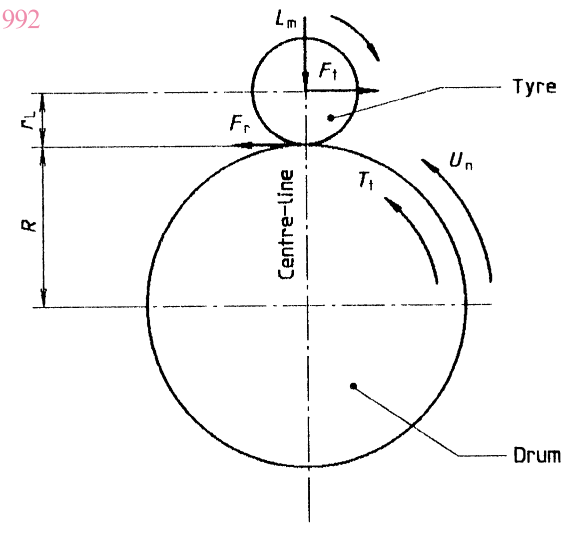
b) Record the spindle force, F_p, input torque, T_p, or the power, whichever applies.

c) Record the load on the tyre normal to the drum surface, L_p.

6.6.2 Machine reading

a) Remove the tyre from the test drum surface.

b) At the test velocity, U_n, record the input torque, T_p, the power, or the test drum deceleration, whichever applies.



F_r is the rolling resistance
T_t is the torque driving the drum
F_t is the spindle force on the tyre axle
U_n is the test drum velocity
L_m is the test load
R is the drum radius
r_L is the distance from the tyre axis to the drum outer surface under steady-state conditions

Figure 1 — Free-body diagram of tyre/drum system, assuming no bearing and windage losses

6.6.3 Deceleration method

a) Remove the tyre from the test drum surface.

b) Record the deceleration of the test drum, $\Delta\omega_o/\Delta t$, and that of the unloaded tyre, $\Delta\omega_{po}/\Delta t$.

7 Data interpretation

7.1 Subtraction of parasitic losses

The parasitic losses shall be subtracted as shown in 7.1.1, 7.1.2 or 7.1.3.

7.1.1 Skim reading

Subtract the skim reading from the test measurement.

7.1.2 Machine reading

Subtract the machine reading from the test measurement.

7.1.3 Parasitic losses

Calculate the parasitic losses, F_p, in newtons, as

$$F_p = \frac{I_D}{R}\left(\frac{\Delta\omega_{vo}}{\Delta t_o}\right) + \frac{I_T}{R_r}\left(\frac{\Delta\omega_{po}}{\Delta t_o}\right)$$

where

I_D is the test drum inertia in rotation, in kilogram metres squared;

R is the test drum surface radius, in metres;

ω_{vo} is the test drum angular velocity, without tyre, in radians per second;

Δt_o is the time increment chosen for the measurement of the parasitic losses without tyre, in seconds;

I_T is the tyre and wheel inertia in rotation, in kilogram metres squared;

R_r is the tyre rolling radius, in metres;

ω_{po} is the tyre angular velocity, unloaded tyre, in radians per second.

7.2 Rolling resistance calculation

The net values of driving torque, spindle force, power or deceleration are to be converted to rolling resistance, F_r, expressed in newtons, using the appropriate method, as shown in 7.2.1 to 7.2.4.

7.2.1 Force method

The rolling resistance, F_r, in newtons, is calculated with the equation

$$F_r = F_t[1 + (r_L/R)]$$

where

F_t is the tyre spindle force, in newtons;

r_L is the distance from the tyre axis to the drum outer surface under steady-state conditions, in metres;

R is the test drum radius, in metres.

7.2.2 Torque method

The rolling distance, F_r, in newtons, is calculated with the equation

$$F_r = \frac{T}{R}$$

where

T is the input torque, in newton metres;

R is the test drum radius, in metres.

7.2.3 Power method

The rolling resistance, F_r, in newtons, is calculated with the equation

$$F_r = \frac{3{,}6V \times A}{U_n}$$

where

V is the electrical potential applied to the machine drive, in volts;

A is the electric current drawn by the machine drive, in amperes;

U_n is the test drum velocity, in kilometres per hour.

7.2.4 Deceleration method

The rolling resistance, F_r, in newtons, is calculated with the equation

$$F_r = \frac{I_D}{R}\left(\frac{\Delta\omega_v}{\Delta t_v}\right) + \frac{RI_T}{R_r^2}\left(\frac{\Delta\omega_v}{\Delta t_v}\right) + \frac{M_{AP}}{R_r} - F_P$$

where

I_D is the test drum inertia in rotation, in kilogram metres squared;

R is the test drum surface radius, in metres;

Δt_V is the time increment chosen for the measurement, in seconds;

ω_V is the test drum angular velocity, loaded tyre, in radians per second;

I_T is the tyre and wheel inertia in rotation, in kilogram metres squared;

R_r is the tyre rolling radius, in metres;

M_{AP} is the tyre aerodynamic torque;

F_P is as defined in 7.1.3.

Annex C gives guidelines and practical examples to measure the moments of inertia for the deceleration method.

8 Data analysis

8.1 Rolling resistance coefficient

The rolling resistance coefficient, C_r, is calculated by dividing the rolling resistance by the load on the tyre:

$$C_r = \frac{F_r}{L_m}$$

where

F_r is the rolling resistance, in newtons;

L_m is the test load, in newtons.

8.2 Temperature correction

If measurements at temperatures other than 25 °C are unavoidable (only temperatures not less than 20 °C nor more than 30 °C are acceptable), then a correction for temperature shall be made using the following equation, where F_{r25} is the rolling resistance at 25 °C, in newtons:

$$F_{r25} = F_r[1 + K(t_{amb} - 25)]$$

where

F_r is the rolling resistance, in newtons;

t_{amb} is the ambient temperature, in degrees Celsius;

K is equal to

0,006 for truck and bus tyres with load index 122 and above,

0,01 for truck and bus tyres with load index 121 and lower.

8.3 Drum diameter correction

Test results obtained from different drum diameters may be compared by using the following theoretical formula:

$$F_{r02} \simeq K F_{r01}$$

with

$$K = \sqrt{\frac{(R_1/R_2)(R_2 + r_T)}{(R_1 + r_T)}}$$

where

R_1 is the radius of drum 1, in metres;

R_2 is the radius of drum 2, in metres;

r_T is the nominal tyre radius, in metres;

F_{r01} is the rolling resistance value measured on drum 1, in newtons;

F_{r02} is the rolling resistance value measured on drum 2, in newtons.

Annex A
(normative)

Test equipment tolerances

A.1 Purpose

The limits specified in this annex are necessary in order to achieve suitable levels of repeatable test results, which can also be correlated among various test laboratories. These tolerances are not meant to represent a complete set of engineering specifications for test equipment: instead, they should serve as guidelines for achieving reliable test results.

A.2 Test rims

A.2.1 Width

The test rim width shall be equal to the standardized measuring rim. If this is not available, then the next wider rim may be chosen. It should be noted that a change in rim width will result in different test results.

A.2.2 Runout

Runout shall meet the following criteria:

— maximum radial runout: 0,5 mm

— maximum lateral runout: 0,5 mm

A.3 Alignment

Angle deviations are critical to the test results.

A.3.1 Load application

The direction of tyre loading application shall be kept normal to the test surface and shall pass through the wheel centre within

— 1 mrad for the force and deceleration methods;

— 5 mrad for the torque and power methods.

A.3.2 Tyre alignment

A.3.2.1 Camber angle

The plane of the tyre shall be normal to the test surface within 2 mrad for all methods.

A.3.2.2 Slip angle

The plane of the tyre shall be parallel to the direction of the test surface motion within 1 mrad for all methods.

A.4 Control accuracy

A.4.1 General accuracy

Exclusive of perturbations induced by the tyre and rim non-uniformities, the test equipment shall be capable of checking the test variables within the following limits:

— tyre loading: ± 20 N

— inflation pressure: ± 3 kPa

— surface velocity:

± 0,2 km/h for the power, torque and deceleration methods,

± 0,5 km/h for the force method;

— time: ± 0,02 s

— angular velocity: ± 0,2 %

A.4.2 Optional compensation for load/spindle force interaction and load misalignment

NOTE 2 This compensation applies for the force method only.

Compensation of both load/spindle force interaction ("crosstalk") and load misalignment may be accomplished either by recording the spindle force for both forward and reverse tyre rotation or by dynamic machine calibration. If spindle force is recorded for forward and reverse directions (at each test condition), compensation is achieved by subtracting the "reverse" value from the "forward" value and dividing the result by two. If dynamic machine calibration is intended, the compensation terms may be easily incorporated in the data reduction.

A.5 Instrumentation accuracy

The instrumentation used for readout and recording of test data shall be accurate within the tolerances stated below:

- tyre load: ± 10 N
- inflation pressure: ± 1 kPa
- spindle force: ± 0,5 N
- torque input: ± 0,5 N·m
- distance: ± 1 mm
- electrical power: ± 10 W
- temperature: ± 0,2 °C
- surface velocity: ± 0,1 km/h (for all methods)
- time: ± 0,01 s
- angular velocity: ± 0,1 %

A.6 Test surface roughness

The roughness, measured laterally, of the smooth steel drum surface shall have a maximum centre-line average height value of 6,3 µm.

A.7 Tyre spindle bearing friction

When using the machine reading as a method for determining the parasitic losses, tyre spindle bearing friction should be regularly verified as being sufficiently small as to be considered negligible (e.g., a coastdown from 80 km/h to 0 km/h in not less than 5 min with a freely rotating tyre).