INTERNATIONAL STANDARD

ISO 28580

First edition
2009-07-01

Passenger car, truck and bus tyres — Methods of measuring rolling resistance — Single point test and correlation of measurement results

Pneumatiques pour voitures particulières, camions et autobus — Méthodes de mesure de la résistance au roulement — Essai à condition de mesure unique et corrélation des résultats de mesure

Reference number
ISO 28580:2009(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 28580 was prepared by Technical Committee ISO/TC 31, *Tyres, rims and valves*.

Passenger car, truck and bus tyres — Methods of measuring rolling resistance — Single point test and correlation of measurement results

1 Scope

This International Standard specifies methods for measuring rolling resistance, under controlled laboratory conditions, for new pneumatic tyres designed primarily for use on passenger cars, trucks and buses. Tyres intended for temporary use only are not included in this International Standard.

This International Standard includes a method for correlating measurement results to allow inter-laboratory comparisons. Measurement of tyres using this method enables comparisons to be made between the rolling resistance of new test 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 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4000-1:2007, *Passenger car tyres and rims — Part 1: Tyres (metric series)*

ISO 4209-1:2001, *Truck and bus tyres and rims (metric series) — Part 1: Tyres*

ISO 4223-1, *Definitions of some terms used in the tyre industry — Part 1: Pneumatic tyres*

ISO 8855, *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in 4223-1 and the following apply.

3.1
rolling resistance
F_r
loss of energy (or energy consumed) per unit of distance travelled

NOTE The International System of Units (SI) unit conventionally used for the rolling resistance is the newton-metre per metre, which is equivalent to a drag force in newtons.

3.2
rolling resistance coefficient
C_r
ratio of the rolling resistance to the load on the tyre

NOTE The rolling resistance is expressed in newtons and the load is expressed in kilonewtons. The rolling resistance coefficient is dimensionless.

3.3
capped inflation
process of inflating the tyre and allowing the inflation pressure to build up, as the tyre is warmed up while running

3.4
parasitic loss
loss of energy (or energy consumed) per unit distance excluding internal tyre losses, attributable to aerodynamic loss of the different rotating elements of the test equipment, bearing friction and other sources of systematic loss which may be inherent in the measurement

NOTE This International Standard describes which sources of loss are to be excluded from the result of the measurement.

3.5
skim test 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

3.6
inertia
moment of inertia
ratio of the torque applied to a rotating body to the rotational acceleration of this body

NOTE 1 The rotating body can be, for example, a tyre assembly or machine drum.

NOTE 2 See Annex B.

3.7
new test tyre
tyre which has not previously been used in a rolling deflected test that raises its temperature above that generated in rolling resistance tests, and which has not previously been exposed to a temperature above 40 °C

NOTE 1 In addition to the tests described in this International Standard, rolling resistance tests are also described in ISO 18164, SAE J1269 and SAE J2452.

NOTE 2 It is permissible to repeat an accepted test procedure.

3.8
measurement result correlation
set of rolling resistance measurements to be carried out on a regular time basis by separate laboratories, in order to allow direct comparisons between their rolling resistance results

NOTE The results of these measurements are used to compute “alignment” corrective coefficients and permit calculation of aligned rolling resistance measurement, $C_{r,aligned}$ (see Clause 10).

3.9
reference machine
machine considered as a reference for an alignment

3.10
alignment tyres
set of two predetermined tyres measured by both the candidate and reference machines to perform machine alignment

NOTE See Clause 10.

3.11
laboratory control tyre
tyre used by an individual laboratory to control machine behaviour as a function of time

NOTE An example of machine behaviour is drift.

3.12
measurement reproducibility
σ_m
capability of a machine to measure rolling resistance

NOTE σ_m can be estimated by measuring n times (where $n \geqslant 3$) the whole procedure described in Clause 7 for the two alignment tyres, assuming that the variances of the two alignment tyres are homogeneous, as follows:

$$\sigma_m = \sqrt{\frac{1}{2}\sum_i^2 \sigma_{m,i}{}^2}$$

$$\sigma_{m,i} = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left[C_{r,i,j} - \left(\frac{1}{n}\sum_{j=1}^{n} C_{r,i,j}\right)\right]^2}$$

where

i is either 1 or 2, corresponding to each of the alignment tyres;

j is the counter from 1 to n for the number of repetitions of each measurement for a given tyre;

n is the number of repetitions of tyre measurements.

3.13
deviation of alignment tyre
difference in terms of time compared with the mean rolling resistance coefficient measurement results for a given alignment tyre with the appropriate number of repetitions

NOTE See 10.4.

4 Test methods

The alternative measurement methods listed below 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 force acting at the tyre/drum interface. The measured parameters are:

a) in the force method: the reaction force measured or converted at the tyre spindle;

NOTE 1 The measured value in the force method also includes the bearing and aerodynamic losses of the wheel and the tyre, which are also to be considered for further data interpretation.

b) in the torque method: the torque input measured at the test drum;

c) in the deceleration method: the measurement of deceleration of the test drum and tyre assembly;

d) in the power method: the measurement of the power input to the test drum.

NOTE 2 The measured value in the torque, deceleration and power methods also includes the bearing and aerodynamic losses of the wheel, the tyre and the drum, which are also to be considered for further data interpretation.

5 Test equipment

5.1 Drum specifications

5.1.1 Diameter

The test dynamometer shall have a cylindrical flywheel (drum) with a diameter of at least 1,7 m.

The F_r and C_r values shall be expressed relative to a drum diameter of 2,0 m. If a drum diameter other than 2,0 m is used, a correlation adjustment shall be made in accordance with 9.3.

5.1.2 Surface

The surface of the drum shall be smooth steel. Alternatively, in order to improve skim test reading accuracy, a textured surface may also be used, which shall be kept clean.

The F_r and C_r values shall be expressed relative to the “smooth” drum surface. If a textured drum surface is used, see Clause A.7.

5.1.3 Width

The width of the drum test surface shall exceed the width of the test tyre contact patch.

5.2 Measuring rim

The tyre shall be mounted on a steel or light alloy measuring rim, as follows:

— for passenger car tyres, the width of the rim shall be as defined in ISO 4000-1:2007, 6.2.2;

— for truck and bus tyres, the width of the rim shall be as defined in ISO 4209-1:2001, 5.1.3.

No other rim width shall be allowed.

See Annex C.

5.3 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.

5.4 Thermal environment

5.4.1 Reference conditions

The reference ambient temperature, measured at a distance not less than 0,15 m and not more than 1 m from the tyre sidewall, shall be 25 °C.

5.4.2 Alternative conditions

If the test ambient temperature is different from the reference ambient temperature, the rolling resistance measurement shall be corrected to the reference ambient temperature in accordance with 9.2.

5.4.3 Drum surface temperature

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

6 Test conditions

6.1 General

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

6.2 Test speeds

The value shall be obtained at the appropriate drum speed specified in Table 1.

Table 1 — Test speeds

	Tyre type			
	Passenger car	**Truck and bus**		
Load index **LI**	All	LI ⩽ 121	LI > 121	LI > 121
Speed symbol	All	All	J [a] and lower or tyres not marked with speed symbol	K [b] and higher
Test speed **km/h**	80	80	60	80

[a] 100 km/h.

[b] 110 km/h.

6.3 Test load

The standard test load shall be computed from the values shown in Table 2 and shall be kept within the tolerance specified in Annex A.

6.4 Test inflation pressure

The inflation pressure shall be in accordance with that shown in Table 2 and shall be capped with the accuracy specified in Clause A.4.

Table 2 — Test loads and inflation pressures

	Tyre type		
	Passenger car		Truck and bus
	Standard load	Reinforced or extra load	
Load % of maximum load capacity	80 [a]	80 [a]	85 [b]
Inflation pressure kPa	210	250	Corresponding to maximum load capacity for single application [c]

NOTE The inflation pressure is capped with the accuracy specified in Clause A.4.

[a] For those passenger car tyres belonging to categories not shown in ISO 4000-1:2007, Annex B, the inflation pressure shall be the inflation pressure recommended by the tyre manufacturer, corresponding to the maximum tyre load capacity, reduced by 30 kPa.

[b] As a percentage of single load, or 85 % of maximum load capacity for single application specified in applicable tyre standards manuals if not marked on tyre.

[c] Inflation pressure marked on sidewall, or if not marked on sidewall, as specified in applicable tyre standards manuals corresponding to maximum load capacity for single application.

6.5 Duration and speed

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 speed shall not exceed 1 km/h within one time increment.

7 Test procedure

7.1 General

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

7.2 Thermal conditioning

The inflated tyre shall be placed in the thermal environment of the test location for a minimum of:

— 3 h for passenger car tyres;

— 6 h for truck and bus tyres.

7.3 Pressure adjustment

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

7.4 Warm-up

The warm-up durations shall be as specified in Table 3.

Table 3 — Warm-up durations

	Tyre type			
	Passenger car	Truck and bus		
Load index LI	All	LI ⩽ 121	LI > 121	LI > 121
Nominal rim diameter code	All	All	< 22.5	⩾ 22.5
Warm-up duration min	30	50	150	180

7.5 Measurement and recording

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

a) the test speed, U_n;

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

c) the initial test inflation pressure, as defined in 6.4;

d) the rolling resistance coefficient, C_r, and its corrected value, $C_{r,corrected}$, at 25 °C and for a drum diameter of 2 m;

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

f) the ambient temperature, t_{amb};

g) the test drum radius, R;

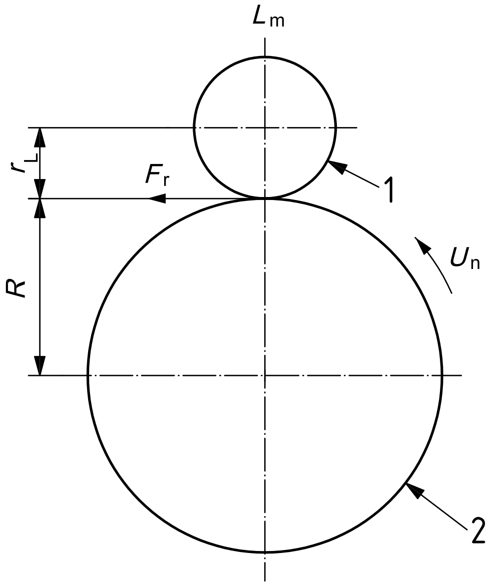
h) the test method chosen;

i) the test rim (size and material);

j) the tyre size, manufacturer, type, identity number (if one exists), speed symbol, load index, DOT number[1]).

All the mechanical quantities (forces, torques) shall be oriented in accordance with the axis systems specified in ISO 8855. The directional tyres shall be run in their specified rotation direction.

1) DOT: Department of Transportation.



Key

1 tyre
2 drum
F_r rolling resistance
L_m load on tyre normal to drum surface
R test drum radius
r_L distance from tyre axis to drum outer surface under steady-state conditions
U_n test speed

Figure 1 — Measurement orientation

7.6 Measurement of parasitic losses

7.6.1 General

The parasitic losses shall be determined by one of the procedures given in 7.6.2 or 7.6.3.

7.6.2 Skim test reading

Skim test reading follows the procedure below.

a) Reduce the load to maintain the tyre at the test speed without slippage. The load values should be as follows:

— passenger car tyres: recommended value of 100 N, but not exceeding 200 N;

— truck and bus tyres (LI $\leqslant$ 121): recommended value of 150 N, but not exceeding 200 N for machines designed for passenger car tyre measurement or 500 N for machines designed for truck and bus tyres;

— truck and bus tyres (LI $>$ 121): recommended value of 400 N, but not exceeding 500 N;

— skim values shall be the same for both standard testing and alignment (see Clause 10).

b) Record the spindle force, F_t, the input torque, T_t, or the power, whichever applies.

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

NOTE 1 With the exception of the force method, the measured value includes the bearing and aerodynamic losses of the wheel, the tyre and the drum, which also need to be considered.

NOTE 2 It is known that the spindle and drum bearing friction depends on the applied load; consequently, it is different for loaded system measurement and skim test reading. However, for practical reasons, this difference can be disregarded.

7.6.3 Deceleration method

The deceleration method follows the procedure below.

a) Remove the tyre from the test surface.

b) Record the deceleration of the test drum, $\frac{\Delta\omega_{D0}}{\Delta t}$, and that of the unloaded tyre, $\frac{\Delta\omega_{T0}}{\Delta t}$.

NOTE 1 The measured value includes the bearing and aerodynamic losses of the wheel, the tyre and the drum, which also need to be considered.

NOTE 2 It is known that the spindle and drum bearing friction depends on the applied load; consequently, it is different for loaded system measurement and free deceleration. However, for practical reasons, this difference can be disregarded.

7.7 Allowance for machines exceeding σ_m criterion

The steps described in 7.4 to 7.6 shall be carried out once if the measurement standard deviation, determined in accordance with 10.3.3, is:

— not greater than 0,075 N/kN for passenger car and smaller truck and bus tyres (LI $\leqslant$ 121);

— not greater than 0,06 N/kN for larger truck and bus tyres (LI > 121).

If the measurement standard deviation exceeds this criterion, the measurement process shall be repeated n times, as described in 10.3.3. The rolling resistance value reported shall be the average of the n measurements.

8 Data interpretation

8.1 Determination of parasitic losses

8.1.1 General

The laboratory shall perform the measurements described in 7.6.2 for the force, torque and power methods, or those described in 7.6.3 for the deceleration method, in order to determine precisely in the test conditions (load, speed, temperature) the tyre spindle friction, the tyre and wheel aerodynamic losses, the drum (and as appropriate, engine and/or clutch) bearing friction, and the drum aerodynamic losses.

The parasitic losses related to the tyre/drum interface, F_{pl}, expressed in newtons, shall be calculated from the force (F_t), torque, power or deceleration, as shown in 8.1.2 to 8.1.5 below.

8.1.2 Force method at tyre spindle

The parasitic losses, F_{pl}, expressed in newtons, are calculated by means of Equation (1):

$$F_{pl} = F_t \left(1 + \frac{r_L}{R}\right) \quad (1)$$

where

F_t is the tyre spindle force, expressed in newtons (see 7.6.2);

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

R is the test drum radius, expressed in metres.

8.1.3 Torque method at drum axis

The parasitic losses, F_{pl}, expressed in newtons, are calculated by means of Equation (2):

$$F_{pl} = \frac{T_t}{R} \quad (2)$$

where

T_t is the input torque, expressed in newton-metres (see 7.6.2);

R is the test drum radius, expressed in metres.

8.1.4 Power method at drum axis

The parasitic losses, F_{pl}, expressed in newtons, are calculated by means of Equation (3):

$$F_{pl} = \frac{3{,}6 V \times A}{U_n} \quad (3)$$

where

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

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

U_n is the test drum speed, expressed in kilometres per hour.

8.1.5 Deceleration method

The parasitic losses, F_{pl}, expressed in newtons, are calculated by means of Equation (4):

$$F_{pl} = \frac{I_D}{R}\left(\frac{\Delta\omega_{D0}}{\Delta t_0}\right) + \frac{I_T}{R_r}\left(\frac{\Delta\omega_{T0}}{\Delta t_0}\right) \quad (4)$$

where

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

R is the test drum radius, expressed in metres;

ω_{D0} is the test drum angular speed, without tyre, expressed in radians per second;

Δt_0 is the time increment chosen for the measurement of the parasitic losses without tyre, expressed in seconds;

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

R_r is the tyre rolling radius, expressed in metres;

ω_{T0} is the tyre angular speed, unloaded tyre, expressed in radians per second.

8.2 Rolling resistance calculation

8.2.1 General

The rolling resistance, F_r, expressed in newtons, is calculated using the values obtained by testing the tyre to the conditions specified in this International Standard and by subtracting the appropriate parasitic losses, F_{pl}, calculated in accordance with 8.1.

8.2.2 Force method at tyre spindle

The rolling resistance, F_r, expressed in newtons, is calculated by means of Equation (5):

$$F_r = F_t \left(1 + \frac{r_L}{R} \right) - F_{pl} \qquad (5)$$

where

F_t is the tyre spindle force, expressed in newtons;

F_{pl} are the parasitic losses, as calculated in 8.1.2;

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

R is the test drum radius, expressed in metres.

8.2.3 Torque method at drum axis

The rolling resistance, F_r, expressed in newtons, is calculated by means of Equation (6):

$$F_r = \frac{T_t}{R} - F_{pl} \qquad (6)$$

where

T_t is the input torque, expressed in newton-metres;

F_{pl} are the parasitic losses, as calculated in 8.1.3;

R is the test drum radius, expressed in metres.

8.2.4 Power method at drum axis

The rolling resistance, F_r, expressed in newtons, is calculated by means of Equation (7):

$$F_r = \frac{3{,}6V \times A}{U_n} - F_{pl} \tag{7}$$

where

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

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

U_n is the test drum speed, expressed in kilometres per hour;

F_{pl} are the parasitic losses, as calculated in 8.1.4.

8.2.5 Deceleration method

The rolling resistance, F_r, expressed in newtons, is calculated by means of Equation (8):

$$F_r = \frac{I_D}{R}\left(\frac{\Delta\omega_v}{\Delta t_v}\right) + \frac{RI_T}{R_r{}^2}\left(\frac{\Delta\omega_v}{\Delta t_v}\right) - F_{pl} \tag{8}$$

where

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

R is the test drum radius, expressed in metres;

F_{pl} are the parasitic losses, as calculated in 8.1.5;

Δt_v is the time increment chosen for measurement, expressed in seconds;

$\Delta\omega_v$ is the test drum angular speed increment, without tyre, expressed in radians per second;

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

R_r is the tyre rolling radius, expressed in metres;

F_r is the rolling resistance, expressed in newtons.

NOTE Annex B provides guidelines and practical examples for measuring the moments of inertia for the deceleration method.

9 Data analysis

9.1 Rolling resistance coefficient

The rolling resistance coefficient, C_r, is calculated as shown in Equation (9) by dividing the rolling resistance by the load on the tyre:

$$C_r = \frac{F_r}{L_m} \tag{9}$$

where

F_r is the rolling resistance, expressed in newtons;

L_m is the test load, expressed in kilonewtons.

9.2 Temperature correction

Only temperatures $\geqslant$ 20 °C and $\leqslant$ 30 °C are acceptable. If measurements at temperatures other than 25 °C are unavoidable, then a correction for temperature shall be made by means of Equation (10), where F_{r25} is the rolling resistance at 25 °C, expressed in newtons:

$$F_{r25} = F_r \left[1 + K_t \left(t_{amb} - 25 \right) \right] \qquad (10)$$

where

F_r is the rolling resistance, expressed in newtons;

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

K_t is the constant, with the following values:

- 0,008 for passenger tyres;
- 0,010 for truck and bus tyres with LI $\leqslant$ 121;
- 0,006 for truck and bus tyres with LI $>$ 121.

9.3 Drum diameter correction

Test results obtained from different drum diameters may be compared by using the theoretical formulae in Equations (11) and (12):

$$F_{r02} \cong K_r F_{r01} \qquad (11)$$

$$K_r = \sqrt{\frac{\left(R_1 / R_2 \right)\left(R_2 + r_T \right)}{\left(R_1 + r_T \right)}} \qquad (12)$$

where

R_1 is the radius of drum 1, expressed in metres;

R_2 is the radius of drum 2, expressed in metres;

r_T is one-half of the nominal design tyre diameter, expressed in metres;

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

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

9.4 Measurement result

Where the number n of measurements is greater than 1, if required by 10.3, the measurement result shall be the average of the C_r values obtained for the n measurements, after the corrections described in 9.2 and 9.3 have been made.

10 Measurement machines alignment and monitoring requirements

10.1 General

This clause describes the procedure to be followed to align measurement results and allow direct inter-laboratory comparisons. This procedure shall be applied to each measurement machine for whose results conformance is claimed with this International Standard.

This machine alignment procedure requires two predetermined alignment tyres used by the candidate laboratory operating the machine. These tyres are used to align candidate machine(s) by comparing the measured C_r results to those obtained on a reference machine. An alignment formula is then established and shall be used to translate the results obtained on the candidate machine into aligned results.

10.2 Conditions for reference machine

10.2.1 The laboratory operating the reference machine shall comply with either ISO/TS 16949 or ISO/IEC 17025.

10.2.2 Monitoring of the reference machine laboratory control tyre shall be carried out at intervals no greater than one month. Monitoring shall include a minimum of three separate measurements taken during this one-month period. The average of the three measurements taken during a given one-month period shall be evaluated for drift from one monthly evaluation to another.

10.2.3 The laboratory shall ensure that, based on a minimum of three measurements, the reference machine maintains a value of $\sigma_m \leqslant 0{,}05$ N/kN. This may be done using the laboratory control tyres (as specified in 10.2.2).

10.3 Conditions for candidate machine

10.3.1 The laboratory operating the candidate machine shall comply with either ISO/TS 16949 or ISO/IEC 17025.

10.3.2 Monitoring of the candidate machine laboratory control tyre shall be carried out at intervals no greater than one month. Monitoring shall include a minimum of three separate measurements taken during this one-month period. The average of the three measurements taken during a given one-month period shall be evaluated for drift from one monthly evaluation to another.

10.3.3 The laboratory shall ensure that, based on a minimum of three measurements, the candidate machine maintains the following values of σ_m, as measured on a single tyre:

— $\sigma_m \leqslant 0{,}075$ N/kN for passenger car and small truck and bus tyres (LI $\leqslant$ 121);

— $\sigma_m \leqslant 0{,}060$ N/kN for larger truck and bus tyres (LI > 121).

If the above requirement for σ_m is not met, the formula specified in Equation (13) shall be applied to determine the minimum number of measurements, n (rounded to the immediate superior integer value), that are required by the candidate machine to qualify for conformance with this International Standard.

$$n = \left(\frac{\sigma_m}{x} \right)^2 \quad (13)$$

where

$x = 0{,}075$ for passenger car and small truck and bus tyres (LI $\leqslant$ 121);

$x = 0{,}060$ for larger truck and bus tyres (LI > 121).

If a tyre needs to be measured several times, the tyre/wheel assembly shall be removed from the machine between the successive measurements.

If the removal/refitting operation duration is less than 10 min, the warm-up durations indicated in 7.4 may be reduced to:

a) 10 min for passenger car tyres;

b) 20 min for truck and bus tyres with (LI $\leqslant$ 121);

c) 30 min for larger truck and bus tyres (LI $>$ 121).

10.4 Alignment tyre requirements

10.4.1 The predetermined alignment tyres used to conduct the alignment procedure shall be identified to cover the needed usage range in terms of load index, C_r and F_r, as follows:

a) C_r values shall have a minimum range of:

- 3 N/kN for passenger car and smaller truck and bus tyres;
- 2 N/kN for larger truck and bus tyres;

b) the alignment tyre section width should be:

- $\leqslant$ 245 mm for passenger car and smaller truck and bus machines;
- $\leqslant$ 345 mm for larger truck and bus tyre machines;

c) the alignment tyre outer diameter should be:

- between 510 mm and 800 mm for passenger car and smaller truck and bus machines;
- between 771 mm and 1143 mm for larger truck and bus tyre machines;

d) load index values shall adequately cover the range for the tyres to be tested, ensuring that the F_r values also cover the range for the tyres to be tested;

e) the number of alignment tyres shall be equal to two, i.e. there shall be

- two alignment tyres for passenger car and smaller truck and bus tyres, and
- two alignment tyres for larger truck and bus tyres.

10.4.2 Each alignment tyre shall be checked prior to use and replaced when:

a) it shows a condition that makes it unusable for further tests;

b) there are deviations of C_r for alignment tyre measurement greater than 1,5 % relative to earlier measurements after correction for any machine drift.

10.5 Alignment procedure

10.5.1 Each time an alignment tyre is measured, the tyre/wheel assembly shall be removed from the machine and the entire test procedure specified in Clause 7 shall be followed again. This requirement applies to both the reference laboratory and the candidate laboratory.

10.5.2 The laboratory operating the reference machine shall measure each alignment tyre three times in accordance with Clause 7 and applying the conditions in Clause 6, and provide the mean value and standard deviation established from the three measurements for each tyre.

10.5.3 The candidate machine shall measure each alignment tyre three times in accordance with Clause 7 and applying the conditions in Clause 6, with a measurement standard deviation for each tyre of

— not greater than 0,075 N/kN for passenger car and smaller truck and bus tyres (LI $\leqslant$ 121),and

— not greater than 0,060 N/kN for larger truck and bus tyres (LI > 121).

If this measurement standard deviation exceeds this criterion with three measurements, then the number n of measurement repetitions shall be increased to meet the criterion in Equation (14):

$$n = \left(\frac{\sigma_{\mathrm{m}}}{\gamma}\right)^2 \qquad (14)$$

where

γ = 0,043 for passenger car and small truck and bus tyres (LI $\leqslant$ 121);

γ = 0,035 for larger truck and bus tyres (LI > 121).

10.5.4 The correlation shall be performed by the candidate laboratory and shall be a linear regression technique with the alignment results, A and B, given in Equation (15):

$$C_{\mathrm{r,aligned}} = A C_{\mathrm{r,corrected}} + B \qquad (15)$$

where $C_{\mathrm{r,corrected}}$ is the C_{r} of the candidate machine.

The measurement standard deviation estimate, σ_{m}, shall also be given.

10.5.5 The alignment process shall be repeated at least every second year, and always after any significant machine change or any drift in candidate machine control tyre monitoring data.

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 intended to represent a complete set of engineering specifications for test equipment; rather, they should serve as guidelines for achieving reliable test results.

A.2 Test rims

A.2.1 Width

For passenger car tyre rims, the test rim width shall be the same as the measuring rim determined in ISO 4000-1:2007, 6.2.2;

For truck and bus tyre rims, the test rim width shall be the same as the measuring rim determined in ISO 4209-1:2001, 5.1.3.

See Annex C.

A.2.2 Run-out

Run-out shall meet the following criteria:

— maximum radial run-out: 0,5 mm;

— maximum lateral run-out: 0,5 mm.

A.3 Alignment

A.3.1 General

Angle deviations are critical to the test results.

A.3.2 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.3.3 Tyre alignment

A.3.3.1 Camber angle

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

A.3.3.2 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

Test conditions shall be maintained at their specified values, independent of perturbations induced by the tyre and rim non-uniformity, such that the overall variability of the rolling resistance measurement is minimized. In order to meet this requirement, the average value of measurements taken during the rolling resistance data collection period shall be within the accuracies stated as follows:

— tyre loading:

  — (for LI $\leqslant$ 121) ± 20 N or ± 0,5 %, whichever is the greater;

  — (for LI > 121) ± 45 N or ± 0,5 %, whichever is the greater;

— inflation pressure: ± 3 kPa;

— surface speed:

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

  — ± 0,5 km/h for the force method;

— time: ± 0,02 s.

A.5 Instrumentation accuracy

The instrumentation used for readout and recording of test data shall be accurate within the tolerances stated in Table A.1.

Table A.1 — Instrumentation accuracy

Parameter	Load index	
	LI ≤ 121	LI > 121
Tyre load	± 10 N or ± 0,5 % [a]	± 30 N or ± 0,5 % [a]
Inflation pressure	± 1 kPa	± 1,5 kPa
Spindle force	± 0,5 N or ± 0,5 % [a]	± 1,0 N or ± 0,5 % [a]
Torque input	± 0,5 N·m or ± 0,5 % [a]	± 1,0 N·m or ± 0,5 % [a]
Distance	± 1 mm	± 1 mm
Electrical power	± 10 W	± 20 W
Temperature	± 0,2 °C	± 0,2 °C
Surface speed	± 0,1 km/h	± 0,1 km/h
Time	± 0,01 s	± 0,01 s
Angular velocity	± 0,1 %	± 0,1 %

[a] Whichever is the greater.

A.6 Compensation for load/spindle force interaction and load misalignment (for force method only)

Compensation of both load/spindle force interaction (“cross talk”) and load misalignment may be achieved 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.

In cases where reverse tyre rotation immediately follows the completion of the forward tyre rotation, there shall be a warm-up time for reverse tyre rotation of at least 10 min for passenger car tyres and at least 30 min for all other tyre types.

A.7 Test surface roughness

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

NOTE In cases where a textured drum surface is used instead of a smooth steel surface, this fact is noted in the test report. The surface texture is then 180 µm deep[2)] and the laboratory is responsible for maintaining the surface roughness characteristics. No specific correction factor is recommended for cases where a textured drum surface is used, because the correlation applied in Clause 10 will already account for this test condition difference. Additionally, the surface roughness evolves with time and a correction factor specifically to address surface roughness would only be precise at the point it is established.

2) (Nominally) 80 grit.

Annex B
(informative)

Measurement methods of moment of inertia for drum and tyre assembly (deceleration method)

B.1 Limitation

The methods presented here should be considered only as guidelines or practical examples of methods used to measure moments of inertia for the deceleration method to achieve reliable test results.

B.2 Test drum inertia

B.2.1 Measurement method

B.2.1.1 Equipment and test set-up

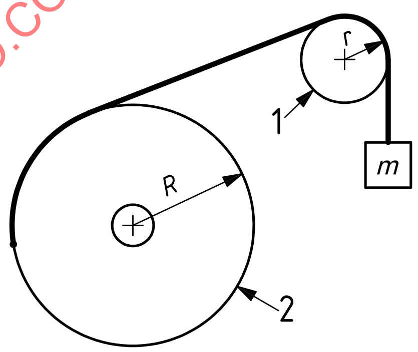
In addition to the drum and its angular encoder, the test set-up shown in Figure B.1 requires the following equipment:

— a lightweight pulley mounted on low-friction bearings;

— a weight of known mass, m, in the range 50 kg to 100 kg;

— suitable wire rope and attachments.

Figure B.1 shows the test set-up.



Key

1 pulley

2 drum

m mass

r pulley radius

R drum radius

Figure B.1 — Test set-up for measurement method

B.2.1.2 Theory

Application of the laws of mechanics to the system shown in Figure B.1 leads to Equation (B.1):

$$I_D = \frac{mgR - C}{(\Delta\omega_D / \Delta t)} - mR^2 - I_p \frac{R^2}{r^2} \tag{B.1}$$

where

m is the mass, expressed in kilograms;

I_p is the pulley inertia, expressed in kilogram metres squared;

r is the pulley radius, expressed in metres;

R is the drum radius, expressed in metres;

I_D is the drum inertia, expressed in kilogram metres squared;

C is the friction torque of drum bearings, expressed in newton-metres;

g earth's gravity equal to 9,81 m/s^2;

$\Delta\omega_D/\Delta t$ is the angular acceleration or deceleration.

NOTE The friction torque of pulley bearings, C, can be neglected.

B.2.1.3 Method

When the mass, m, is released, the angular acceleration is measured through the angular encoder fitted to the drum axle (and otherwise used to measure drum decelerations). The friction torque, C, of drum bearings can also be measured, provided that the rope can be separated from the drum when mass m has given sufficient momentum to the drum, given that the subsequent drum deceleration is directly related to C by Equation (B.2):

$$C = I_D \left(\frac{\Delta\omega_D}{\Delta t} \right) \tag{B.2}$$

where the values are as defined in B.2.1.2.

B.2.2 Determination method

The drum inertia is estimated by calculation.

The drum inertia, I_D, expressed in kilogram metres squared, is determined by the summation of the inertia of each drum part (flange, disc, reinforced rib), as shown in Equation (B.3):

$$I_D = I_f + I_d + I_r \tag{B.3}$$

where

I_f is the drum flange inertia, expressed in kilogram metres squared;

I_d is the drum disc inertia, expressed in kilogram metres squared;

I_r is the reinforced rib inertia, expressed in kilogram metres squared.