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Tyre stiffness index testing procedure for passenger car extended mobility and run flat tyres

Procédure d'essai de l'indice de rigidité de pneumatiques à mobilité étendue et pour roulage à plat pour voiture particulière

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Foreword

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This document was prepared by Technical Committee ISO/TC 31, *Tyres, rims and valves*, Subcommittee SC 3, *Passenger car tyres and rims*.

Tyre stiffness index testing procedure for passenger car extended mobility and run flat tyres

1 Scope

This document specifies the testing method for determining the tyre stiffness index of passenger car tyres for the products capable of supplying the vehicle with the basic tyre functions, at least, at a speed of 80 km/h (50 mph) and a distance of 80 km when operating in flat tyre running mode, as per ISO 16992.

This method is meant to determine the above mentioned index, for the characterization of the expected tyre's stiffness through its air and structural components.

To reach the target, the vertical force and the vertical deflection, in the sense of absolute position in *Z* direction under different operating conditions, are measured (approximated in case of zero inflation pressure) and combined through the metrics defined in this document.

This method is not intended to be used for conventional tyres.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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, *Passenger car tyres and rims — Part 1: Tyres (metric series)*

ISO 4000-2, *Passenger car tyres and rims — Part 2: Rims*

ISO 16992, *Passenger car tyres — Spare unit substitutive equipment (SUSE)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
conventional tyre
pneumatic tyre designed for use in an inflated state

3.2
run flat tyre
self supporting tyre
SST
pneumatic tyre structure provided with any technical solutions (for example, reinforced sidewalls, etc.) designed to operate in an inflated mode and allowing the tyre, mounted on the appropriate wheel and in the absence of any supplementary component, to supply the vehicle with the basic tyre functions at a specified speed and distance when operating in flat tyre running mode

3.3
extended mobility tyre
EMT
pneumatic tyre featuring technology designed on purpose to operate in an inflated mode and allowing the tyre, mounted on the appropriate wheel and in the absence of any supplementary component, to supply the vehicle with the basic tyre functions at a specified speed and distance when operating in flat tyre running mode

3.4
test rim
rim on which a tyre is required to be fitted for testing

3.5
inflation pressure
pressure taken with the tyre at ambient temperature, as indicated by the tyre manufacturer and which does not include any pressure build-up due to tyre usage

3.6
zero inflation pressure running mode
state of the tyre while operating in deflated condition, obtained by removing the valve-core

3.7
speed symbol
code signifying the maximum speed at which the tyre can carry a load corresponding to its *load index* (3.8) under service conditions specified by the tyre manufacturer

Note 1 to entry: Refer to ISO 4000-1:2015, Table 3.

3.8
load index
LI
numerical code associated to the maximum load that a tyre can carry at the speed indicated by its *speed symbol* (3.7) under service conditions specified by the tyre manufacturer

Note 1 to entry: Refer to ISO 4000-1:2015, Table 2.

3.9
loading force
F_Z
force measured during the loading condition (either in wheel spindle axle or in the loading plate), in the loading direction

3.10
loading speed
v_L
speed used to apply the load on the tyre

3.11
absolute position
z
position of either the tyre or the loading plate

Note 1 to entry: Absolute position is expressed in mm.

3.12
reference inflation pressure
P_{ref}
inflation pressure (3.5) to be used as a first step in testing conditions

Note 1 to entry: See Table 1.

3.13
test inflation pressure
P_i
inflation pressure ([3.5](#)) at each step "*i*"

Note 1 to entry: Inflation pressure is expressed in kPa.

3.14
vertical stiffness
K_Z
tyre stiffness measured under vertical force input in inflated conditions

Note 1 to entry: Vertical stiffness is expressed in N/mm.

3.15
total stiffness
K_{tot}
tyre characteristic linked to tyre *structural stiffness* ([3.16](#)) and *air stiffness* ([3.17](#)), for each test inflation pressure value

Note 1 to entry: In case the test inflation pressure is P_{ref} ([3.12](#)), then K_{tot} is equal to tyre's *vertical stiffness*, K_Z ([3.14](#)).

3.16
structural stiffness
K_{str}
tyre *vertical stiffness* ([3.14](#)) measured in "zero i.p. running mode"

Note 1 to entry: Structural stiffness is expressed in N/mm.

Note 2 to entry: It is a function of the tyre's construction and technological content.

3.17
air stiffness
K_{air}
tyre characteristic, calculated as the difference between tyre *vertical stiffness* ([3.14](#)) and tyre *structural stiffness* ([3.16](#))

Note 1 to entry: Air stiffness is expressed in N/mm.

Note 2 to entry: It is a function of the air volume and the *inflation pressure* ([3.5](#)) of the tyre itself.

3.18
deflection
S_Z
vertical displacement of the plate in the z direction

3.19
tyre diameter offset
IG
change of the outer diameter due to the inflation of the tyre

4   Test method

4.1   General

Tyres, to be considered run flat tyre or self-supporting tyre (SST) or extended mobility tyre (EMT) shall successfully complete the related endurance tests as described in ISO 16992.

4.2 Inflated tyre — Vertical stiffness measurement

4.2.1 Tyre inflation pressure

Set the tyre inflation pressure according to the ISO 4000-1 reference pressure:

— 250 kPa for the standard load tyres;

— 290 kPa for the reinforced or extra load tyres.

After fitting the tyre on the proper rim, the assembly shall be stored for at least 3 h at (25 ± 3) °C.

The accuracy for the inflation pressure shall be ±3 kPa.

4.2.2 Tyre positioning

The tyre shall be measured at three locations equally distributed around the tyre's circumference:

— at the reference position, free to be chosen, but it needs to be in contact with the platform and free from splices, if visible;

— two additional positions equally distributed around the tyre's circumference: distance between measurement positions approximately 120°.

4.2.3 Rims

The rims for the measurement shall have humps (flat or round) on both rim sides, in accordance with ISO 4000-2; the measuring rim width shall be in accordance with ISO 4000-1. As a general rule, stiff alloy or heavy duty rims should be used.

4.2.4 Equipment minimum requirements

A system able to apply a relative load between the tyre and a plate, with plate dimensions higher than the tyre footprint and relative movement of the two (tyre towards plate or plate towards tyre) is needed.

The theoretic tyre rotational axis shall be parallel to the plate and the relative movement of the two parts shall be as such to be able to keep the parallelism (e.g. as for plunger or footprint machine).

The machine maximum speed shall be 1 mm/s and the acquisition rate shall be at least 5 data points for each millimetre of displacement.

4.2.5 Machine set-up

a) Reset the tyre load cell before testing:

— as the load cells usually start the data acquisition at approximately 100 N, the measurement data acquisition shall start at 100 N or below.

b) At least the following channels shall be recorded:

— loading force (F_Z) (N), accuracy ±0,5 % of maximum load cell capacity, but in any case, maximum 100 N.

— absolute position (z) (mm) accuracy ±0,5 mm.

One vertical load value (F_Z) shall correspond to only one absolute position value (z) and vice versa.

The ambient temperature at the measuring machine shall be (25 ± 5) °C.

The total number of acquired data points shall be in the range between 100 and 1 000 per inflation pressure step (refer to Table 1).

The surface of the platform in contact with the tyre during the measurement shall be smooth steel. The surface shall be cleaned with appropriate liquids according to the maintenance instructions of the machine.

4.2.6 Maximum testing load

The maximum load at P_{ref} to be reached during the test is 150 % of the maximum load associated to the load index value of the tyre (refer to ISO 4000-1:2015, Table 2).

4.2.7 Procedure

4.2.7.1 Mount the tyre on the machine.

4.2.7.2 The initial distance between the tyre and the plate shall be at least 10 mm, measured as vertical distance between the lowest tyre point and the plate.

To set the starting point for data acquisition, the inflated tyre is loaded with a light load ($F_Z \leq 100$ N) to determine the contact point between the tyre and the loading plate. From this point, the tyre is moved back by at least 10 mm. This last position is the starting point (0,0) to be used for all of the next inflation pressure steps.

4.2.7.3 Start the channel recording.

4.2.7.4 Start loading the tyre using a constant loading speed of maximum 1 mm/s.

4.2.7.5 Inflation pressure step 1 is stopped at the maximum load (150 % LI), where the maximum deflection, S_{Zmax}, is recorded and set as stopping criterion for the following inflation pressure steps.

4.2.7.6 Unload the tyre and move back to the (0,0) position as defined in 4.2.7.2.

4.2.7.7 Repeat 4.2.7.3, 4.2.7.4 and 4.2.7.6 for the inflation pressure steps 2, 3 and 4. For each of them, the proper test inflation pressure is reported in Table 1, while the loading stop criterion is S_{zmax} for all of them.

Table 1 — Testing conditions for each inflation pressure step

Inflation pressure steps, i	Stop criterion	Test inflation pressure, P_i (kPa)
1	150 % LI	P_{ref}
2	S_{Zmax}	100
3	S_{Zmax}	70
4	S_{Zmax}	30

An example of the measurement results at 30 kPa, 70 kPa, 100 kPa and P_{ref} is shown in Figure 1.
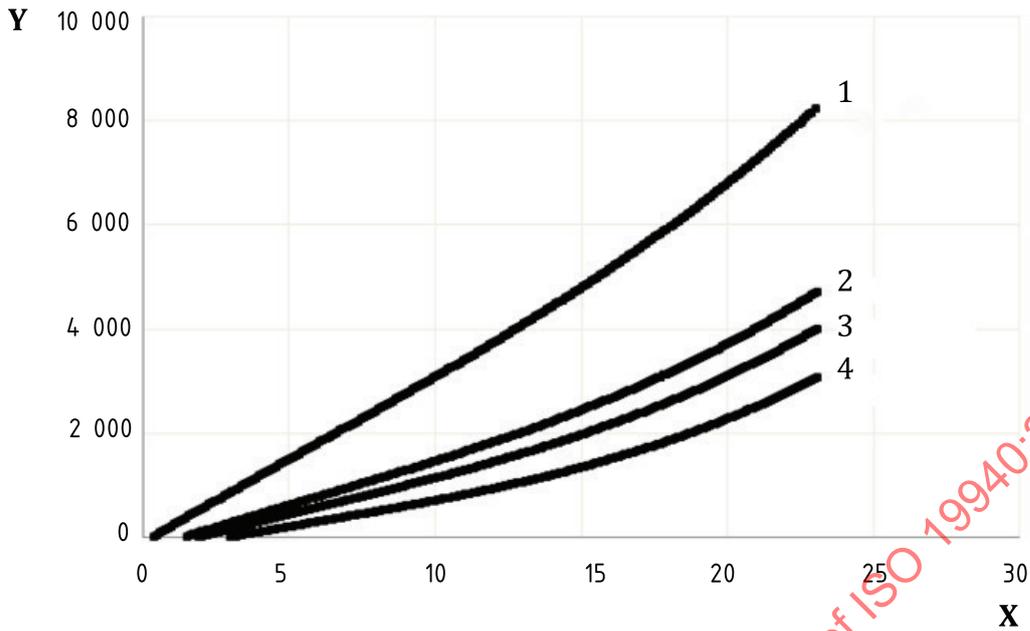
Key

X   axle represents the vertical deflection S_Z, in mm
Y   axle represents the vertical load F_Z, in N
1   P_{ref}
2   100 kPa
3   70 kPa
4   30 kPa

Figure 1 — Load vs deflection, Steps 1 to 4 — Schematic illustration of measured deflection characteristics at one measuring position, where S_Z offset was not implemented

4.2.7.8   The procedure from 4.2.7.3 to 4.2.7.7 shall be repeated for each turning position.

4.3   Zero inflation pressure tyre — Structural stiffness determination

4.3.1   General

Possible tyre sidewall buckling and tyre tread bulging can occur when performing the measurement at zero inflation pressure; such phenomena can lead to measurement problems and generate different results.

Therefore, the determination of the 0 kPa curve is based on Formula (1), using the data acquired while measuring the inflated tyre in the four steps reported in 4.2.7.7:

$$F_Z\left(S_Z, P_i\right) = F_{str} + F_{air} + \text{IG} \tag{1}$$

The slope of the calculated 0 kPa curve represents the structural stiffness of the tyre.

An example of the determined 0 kPa curve is shown in Figure 2.
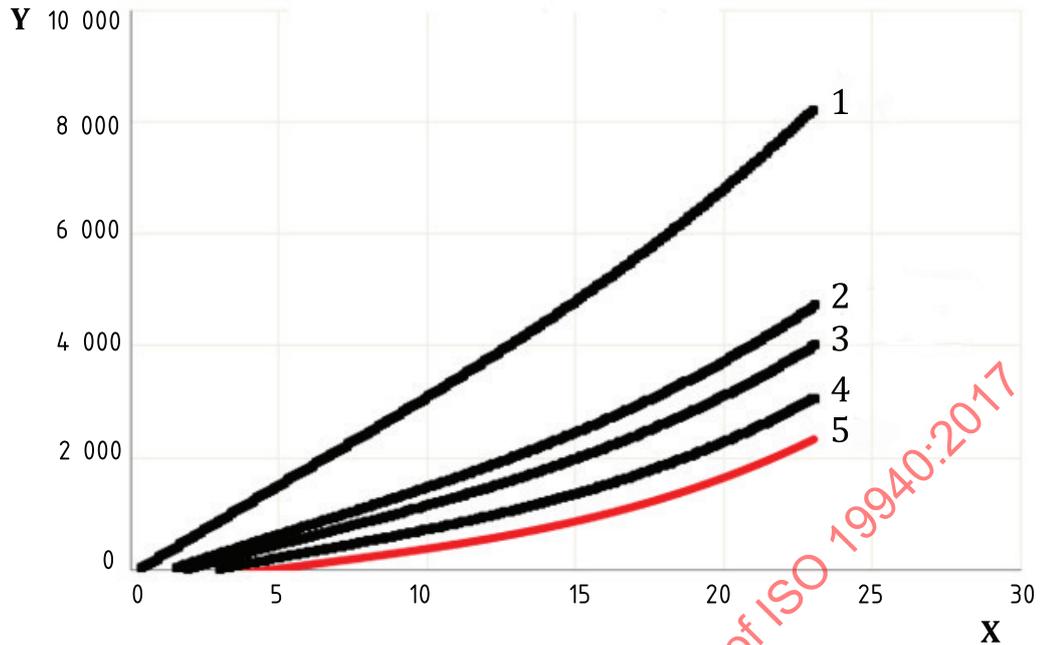
Key

X   axle represents the vertical deflection S_Z, in mm

Y   axle represents the vertical load F_Z, in N

1   P_{ref}

2   100 kPa

3   70 kPa

4   30 kPa

5   0 kPa

—   fitting curve, mathematical model

—   0 kPa fitting extrapolation curve

Figure 2 — Test steps 1 to 4, Fitting load-deflection curves from P_{ref} to 30 kPa and calculated curve for 0 kPa condition, where S_Z offset was not implemented

4.3.2   Mathematical model of the vertical forces

The mathematical model describing the dependence of the vertical force with the deflection S_Z and the test inflation pressure P_i is described by Formula (2):

$$F_Z(S_Z, P_i) = \left(a \cdot S_Z{}^3 + b \cdot S_Z{}^2 + c \cdot S_Z \right) + d_{air} \cdot P_i \cdot S_Z + f_{air} \cdot P_i + e \tag{2}$$

where

a, b, c, d_{air}, f_{air}, e   are the fitting parameters;

S_Z is the vertical deflection, in mm;

P_i is the test inflation pressure, in kPa as per the inflation pressure steps "i" from 1 to 4

The fitting curves for the corresponding four inflation pressure steps shall be computed.

4.3.3 Quality of the approximation

The relative error "r" is defined as given in Formula (3):

$$r = \sqrt{\frac{\sum\limits_{j=1}^{n}\left[F_{Zj} - F_{Zj(\text{Fit})}\right]^2}{\sum\limits_{j=1}^{n}F_{Zj}^{\,2}}} \tag{3}$$

where

F_{Zj} is the measured vertical force, in N;

$F_{Zj(\text{Fit})}$ is the calculated vertical force Formula (2), in N;

n is the number of measurement points;

and may not exceed 3,5 %. If the value is exceeded, the approximation shall be repeated.

4.3.4 Mathematical model of the total stiffness

The total stiffness, K_Z, is calculated as the slope of the load-deflection curve from Formula (2) as given in Formula (4):

$$K_Z\left(S_Z, P_i\right) = \frac{dF_Z}{dS_Z} = 3a \cdot S_Z^{\,2} + 2b \cdot S_Z + c + d_{\text{air}} \cdot P_i \tag{4}$$

where

$3a + S_Z^2 + 2b \cdot S_Z + c$ is the structural part;

$d_{\text{air}} \cdot P_i$ is the air part.

K_Z can be separated into a structural stiffness and an air stiffness part as given in Formula (5):

$$K_Z\left(S_Z, P_i\right) = K_{\text{str}}\left(S_Z\right) + K_{\text{air}}\left(P_i\right) \tag{5}$$

where the structural stiffness is given in Formula (6):

$$K_{\text{str}}\left(S_Z\right) = 3a \cdot S_Z^{\,2} + 2b \cdot S_Z + c \tag{6}$$

and the air stiffness at the test inflation pressure P_i is given in Formula (7):

$$K_{\text{air}}\left(P_i\right) = d_{\text{air}} \cdot P_i \tag{7}$$

As can be seen from Formula (6), the structural stiffness, K_{str}, depends only on the deflection, S_Z.

4.3.5 Deflection calculation

Calculate the vertical forces F_{Z08} at 0,8 LI and F_{Z13} at 1,3 LI at the reference pressure, P_{ref}, as given in Formula (8) and Formula (9):

$$F_{Z08}\left(S_{Z08}, P_{\text{ref}}\right) = 0,8 \cdot \text{LI} \quad \text{for } S_{Z08} \tag{8}$$
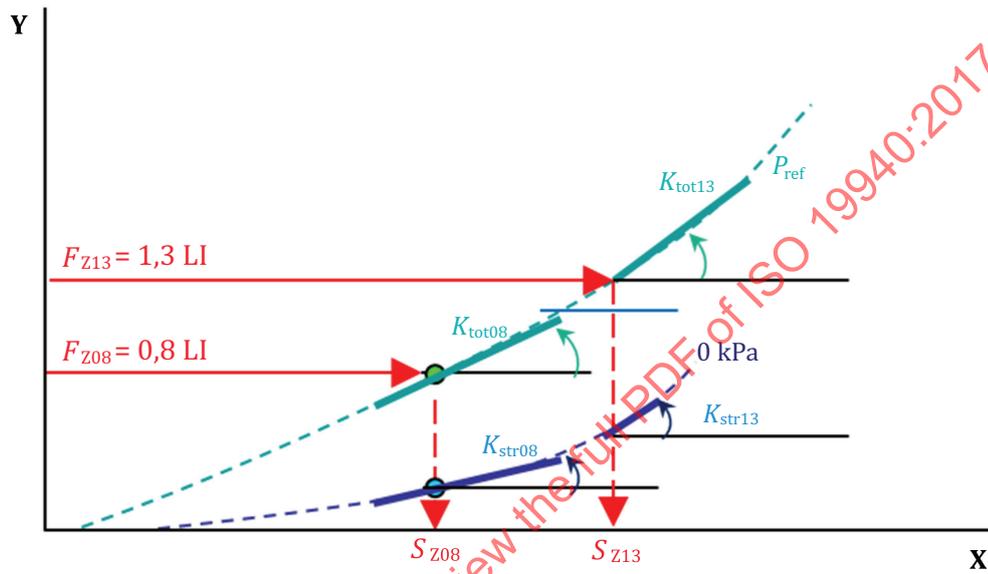
$$F_{Z13}\left(S_{Z13}, P_{ref}\right) = 1,3 \cdot LI \text{ for } S_{Z13} \tag{9}$$

where

S_{Z08} is the deflection corresponding to the vertical force F_{Z08}, with $F_{Z08} = 0,8$ LI;

S_{Z13} is the deflection corresponding to the vertical force F_{Z13}, with $F_{Z13} = 1,3$ LI.

Figure 3 shows schematically how S_{Z08} and S_{Z13} are determined.

Key

X   axle represents the vertical deflection S_Z, in mm

Y   axle represents the vertical load F_Z, in N

Figure 3 — Schematic illustration of K_{tot} and K_{str}, as well as the determination of the deflections S_{Z08} and S_{Z13} on the load-deflection curve at reference inflation pressure

4.3.6   Structural stiffness calculation

Using Formula (6), the structural stiffness K_{str08} and K_{str13} are calculated based on the deflections S_{Z08} and S_{Z13} determined in 4.3.5, as given in Formula (10) and Formula (11):

$$K_{str08} \equiv K_{str08}\left(S_{Z08}\right) = 3a \cdot S_{Z08}^2 + 2b \cdot S_{Z08} + c \tag{10}$$

$$K_{str13} \equiv K_{str13}\left(S_{Z13}\right) = 3a \cdot S_{Z13}^2 + 2b \cdot S_{Z13} + c \tag{11}$$

4.4   Structural part of the TSI

Based on Formulae (10) and (11), the structural part of the TSI is calculated as their arithmetic mean given in Formula (12):

$$TSI_{str} = \frac{1}{2}\left(K_{str08} + K_{str13}\right) \tag{12}$$

4.5 Air part of the TSI

Using Formula (7), the air part of the TSI is calculated from the air stiffness, K_{air}, as given in Formula (13):

$$\text{TSI}_{air} = K_{air}\left(P_{ref}\right) = d_{air} \cdot P_{ref} \tag{13}$$

As an alternative, the air stiffness of the tyre may be determined from the difference of total stiffness K_{tot} and structural stiffness K_{str}.

4.6 Tyre stiffness index (TSI) calculation

The TSI is obtained according to Formula (14) and Formula (15):

TSI, Air component: $K_{air} = K_{tot} - K_{str}$ (14)

TSI, Structural component: $K_{str} = \dfrac{1}{2}\left(K_{str08} + K_{str13}\right)$ (15)

The TSI value shall be calculated for each of the three measurement positions defined in 4.2.2.

The standard deviation of the three calculated TSI values may not exceed 4,5 % for K_{air}, and 7,0 % for K_{str}.

If the above values are exceeded, the approximation/measurements shall be repeated.

For final consideration, the median of these three values is used.

In Annex A, an example of a test report is given.

Figure 4 shows an example for the determination of the structural and air stiffness.