Publicly Available Specification

ISO/PAS 13146

First edition
2024-11

Road vehicles — Brake lining friction materials — Drag mode friction test for hydraulic and pneumatic vehicle brakes

Véhicules routiers — Matériaux de friction des garnitures de freins — Essai de frottement pour les freins hydrauliques et pneumatiques de véhicules

Reference number
ISO/PAS 13146:2024(en)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 33, *Vehicle dynamics, chassis components and driving automation systems testing*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Assessing friction performance is a primary concern when developing friction materials and conducting quality control. The brake assembly simulation test plays an important role here. However, the dyno test is not adapted to all vehicle models and brakes, and the assembly test is expensive and time-consuming. Therefore, a test method that can simulate real working conditions while only targeting friction materials is needed for the quality control of friction materials.

There are two ways to evaluate the friction performance of vehicle friction materials. One is through constant speed dragging, and the other is deceleration braking. The constant speed dragging braking mode can be used for the small sample test and assembly test. This braking mode is similar to actual driving conditions, brake system characteristics and automotive vehicle dynamics.

This document proposes a constant speed dragging test procedure for vehicle friction materials, which is used to evaluate the consistency of the performance of friction materials. Users assess and report on the test result according to their own specific requirements, such as friction levels or brake lining or rotor wear.

This test procedure has the following characteristics.

— The test data is comparable to the full-size assembly test.

— The test results can be used to compare friction materials.

— The test method is used to test the performance of friction materials. The test can be applied to raw material screening, early product development, process quality control and sample testing. The test is also an important means to test product consistency and quality control.

— The test method is made more efficient by using full-size brake linings, calipers and rotors. It is less expensive than testing on a full-size dynamometer test bench.

Road vehicles — Brake lining friction materials — Drag mode friction test for hydraulic and pneumatic vehicle brakes

1 Scope

This document specifies a method for the drag mode friction test for hydraulic and pneumatic vehicle brakes.

This document is applicable to the friction performance test of brake linings used in vehicles of categories M, N, O, and L.

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 611, *Road vehicles — Braking of automotive vehicles and their trailers — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 611 and the following apply.

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

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

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

3.1
cycle
braking process consisting of several brake applications

Note 1 to entry: Each braking cycle consists of several brake applications or brake manoeuvres.

Note 2 to entry: Each individual braking manoeuvre consists of a 5 s application of the brake followed by a 10 s brake release.

3.2
constant torque mode
control mode for maintaining constant braking torque during braking process

3.3
constant pressure mode
control mode for maintaining constant line pressure during braking process

4 Symbols

Table 1 — Symbols, definitions and units

Symbol	Definition	Unit
A_k	area of caliper piston(s)	cm^2
A_{BS}	radiating surface of brake rotor(s)	m^2
c_p	specific heat storage capacity	J/(N K)
g	gravity acceleration	m/s^2
G_{BS}	weight of brake rotor; $G_{BS} = m_{BS}\,g$	N
m_{BS}	mass of rotor	kg
M_d, M_1, M_2, M_3	torque	N m
n	speed	$r\ min^{-1}$
P	applied pressure	MPa
r_{eff}	brake effective radius	mm
t	time	s
$T_{Initial}$	initial temperature	°C
T_{end}	final temperature	°C
T_E	final temperature	K
T_A	start temperature	K
α	transmission coefficient	$J/(m^2\ s\ K)$
η	efficiency	—
μ	friction coefficient	—
μ_F	fading coefficient of friction	—
μ_K	cold coefficient of friction	—
μ_{max}	maximum coefficient of friction	—
μ_{min}	minimum coefficient of friction	—
μ_{op}	operational coefficient of friction	—

5 Test conditions

5.1 Test equipment and parts

The test shall be conducted using a test bench with appropriate hardware and software as specified in Annex A.

A suitable fixture shall be used to mount the brake caliper on the test bench so that the brake caliper and the brake rotor stay in position. The effective friction radius is adjusted according either to the requester specification or to Annex B.

Before starting the test, the entire system, including the brake caliper, shall be adequately bled. Assembling the caliper shall not interfere with the torque measurement.

5.2 Requirement

New brake linings from current production shall be used. For pads with a surface coating, the coating shall be removed before assembling the test configuration. The brake caliper and rotor to be used shall be as specified by the test requester.

New brake rotors shall be thoroughly cleansed to remove any corrosion protection coatings. The brake rotor may be reused until the minimum thickness specified by the manufacturer is reached. In the absence of a specification, discard the rotor when it reaches 90 % of the wearable thickness.

Before each test, the surface of the brake rotor shall be cleaned with sandpaper to remove wear marks and rust from the surface. Dust and oil on the surface of the brake rotor should be removed with a soft cloth or anhydrous ethanol.

Recondition a new or reworked brake rotor by conducting at least one complete test programme with the same friction material intended for the tests. Do not include these conditioning tests as part of the report. It is recommended to use a single rotor for each lining material. The same applies to every re-use of the rotor after a period in storage.

Replace the brake rotor when the torque variations exceed ±5 % of the set value or the surface roughness exceeds 15 µm. Measure roughness in the radial direction in the middle of the friction ring at three or more equally spaced angular positions.

On calipers with integral parking brakes, remove the mechanical parking brake actuation (spindle) to minimize efficiency loss and to simplify the retraction of the piston when changing a pad.

When a vehicle has several variants of brake rotors for a given brake pad number, use the variant with the highest (most critical) ratio of kinetic energy to rotor mass.

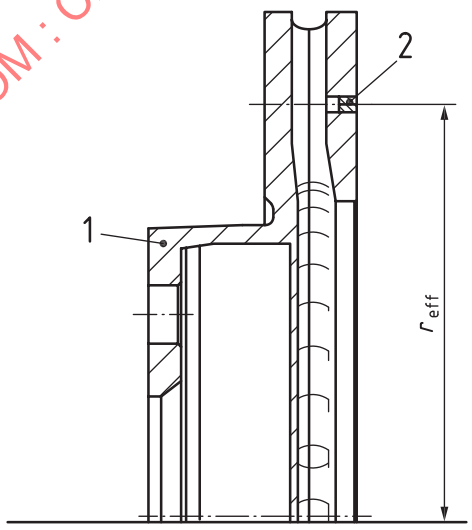
5.3 Brake temperature measurement

The temperature is measured at the outboard side of the rotor by means of an embedded (caulked) thermocouple, in the friction effective radius (see Annex B) it is measured at the surface of a thermocouple pressed in by a copper pin. For alternative temperature measurement methods, the fixed thermocouple is the reference sensor:

— in the case of ventilated brake rotors in the outer friction ring, located at 0,5 mm below friction surface (see Figure 1);

— in the case of solid brake rotors half way up the friction ring thickness (see Figure 2).

After demonstrating that the alternative temperature measurement method is comparable to the standard thermocouple installation, an infrared or rubbing thermocouple measurement methods can be used. Aim for a measurement position as close as possible to the equivalent thermocouple. Record the measurement position in the comparison test report. The rotor runout shall be measured when the brake rotor is mounted on the test bench. The maximum permissible rotor runout is 0,08 mm.



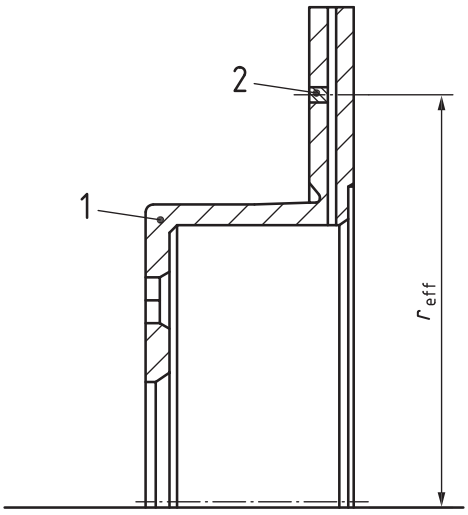
Key

1 brake rotor

2 thermocouple

r_{eff} brake effective radius

Figure 1 — Example of a ventilated brake rotor



Key

1 brake rotor
2 thermocouple
r_{eff} brake effective radius

Figure 2 — Example of a solid brake rotor

6 Test type

The two test types are the original sample method and the sampling method. The original sample method is used to test the original size of the sample (the original brake lining). The sampling method is used to shrink a brake lining to a specified size to be tested in a standardized brake application.

Brake lining assemblies for vehicles of categories M, N, O and L can be tested using either the original sample method or the sampling method.

7 Method A: Brake lining assemblies for vehicles of categories M_1, M_2, N_1, O_1, O_2 and L

7.1 General

For this category of vehicles, the test types are the original method and the sampling method.

7.2 Determination of test pressure and torque

7.2.1 Determination of test pressure and torque of the original sample method

7.2.1.1 Determination of test pressure

The hydraulic pressure, P, under the piston(s) of the caliper shall be constant when calculated using Formula (1):

$$P = \frac{M_d}{0{,}57 \cdot r_w \cdot A_k} \quad (1)$$

where

M_d is the braking torque, expressed in N m;

A_k is the area of the caliper piston(s), expressed in m^2;

r_w is the effective radius of the rotor, expressed in m;

— when $A_k \leq 18{,}1\ cm^2$, M_d is 150 N m;

— when $A_k > 18{,}1\ cm^2$, M_d is 300 N m.

NOTE The total piston area acting on one side of the caliper is considered, regardless of the number of pistons.

7.2.1.2 Determination of test torque

The brake torque, M, shall be constant when calculated in accordance with Annex C, Formula (C.1).

7.2.2 Determination of test pressure and torque of the sampling method

In constant pressure mode, the mean contact pressure at the brake lining friction surface shall be constant at (75 ± 10) N/cm^2. The mean brake line pressure shall be constant at 0,89 MPa.

In constant torque mode, M_1 is 103 N m, M_2 is 186 N m and M_3 is 194 N m.

7.3 Brake rotor and brake caliper conditions

When conducting the original sample method, the brake rotor and brake caliper shall meet the requirements specified in the drawings and technical documentation of the brake application used.

When conducting the sampling method, a fixed rotor brake caliper with a piston diameter of 36 mm shall be installed on the test machine. The effective friction radius (see Annex B) shall be 116,5 mm after installation. The brake rotor is solid with a diameter of (278 ± 2) mm and a thickness of (9 ± 0,5) mm and made of standard grey cast iron materials.

7.4 Sample preparation

7.4.1 Sample preparation of the original sample method

Select a brake lining at random from the samples to be tested and mark five points (point 1 to point 5) on the back of the lining. These are the points at which thickness is measured (see Figure 3). Determine the average wear by taking the arithmetic mean of all the points measured. If the measurement at point no. 5 is located on the groove, offset the measurement point horizontally by 10 mm.

Dimensions in mm

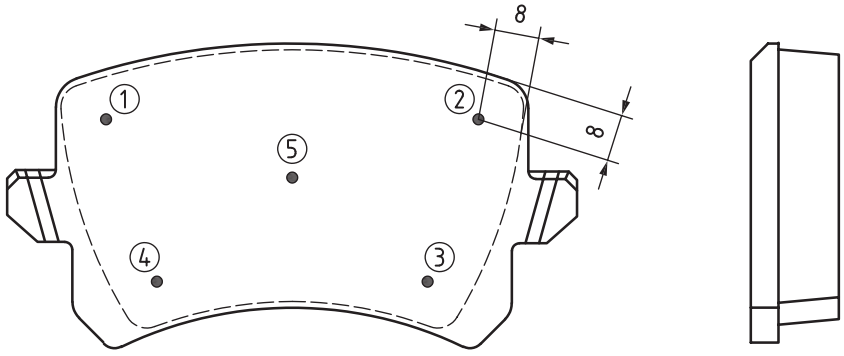


Figure 3 — Position of thickness measurement points

7.4.2 Sample preparation of the sampling method

Randomly select a brake lining from the samples to be tested. Cut a rectangular piece of the friction material, with a length of (40,0 ± 0,2) mm, a width of (30,0 ± 0,2) mm and a thickness of no less than 5,0 mm from the middle of the brake lining. The test piece shall fit tightly to the carrier plate (see Figure 4).

If the brake lining is too small to take the friction material (40 mm × 30 mm), randomly select two brake linings from the samples to be tested, take two rectangular pieces of friction material and assemble them into the specified size. The difference in thickness between the two rectangular pieces of friction materials shall not exceed 0,05 mm. Mark four points on the sample non-friction surface as positions for thickness measurement (see Figure 4).

Dimensions in mm

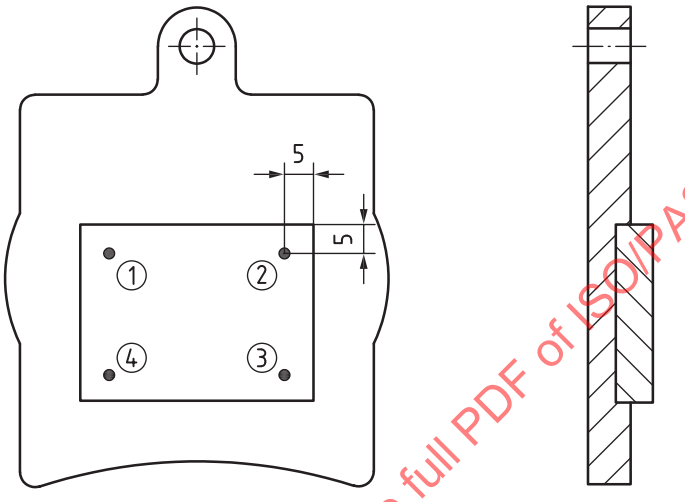


Figure 4 — Position of thickness measurement points

7.5 Thickness and mass measurement

Wear shall be determined by weighing the sample and measuring thickness before and after the test. Measure and record the thickness of each measurement point to an accuracy of 0,01 mm. Weigh and record the mass of the sample to an accuracy of 0,01 g.

7.6 Test procedure

7.6.1 Test procedure 1: Constant torque mode

The braking interval consists of:

— 5 s braking time;

— 10 s idle time between signal brake off and on.

The rotor speed shall be:

— n = 660 r min^{-1} = constant.

No cooling air is applied during the test cycles, only exhaust air is extracted.

Table 2 — Constant torque test programme

Test programme groups	Cycle	Brake applications per cycle	Brake torque M_d	$T_{Initial}$ [°C]	T_{End}[a] [°C]
I. Burnish	1—6	5	M_1	100 (the first brake < 50)	Max. 250
II. μ_{K1}	7	5	M_2	< 60	300—350
III. μ_{op1}	8—10	5	M_2	100	300—350
IV.μ_{F1}	11	10	M_3	100	500—550
V. μ_{op2}	12—15	5	M_2	100	300—350
VI. μ_{F2}	16	10	M_3	100	500—550
VII. μ_{op3}	17—19	5	M_2	100	300—350
VIII. μ_{K2}	20	5	M_2	< 60	300—350

[a] Temperature values are determined by the programme flow. For group I (Burnish procedure), interrupt the cycle when the temperature T_{End} reaches 250 °C. For subsequent cycles, continue with a $T_{Initial}$ of 100 °C.

For brake torques, see Annex C, which is valid for standard grey cast iron materials only. For other materials, the brake torques shall be recalculated using the specific material parameters in accordance with the requester's specifications.

During all cycles, exhaust air extraction is on and cooling air application is off. Cooling is on between cycles when the rotor shall cool down to $T_{Initial}$.

7.6.2 Test procedure 2: Constant pressure mode

The braking interval consists of:

— 5 s braking time;

— 10 s idle time between signal brake off and on.

The rotor speed shall be:

— n = 660 r min^{-1} = constant.

Cooling is on during the Burnish group, last test group and between the cycles when the rotor shall cool down to $T_{Initial}$. The exhaust air extracted is on during the entire test programme.

Apply a constant hydraulic pressure, P, to the caliper piston(s) as presented in Formula (1) (7.2.1.1).

Table 3 — Constant pressure test programme

Test programme groups	Cycle	Brake applications per cycle	Initial brake rotor temperature [°C]	Max. brake rotor temperature [°C]	Forced cooling
I. Burnish	1 — 6	5	100 (the first brake < 50)	200	Yes
II.	7	10	≤ 60	No limitation	No
III.	8 — 12	10	100	No limitation (350)[a]	No
IV.	13	10	100	No limitation	Yes

[a] For vehicles of category L, the temperature shall be limited to 350 °C. If necessary, the number of applications per cycle shall be reduced accordingly. However, in this case, the number of cycles shall be increased to keep the total number of applications constant.

7.7 Evaluation of test results

7.7.1 General

Carry out a visual inspection of the test samples. The detachment of the friction material from the backing plate shall be documented. Tearing of the pad, structural cracks, spalling, plasticity, inclusion of casting particles in the friction surface of the pad, noise and brake rotor condition (hotspots, cracks) shall be noted.

Only measured torque values shall be used to calculate the coefficients of friction. The test value of the actual values shall be recorded with a scanning frequency of a minimum of 20 Hz.

Unless otherwise specified by the entity that requested the test, the constants used to calculate the friction coefficients are η = 0,95 for sliding calipers and η = 0,98 for fixed calipers.

The test report shall include the following characteristic values and tolerance bands:

for the constant torque method:

— cold coefficients of friction, μ_{K1}, μ_{K2};

— coefficients of friction during normal operation, μ_{op1}, μ_{op2}, μ_{op3};

NOTE 1 This can be represented as μ_{op} or μ_B.

— fading coefficients of friction, μ_{F1}, μ_{F2};

— minimum coefficient of friction, μ_{min};

— maximum coefficient of friction, μ_{max};

— wear (weight and thickness variation for the single sample);

for the constant pressure method:

— cold coefficient of friction, μ_K;

— coefficient of friction during normal operation, μ_{op};

NOTE 2 This can be represented as μ_{op} or μ_B.

— fading coefficient of friction, μ_F;

— minimum coefficient of friction, μ_{min};

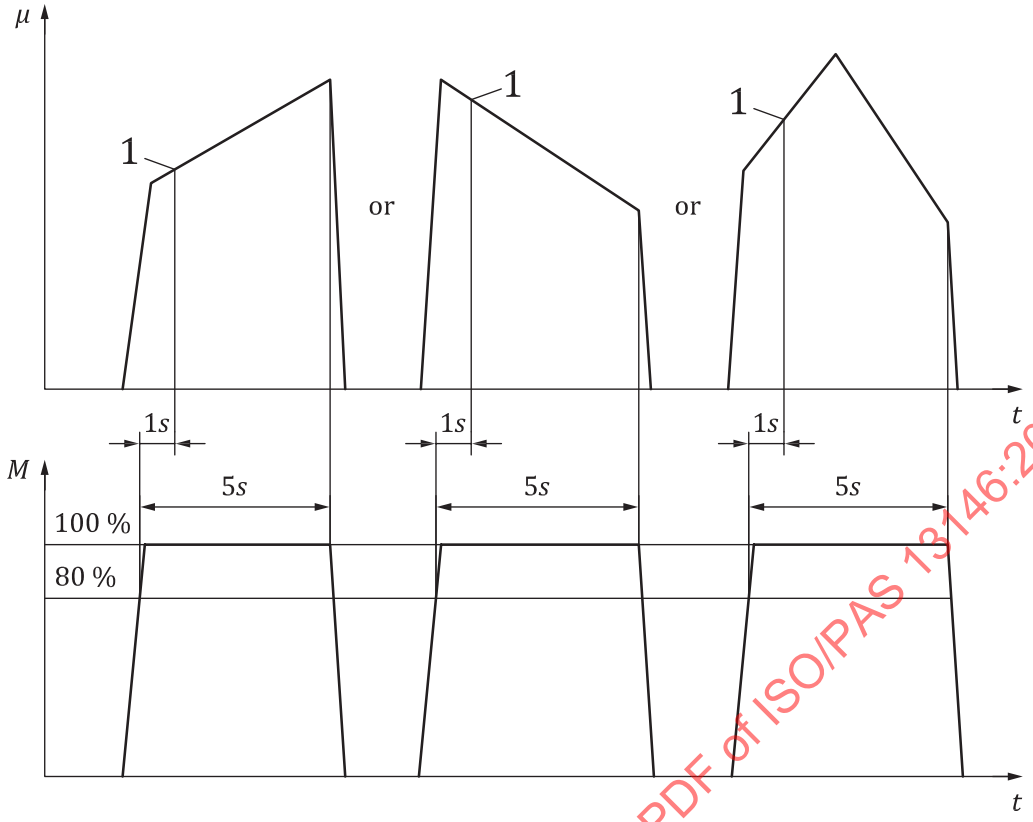
— maximum coefficient of friction, μ_{max};

— wear (weight and thickness variation for the single sample).

Additional friction coefficients and specific tolerances should be agreed with the entity that requested the test.

7.7.2 Cold coefficients of friction and coefficients of friction during normal operation

To determine the cold coefficient(s) of friction and the coefficient(s) of friction during normal operation, calculate the coefficients of friction after one second. To this end, all values measured during one brake application shall be averaged when torque or pressure reach 80 % + 1 s in the time window of ±0,1 s (see Figure 5 for the constant torque method and Figure 6 for the constant pressure method).



Key

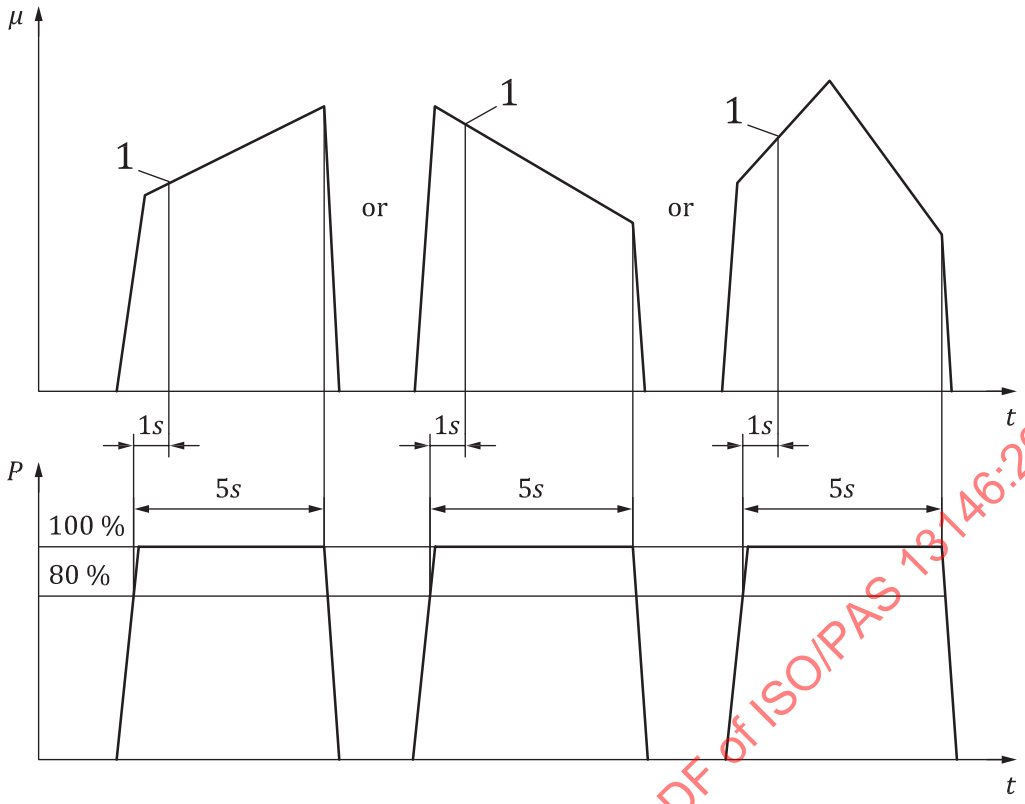
t time

μ coefficient of friction

M controlled variable torque

1 cold coefficient of friction, μ_K / coefficient of friction during normal operation, μ_{op} or μ_B

Figure 5 — Example of cold coefficients of friction and coefficients of friction during normal operation for the constant torque method



Key

t time

μ coefficient of friction

P controlled variable pressure

1 cold coefficient of friction, μ_K / coefficient of friction during normal operation, μ_{op} or μ_B

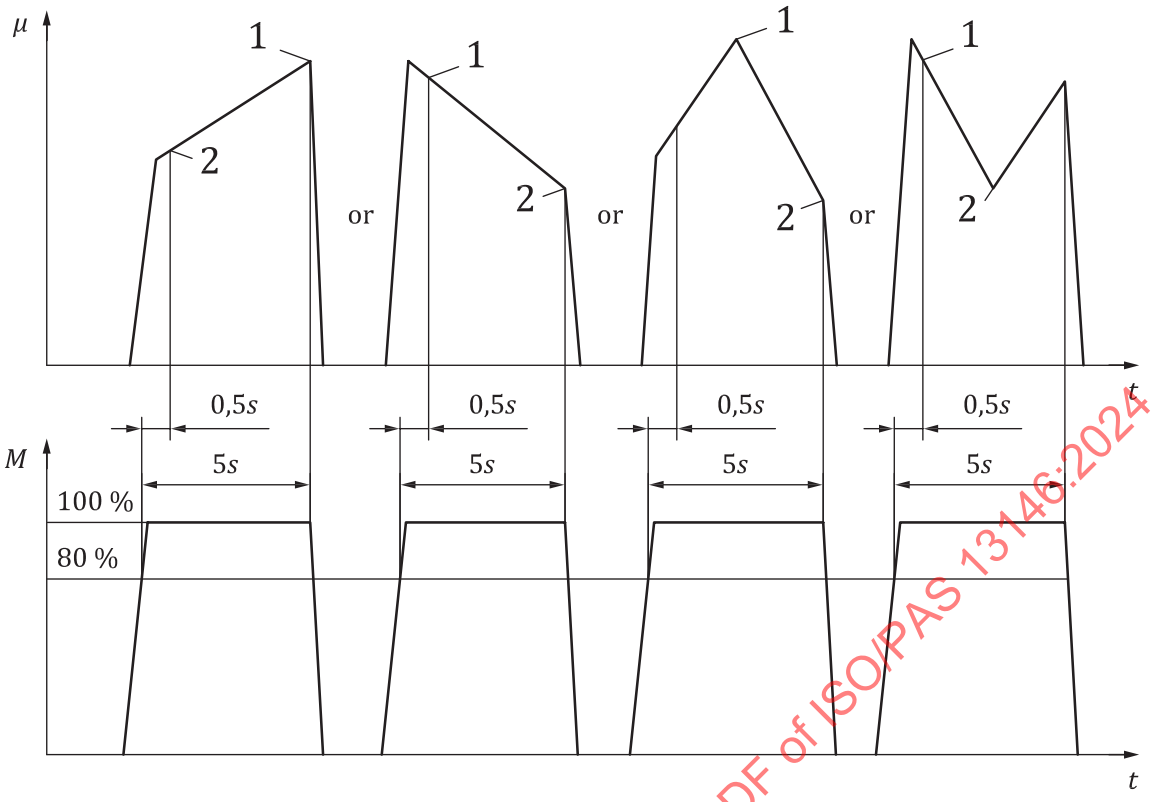
Figure 6 — Example of cold coefficients of friction and coefficients of friction during normal operation for the constant pressure method

The cold coefficients of friction, μ_{K1}, μ_{K2}, are the coefficients of friction after one second of the first brake application. This applies to each first cycle in test programme group II (Table 2) and the last cycle in test programme group VIII (Table 2) for the constant torque method. The cold coefficient of friction, μ_K, is the coefficient of friction after one second of the first brake application of the first cycle in test programme group II (Table 3) for the constant pressure method. The starting temperature of each of these brake applications is 60 °C.

The coefficients of friction during normal operation are the coefficients of friction after one second of each first brake application. This applies to cycles with a starting temperature of 100 °C, i.e. groups III, V and VII (Table 2) for the constant torque method and groups III and IV (Table 3) for the constant pressure method. In the constant torque method, three coefficients of friction during normal operation shall be determined in groups III and VII (Table 2). Four coefficients shall be determined in group V (Table 2). The single values are combined into one mean value for each group: μ_{op1}, μ_{op2}, μ_{op3}. In the constant pressure method, six coefficients of friction during normal operation shall be determined in groups III and IV (Table 3). The single values are combined into one mean value μ_{op}.

7.7.3 Minimum, maximum and fading coefficients of friction

The minimum, maximum and fading coefficients of friction shall be evaluated from when the torque or pressure reach 80 % + 0,5 s to the end of braking (see Figure 7 for the constant torque method and Figure 8 for the constant pressure method).



Key

t time

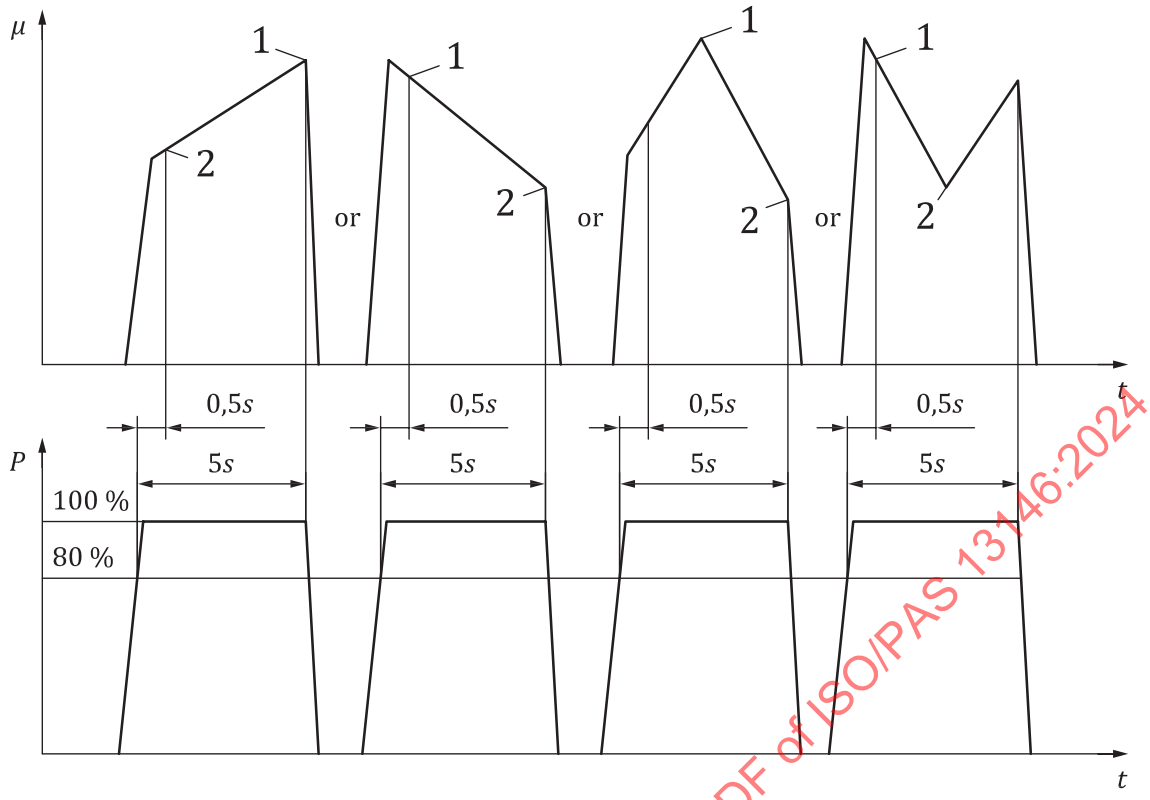
μ coefficient of friction

M controlled variable torque

1 maximum coefficient of friction, μ_{max}

2 minimum coefficient of friction, μ_{min} / fading coefficients of friction, μ_{F1}, μ_{F2}

Figure 7 — Example of minimum, maximum and fading coefficients of friction for the constant torque method



Key

t time

μ coefficient of friction

P controlled variable pressure

1 maximum coefficient of friction, μ_{max}

2 minimum coefficient of friction, μ_{min} / fading coefficient of friction, μ_F

Figure 8 — Example of minimum, maximum and fading coefficients of friction for the constant pressure method

The minimum coefficient of friction without thermal overload, μ_{min}, is the smallest coefficient of friction in groups II, III, V, VII and VIII (Table 2) for the constant torque method and groups II and IV (Table 3) for the constant pressure method. In each case, this applies from ($t_{80\,\%\,M,\,P}$ + 0,5) s to the end of braking.

The maximum coefficient of friction, μ_{max}, is the greatest coefficient of friction in groups II to VIII (Table 2) for the constant torque method and groups II to IV (Table 3) for the constant pressure method. In each case, this applies from ($t_{80\,\%\,M,\,P}$ + 0,5) s to the end of braking.

The fading coefficients of friction, μ_{F1}, μ_{F2}, are the smallest coefficients of friction occurring in groups IV (Fading 1) and VI (Fading 2) (Table 2) for the constant torque method. The fading coefficient, μ_F, is the smallest coefficient of friction occurring in group III (Table 3) for the constant pressure method, in each case this applies from ($t_{80\,\%\,M,\,P}$ + 0,5) s to the end of braking.

8 Method B: Rotor and drum brake lining assemblies for vehicles of categories M_3, N_2, N_3, O_3 and O_4

8.1 General

For this categories of vehicle, the test can be performed using either the original sample method (see 7.2 to 7.6) or the sampling method. The sampling method is presented in this clause.

8.2 Determination of test pressure for sampling method

The mean contact pressure at the brake lining working surface shall be constant at (75 ± 10) N/cm^2, the brake line pressure shall be constant at 1,17 MPa.

8.3 Brake rotor and brake caliper conditions for the sampling method

A fixed rotor brake caliper with a piston diameter of 60 mm shall be installed on the test machine. The effective radius shall be 105,5 mm after installation.

The brake rotor is solid with a diameter of (278 ± 2) mm and a thickness of (12 ± 0,5) mm. The brake rotor is made of standard grey cast iron materials.

Alternatively, if agreed with the test requestor, the machine may be equipped with a caliper and corresponding brake rotor with a diameter of (278 ± 2) mm. This means a rectangular piece of the friction material with the dimensions outlined in 8.4 can be attached to the backing plate of the rotor brake.

8.4 Sample preparation

Randomly select a brake lining from the samples to be tested. Cut a rectangular piece out of the friction material with a length of (84 ± 0,2) mm, a width of (52 ± 0,2) mm, and a thickness of no less than 6,0 mm from the middle of the brake lining, the test piece shall fit tightly to the carrier plate .

If the brake lining is too small to take the friction material (84 mm × 52 mm), randomly select two brake linings from the samples to be tested, take two rectangular pieces of friction material and assemble them into the specified size. The difference in thickness between the two rectangular pieces of friction materials shall not exceed 0,05 mm. Mark four points on the sample non-friction surface as positions for thickness measurement (see Figure 9).

Dimensions in mm

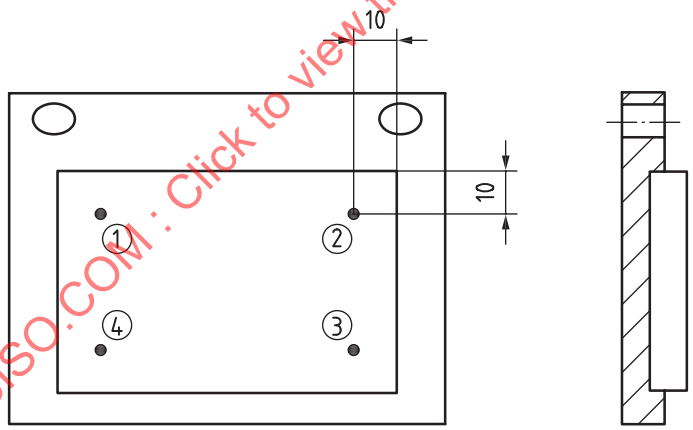


Figure 9 — Position of thickness measurement points

8.5 Thickness and mass measurement

Wear shall be determined by weighing the sample and measuring thickness before and after the test. Measure and record the thickness of each measurement point to an accuracy of 0,01 mm. Weigh and record the mass of the sample to an accuracy of 0,01 g.

8.6 Test procedure

In this test procedure, the line pressure is constant during the braking process.

The braking interval consists of:

— 5 s braking time;

— 10 s idle time between signal brake off and on.

The rotor speed shall be :

— n = 660 r min^{-1} = constant.

Cooling air is applied during the Burnish group, test programme group II, test programme groups VII to X and between the cycles when the rotor shall cool down to $T_{Initial}$. The exhaust air extracted is on during the entire test programme.

Table 4 — Constant pressure test programme

Test programme groups	Cycle	No. of brake applications	Initial brake rotor temperature [°C]	Forced cooling
I. Burnish	1—6	5	100 (the first brake < 50, maximum temperature 200)	Yes
II.	7	5	100	Yes
III.	8	5	increasing ≤200	No
IV.	9	5	200	No
V.	10	5	increasing ≤300	No
VI.	11	5	300	No
VII.	12	3	250	Yes
VIII.	13	3	200	Yes
IX.	14	3	150	Yes
X.	15	10	100	Yes
XI.	16	5	increasing ≤300	No
XII.	17	5	300	No

8.7 Evaluation of test results

Carry out a visual inspection of the test samples. Tearing of the friction material, structural cracks, spalling, plasticity, inclusion of casting particles in the friction surface of the pad, noise and brake rotor condition (hotspots, cracks) shall be noted.

Only measured torque values shall be used to calculate the coefficients of friction. The test value of the actual values shall be recorded with a scanning frequency of a minimum of 20 Hz.

For original sample method, see 7.7.

Unless otherwise specified by the entity that requested the test, the constants used to calculate the friction coefficients are η = 0,95 for sliding calipers and η = 0,98 for fixed calipers.

The following coefficients shall be determined for the sampling method:

— coefficients of friction during normal operation, μ_{op1} and μ_{op2};

NOTE The coefficient of friction during normal operation can be represented as μ_{op} or μ_B.

— minimum coefficient of friction, μ_{min};

— maximum coefficient of friction, μ_{max};

— wear (weight and thickness variation for the single sample).

Additional friction coefficients and specific tolerances should be agreed with the test requester.

The coefficients of friction during normal operation are coefficients of each first brake application of the groups with a starting temperature of 100 °C. All values measured during one brake application shall be averaged at ($t_{80\,\%\,M,P}$ + 1) s in the time window of ±0,1 s. Two coefficients of friction during normal operation shall be determined in each of the test programme groups II and X (Table 4). The single values are combined into one mean value for each group, μ_{op1} and μ_{op2}.

The maximum coefficient of friction, μ_{max}, is the greatest coefficient of friction occurring in the test programme groups II to XII (Table 4). In each case, this applies from ($t_{80\,\%\,M,P}$ + 0,5) s to the end of braking.

The minimum coefficient of friction, μ_{min}, is the smallest coefficient of friction occurring in the test programme cycles II to XII (Table 4). In each case, this applies from ($t_{80\,\%\,M,P}$ + 0,5) s to the end of braking.

9 Test report

The test report shall contain at least the following information (see Annex D for the templates):

a) sample basic information;

b) reference to the International Standard (including its year of publication) used for the test, i.e. this document;

c) test parameter;

d) test data (including main information on tested brake application);

e) test type and test method;

f) test results (including a reference to the clause which explains how the results were calculated);

g) after-test brake lining and brake rotor surface conditions, and any unusual features observed;

h) any deviations from the procedure;

i) the date of the test.

The standard documentation of test results shall be kept in databases following the retention period defined by requester. This includes the comparison evaluation and the pad data sheet. Characteristic values shall be defined on the test result.

Annex A
(normative)

Test bench

The machine shall be designed to accept and operate a full-size brake similar to those fitted to the vehicle axle used for approval testing.

The rotor or drum rotational speed shall be (660 ± 10) r min^{-1} without load and shall not fall below 600 r min^{-1} on full load.

The execution of the test cycles and their braking sequences shall be programmable and run independently through automation. The braking torque, the braking pressure and the working surface temperature on the brake rotor or brake drum shall be recorded. Unless otherwise specified, the equipment shall meet the following accuracy in the procedures:

— brake output torque: ±5 %;

— brake pressure: ±5 %;

— temperature: ±5 %.

The recommended cooling air volume for direct cooling of the brake is (600 ± 60) m^3/h. The temperature of cooling air should not exceed 25 °C.

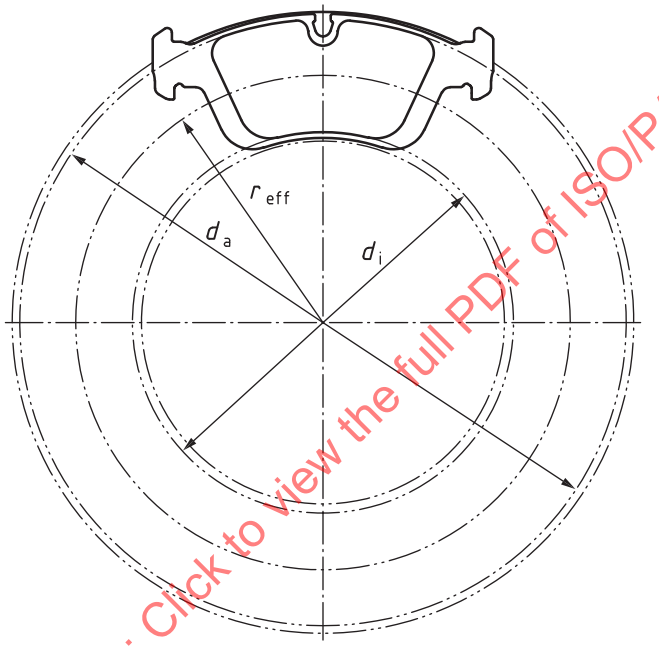
Annex B
(informative)

Effective friction radius (r_{eff})

The physical meaning of effective radius is determined by geometric factors and illustrated in Figure B.1.

The definition of the effective radius is shown in Formula (B.1).

$$r_{eff} = \frac{1}{3} x \frac{d_a^3 - d_i^3}{d_a^2 - d_i^2} \quad \text{(B.1)}$$



Key

r_{eff} effective friction radius
d_i inner diameter
d_a outer diameter

Figure B.1 — Effective friction radius

Annex C
(normative)

Brake torque

C.1 Brake torque calculation

Calculate brake torque using Formula (C.1):

$$M = \frac{(T_E - T_A)\cdot\alpha\cdot A_{BS}}{\left[1 - e^{\left(-\frac{\alpha\cdot A_{BS}}{c_p\cdot G_{BS}}\times t\right)}\right] 2\cdot\pi\cdot n} \quad \text{(C.1)}$$

where

M is the brake torque, expressed in N m;

T_E is the final temperature, expressed in K;

T_A is the start temperature, expressed in K;

α is the transmission coefficient, expressed in J/(m^2 s K);

A_{BS} is the radiating surface of brake rotor(s), expressed in m^2;

c_p is the specific heat storage capacity, expressed in J/(N K);

G_{BS} is the weight of brake rotor, expressed in N; $G_{BS} = m_{BS}\,g$;

m_{BS} is the the mass of rotor, expressed in kg;

g is the gravity acceleration, expressed in m/s^2;

t is the braking time, expressed in s;

n is the rotor speed, expressed in r min^{-1}.

NOTE In calculation for gravity, acceleration can be used g = 10 m/s^2.

The values given in Table C.1 are used for calculation.

Tables C.2 provides the brake torques for solid rotors and Table C.3 provides the brake torques for internally vented rotors.

Table C.1 — Values used for torque calculation

Description	Value / calculation	Remark
α	59,7 [J/(m^2 s K)]	Constant for grey cast iron material
c_p	51 [J/(N K)]	Constant for grey cast iron material
M_1	$T_E - T_A$ = 125 K t =25 s	Temperature and time to be used for calculation
M_2	$T_E - T_A$ = 225 K t =25 s	Temperature and time to be used for calculation
M_3	$T_E - T_A$ = 450 K t =50 s	Temperature and time to be used for calculation
A_{BS}	$A_{BS} = 2 \cdot \frac{(d_{BS})^2 \cdot \pi}{4}$	For solid rotor d_{BS} is rotor diameter [m]
A_{BS}	$A_{BS} = 4 \cdot \frac{(d_{BS})^2 \cdot \pi}{4}$	For internally vented rotor d_{BS} is rotor diameter [m]
Euler's number (e)	2,72	Constant
π (pi)	3,14	Constant
n	660 r min^{-1}	To be used for calculation 11 r s^{-1}

C.2 Brake torque for solid rotors

Table C.2 — Brake torque for solid rotors

Brake torques for solid rotors [N m]										
∅ [mm]	Outer diameter									
***m* [kg]**	220	240	260	280	300	320	340	360	380	400
2,50	96	97	98	99	100	101	102	104	105	107
	174	175	177	178	180	182	184	187	189	192
	181	184	188	191	195	199	204	209	214	220
2,60	100	101	102	103	104	99	106	107	109	110
	180	182	183	185	187	189	191	193	196	198
	188	191	194	198	202	206	210	215	221	226
2,70	104	105	106	106	107	103	110	111	112	114
	187	188	190	192	193	195	198	200	202	205
	195	198	201	204	208	212	217	222	227	233
2,80	108	108	109	110	111	107	113	115	116	118
	194	195	197	198	200	202	204	207	209	202
	201	204	207	211	215	219	224	228	234	239
2,90	111	112	113	114	115	111	117	118	120	121
	200	202	203	205	207	209	211	213	216	218
	208	211	214	218	221	226	230	235	240	246
3,00	115	116	117	118	119	115	121	122	123	125
	207	208	210	212	213	215	218	220	222	225
	214	217	221	224	228	232	237	242	247	252
3,10	119	119	120	121	122	119	125	126	127	129
	213	215	216	218	220	222	224	226	229	231
	221	224	227	231	235	239	243	248	253	259
3,20	122	123	124	125	126	123	128	129	131	132
	220	222	223	225	227	229	231	233	235	238

Table C.2 *(continued)*

Brake torques for solid rotors [N m]										
∅ [mm]	Outer diameter									
***m* [kg]**	220	240	260	280	300	320	340	360	380	400
	228	231	234	237	241	245	250	255	260	265
	126	127	128	129	130	127	132	133	134	136
3,30	227	228	230	231	233	235	237	240	242	245
	234	237	241	244	248	252	256	261	266	272
	130	130	131	132	133	131	136	137	138	140
3,40	233	235	236	238	240	242	244	246	249	251
	241	244	247	251	255	259	263	268	273	278
	133	134	135	136	137	135	139	141	142	143
3,50	240	241	243	245	247	249	251	253	255	258
	248	251	254	257	261	265	270	274	279	285
	137	138	139	140	141	139	143	144	146	147
3,60	247	248	250	251	253	255	257	260	262	264
	254	257	260	264	268	272	276	281	286	291
	141	142	142	143	144	143	147	148	149	151
3,70	253	255	256	258	260	262	264	266	269	271
	261	264	267	271	274	278	283	288	293	298
	144	145	146	147	148	147	150	152	153	154
3,80	260	261	263	265	266	268	271	273	275	278
	268	270	274	277	281	285	289	294	299	305
	148	149	150	151	152	151	154	155	157	158
3,90	267	268	270	271	273	275	277	279	282	284
	274	277	280	284	288	292	296	301	306	311
	152	153	153	154	155	155	158	159	160	162
4,00	273	275	276	278	280	282	284	286	288	291
	281	284	287	290	294	298	303	307	312	318
	155	156	157	158	159	159	161	163	164	165
4,10	280	281	283	285	286	288	290	293	295	298
	287	290	294	297	301	305	309	314	319	324
	159	160	161	162	163	163	165	166	168	169
4,20	287	288	290	291	293	295	297	299	302	304
	294	297	300	304	307	312	316	321	325	331
	163	164	165	165	166	167	169	170	171	173
4,30	293	295	296	298	300	302	304	306	308	311
	301	304	307	310	314	318	322	327	332	337
	167	167	168	169	170	171	172	174	175	176
4,40	300	301	303	304	306	308	310	313	315	317
	307	310	313	317	321	325	329	334	339	344
	170	171	172	173	174	175	176	177	179	180
4,50	306	308	309	311	313	315	317	319	322	324
	314	317	320	324	327	331	336	340	345	351
	174	175	176	177	178	179	180	181	182	184
4,60	313	315	316	318	320	322	324	326	328	331
	321	324	327	330	334	338	342	347	352	357
	178	178	179	180	181	183	183	185	186	187

Table C.2 *(continued)*

Brake torques for solid rotors [N m]										
∅ [mm]	Outer diameter									
***m* [kg]**	220	240	260	280	300	320	340	360	380	400
4,70	320	321	323	324	326	328	330	333	335	337
	327	330	333	337	341	345	349	354	358	364
4,80	181	182	183	184	185	187	187	188	190	191
	326	328	329	331	333	335	337	339	341	344
	334	337	340	343	347	351	356	360	365	370
4,90	185	186	187	188	189	192	191	192	193	195
	333	334	336	338	340	341	344	346	348	351
	341	343	347	350	354	358	362	367	372	377
5,00	189	189	190	191	192	196	195	196	197	198
	340	341	343	344	346	348	350	352	355	357
	347	350	353	357	360	364	369	373	378	383
5,10	192	193	194	195	196	200	198	199	201	202
	346	348	349	351	353	355	357	359	361	364
	354	357	360	363	367	371	375	380	385	390
5,20	196	197	198	199	200	204	202	203	204	206
	353	354	356	358	359	361	363	366	368	371
	361	363	367	370	374	378	382	387	391	397
5,30	200	201	201	202	203	208	206	207	208	210
	360	361	363	364	366	368	370	372	375	377
	367	370	373	377	380	384	389	393	398	403
5,40	203	204	205	206	207	212	209	211	212	213
	366	368	369	371	373	375	377	379	381	384
	374	377	380	383	387	391	395	400	405	410
5,50	207	208	209	210	211	216	213	214	216	217
	373	374	376	378	379	381	383	386	388	390
	380	383	386	390	394	398	402	406	411	416
5,60	211	212	213	213	214	220	217	218	219	221
	380	381	383	384	386	388	390	382	395	397
	387	390	393	397	400	404	409	413	418	423
5,70	215	215	216	217	218	225	220	222	223	224
	386	388	389	391	393	395	397	399	401	404
	394	397	400	403	407	411	415	420	425	430
5,80	218	219	220	221	222	229	224	225	227	228
	393	394	396	397	399	401	403	406	408	410
	400	403	406	410	414	418	422	426	431	436
5,90	222	223	224	225	226	233	228	229	230	232
	399	401	402	404	406	408	410	412	414	417
	407	410	413	416	420	424	428	433	438	443
6,00	226	226	227	228	229	237	231	233	234	235
	406	408	409	411	413	415	417	419	421	424
	414	417	420	423	427	431	435	440	444	450
6,10	229	230	231	232	233	241	235	236	238	239
	413	414	416	417	419	421	423	425	428	430
	420	423	426	430	433	437	442	446	451	456

Table C.2 *(continued)*

Brake torques for solid rotors [N m]										
∅ [mm]	Outer diameter									
***m* [kg]**	220	240	260	280	300	320	340	360	380	400
	233	234	235	236	237	245	239	240	241	243
6,20	419	421	422	424	426	428	430	432	434	437
	427	430	433	436	440	444	448	453	458	463
	237	237	238	239	240	250	243	244	245	246
6,30	426	427	429	431	432	434	437	439	441	444
	434	436	440	443	447	451	455	459	464	469
	240	241	242	243	244	254	246	247	249	250
6,40	433	434	436	437	439	441	443	445	448	450
	440	443	446	450	453	457	462	466	471	476
	244	245	246	247	248	258	250	251	252	254
6,50	439	441	442	444	446	448	450	452	454	457
	447	450	453	456	460	464	468	473	477	483
	248	249	249	250	251	262	254	255	256	257
6,60	446	447	449	451	452	454	456	459	461	463
	453	456	460	463	467	471	475	479	484	489
	251	252	253	254	255	267	257	258	260	261
6,70	453	454	456	457	459	461	463	465	468	470
	460	463	466	470	473	477	481	486	491	496
	255	256	257	258	259	271	261	262	263	265
6,80	459	461	462	464	466	468	470	472	474	477
	467	470	473	476	480	484	488	493	497	502
	259	260	260	261	262	275	265	266	267	269
6,90	466	467	469	471	472	474	476	479	481	483
	473	476	479	483	487	490	495	499	504	509
	263	263	264	265	266	279	268	270	271	272
7,00	473	474	476	477	479	481	483	485	488	490
	480	483	486	489	493	497	501	506	511	516
	266	267	268	269	270	284	272	273	275	276
7,10	479	481	482	484	486	488	490	492	494	497
	487	490	493	496	500	504	508	512	517	522
	270	271	272	272	273	288	276	277	278	280
7,20	486	487	489	490	492	494	496	498	501	503
	493	496	499	503	506	510	515	519	524	529
	274	274	275	276	277	292	279	281	282	283
7,30	492	494	495	497	499	501	503	505	507	510
	500	503	506	509	513	517	521	526	530	536
	277	278	279	280	281	296	283	284	286	287
7,40	499	501	502	504	506	507	510	512	514	517
	507	509	513	516	520	524	528	532	537	542
	281	282	283	284	285	301	287	288	289	291
7,50	506	507	509	510	512	514	516	518	521	523
	513	516	519	523	526	530	534	539	544	549
	285	285	286	287	288	305	290	292	293	294
7,60	512	514	515	517	519	521	523	525	527	530

Table C.2 *(continued)*

Brake torques for solid rotors [N m]										
∅ [mm]	Outer diameter									
***m* [kg]**	220	240	260	280	300	320	340	360	380	400
	520	523	526	529	533	537	541	546	550	555
	288	289	290	291	292	309	294	295	297	298
7,70	519	520	522	524	525	527	529	532	534	536
	527	529	533	536	540	544	548	552	557	562
	292	293	294	295	296	314	298	299	300	302
7,80	526	527	529	530	532	534	536	538	541	543
	533	536	539	543	546	550	554	559	564	569
	296	297	297	298	299	318	302	303	304	305
7,90	532	534	535	537	539	541	543	545	547	550
	540	543	546	549	553	557	561	565	570	575
	299	300	301	302	303	322	305	306	308	309
8,00	539	540	542	544	545	547	549	552	554	556
	546	549	552	556	560	563	568	572	577	582

C.3 Brake torques for internally vented rotors

Table C.3 — Brake torques for internally vented rotors

Brake torques for internally vented rotors [N m]										
∅ [mm]	Outer diameter									
***m* [kg]**	220	240	260	280	300	320	340	360	380	400
	193	195	196	198	200	202	195	207	210	198
5,00	347	350	353	357	360	364	369	373	378	357
	363	369	375	382	390	399	408	418	428	439
	197	198	200	202	204	206	198	211	214	202
5,10	354	357	360	363	367	371	375	380	385	364
	369	375	382	389	397	405	414	424	435	446
	200	202	204	206	208	210	202	215	217	206
5,20	361	363	367	370	374	378	382	387	391	371
	376	382	388	396	403	412	421	431	441	452
	204	206	207	209	211	214	206	218	221	210
5,30	367	370	373	377	380	384	389	393	398	377
	383	389	395	402	410	418	427	437	448	459
	208	209	211	213	215	217	209	222	225	213
5,40	374	377	380	383	387	391	395	400	405	384
	389	395	402	409	417	425	434	444	454	465
	211	213	215	217	219	221	213	226	229	217
5,50	380	383	386	390	394	398	402	406	411	390
	396	402	408	415	423	432	441	450	461	472
	215	217	218	220	222	225	217	229	232	221
5,60	387	390	393	397	400	404	409	413	418	397
	402	408	415	422	430	438	447	457	467	478
	219	220	222	224	226	228	220	233	236	224
5,70	394	397	400	403	407	411	415	420	425	404
	409	415	422	429	436	445	454	463	474	485

Table C.3 *(continued)*

Brake torques for internally vented rotors [N m]										
∅ [mm]	Outer diameter									
***m* [kg]**	220	240	260	280	300	320	340	360	380	400
	222	224	226	228	230	232	224	237	240	228
5,80	400	403	406	410	414	418	422	426	431	410
	416	422	428	435	443	451	460	470	480	491
	226	228	229	231	233	236	228	241	243	232
5,90	407	410	413	416	420	424	428	433	438	417
	422	428	435	442	450	458	467	477	487	498
	230	231	233	235	237	239	231	244	247	235
6,00	414	417	420	423	427	431	435	440	444	424
	429	435	441	448	456	464	473	483	493	504
	233	235	237	239	241	243	235	248	251	239
6,10	420	423	426	430	433	437	442	446	451	430
	436	442	448	455	463	471	480	490	500	511
	237	239	241	242	244	247	239	252	254	243
6,20	427	430	433	436	440	444	448	453	458	237
	442	448	455	462	469	478	487	496	506	517
	241	242	244	246	248	250	243	255	258	246
6,30	434	436	440	443	447	451	455	459	464	444
	449	455	461	468	476	484	493	503	513	524
	245	246	248	250	252	254	246	259	262	250
6,40	440	443	446	450	453	457	462	466	471	450
	455	461	468	475	483	491	500	509	520	530
	248	250	252	253	256	258	250	263	265	254
6,50	447	450	453	456	460	464	468	473	477	457
	462	468	475	482	489	497	506	516	526	537
	252	254	255	257	259	261	254	266	269	257
6,60	453	456	460	463	467	471	475	479	484	463
	469	475	481	488	496	504	513	522	533	544
	256	257	259	261	263	265	257	270	273	261
6,70	460	463	466	470	473	477	481	486	491	470
	475	481	488	495	502	511	520	529	539	550
	259	261	263	265	267	269	261	274	276	265
6,80	467	470	473	476	480	484	488	493	497	477
	482	488	494	501	509	517	526	536	546	557
	263	265	266	268	270	272	265	277	280	269
6,90	473	476	479	483	487	490	495	499	504	483
	489	495	501	508	516	524	533	542	552	563
	267	268	270	272	274	276	268	281	284	272
7,00	480	483	486	489	493	497	501	506	511	490
	495	501	508	515	522	530	539	549	559	570
	270	272	274	276	278	280	272	285	287	276
7,10	487	490	493	496	500	504	508	512	517	497
	502	508	514	521	529	537	546	555	565	576
	274	276	277	279	281	284	276	288	291	280
7,20	493	496	499	503	506	510	515	519	524	503