INTERNATIONAL STANDARD

ISO 26867

First edition
2009-07-01

Road vehicles — Brake lining friction materials — Friction behaviour assessment for automotive brake systems

Véhicules routiers — Matériaux de friction pour garnitures de freins — Évaluation du comportement au frottement pour les systèmes de freinage automobiles

Reference number
ISO 26867:2009(E)

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Published in Switzerland

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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.

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 26867 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 2, *Braking systems and equipment*.

Introduction

In the process of harmonizing automotive brake system applications, the modernization of friction behaviour characterization is a top priority. This International Standard is intended to replace previous friction evaluation test procedures based solely on drag brake applications, which do not take into account real-life driving conditions or vehicle specific parameters.

The varied conditions under which the friction material is evaluated ensures a wide spectrum of data, which is critical during the various phases of product life, such as product and manufacturing process development, production validation, quality control, product auditing and field issues evaluation.

This International Standard is intended to be used in conjunction with other applicable standards or test procedures (ISO, SAE, JIS/JASO, Federal Codes or Regulations, and other project or company-specific testing programmes) to fully assess the adequacy of a friction material for use in a certain application, market or vehicle platform. This International Standard does not include performance requirements related to stopping distance or braking force distribution, under different vehicle conditions of speed, temperature, tyre-to-road adhesion, loads and operating conditions of the braking system, as indicated in Federal Codes or Regulations.

This International Standard is intended as a friction evaluation inertia-dynamometer test procedure to replace previous test protocols that depend solely upon drag applications. This International Standard supports the friction assessment during the life cycle of a friction material.

Friction evaluation and characterization by performing drag applications, which were once a valid replacement for sample and scale testing, have now proven a limited approach. Drag applications do not correlate with real-world driving conditions, brake system characteristics or vehicle dynamics. The chemistry and structure of the transfer layers developed at the surface of the friction couple (friction lining and mating rotor or drum) and the resulting coefficient of friction varies as a function of changing characteristics, e.g. sliding speed, surface and bulk temperatures, braking pressure, braking energy and surface topology. During any given brake application, the braking energy varies as a result of the mass distribution and dynamic mass transfer on the vehicle. This is directly related to the vehicle's wheelbase, centre of gravity and vehicle height, which in itself can directly influence the friction material behaviour. The same brake lining or part number, when used on different vehicles, can perform differently depending upon its load, velocity, operating temperature, application force and work history. Modern testing equipment enables friction formulators, process designers, applications engineers and manufacturing personnel to obtain a wide and detailed characterization on the different levels of friction witnessed by the brake lining or pad during various brake conditions.

This International Standard is designed to evaluate the friction behaviour under a wide array of driving speeds, brake temperatures, brake pressure and deceleration levels. This new procedure provides the following benefits:

- a standard method for determining friction characteristics during early screening, benchmarking; development or production monitoring;
- the use of average by distance torque and pressure calculations;
- instantaneous friction statistics;
- an estimation of stopping distance using mean fully developed deceleration;
- controlled and recorded environmental conditions.

Road vehicles — Brake lining friction materials — Friction behaviour assessment for automotive brake systems

1 Scope

This International Standard describes a test procedure for assessing the influence of pressure, temperature, and linear speed on the coefficient of friction of a given friction material in combination with a specific mating component (rotor or drum).

This International Standard is intended for use when comparing friction materials under the same conditions, or when controlling friction behaviour against a specification or certain performance limits. In order to take into account the different types of dynamometer cooling systems and to ensure repeatable temperature increments, the brake temperature is the control item during the fade sections. The types of brakes and discs used will vary according to individual projects.

Production verification testing can use the results from this test in conjunction with a statistical process control system as part of a quality assurance plan. The specific project or programme will detail the applicable limits and assessment criteria.

This International Standard also allows for additional sections and brake applications that can prove useful during product development testing.

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

ISO 15484, *Road vehicles — Brake lining friction materials — Product definition and quality assurance*

UNECE Regulation No.13-H, *Uniform provisions concerning the approval of passenger cars with regard to braking*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 611, ISO 15484, UNECE Regulation No.13-H and the following apply.

3.1
friction value
μ
average by distance of all instantaneous friction values for disc brakes or for drum brakes after the brake reaches 95 % of the set point value (pressure or deceleration) until it falls below 95 % of the set point level

NOTE 1 For disc brakes, the friction value is obtained using Equation (1) (see definition 3.2).

NOTE 2 For drum brakes, the friction value is obtained using Equation (2) (see definition 3.3).

NOTE 3 The average by distance friction value from each individual brake application is the value referenced as “friction value” in Table 4.

3.2
instantaneous friction value
μ^*
⟨disc brake⟩ ratio of instantaneous output torque to instantaneous input torque at any specific point in time, calculated as follows:

$$\mu^* = \frac{10^5 \times M_{\mathrm{d,brake}}}{2 \times \left(p - p_{\mathrm{threshold}}\right) \times A_{\mathrm{p}} \times r_{\mathrm{eff}} \times \eta} \tag{1}$$

where

$M_{\mathrm{d,brake}}$ is the measured torque;

p is the applied pressure;

$p_{\mathrm{threshold}}$ is the threshold pressure or minimum pressure required to develop braking torque;

A_{p} is the piston area;

r_{eff} is the brake effective radius;

η is the efficiency

3.3
instantaneous effectiveness value
C^*
⟨drum brake⟩ ratio instantaneous output torque to instantaneous input torque at any specific point in time, calculated as follows:

$$C^* = \frac{10^5 \times M_{\mathrm{d,brake}}}{\left(p - p_{\mathrm{threshold}}\right) \times A_{\mathrm{p}} \times r_{\mathrm{eff}} \times \eta} \tag{2}$$

where

$M_{\mathrm{d,brake}}$ is the measured torque;

p is the applied pressure;

$p_{\mathrm{threshold}}$ is the threshold pressure or minimum pressure required to develop braking torque;

A_{p} is the piston area;

r_{eff} is the brake effective radius;

η is the efficiency

3.4
mean fully developed deceleration
d_{mfd}
deceleration calculated as follows:

$$d_{\mathrm{mfd}} = \frac{v_{\mathrm{b}}^2 - v_{\mathrm{e}}^2}{25{,}92 \times \left(s_{\mathrm{e}} - s_{\mathrm{b}}\right)} \tag{3}$$

where

v_e is the release speed;

v_b is the linear speed at $0,8v_p$;

v_p is the prescribed or braking speed for the brake application;

s_e is the calculated distance travelled between v_p and v_e;

s_b is the calculated distance travelled between v_p and v_b

NOTE Equation (3) applies only when the release speed v_e is lower than $0,5v_p$. The d_{mfd} calculation for brake applications with v_e higher than $0,5v_p$ provides a very short range of data to perform a useful calculation. For certain brake applications, $0,8v_p$ can be lower than the release speed.

3.5
step
sequence number to label the different **sections** (3.6) during the test and ensure the test is conducted in the prescribed order

3.6
section
group of similar brake applications under similar conditions or following a specific logic

NOTE 1 The brake applications can be **stops** (3.7) or **snubs** (3.8).

NOTE 2 The specific logic can be increasing brake pressure, increasing initial speed, or increasing brake temperature.

3.7
stop
brake stop
brake application where the brake slows down the test inertia until the equivalent linear speed is 0,5 km/h or less

3.8
snub
brake snub
brake application where the brake slows down the test inertia to an equivalent linear speed above 5 km/h

3.9
characteristic section
series of **brake snubs** (3.8) at moderate speed, brake pressure and temperature, in order to assess how the friction level changes as the test progresses

NOTE This involves green or new characteristic, stability checks after each burnish cycle, and immediately before or after **low speed/low pressure sections (3.6)**.

3.10
burnish section
series of **brake snubs** (3.8) at varying braking power in order to condition the friction couple and develop a steady coefficient of friction

NOTE Varying braking power involves changing deceleration at constant kinetic energy dissipation.

3.11
ramp application section
series of **brake stops** (3.7) where the brake pressure increases steadily and slowly, in order to assess the friction change with increasing input force

NOTE This is especially useful for drum brake systems.

3.12
low speed/low pressure section
series of **brake stops** (3.7) at low energy and low brake pressure

EXAMPLE In stop-and-go traffic or low speed manoeuvring.

3.13
pressure line section
series of **brake snubs** (3.8) at moderate energy in order to assess the effect on friction level as a function of increasing input brake pressure

3.14
speed line section
series of **brake snubs** (3.8) at constant input brake pressure and increasing speeds, and hence kinetic energy

3.15
failed booster section
series of **brake stops** (3.7) in order to assess the torque output while simulating a failed condition when the vacuum or hydraulic assist unit is fully depleted, and when only the driver input load at the brake pedal, brake pedal amplification and master cylinder multiplication factors are used to generate input pressure to the brake corner

3.16
motorway applications section
series of **brake snubs** (3.8) in order to assess the ability of the brake to develop torque at or near highway speeds

3.17
fade section
series of **brake stops** (3.7) intended to heat the brake and assess the coefficient of friction sensitivity to the increasing elevated temperatures on the surface of the mating couple

3.18
hot performance section
series of **brake snubs** (3.8) similar to the pressure line but at elevated temperatures, in order to simulate heavy braking or overloaded conditions

4 Symbols and abbreviated terms

4.1 Symbols

Symbol	Definition	Unit
A_{p}	Total piston area	mm^2
C^*	Instantaneous effectiveness value for drum brakes	—
d_{mfd}	Mean fully developed deceleration when $v_{\mathrm{e}} > 0{,}5 v_{\mathrm{p}}$ [a]	m/s^2
F	Test wheel load	N [b]
$F_{\mathrm{f,dyn}}$	Test wheel load for front brakes at m_{GV}	N [b]
$F_{\mathrm{r,dyn}}$	Test wheel load for rear brakes at m_{GV}	N [b]
$F_{\mathrm{r,static}}$	Static axle load on the rear axle at m_{GV}	N [b]
H	Centre of gravity height	m
I	Test inertia reflected at the brake	$kg \cdot m^2$

L	Vehicle wheel base	m
m_{GV}	Gross vehicle mass	kg
M_d	Brake torque at 1,0 g deceleration	N·m
$M_{d,brake}$	Measured torque	N·m
N	Brake application number during the fade section	—
p	Applied pressure	kPa
p_{max}	Maximum hydraulic pressure	kPa
$p_{threshold}$	Threshold pressure or minimum pressure required to develop braking torque	kPa
$p_{500,nopower}$	Pressure at 500 N pedal force with no power assist for FMVSS 135 vehicles	kPa
$p_{667,nopower}$	Pressure at 667 N pedal force with no power assist for FMVSS 105 vehicles	kPa
r_{eff}	Brake effective radius	mm
R	Dynamic tyre effective rolling radius	m
s_b	Calculated distance travelled between v_p and v_b	m
s_e	Calculated distance travelled between v_p and v_e	m
s_{norm}	Normalized stopping distance [c]	m
T_{max}	Maximum temperature for fade sections [d]	°C
$T_{start,N}$	Starting temperature for the Nth brake application during the fade section	°C
$T_{start,1}$	Starting temperature for the first brake application during the fade section	°C
$T_{start,15}$	Starting temperature for the fifteenth brake application during the fade section	°C
v_b	Linear speed at $0,8v_p$	km/h
v_e	Linear speed at $0,1v_p$ for stops or release speed for brake snubs	km/h
v_{max}	Vehicle maximum rated speed	km/h
v_p	Prescribed or braking speed for the brake application	km/h
z	Deceleration	m/s^2
μ	Average by distance friction value for disc brakes	—
μ^*	Instantaneous friction value for disc brakes	—
η	Brake efficiency	%

[a] In accordance with UNECE Regulation No.13-H.

[b] 9,806 65 = 1 kgf. The use of the unit kgf is deprecated.

[c] Using FMVSS 135 and UNECE Regulation No.13-H nominal values.

[d] If different from nominal.

4.2 Abbreviated terms

ABS antilock braking system

DTV disc thickness variation

ESP electronic stability programme

FMVSS Federal Motor Vehicle Safety Standard

LRO lateral run-out

NVH noise, vibration and harshness

OE original equipment

UNECE United Nations Economic Commission for Europe

VSC vehicle stability control

5 Test conditions and preparation

5.1 Inertia for the front axle

The inertia for the front axle shall be calculated using 75 % of half the gross vehicle mass, unless otherwise specified for the project and the tyre rolling radius.

5.2 Inertia for the rear axle

The inertia for the rear axle shall be calculated using 25 % of half the gross vehicle mass, unless otherwise specified for the project and the tyre rolling radius.

5.3 Test wheel load

When vehicle parameters are available for the project, the test wheel load can also be calculated according to Equation (4) for front brakes or Equation (5) for rear brakes. Wheel load shall take into account static loading and dynamic mass transfer at a vehicle deceleration of 0,3 g.

$$F_{\mathrm{f,dyn}} = \left(1 - \frac{F_{\mathrm{r,static}}}{m_{\mathrm{GV}}} + \frac{H}{L} z\right) \times \frac{m_{\mathrm{GV}}}{2} \quad (4)$$

$$F_{\mathrm{r,dyn}} = \left(1 - \frac{F_{\mathrm{r,static}}}{m_{\mathrm{GV}}} - \frac{H}{L} z\right) \times \frac{m_{\mathrm{GV}}}{2} \quad (5)$$

5.4 Pressure ramp rate

The pressure ramp rate shall be (25 000 ± 5 000) kPa/s for all brake applications.

5.5 Maximum pressure

The maximum pressure applied to the brake can be lower than that specified in this International Standard in order to accommodate specific brake configurations or brake system design parameters.

5.6 Pressure level with no power assist

If vehicle-specific data is available, pressure shall be used that is equivalent to the maximum allowable pedal force with the power assist unit fully depleted:

— for vehicles certified under FMVSS 105, the maximum allowable pedal force is 667 N;

— for vehicles certified under FMVSS 135, the maximum allowable pedal force is 500 N.

5.7 Sampling rate

The sampling rate shall be at least 100 Hz for pressure and torque.

5.8 Initial brake temperature

The initial brake temperature shall be the real-time temperature on the rotor or drum at the start of the brake application.

5.9 Brake warm-up

When the rotor or drum temperature is below the initial temperature required for the brake application, the brake shall be dragged at the braking speed of the intended brake event without exceeding 80 km/h at 2 m/s^2 equivalent torque for 20 s.

Alternatively, brake applications of the intended brake event shall be performed to raise the temperature.

5.10 Temperature measurement

One thermocouple shall be positioned at the centre of the friction path (0,5 ± 0,1) mm deep in the outer face of the disc or drum contact face. The initial brake temperature shall be measured using the disc or drum thermocouple. Additional thermocouple(s) can be set in the friction material for temperature recording purposes.

5.11 Brake fluid displacement measurement

Fluid displacement of the brake during all brake application shall be recorded and reported at the end of the test.

5.12 Cooling air conditions

For steps 13, 14 and 18 (see Tables 2 and 3), the cooling air speed shall be set to 1 m/s or the equivalent air volume. If the dynamometer has exhaust cooling air capabilities, it shall be kept running during the entire test. For all other sections, the cooling air speed may be adjusted depending upon the brake being tested or the dynamometer being used, in order to maintain the efficiency of the test.

5.13 Cooling air velocity or volume

The cooling air velocity or volume shall be specified in m/s or m^3/h, as measured in the duct. The duct outlet shall be nominally 300 mm to 400 mm away from the test hardware. For more details for determining the approximate relationship between air volume, air speed, duct size and duct outlet distance to the brake, see Annex C.

5.14 Conditioning settings for temperature and absolute humidity (humidity ratio)

The cooling air conditioning for temperature and absolute humidity shall be reported as the average of all brake events taken at the start of the brake application. The nominal cooling air temperature is (20 ± 5) °C and absolute humidity 7,29 g/kg (8,68 g/m^3) measured at sea level. The appropriate psychrometric chart shall be used to find operating limits at temperatures other than 20 °C, or elevations other than sea level.

NOTE Nominal cooling air conditions are equivalent to (20 ± 5) °C and (50 ± 10) % relative humidity.

5.15 Dynamometer rotational speed between brake applications

The dynamometer rotational speed during cooling between brake event shall be equal to 50 % of the braking speed for the next brake application, except for steps 13, 14, and 18 (see Tables 2 and 3), where it can be equal to the braking speed for the next brake application in order to minimize warm-up brake applications. Alternatively, 10 km/h is applicable for European programmes.

5.16 Orientation of brake set-up

The fixture shall be mounted as close as possible to the vehicle position. In general, this helps correlation with issues such as brake drag, off-brake wear, off-brake disc thickness variation (DTV), system stiffness and noise, vibration and harshness (NVH) assessment.

5.17 Direction of air concerning brake set-up

The air flow inlet shall be documented regarding direction (vertical or horizontal) and orientation (from forward, rear, top or bottom).

5.18 Brake cooling rate

The brake cooling rate should be recorded and reported as the cooling time, in seconds

— from 500 °C to 200 °C for disc brakes, and

— from 300 °C to 100 °C for drum brakes.

This evaluation shall be performed immediately following the hot performance 500 °C/300 °C section (see step 14, Tables 2 and 3).

5.19 Wear measurement

The initial and final rotor and lining thickness and mass shall be measured and recorded.

5.20 Lateral run-out

Initial lateral run-out (LRO) shall be set to 50 µm or less when measured 10 mm from the outer diameter on the outboard side of the rotor for disc brakes.

5.21 Rotor or drum condition

The brake rotor or drum to be used for the test shall be new and original equipment (OE) level. For production monitoring testing, the rotor can be re-used following the instructions from the test requestor.

5.22 Fade sections

Fade sections are controlled by deceleration and brake initial temperature. The braking torque is determined by the vehicle mass, the braking force distribution, the tyre rolling radius and the specified deceleration (see Table 1).

Table 1 — Initial temperature for fade (1) and fade (2) sections

Stop	Initial temperature for disc brake °C	Initial temperature for drum brake °C
1	150	100
2	252	151
3	312	181
4	355	202
5	388	219
6	415	232
7	437	244
8	457	254
9	475	262
10	490	270
11	504	277
12	517	284
13	529	289
14	540	295
15	550	300

The starting temperatures are calculated using Equation (6).

$$T_{\text{start},N} = \frac{T_{\text{start},15} - T_{\text{start},1}}{\ln(15)} \ln(N) + T_{\text{start},1} \tag{6}$$

where

$T_{\text{start},N}$ is the starting temperature for the Nth brake application;

$T_{\text{start},1}$ is the starting temperature for the first brake application;

$T_{\text{start},15}$ is the starting temperature for the fifteenth brake application;

N is the brake application number.

If the initial temperatures cannot be reached during the fade (1), hot performance 500 °C/300 °C, or fade (2) sections, brake warm-up applications shall be performed in accordance with 5.9. However, only the temperatures described in the programme shall be collected for test report purposes. If initial temperatures are not reached in steps 13 or 18 (see Tables 2 and 3), the temperature levels can be the final temperature of the previous stop or defined specifically for the project. Special attention should be paid in the case of drum brake applications.

5.23 Data collection

The inertia-dynamometer data collection system shall be configured to collect automatically and in real-time the following values:

a) time;

b) shaft rotational speed;

c) hydraulic pressure;

d) brake torque;

e) brake rotor/drum temperature;

f) friction material temperature;

g) brake fluid displacement;

h) cooling air temperature;

i) cooling air speed or airflow;

j) cooling air absolute humidity;

k) means to identify the specific section and brake application.

6 Test procedures

6.1 Test procedure for product monitoring with no optional brake applications

Table 2 outlines the test procedure for product monitoring with no optional brake applications.

Table 2 — Product monitoring test procedure

Step	Section	Number of stops or snubs	Braking speed km/h	Release speed km/h	Brake application control	Initial rotor/drum temperature °C
1	Green μ characteristic	10	80	30	3 000 kPa	First at ambient temperature, then $\leqslant$ 150 with no warm-ups
2	Burnish [a]	32	80	30	0,17 g; 0,35 g; 0,17 g; 0,20 g; 0,25 g; 0,42 g; 0,17 g; 0,30 g; 0,20 g; 0,37 g; 0,17 g; 0,30 g; 0,17 g; 0,25 g; 0,35 g; 0,50 g; 0,30 g; 0,57 g; 0,25 g; 0,20 g; 0,47 g; 0,17 g; 0,20 g; 0,50 g; 0,30 g; 0,17 g; 0,37 g; 0,25 g; 0,20 g; 0,25 g; 0,20 g; 0,42 g	200
3	Characteristic value (stability check) [a]	5	80	30	3 000 kPa	150
4	Ramp applications	2	50	0,5	2 800 kPa at 700 kPa/s	100
5	(Cold) characteristic section	1	40	0,5	3 000 kPa	40
		5	80	30	3 000 kPa	150
6	Low speed/ low pressure (1)	3	20	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
		3	30	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
7	Pressure line (1)	6	80	40	1 000 kPa to 6 000 kPa in 1 000 kPa increments	150
8	Speed line (1)	5	80	40	3 000 kPa	150
			120	80		
			160	130		
			180	150		
			200	170		

Table 2 (*continued*)

Step	Section	Number of stops or snubs	Braking speed km/h	Release speed km/h	Brake application control	Initial rotor/drum temperature °C
9	Failed booster	1	100	0,5	2 800 kPa or vehicle specific	65
		5	100	0,5	2 800 kPa or vehicle specific	100
10	Motorway applications	1	100	0,5	0,60 g	150
		1	90 % v_{max}	50 % v_{max}	0,30 g	150
11	Low speed/ low pressure (2)	3	20	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
		3	30	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
12	Characteristic/ recovery (1)	10	80	30	3 000 kPa	150
13	Fade (1)	15	100	0,5	0,40 g	150 to 550 for disc; 100 to 300 for drum [b]
14	Hot performance 500 °C/300 °C	6	80	40	1 000 kPa to 6 000 kPa in 1 000 kPa increments	500 for disc; 300 for drum
15	Low speed/ low pressure (3)	3	20	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
		3	30	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
16	Characteristic/ recovery (2)	10	80	30	3 000 kPa	150
17	Pressure line (2)	6	80	40	1 000 kPa to 6 000 kPa in 1 000 kPa increments	150
18	Fade (2)	15	100	0,5	0,40 g	150 to 550 for disc; 100 to 300 for drum [b]
19	Low speed/ low pressure (4)	3	20	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
		3	30	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
20	Final characteristic	5	80	30	3 000 kPa	150
End of the test		Measure lining and rotor wear in mass and thickness loss; inspect brake components, and prepare test report				

[a] If average by distance torque variation from snub 3 to 5 is higher than 5 %, run an additional burnish cycle section and characteristic value (stability check). The total number of repeats should be defined for the project. Use six cycles as default.

[b] Refer to Table 1.

6.2 Test procedure for product development with additional brake applications

Table 3 outlines the test procedure for product development with additional brake applications.

NOTE Test conditions for additional brake applications used during development testing are indicated by a footnote.

Table 3 — Product development test procedure

<table>
<tr><th>Step</th><th>Section</th><th>Number of stops or snubs</th><th>Braking speed
km/h</th><th>Release speed
km/h</th><th>Brake application control</th><th>Initial rotor/drum temperature
°C</th></tr>
<tr><td>1</td><td>Green μ characteristic</td><td>10</td><td>80</td><td>30</td><td>3 000 kPa</td><td>First at ambient temperature, then $\leqslant$ 150 with no warm-ups</td></tr>
<tr><td>2</td><td>Burnish [a]</td><td>32</td><td>80</td><td>30</td><td>0,17 g; 0,35 g; 0,17 g; 0,20 g; 0,25 g; 0,42 g; 0,17 g; 0,30 g; 0,20 g; 0,37 g; 0,17 g; 0,30 g; 0,17 g; 0,25 g; 0,35 g; 0,50 g; 0,30 g; 0,57 g; 0,25 g; 0,20 g; 0,47 g; 0,17 g; 0,20 g; 0,50 g; 0,30 g; 0,17 g; 0,37 g; 0,25 g; 0,20 g; 0,25 g; 0,20 g; 0,42 g</td><td>200</td></tr>
<tr><td>3</td><td>Characteristic value (stability check) [a]</td><td>5</td><td>80</td><td>30</td><td>3 000 kPa</td><td>150</td></tr>
<tr><td>4</td><td>Ramp applications</td><td>2</td><td>50</td><td>0,5</td><td>2 800 kPa at 700 kPa/s</td><td>100</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">(Cold) characteristic section</td><td>1</td><td>40</td><td>0,5</td><td>3 000 kPa</td><td>40</td></tr>
<tr><td>5</td><td>80</td><td>30</td><td>3 000 kPa</td><td>150</td></tr>
<tr><td rowspan="4">6</td><td rowspan="4">Low speed/
low pressure (1)</td><td>4 disc</td><td rowspan="2">20</td><td rowspan="2">0,5</td><td>500 kPa [b], 1 000 kPa, 2 000 kPa, 3 000 kPa for disc</td><td rowspan="2">150</td></tr>
<tr><td>3 drum</td><td>2 000 kPa, 3 000 kPa, 4 000 kPa for drum</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">30</td><td rowspan="2">0,5</td><td>1 000 kPa, 2 000 kPa, 3 000 kPa for disc</td><td rowspan="2">150</td></tr>
<tr><td>2 000 kPa, 3 000 kPa, 4 000 kPa for drum</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Pressure line (1)</td><td rowspan="2">9</td><td rowspan="2">80</td><td rowspan="2">40</td><td>1 000 kPa to 6 000 kPa in 1 000 kPa increments</td><td rowspan="2">150</td></tr>
<tr><td>8 000 kPa [b], 10 000 kPa [b], 12 000 kPa [b]</td></tr>
<tr><td rowspan="10">8</td><td rowspan="10">Speed line (1)</td><td rowspan="10">10</td><td>80</td><td>40</td><td rowspan="5">3 000 kPa</td><td rowspan="5">150</td></tr>
<tr><td>120</td><td>80</td></tr>
<tr><td>160</td><td>130</td></tr>
<tr><td>180</td><td>150</td></tr>
<tr><td>200</td><td>170</td></tr>
<tr><td>80 [b]</td><td>40 [b]</td><td rowspan="5">8 000 kPa [b]</td><td rowspan="5">150 [b]</td></tr>
<tr><td>120 [b]</td><td>80 [b]</td></tr>
<tr><td>160 [b]</td><td>130 [b]</td></tr>
<tr><td>180 [b]</td><td>150 [b]</td></tr>
<tr><td>200 [b]</td><td>170 [b]</td></tr>
<tr><td rowspan="2">9</td><td rowspan="2">Failed booster</td><td>1</td><td>100</td><td>0,5</td><td>2 800 kPa or vehicle specific</td><td>65</td></tr>
<tr><td>5</td><td>100</td><td>0,5</td><td>2 800 kPa or vehicle specific</td><td>100</td></tr>
</table>

Table 3 (*continued*)

Step	Section	Number of stops or snubs	Braking speed km/h	Release speed km/h	Brake application control	Initial rotor/drum temperature °C
10	Motorway applications	1	100	0,5	0,60 g	150
		1	90 % v_{max}	50 % v_{max}	0,60 g	150
11	Low speed/ low pressure (2)	4 disc	20	0,5	500 kPa [b], 1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
		3 drum			2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
		3	30	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
12	Characteristic/ recovery (1)	10	80	30	3 000 kPa	150
13	Fade (1)	15	100	0,5	0,40 g	150 to 550 for disc; 100 to 300 for drum [c]
14	Hot performance 500 °C/300 °C	9	80	40	1 000 kPa to 6 000 kPa in 1 000 kPa increments	500 for disc; 300 for drum
					8 000 kPa [b], 10 000 kPa [b], 12 000 kPa [b]	
15	Low speed/ low pressure (3)	4 disc	20	0,5	500 kPa [b], 1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
		3 drum			2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
		3	30	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
16	Characteristic/ recovery (2)	10	80	30	3 000 kPa	150
17	Pressure line (2)	9	80	40	1 000 kPa to 6 000 kPa in 1 000 kPa increments	150
					8 000 kPa [b], 10 000 kPa [b], 12 000 kPa [b]	
18	Fade (2)	15	100	0,5	0,40 g	150 to 550 for disc; 100 to 300 for drum [c]
19	Low speed/ low pressure (4)	4 disc	20	0,5	500 kPa [b], 1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
		3 drum			2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
		3	30	0,5	1 000 kPa, 2 000 kPa, 3 000 kPa for disc	150
					2 000 kPa, 3 000 kPa, 4 000 kPa for drum	
20	Final characteristic	5	80	30	3 000 kPa	150
End of the test		Measure lining and rotor wear in mass and thickness loss; inspect brake components, and prepare test report				

[a] If average by distance torque variation from snub 3 to 5 is higher than 5 %, run an additional burnish cycle section and characteristic value (stability check). The total number of repeats should be defined for the project. Use six cycles as default.

[b] Test conditions for additional brake applications used during development testing.

[c] Refer to Table 1.

6.3 Standard friction values calculated during test procedure

Table 4 lists the standard friction values calculated in the course of the test procedure (see Tables 2 and 3).

For the purposes of Table 4, the friction value, μ, corresponds to the average by distance friction value from each individual brake application, as specified in definition 3.1.

Table 4 — Standard friction values calculated during test procedure

Value	Calculation method
test average μ value	Average friction value from all brake applications from steps 3, 5 (last five snubs), 7, 8, 12, 16, 17 and 20, without optional brake applications.
test minimum μ values	Lowest friction values from steps 3, 5 (last five snubs), 7, 8, 12, 16, 17 and 20, without including optional brake applications.
test maximum μ values	Highest friction values from steps 3, 5 (last five snubs), 7, 8, 12, 16, 17 and 20, without including optional brake applications.
characteristic/stability check μ values	Average and minimum friction values from last three brake applications from step 3.
ramp applications μ values	Average and minimum friction values from the two brake applications from step 4.
cold characteristic μ value	Friction value from first brake application from step 5.
stability during cold characteristic μ values	Average and minimum friction values from last three brake applications from step 5.
low speed/low pressure (1) μ values	Average and minimum friction values from all brake applications from step 6.
pressure line (1) μ value at 6 000 kPa	Friction value from brake application at 6 000 kPa from step 7.
high speed μ values	Friction values from last brake application from step 8, without including optional brake applications.
normalized stopping distance during FMVSS 135 failed booster [a]	Normalized stopping distance from step 9 (stops 1 and 6).
$0{,}9v_{max}$ motorway μ value	Friction value from last brake application from step 10.
low speed/low pressure (2) μ values	Average and minimum friction values from all brake applications from step 11.
characteristic/recovery (1) μ values	Average and minimum friction values from last three brake applications from step 12.
fade (1) minimum μ value	Minimum friction value from step 13.
hot performance μ value	Minimum friction value from last five brake applications from step 14.
low speed/low pressure (3) μ values	Average and minimum friction values from all brake applications from step 15.
characteristic/recovery (2) μ values	Average and minimum friction values from last three brake applications from step 16.
pressure line (2) μ values at 6 000 kPa	Friction values from brake application at 6 000 kPa from step 17.
fade (2) minimum μ value	Minimum friction value from step 18.
low speed/low pressure (4) μ values	Average and minimum friction values from all brake applications from step 19.
final characteristic μ values	Average and minimum friction values from last three brake applications from step 20.

[a] The equation below provides an alternative method of estimating stopping distance ability using the brake torque output from the friction material tested. This equation is normalized for the allowable reaction and pressure build-up time based on best driver effort, and a test speed from 100 km/h to 0 km/h from the federal code FMVSS 135.

$$s_{norm} = 10 + \frac{386{,}7}{d_{mfd}}$$

7 Test report

7.1 General

The test report graphs and tabular data can use previous test report layouts or have a layout specific to the project (see Annex A).

7.2 Graphical report

The following items shall be presented in graphical format for the entire test:

a) instantaneous pressure, brake temperature and friction for meaningful brake applications: applicable or reference friction value can be included on the corresponding graph;

b) marker for average by distance friction value;

c) histogram and cumulative frequency curve indicating the in-stop friction for the entire data collection range including all sections except the green effectiveness and the burnish: use 0,02 as the recommended frequency class size (see Annex B);

d) histogram and cumulative frequency curve indicating the in-stop friction for the entire data collection range including only the low speed/low pressure sections: use 0,02 as the recommended frequency class size (see Annex B).

7.3 Tabular data for each brake application

The following items shall be presented in tabular format for the entire test and for each brake application, unless otherwise specified for the project:

a) braking and release speed;

b) average by distance, maximum and minimum values for friction, torque and pressure;

c) initial and final brake temperature at the rotor and brake linings (optional);

d) maximum fluid displacement;

e) d_{mfd} (when applicable) and calculated stopping distance for failed booster section;

f) cooling air temperature and humidity.

7.4 Wear measurements

The wear measurements are the rotor or drum and lining loss in thickness and mass. Any cracks, detachment, delaminating or any unusual condition on the rotor or lining shall be recorded and reported.

7.5 Test conditions

Brake parameters, test inertia, rolling radius, brake hand, rotor and lining identification, test conditions and total test run-time shall be recorded and reported.

7.6 Cooling air conditions

The cooling air direction and orientation shall be recorded and reported.

7.7 Brake cooling rate

The following brake cooling times after the hot performance section shall be recorded and reported:

- from 500 °C to 200 °C for disc brakes;
- from 300 °C to 100 °C for drum brakes.

7.8 Friction values

Calculate and report standard friction values in accordance with Table 4. These friction values shall not include the optional brake applications used during development testing.

7.9 Statistical analysis

Depending upon the project or customer request, statistical friction evaluation shall be added to the test report. This may include several distribution and statistical parameters (see Annex A).

When the statistical analysis includes the optional brake application used during development testing, this shall be indicated specifically on the test report, together with the calculations influenced by the values.

Annex A
(informative)

Sample report for disc brakes

Figures A.1 to A.3 provide a sample report for disc brakes.

When preparing the graphical summaries, the following should be noted:

— **general**: for each section, plot the instantaneous values for friction, temperature, pressure and fluid displacement in accordance with 7.1 and 7.2;

— **constant deceleration or pressure sections**: plot the instantaneous values against the stop or snub number;

— **burnish section**: plot snubs 2, 15 and 30;

— **average by distance friction marker**: include a marker for the average by distance friction for all the stops or snubs plotted.

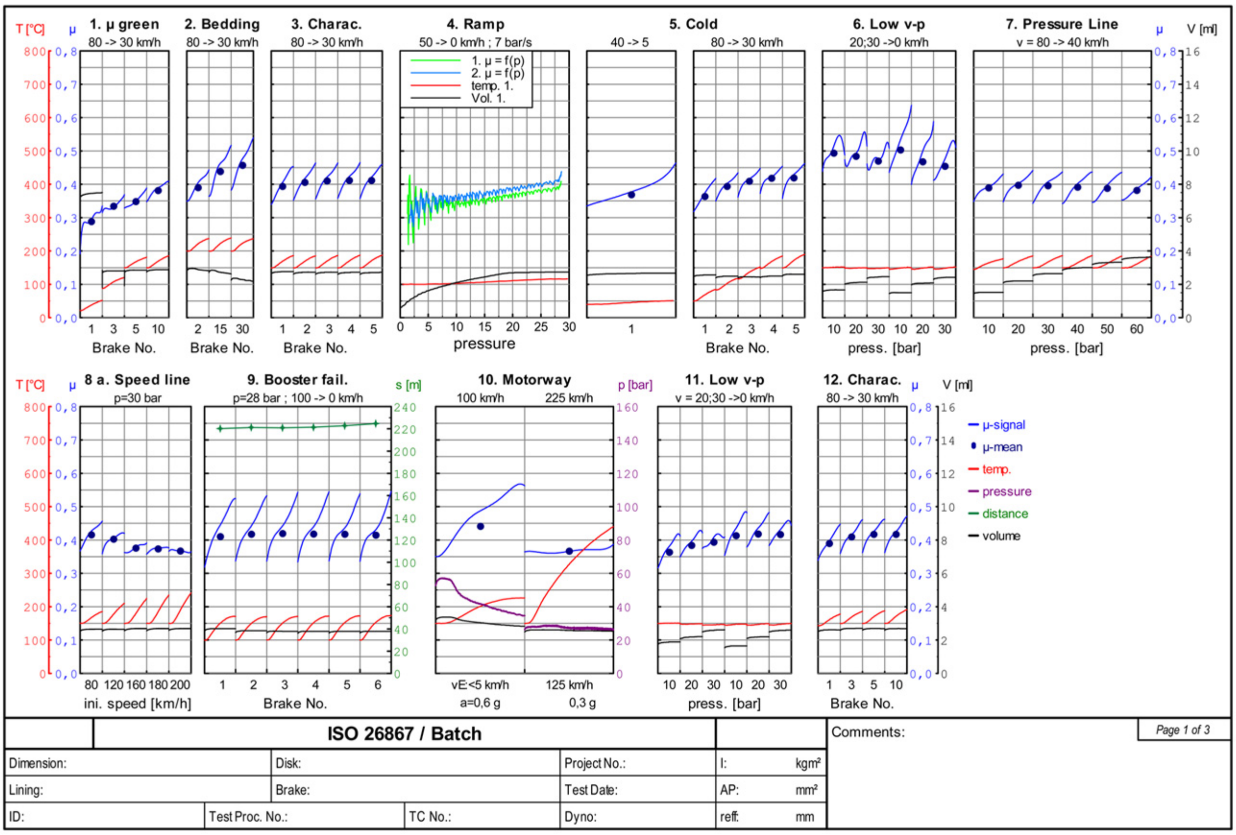
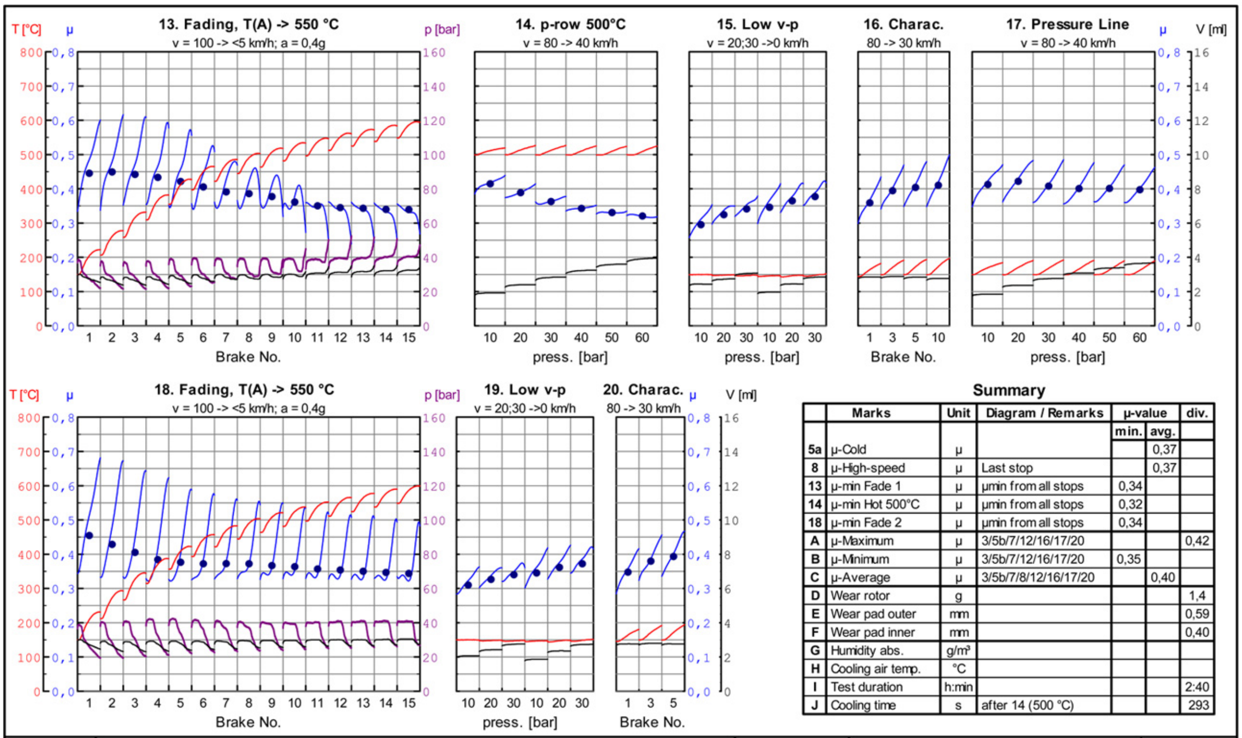


Figure A.1 — Graphical report for product monitoring of disc brakes (page 1 of 3)



Summary

	Marks	Unit	Diagram / Remarks	μ-value		div.
				min.	avg.	
5a	μ-Cold	μ			0,37	
8	μ-High-speed	μ	Last stop		0,37	
13	μ-min Fade 1	μ	μmin from all stops	0,34		
14	μ-min Hot 500°C	μ	μmin from all stops	0,32		
18	μ-min Fade 2	μ	μmin from all stops	0,34		
A	μ-Maximum	μ	3/5b/7/12/16/17/20			0,42
B	μ-Minimum	μ	3/5b/7/12/16/17/20	0,35		
C	μ-Average	μ	3/5b/7/8/12/16/17/20		0,40	
D	Wear rotor	g				1,4
E	Wear pad outer	mm				0,59
F	Wear pad inner	mm				0,40
G	Humidity abs.	g/m³				
H	Cooling air temp.	°C				
I	Test duration	h:min				2:40
J	Cooling time	s	after 14 (500 °C)			293

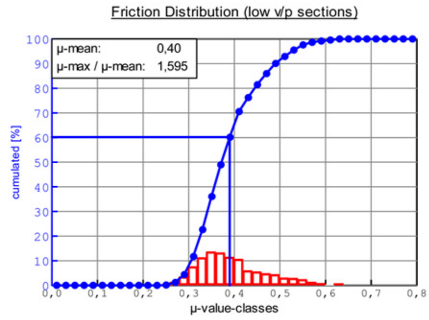
ISO 26867 / Batch				Page 2 of 3
Dimension:	Disk:	Project No.:	I: kgm²	
Lining:	Brake:	Test Date:	AP: mm²	
ID: Test Proc. No.:	TC No.:	Dyno:	reff: mm	

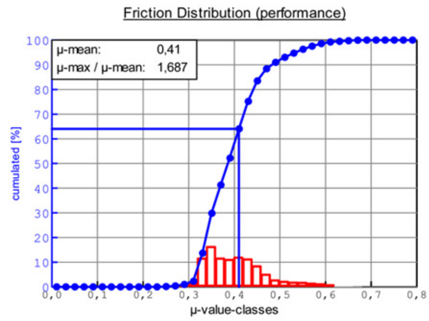
Figure A.2 — Graphical report for product monitoring of disc brakes (page 2 of 3)

Summary & Statistics

	Marks	Unit	Diagram / Remarks		μ-value min.	μ-value avg.	div.
3	μ-Charact. / Stabil.	μ	μ average:	Last 3 stops	0,41	0,41	
4	Ramp Application						
5a	μ-Cold	μ				0,37	
5b	μ-Cold / Stabil.	μ	μ average:	Last 3 stops	0,41	0,42	
6	Low-Speed/Low-Pressure	μ			0,45	0,48	
7	μ-Press. 60 bar / Stabil.	μ		60 bar stop		0,38	
8	μ-High-Speed / Last Stop	μ				0,37	
9.1	μ-Booster Fail. 1st Stop	m	Stopping distance:	First stop			220,29
9.6	μ-Booster Fail. 6th Stop	m	Stopping distance:	Last stop			224,73
10	μ-Motorway 0.9xVmax	μ		Second stop		0,37	
11	Low-Speed/Low-Pressure	μ			0,36	0,40	
12	μ-Charact. / Stabil.	μ	μ average:	Last 3 stops	0,42	0,42	
13	μmin Fade 1	μ	μ minimum:	From all stops	0,34		
14	μmin Hot 500 °C	μ	μ minimum:	From all (except 10 bar)	0,32		
15	Low-Speed/Low-Pressure	μ			0,30	0,34	
16	μ-Charact. / Stabil.	μ	μ average:	Last 3 stops	0,41	0,41	
17	μ-Press. 60 bar / Stabil.	μ		60 bar stop		0,40	
18	μmin Fade 2	μ	μ minimum:	From all stops	0,34		
19	Low-Speed/Low-Pressure	μ			0,31	0,34	
20	μ-Charact. / Stabil.	μ	μ average:	Last 3 stops	0,38	0,39	
A	μ-Maximum	μ		3/5b/7/12/16/17/20			0,42
B	μ-Minimum	μ		3/5b/7/12/16/17/20	0,35		
C	μ-Average	μ		3/5b/7/8/12/16/17/20		0,40	
E	Wear pad outer	mm					0,59
F	Wear pad inner	mm					0,40
G	Humidity absolute	g/m³					
H	Cooling air temperature	°C					
I	Test duration	h:min					2:40

Figures in red are for batch control.





	ISO 26867 / Batch			Page 3 of 3
Dimension:	Disk:	Project No.:	I: kgm²	
Lining:	Brake:	Test Date:	AP: mm²	
ID: Test Proc. No.:	TC No.:	Dyno:	reff. mm	

Figure A.3 — Extended test report and statistical analysis for disc brakes (page 3 of 3)

Annex B
(informative)

Histograms for instantaneous friction values

See 7.2.

The use of histograms is a valuable tool to assess the instantaneous friction level spread and distribution. These friction attributes are of significance for an automotive engineer when assessing or predicting the performance of modern brake control systems such as ABS, ESP, VSC and the general behaviour of the material. A change of the instantaneous behaviour could also indicate to a manufacturing or brake engineer a change of the friction material caused by raw materials or process changes.

Unless specifically indicated on the test report, the histograms for instantaneous friction values shall not include the optional brake applications used during development testing.

To develop the instantaneous friction histograms and frequency distribution plots, follow the basic steps outlined below (see Figure B.1).

a) For each brake application, generate a file including the instantaneous friction values.

b) Start the file for each brake application after the control parameter (pressure or deceleration) reaches 95 % of the set point.

c) End the file for each brake application after the control parameter (pressure or deceleration) falls below 95 % of the set point.

d) Separate the brake applications into two groups for the following sections:

   1) Friction distribution (all sections without 1 and 2):

      i) characteristic value (stability check);

      ii) ramp applications;

      iii) (cold) characteristic;

      iv) pressure line (1);

      v) speed line (1);

      vi) failed booster;

      vii) motorway applications;

      viii) characteristic/recovery (1);

      ix) fade (1);

      x) hot performance, 500 °C/300 °C;

      xi) characteristic/recovery (2);

      xii) pressure line (2), fade (2);

      xiii) final characteristic.

2) Friction distribution (low speed/pressure sections):

i) low speed/low pressure (1);

ii) low speed/low pressure (2);

iii) low speed/low pressure (3);

iv) low speed/low pressure (4).

e) Generate a histogram for each group indicated above.

f) Use a frequency class size of 0,02.

g) Include the cumulative frequency distribution line.

h) Include frequency distribution and statistical parameters as required by the project.

i) Include lines indicating acceptance or minimum levels for friction level, average values, upper or lower limits or spread parameters such as standard deviation, as required by the project.

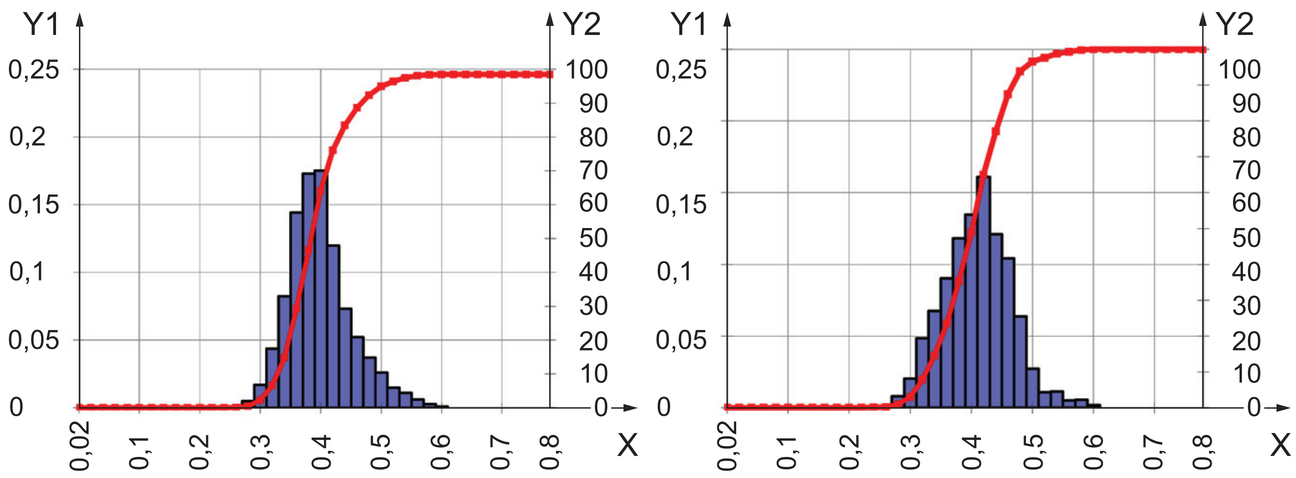
j) If no limits are specified by the test requestor, indicate the friction range for 80 % of the applications (using Figure B.1 a) as an example):

1) 80 % friction range is between 0,35 and 0,49;

2) 10 percentile is 0,35; this means that 10 % of all the instantaneous friction values are 0,35 or less;

3) 50 percentile is 0,41; this means that 50 % of the instantaneous friction values are below 0,41;

4) 90 percentile is 0,49; this means that 10 % of the instantaneous friction values are 0,49 or higher.



a) No limits specified

b) Low speed/pressure

Key

X friction distribution

Y_1 individual frequency

Y_2 cumulative frequency

Figure B.1 — Example of histograms and frequency distribution for instantaneous friction values

Annex C
(informative)

Reference calculations for cooling air speed and flow

C.1 General

See 5.13.

Equations (C.1) to (C.3) are used to estimate cooling air speed or airflow in front of the brake. These calculations apply, in general, under the following conditions:

— cooling air speed of 8 m/s or less;

— airflow of approximately 5 000 m^3/h or less in front of the brake;

— cooling air at mild temperature;

— brake enclosures with a length along the airflow of approximately 2 to 2,5 times the equivalent diameter of a rectangular duct;

— brake enclosures with a cross section area at the brake approximately 1 to 1,2 times the air duct area;

— brake corner mounted inside the brake enclosure with proper sealing to control air leaks.

When specific or actual calculations are required, specific technical literature needs to be consulted for air handling and high volume air conditioning, along with the detailed dimensional layout of the cooling air system installed on the dynamometer.

C.2 Conversion between airflow and cooling air speed

Equation (C.1) uses the equivalent diameter of a circular duct that gives the same pressure loss as an equivalent rectangular duct. This method is more useful for determining the blower size and overall ductwork design. Measure all speeds along the centreline of the air duct.

The cooling air speed in front of the brake, v, expressed in metres per second, is calculated as follows:

$$v = \frac{q}{3\,600 \times A_\mathrm{d}} = \frac{4 \times q}{3\,600 \times \pi \times d_\mathrm{e}^2} \tag{C.1}$$

where

q is the airflow, in metres cubed per hour;

A_d is the duct area, in metres squared;

d_e is the equivalent duct diameter, in metres.

The equivalent diameter of a rectangular duct, d_e, expressed in metres, is calculated using Figure C.1 and Equation (C.2) (in accordance with Huebscher[3]).

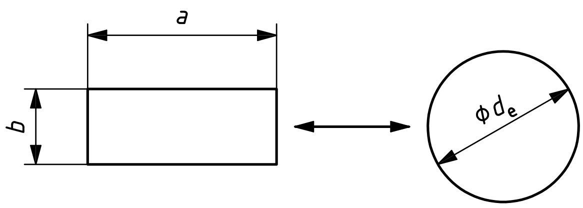


Figure C.1 — Equivalence between rectangular and round duct

$$d_e = 1{,}30 \times \frac{(a \times b)^{0{,}625}}{(a+b)^{0{,}25}} \tag{C.2}$$

where

a is the length of the major or minor side, in metres;

b is the length of the minor or major side, in metres.

C.3 Calculation of cooling air speed passing over the brake

Equation (C.3) is useful to estimate the cooling air speed passing around the brake. It does not take into consideration the following:

— turbulent airflow,

— pressure differentials or losses due to the uneven area distribution inside the brake enclosure around the brake corner,

— localized air heating from the brake and rotor heat dissipation, or

— additional airflow effects caused by the brake rotation.

The cooling air speed passing around the brake, v_{dc}, expressed in metres per second, is calculated as follows:

$$v_{dc} = v \times \frac{A_d}{A_e - A_b} \tag{C.3}$$

where

A_b is the area inside the enclosure covered by the brake corner and adaptors, in metres squared;

A_e is the cross-sectional area of the brake enclosure, in metres squared.

Bibliography

[1] FMVSS 105, *Hydraulic and Electric Brake Systems*

[2] FMVSS 135, *Light Vehicle Brake Systems*

[3] HUEBSCHER, R.G., Friction Equivalents For Round, Square and Rectangular Ducts, *ASHRAE Transactions 54*, pp. 101-44, 1948

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