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Road vehicles — Brake lining friction materials — Dynamometer metal pick-up generation procedure for disc brakes

*Véhicules routiers — Matériaux de friction des garnitures de freins —
Procédure de génération de métal aggloméré sur freins à disque par
dynamomètre*

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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.

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 documents 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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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 and chassis components*.

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

Metal pick-up (MPU) is a phenomenon/issue observed in automotive disc brakes during the braking process. Worn metallic particles may agglomerate under specific conditions and embed in the friction material. It may deteriorate brakes' appearance by scoring (grooves) on the surface of brake discs. MPU is also suspected to be a root cause of brakes NVH (noise, vibrations and harshness) issues as brake squeal or wire brush.

There is no single mechanism for creation of MPU in the automotive brakes so it cannot be only one specific condition for testing it. While the so-called NAO (non-asbestos-organic) friction materials are sensitive to high temperature and pressures, low metallic materials may create MPU under wet conditions or even more under the saltwater influence.

This document describes and covers all known critical conditions for generating MPU, it specifies which conditions are critical for a given friction material type. The methods described apply not only in the development of the material composition, but also in the selection of the materials for new brake applications and optimization of components for a recognised MPU issue.

This document includes three test procedures:

1. MPU generation under water/saltwater influence (typical for low metallic friction materials);
2. MPU generation at low temperatures and low brake pressures (typical for low metallic friction materials);
3. MPU generation at high brake temperatures and brake pressures (typical for NAO friction materials).

Road vehicles — Brake lining friction materials — Dynamometer metal pick-up generation procedure for disc brakes

1 Scope

This document describes test procedures for assessing the influence of pressure, temperature and water/salt water on the generation of metal pick-up (MPU) for a given friction material in combination with a specific brake disc. There are multiple tests to investigate the MPU generation issue for different types of friction materials (so called NAO and low metallic materials) under critical environmental and working conditions: influence of water and salt water, high temperatures and high pressures and low temperatures and low pressures.

This document supports the friction material development process and selection of friction materials for new brake applications.

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*

ISO 21920-2, *Geometrical product specifications (GPS) — Surface texture: Profile — Part 2: Terms, definitions and surface texture parameters*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 611, ISO 15484 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

MPU

metal pick-up

disc material agglomeration or compaction of high hardness on or in the pad material surface

Note 1 to entry: The MPU shapes could be different (flakes, grains with different aspect ratio, colloquially called “fishes”) and have different sizes (up to several millimetres).

3.2

groove

mechanical disc surface defect in the circumferential direction caused by *metal pick-up (MPU)* (3.1) collected in the pad material with a depth of more than several tens of micrometres

3.3 friction value

μ

average by time of all *instantaneous friction values* (3.4)

Note 1 to entry: See [Formula \(1\)](#) for calculation and evaluate after the brake application reaches 95 % of the set point value (pressure or deceleration) until it falls below 95 % of the set point level.

3.4 instantaneous friction value

μ^*

ratio of instantaneous output torque to instantaneous input pressure at any specific point in time

Note 1 to entry: For calculation, see also [Formula \(1\)](#).

3.5 step

sequence number of labelling the different *sections* (3.6) during the test

Note 1 to entry: Sequence number ensures the test conduction in the prescribed order.

3.6 section

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

Note 1 to entry: The brake applications can be stopped.

Note 2 to entry: The specific logic can be increasing brake pressure, increasing initial speed, or increasing brake temperature.

3.7 brake stop

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

Note 1 to entry: Project dependent the final speed can be increased to 5 km/h max.

3.8 brake snub

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

3.9 burnish section

series of *brake stops* (3.7) or *brake snubs* (3.8) to condition the friction couple by developing a steady coefficient of friction and create friction film and brake dust between the brake pads and disc

3.10 water and salt water section

series of *brake snubs* (3.8) while water or salt water is added between pads and disc surface

Note 1 to entry: Water sections are used to create *metal pick-up (MPU)* (3.1) and evaluate friction level under wet conditions.

3.11 heat and pressure section

section (3.6) of test procedure with a series of *brake snubs* (3.8) at elevated initial brake disc temperatures (above 300 °C) and increased brake pressure (up to 50 bar/5 MPa) to simulate heavy braking or overloaded conditions

3.12

low load and pressure section

section (3.6) of test procedure with a series of *brake snubs* (3.8) to generate a significant amount of wear debris at low load and brake pressure

4 Symbols and abbreviated terms

4.1 Symbols

Symbol	Definition	Unit
A_p	Total piston area	mm ²
I	Test inertia reflected at the brake	kg·m ²
$M_{d,brake}$	Measured torque	N·m
P	Applied pressure	kPa
$p_{threshold}$	Threshold pressure or minimum pressure required to develop braking torque	kPa
R_{eff}	Brake effective radius	mm
R	Dynamic tyre effective rolling radius	m
V_p	Prescribed or braking speed for the brake application	km/h
Z	Deceleration	m/s ²
μ	Average by time friction value for disc brakes	—
μ^*	Instantaneous friction value for disc brakes	—
η	Brake efficiency	%

4.2 Abbreviated terms

DTV	Disc Thickness Variation
IBT	Initial Brake Temperature (disc)
GVM	Gross Vehicle Mass
LRO	Lateral Run-Out
MPU	Metal Pick-Up
NAO	Non-Asbestos Organic
NVH	Noise, Vibration and Harshness

5 Test conditions and test preparation

5.1 Inertia for the brake testing

Use inertia calculated based on the real brake force distribution for a deceleration level of 0,3 *g* (2,94 m/s²) and GVM vehicle mass conditions.

Option: if the nominal brake force distribution is not known, use the following approach:

- front inertia: calculate the inertia for the front axle using 75 % of half the gross vehicle mass, and the tyre rolling radius;
- rear inertia: calculate the inertia for the rear axle using 25 % of half the gross vehicle mass and the tyre rolling radius.

5.2 Pressure ramp rate

The pressure ramp rate shall be 3 MPa/s for all brake applications.

5.3 Maximum pressure

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

5.4 Sampling rate

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

5.5 Initial brake temperature

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

5.6 Brake temperature measurement

One thermocouple shall be at the centre of the friction path ($0,5 \pm 0,1$) mm deep in the outer face of the disc or drum contact face. The initial brake temperature shall be measured using the disc thermocouple.

Additional thermocouple(s) can be in the centre of the outer pad recessed 1 mm into the friction material. If a slot through the centre is present, the thermocouple shall be at least 5 mm left or right from the slot (on the radial centre line). Change the thermocouple location towards the trailing (check if trailing or leading edge) edge of the lining if slots, calliper fingers or other brake features interfere with placing the thermocouple in the exact centre of the pad.

5.7 Cooling air conditioning

For specific cooling air definition (speed, temperature, humidity) for every test type (wet, heat and pressure, low temperature and low pressure) refer to the [Tables 1 to 4](#).

Tolerances for cooling air parameters:

- temperature: value ± 2 °C (mandatory);
- humidity: ± 5 % (optional);
- air speed: ± 3 km/h or equivalent air volume (mandatory).

5.8 Cooling air velocity or volume

The cooling air velocity or volume shall be specified in km/h or m³/h, as measured in the duct. The duct outlet shall be nominally (300 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 B](#).

5.9 Exhaust conditions

Use exhaust power shall be higher than cooling air power to keep a light under pressure in the test cabin.

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

The cooling air conditioning for temperature (mandatory) and absolute humidity (optional) shall be reported as the average of all brake events taken at the start of the brake application. The nominal

cooling air temperature is $(20 \pm 2) ^\circ\text{C}$ and the absolute humidity is $7,29 \text{ g/kg}$ ($8,68 \text{ g/m}^3$) measured at sea level. Use the appropriate psychrometric chart to find operating limits at temperatures other than $20 ^\circ\text{C}$, or elevations other than sea level.

NOTE Nominal cooling air conditions are equivalent to $(20 \pm 2) ^\circ\text{C}$ and $(50 \pm 5) \%$ relative humidity (RH).

5.11 Dynamometer rotational speed between brake applications

For specific dynamometer cooling speed for every test type (wet, hot with pressure, low temperature and low pressure) refer to the [Tables 1](#) to [4](#).

5.12 Orientation of brake set-up

Use a knuckle fixture style as default. A universal fixture (plate) is an acceptable option; see [Figures 1](#) and [2](#).

NOTE Reference SAE J3152 for further details on the fixture styles.

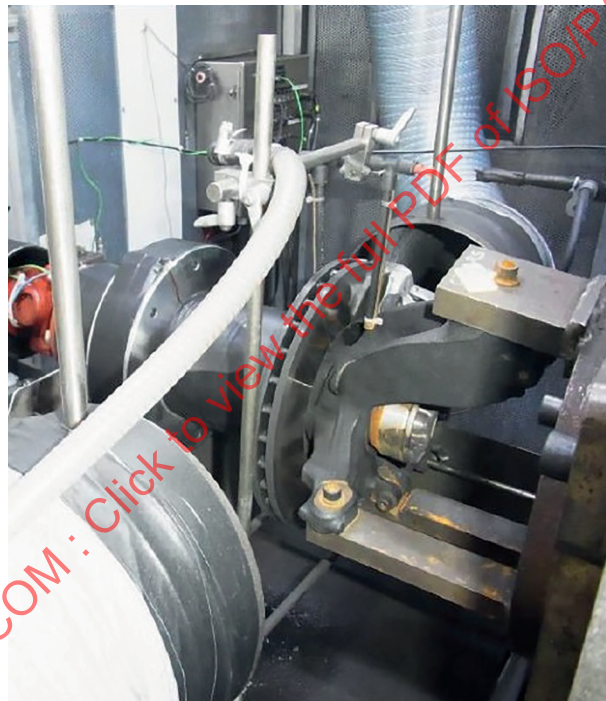


Figure 1 — Example of a knuckle fixture

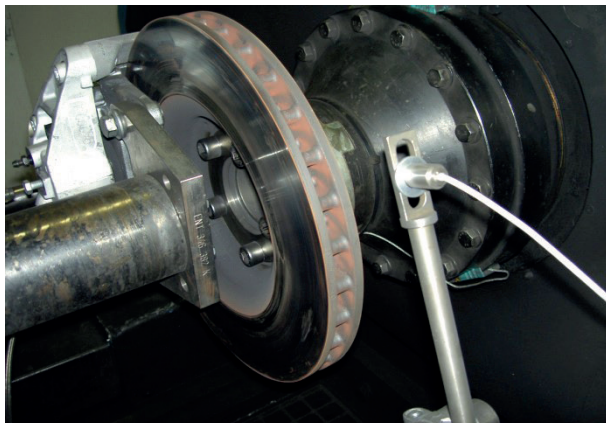


Figure 2 — Example of a universal fixture

The position of the brake on fixture is as on the vehicle as defined by knuckle; in case of universal fixture the vehicle position is preferable. Keep the orientation during the project duration.

5.13 Direction of air relative to the brake set-up

The test report shall document the airflow inlet regarding direction (vertical or horizontal) and orientation relative to the vehicle side under test (from forward, rear, top or bottom). Keep the same orientation during the project duration.

5.14 Wear measurement

Wear measurement is optional. If measured, initial and final disc and lining thickness and mass shall be measured and recorded. Measurements shall be made with following accuracy:

- lining: 0,01 mm (with ball head) and 0,1 g;
- disc 0,001 mm and 0,1 g.

5.15 Disc lateral run-out

Initial lateral run-out (LRO) shall be set to 50 μ m or less when measured 10 mm from the outer diameter on the outboard friction surface of the brake disc.

5.16 Caliper, disc or drum and pads condition

The brake disc used for the test shall be new and original equipment (OE) level. Generally, use new calipers. Used calipers are acceptable if agreed for a specific project.

5.17 Hot brake applications

Control the hot brake applications by pressure and initial brake temperature.

5.18 Water specification

Use city water/tap water, preferably with a water container for water temperature conditioning to (15 to 25) °C. The temperature shall be at the same level for the entire duration of the project, per 5.7. Lower temperatures are acceptable (down to 7 °C).

5.19 Specification of nozzles for water spraying

The nozzles shall have a flow rate of (0,55 $\pm$ 0,1) l/min. The spray angle and spray width of the nozzle is: 90°. Other angles and width are possible if required by dyno design or available space.

The water spray pattern shall impact the disc surface equally over its full width. The spray nozzle shall produce a flat, bar-shaped spray pattern on the target surface.

See [Clause 6](#) for the description of the nozzle setup.

5.20 Saltwater specification

5.20.1 Recommended solution

Use a 5 % solution of sodium chloride (NaCl) per [Annex D](#). See [5.18](#) for the water specification.

5.20.2 Alternative solutions

The test may use (but it is not recommended) a solution with commercial-grade salt with the following composition:

- at least 96 % of NaCl;
- less than 0,5 % of each of the following components: calcium chloride, calcium sulphate, calcium carbonate, magnesium chloride, magnesium sulphate, and potassium chloride;
- a 5 % solution, see [5.18](#) for the water specification.

5.20.3 Other solutions

The test can use other salt compositions.

EXAMPLE De-icing salt used in Germany: NaCl 92,1 % -MgCl₂ 7,9 %: solution 5 % in water.

5.21 Noise and vibration (NVH) measurements

Noise and vibration recording is optional. Simultaneous measurement should help to identify noise events caused by MPU.

Setup for NVH measurement:

- sampling frequency: at least 44 kHz;
- position of the microphone: 0,5 m above and 0,1 m outboard of the hub;
- position of the accelerometer: leading side of the anchor bracket;
- use Hanning windows with 50 % overlap, for noises up to 20 kHz with 800 spectral lines of resolution.

Brake event is noisy when the frequency difference measured by the microphone and accelerometer is not greater than 25 Hz.

5.22 Data collection

It is necessary to configure the data collection system of the inertia dynamometer to collect automatically and in real-time the following values:

- a) time,
- b) shaft rotational speed (vehicle equivalent speed),
- c) hydraulic pressure,
- d) brake torque,
- e) brake disc temperature,
- f) brake fluid displacement,
- g) cooling air temperature,
- h) cooling air speed and airflow,
- i) absolute humidity of cooling air,
- j) means to identify the specific section and brake application.

6 Test procedures

6.1 Basic information

[Annex A](#) contains information about MPU shapes. [Annex B](#) provides a template for test reporting. [Annex C](#) provides a reference calculation for cooling air speed and flow, whilst [Annex D](#) the specification for water and salt water.

6.2 Test procedure: “heat and pressure MPU”

Table 1 — Section overview

Sect. No.	Section description	Control attribute: pressure	Speed (km/h)	IBT (°C)	No. of stops	Air speed (km/h)	Drive shaft speed at cooling (km/h)	Comments / Exceptions
1	Cooling	600 s	0			40	0	Set cooling air to 20 °C, 50 % RH.
2	Burnish	P= 1,5; 3; 1,5; 1,8; 2,2; 3,8; 1,5; 2,6; 1,8; 3,4; 1,5; 2,6; 1,5; 2,2; 3; 4,6; 2,6; 5,1; 2,2; 1,8; 4,2; 1,5; 1,8; 4,6; 2,6; 1,5; 3,4; 2,2; 1,8; 3; 1,8; 3,8	80 → 30	100	64	40	5	Repeat this matrix 2 times for a total of 64 stops.
2.1	Visual check; photographs	Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc without disassembling.						
3	200 °C cycle	P=2,5 MPa	80 → 50	200	120	30	5	1 st stop <100 °C; next stops as quick as possible to 200 °C; all other 300 °C
3.1	Visual check; photographs							Photos of pad surface and disc friction area to identify MPU.
4	300 °C cycle	P=2,5 MPa	80 → 50	300	120	20	5	1 st stop <100 °C; next stops as quick as possible to 300 °C; all other 300 °C
4.1	Visual check; photographs	Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc without disassembling.						
5	400 °C cycle	P=2,5 MPa	80 → 50	400	120	10	5	1 st stop <100 °C; next stops as quick as possible to 400 °C; all other 400 °C
5.1	Visual check; photographs	Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc without disassembling.						
6	DTV measurement			<40 °C				
7	Burnish	P= 1,5; 3; 1,5; 1,8; 2,2; 3,8; 1,5; 2,6; 1,8; 3,4; 1,5; 2,6; 1,5; 2,2; 3; 4,6; 2,6; 5,1; 2,2; 1,8; 4,2; 1,5; 1,8; 4,6; 2,6; 1,5; 3,4; 2,2; 1,8; 3; 1,8; 3,8	80 → 30	100	64	40	5	Repeat this matrix 2 times for a total of 64 stops.
7.1	Visual check; photographs	Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc without disassembling.						
8	200 °C cycle	P=5 MPa	80 → 50	200	120	30	5	1 st stop <100 °C; next stops as quick as possible to 200 °C; all other 200 °C

Table 1 (continued)

Sect. No.	Section description	Control attribute:	Speed (km/h)	IBT (°C)	No. of stops	Air speed (km/h)	Drive shaft speed at cooling (km/h)	Comments / Exceptions
8.1	Visual check; photographs	pressure						Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc without disassembling.
9	300 °C cycle	P=5 MPa	80 → 50	300	120	20	5	1 st stop <100 °C; next stops as quick as possible to 300 °C; all other 300 °C
9.1	Visual check; photographs							Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc without disassembling.
10	400 °C cycle	P=5 MPa	80 → 50	400	120	10	5	1 st stop <100 °C; next stops as quick as possible to 400 °C; all other 400 °C
10.1	Visual check; photographs							Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc without disassembling.
11	Perform the final inspection, pad and disc evaluation, wear and DTV measurements.							

6.3 Test procedures “water and saltwater MPU”

6.3.1 Procedure 1 (core or early development testing)

Table 2 — Overview on procedure steps

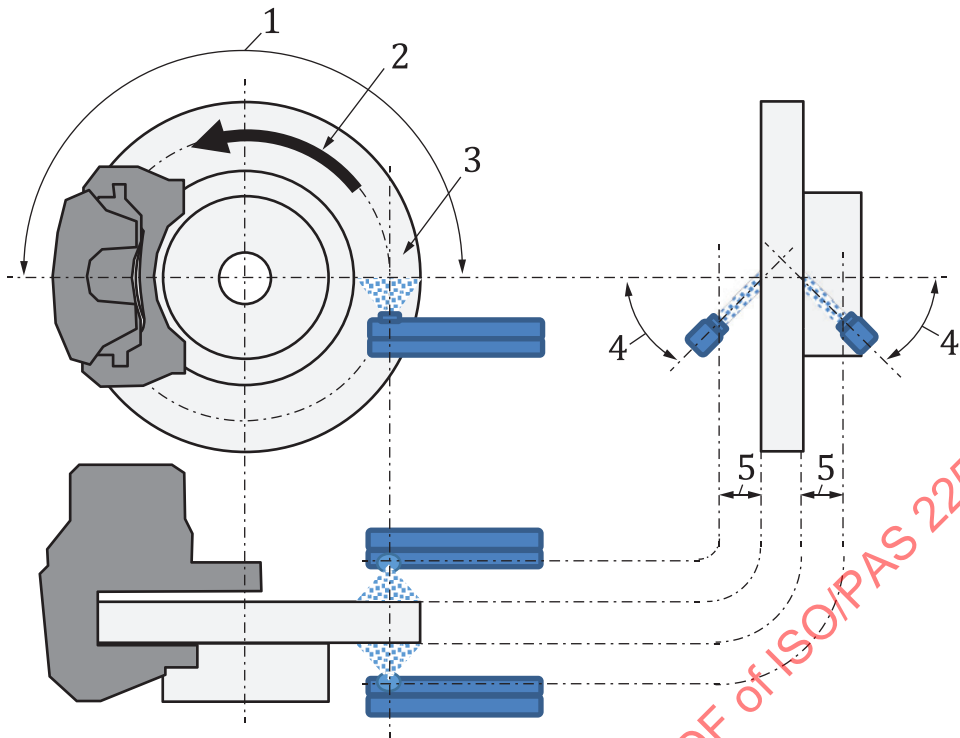
Sect. No.	Section description	Control attribute	Speed (km/h)	Cooling speed (km/h)	IBT (°C) / time interval (sec)	Air speed (km/h)	Water status (on/off)	No. of stops	Comments / exceptions
1	Burnish	Deceleration = 2,94 m/s ² (0,3 g)	65 → 0	65	Pad IBT under 110 °C	40	Off	200	Set cooling air to 20 °C, 50 % RH.
2	Water section	Pressure = 2 MPa	120 → 80	120	Time interval 60 s	Off- brake 40 km/h; on-brake 0 km/h	On/off	50	
2.1	Visual check; photo-graphs	Disc surface (grooving; roughness) and pad surface inspection (with or without MPU) + photographs							
3	Saltwater section	Pressure = 2 MPa	120 → 80	120	Time interval 60 s	Off- brake 40 km/h; on-brake 0 km/h	On/off	50	
3.1	Visual check; photo-graphs	Disc surface (grooving; roughness) and pad surface inspection (with or without MPU) + photographs							

Use a spray angle and spray width of the nozzle of 45°. Other setups are permitted if required by dyno design or the space available.

The nozzle's spray pattern shall produce a flat, bar-shaped spray pattern on the target surface.

Position the nozzle near the effective radius, while the distance depends on disc surface width (to spray water equally over the entire width of the disc), 180° away from the centre of the calliper (see [Figure 3](#) for an example of this procedure).

Use a water (or salt water) amount of (0,55 ± 0,1) l/min for both disc surfaces combined.



- Key**
- 1 180°
 - 2 rotating direction
 - 3 spray nozzle to be set near effective radius
 - 4 45°
 - 5 distance to be adjusted so that water can be applied evenly

Figure 3 — Example test setup for procedure 1 “water and salt MPU”

6.3.2 Procedure 2 (DVP procedure; can also be used in vehicle testing)

Table 3 — Overview of procedure steps

Sect. No.	Section description	Control attribute	Speed (km/h)	Cooling speed (km/h)	Distance (m)	Air speed (km/h)	Water status (on/off)	No. of stops	Comments / exceptions
1	Cycle 1-Dry	Decel = 2,94 m/s ² (0,3 g)	120 → 80	120	2 000 m interval stop begin to stop begin	40		45	Set cooling air to 20 °C, 50 % RH.
^a 0,55 l/min (±0,1 l/min) (both disc surfaces together).									

Table 3 (continued)

S e c t . No.	Section de- scription	Control attribute	Speed (km/h)	Cooling s p e e d (km/h)	Distance (m)	Air speed (km/h)	Water status (on/off)	No . of stops	Comments / exceptions
2	Cycle 2- With water spraying	Water on ^a /off	120 → 80	120	0-1 000 1 001 - 4 000 4 001 - 5 000 5 001 - 8 000 8 001 - 9 000 9 001 - 12 000 12 001 - 13 000 13 001 - 16 000 16 001 - 17 000 17 001 - 20 000 20 001 - 21 000 21 001 - 24 000 24 001 - 25 000 25 001 - 28 000 28 001 – 29 000 29 001-30 000	0	on off on off on off on off on off on off on off on of	15	Combine water spraying with brake applications as specified below.
		D e c e l = 2,94 m/s ² (0,3 g)	120 → 80	120	1 400; 4 400; 5 900; 7 500; 10 500; 12 000; 13 600; 16 600; 18 100; 19 700; 22 700; 24 200; 25 800; 28 800; 30 300		Depends on distance and spraying se- quence		Apply brakes at distance.
2.1	V i s u a l check; pho- to-graphs	Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc shall be documented without disassembling.							
^a 0,55 l/min (±0,1 l/min) (both disc surfaces together).									

Table 3 (continued)

Sect. No.	Section description	Control attribute	Speed (km/h)	Cooling speed (km/h)	Distance (m)	Air speed (km/h)	Water status (on/off)	No. of stops	Comments / exceptions
3	Cycle 3 - With water spraying	Water on ^a /off	120 → 80	120	0-2 000 2 001 - 4 000 4 001 - 6 000 6 001 - 8 000 8 001 - 10 000 10 001 - 12 000 12 001 - 14 000 14 001 - 16 000 16 001 - 18 000 18 001 - 20 000 20 001 - 22 000 22 001 - 24 000 24 001 - 26 000 26 001 - 28 000 28 001 - 30 000 29 001 - 30 000	0	on off on off on off on off on off on off on off on off	15	Combine water spraying with brake applications as specified below.
		D e c e l = 2,94 m/s ² (0,3 g)	120 → 80	120	1 400; 4 400; 5 900; 7 500; 10 500; 12 000; 13 600; 16 600; 18 100; 19 700; 22 700; 24 200; 25 800; 28 800; 30 300		Depends on distance and spraying sequence		Apply brakes at distance.
3.1	V i s u a l check; photo-graphs	Take photographs of pad surface and disc friction area to identify MPU and grooves. Perform profile measurement of the disc in the radial direction (both friction surfaces). For tests without sections with salt water, protect the brake disc and pads from corrosion (e.g. use vacuum bags for pads, penetrating oil for disc surface).							
4 (option)	Cycle 4-dry	D e c e l = 2,94 m/s ² (0,3 g)	120 → 80	120	2 000 m interval stop begin to stop begin	40		45	Set cooling air to 20 °C, 50 % RH.
4.1	V i s u a l check; photo-graphs	Photographs of pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections; pictures of the pad surface are sufficient. The friction area of the disc shall be documented without disassembling.							
^a 0,55 l/min (±0,1 l/min) (both disc surfaces together).									

Table 3 (continued)

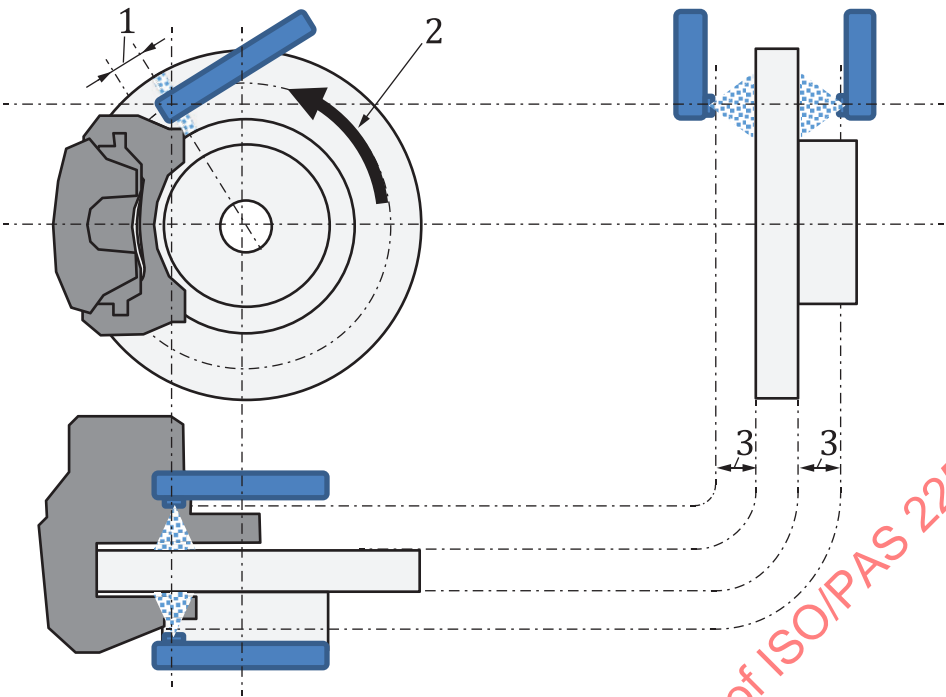
Sect. No.	Section description	Control attribute	Speed (km/h)	Cooling speed (km/h)	Distance (m)	Air speed (km/h)	Water status (on/off)	No. of stops	Comments / exceptions
5 (option)	Cycle 5 - with saltwater spraying	5% saltwater solution on ^a /off	120 → 80	120	0-2 000 2 001 - 4 000 4 001 - 6 000 6 001 - 8 000 8 001 - 10 000 10 001 - 12 000 12 001 - 14 000 14 001 - 16 000 16 001 - 18 000 18 001 - 20 000 20 001 - 22 000 22 001 - 24 000 24 001 - 26 000 26 001 - 28 000 28 001 - 30 000 29 001 - 30 000	0	on off on off on off on off on off on off on off on off	15	Combine salt water spraying with brake applications as specified below.
		Decel = 2,94 m/s ² (0,3 g)	120 → 80	120	1 400; 4 400; 5 900; 7 500; 10 500; 12 000; 13 600; 16 600; 18 100; 19 700; 22 700; 24 200; 25 800; 28 800; 30 300		Depends on distance and spraying sequence		Apply brakes at distance.
5.1	Visual check; photographs	Take photographs of the pad surface and disc friction area to identify MPU and grooves. For the intermediate inspections, pictures of the pad surface are sufficient. Document the friction area of the disc shall be documented without disassembling.							
^a 0,55 l/min (±0,1 l/min) (both disc surfaces together).									

Use a spray angle and spray width of the nozzle of 90°. Other setups are permitted if required by dyno design or the space available.

The nozzle's spray pattern shall produce a flat, bar-shaped spray pattern on the target surface.

Position the nozzle near the effective radius, while the distance depends on disc surface width (to spray water equally over the entire width of the disc), 30 mm in front of the leading side of the calliper (see [Figure 4](#) for an example of this procedure).

Use a water (or salt water) amount of (0,55 ± 0,1) l/min for both disc surfaces combined.



- Key**
- 1 30 mm
 - 2 rotating direction
 - 3 distance to be adjusted so that water can be applied evenly

Figure 4 — Example test setup for procedure 2 “water and salt MPU”

6.4 Test procedure for “low load and pressure”

Run the cycle per Table 4 a total of five times.

Table 4 — Overview of procedure steps

Section No.	Section description	Control attribute	Speed (km/h)	Braking interval	No. of stops	Cooling speed (km/h)		Comments / exceptions
						Air flow	D y n o shaft	
1	Burnish (low load and pressure cycle)	Deceleration 0,5 m/s ²	50 → 20	IBT for pad <60 °C (1 mm depth)	100	40	50	
2	High pressure cycle	Deceleration 6,0 m/s ² ; with acceleration increase rate equal to 1,5 m/s ² /s	80 → 20	Interval time 20 s	3	40	80	1st apply IBT < 30 °C
2.1	Visual check	Inspect disc surface (Grooving; Roughness) and take a photograph.						

7 Test report

7.1 General

See [Annex B](#) for the template proposal.

7.2 Test conditions

Record and report brake parameters, test inertia, rolling radius, brake hand, test setup, total test run-time, and any deviation or anomaly during the test.

7.2.1 Disc and lining identification

Report:

- part numbers for caliper, disc and pads
- batch numbers for disc and pads

Provide the best possible description of the disc machining process of tested discs, including tool and process parameters (see template proposal). Report the calliper hand.

7.2.2 Disc surface characterisation

Report disc surface roughness according to ISO 21920-2 before the test. It is mandatory to report Ra. It is optional to report Rp and Rmc (c).

7.2.3 Photographs of the setup

Document the brake setup when mounted on the dynamometer with the nozzle's visible position for water spraying ("water and salt MPU" only). Report the water amount in litre/minute (as the total amount for inner and outer friction surface) and water temperature. Report the position of air ducting and cooling air specification (temperature and humidity).

7.2.4 Photographs of the test parts

Photographs of pads

Pictures clearly showing pad material surface (all tested pads) allowing evaluation of number and area of MPU (minimum resolution 1 600 × 1 200) after every procedure section as defined in [Tables 1](#) to [4](#). Report the resolution of the pictures. Include a photographic ruler ([Figure 5](#)) in the image of the test part.

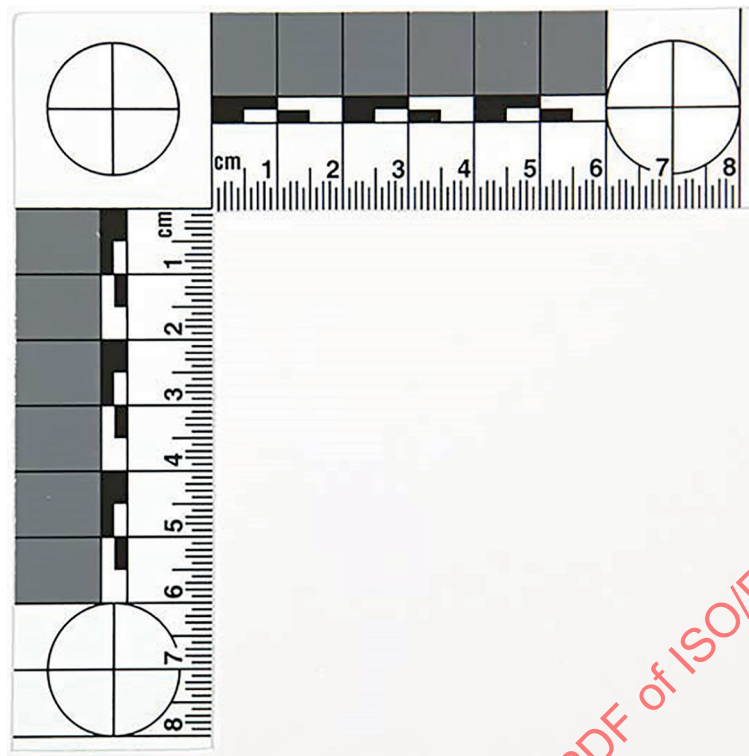


Figure 5 — Photographic ruler

Photographs of disc

Pictures showing disc surface (both surfaces) clearly showing disc surface condition/grooves. Pictures should show a quarter (90° or similar) of the (minimum resolution 1 600 × 1 200) after every procedure section as defined in [Tables 1](#) to [4](#). Report the resolution of the pictures.

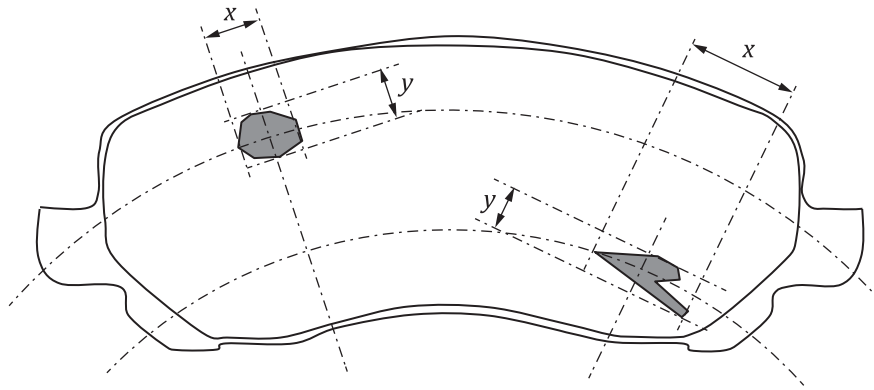
7.2.5 Documentation of pad MPU number and area

Due to different MPU generation mechanisms, the shape, amount, size and hardness of MPU may differ, requiring a specific definition for pad appearance.

[Figure 6](#) demonstrates the way of MPU size estimation in the pad. Additionally, in case, an MPU has been removed from the surface during brake applications (visible “crater” or “comet” shape in pad material), count the area of this MPU by following approach: MPU area = $b \times b$ where $b = 0,7 \times$ width of crater/comet shape.

EXAMPLE For a crater of (5 × 5) mm, the MPU area is assessed with (3,5 × 3,5) mm = 12,25 mm².

Report the number, size and total area of MPU per pad.

**Key**

x, y dimension measurement of MPU

Figure 6 — Method for estimation of MPU size in pad material

7.2.6 Documentation of disc surface profile

The deterioration in disc appearance is described by the number of grooves; width of the grooved disc surface and the depth of the grooves. [Figures 7](#) and [8](#) demonstrate the width and the depth of the grooves in disc material.

Measurement of disc profile over full width of the disc is recommended. Optionally; disc grooving may be evaluated by other means, e.g. equipment for roughness measurement (example). Report depth of grooves (in μm) in the disc surface after completion of the test; see example below.

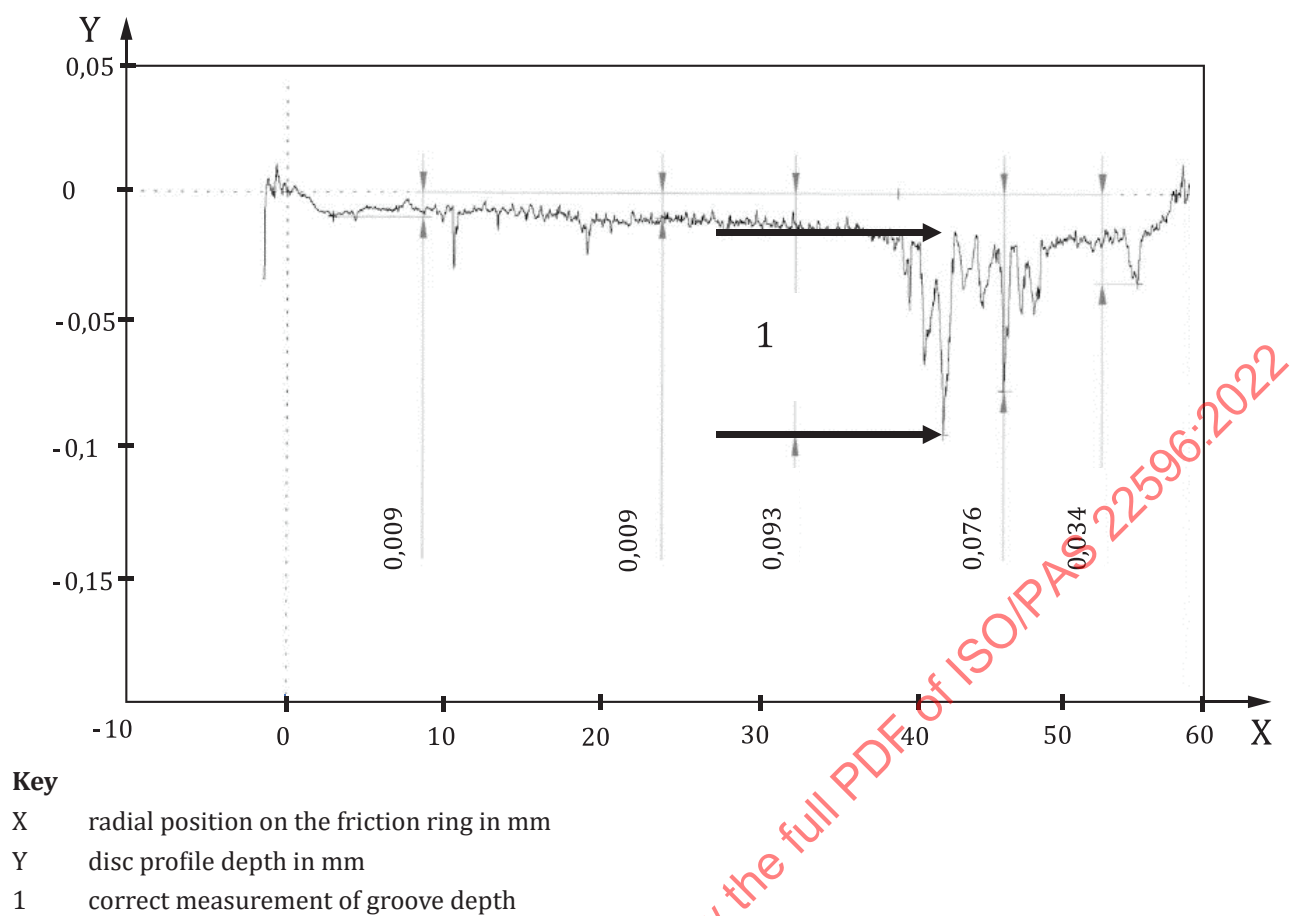
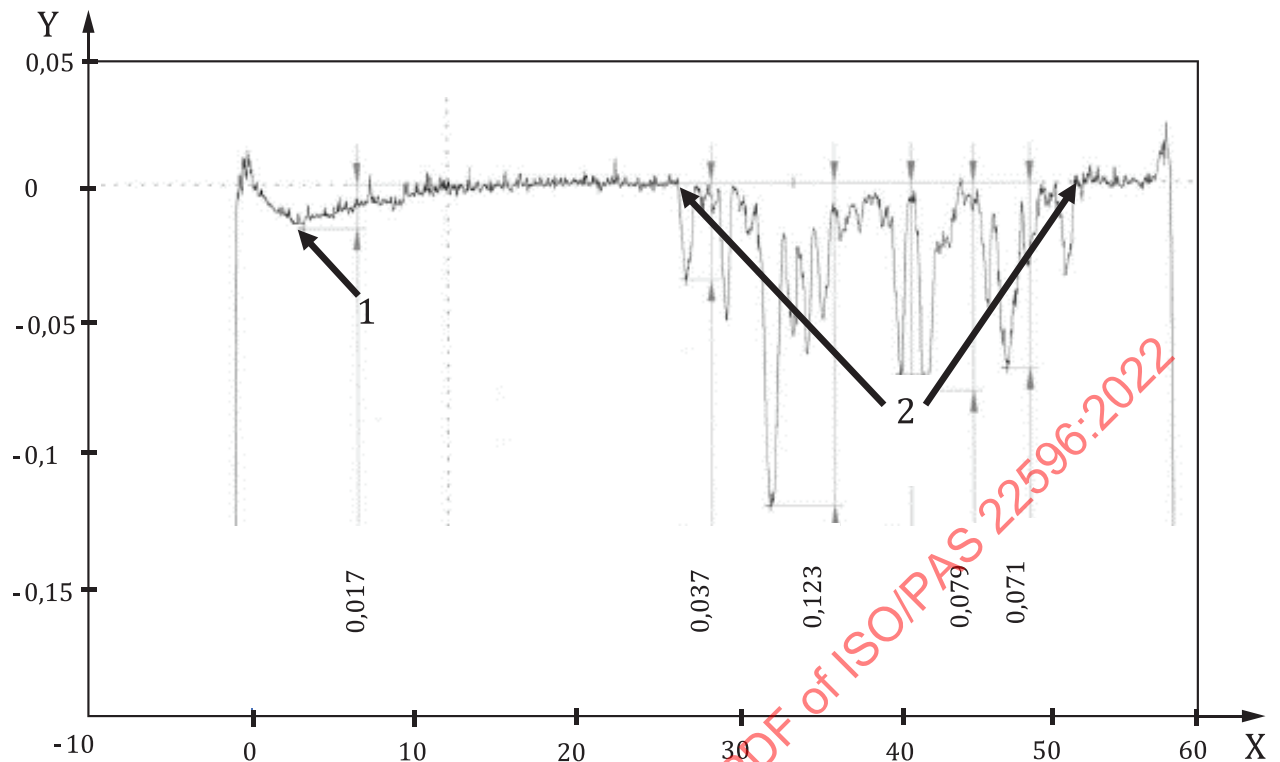


Figure 7 — Example for disc surface profile measured radially with measurement of groove depth for the test report

Report the width of disc surface covered by grooves (each friction side separately); see example below.



Key

- X radial position on the friction ring in mm
 Y disc profile depth in mm
 1 not a groove
 2 grooved area between mm “15” and “42”

Figure 8 — Example for disc surface profile measured radially, including the measurement of the width of the grooved surface to include in the final report

7.2.7 Acceptance criteria

See [Table 5](#).

Table 5 — Recommendations for acceptance criteria

Test procedure	Pad acceptance criteria (per pad)	Disc acceptance criteria (per disc side)	
		Water sections	Saltwater sections
Water and salt	MPU total area after “water sections”: 70 mm ² max. MPU total area after “salt sections”: 140 mm ² max.	Width < 5 mm	Width < 10 mm
		Depth < 50 µm	Depth < 70 µm
		Number of grooves: maximum one above the specified depth	
		Remarks:	
		1. All criteria for width, depth, and number of grooves shall apply 2. Grooves rated for MPU shall be at the same position as pad MPU; MPU shall initially generate grooves 3. Possible grooves without MPU influence should be mentioned as a separate issue, not directly related to MPU	

Table 5 (continued)

Test procedure	Pad acceptance criteria (per pad)	Disc acceptance criteria (per disc side)	
		Water sections	Saltwater sections
Heat and pressure	MPU total area: 1 mm ² max. after 200 °C and 300 °C sections (both pressure levels)	No grooves on disc surface after 200 °C and 300 °C sections (both pressure levels)	
Low load and pressure	No requirement	Total groove width 5 mm max.	

7.3 Graphical report

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

- a) instantaneous deceleration; pressure; fluid consumption; brake temperature and friction value; water/salt water “on/off” (where applicable) for meaningful brake applications; applicable or reference friction value can be included on the corresponding graph:

Calculate friction level as follows:

$$\mu = \frac{10^5 \times M_{d;brake}}{2 \times (p - p_{threshold}) \times A_p \times r_{eff} \times \eta} \quad (1)$$

where

$M_{d;brake}$ is the measured torque;

p is the applied pressure;

$p_{threshold}$ 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 brake efficiency.

- b) friction values: calculate and report standard friction values (by time). Distinguish between dry and wet brake application (in “water and salt MPU” test);
- c) marker for average by time friction value.

7.4 Cooling air conditions and water spraying

The cooling air direction and orientation shall be recorded and reported. Water spraying device, water amount and temperature, and nozzle position shall be reported.

7.5 Tabular data for each brake application

Present the following items in tabular format for the entire test and each brake application, unless otherwise specified for the project:

- a) braking and release speed;
- b) average by time; maximum and minimum values for friction; torque and pressure;
- c) initial and final brake temperature at the disc (mandatory) and brake lining(s) (optional);
- d) maximum fluid displacement (option);

- e) cooling air speed; temperature and humidity;
- f) water temperature and flow rates (where applicable).

7.6 Wear measurement; pad and disc appearance

Report disc and lining loss in thickness and mass. Beside MPU, any cracks, detachment, delaminating or any unusual condition on the disc or lining shall be recorded and reported.

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Annex A (informative)

MPU shapes

A.1 Formless shape

Formless shapes are observed typically during a wet condition, especially for low steel friction materials (see [Figure A.1](#)).

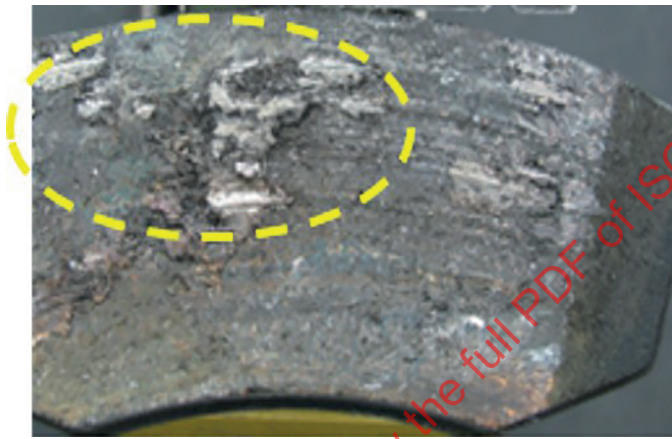


Figure A.1 — Formless shape

A.2 Fish shape

Fish shapes are observed typically during a dry and a high brake temperature condition, especially for NAO friction materials (see [Figure A.2](#)).



Figure A.2 — Fish shape

A.3 Arrow shape

Arrow shapes are observed typically during dry and low-load brake conditions, especially for low steel friction materials (see [Figure A.3](#)).

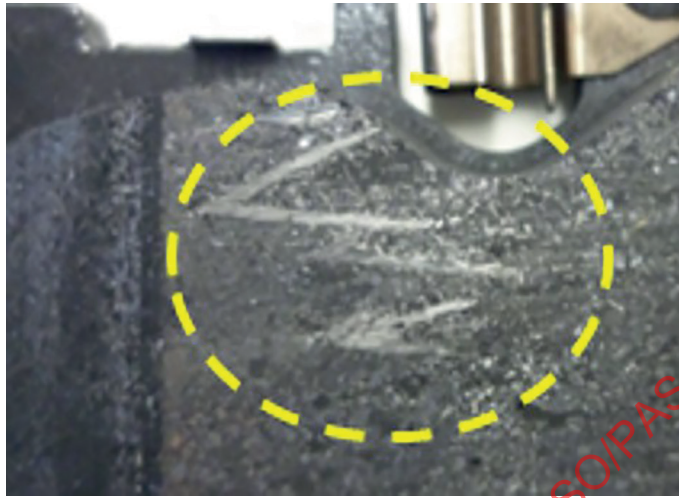


Figure A.3 — Arrow shape

Annex B (informative)

Template proposal

B.1 Content of report template (Table B.1)

Table B.1 — Content of MPU report template

Figure	Description	Water and salt MPU	Heat and pressure MPU	Low temperature and low pressure
B.1	Technical data sheet	x	x	x
B.2	Test setup sheet	x	x	x
B.3	LRO; DTV graph	x	x	x
B.4	Burnish data plot	x	x	x
B.5	In-stop data plot	x	x	x
B.6	Detailed visualisation of disc and pads	x	x	x
B.7	Water and salt MPU evaluation	x		
B.8	Heat and pressure MPU evaluation		x	
B.9	Low load and pressure MPU evaluation			x
B.10	Test accuracy sheet	x	x	x
B.11	Pad wear measurement	x	x	x
B.12	Disc wear measurement	x	x	x
B.13	Evaluation of disc and pad condition	x	x	x
B.14	Tabular data	x	x	x

B.2 Template sheets

MPU brake dynamometer test		
Test information		
Customer name		
Requestor		
Test procedure		
Program number technician		
Dynamometer		
Start and end dates		
Datalog, template version		
Setup details		
Fixture identification		
Fixture design		
Drive adapter method		
Dynamometer information		
Rolling radius		
Requested inertia		
Actual inertia		
Requested wheel load		
Brake information		
Brake platform		
Brake type		
Rotor size		
Drum/rotor ID number		
Drum/rotor type		
Drum/rotor finish		
Caliper/drum assy ID number		
Caliper/drum assy condition		
Pri/lead/inner lining and batch #		
Sec/trail/outer lining and batch #		
Compressibility (inner/prim)		
Compressibility (outer/prim)		
Chamfer outer pad		
Chamfer inner pad		
Shim outer pad		
Shim inner pad		
Orientation		
Effective radius		
Number of pistons/cyls		
Coefficient multiplier		
Piston diameter		
Threshold pressure		
Caliper efficiency		
Comments:		
Processed by:	Title:	Date:
Reviewed by:	Title:	Date:

Figure B.1 — Proposal for general MPU test report — “technical data sheet”

SETUP

Custom view



Detailed view



Figure B.2 — Proposal for general MPU test report — “test setup sheet”

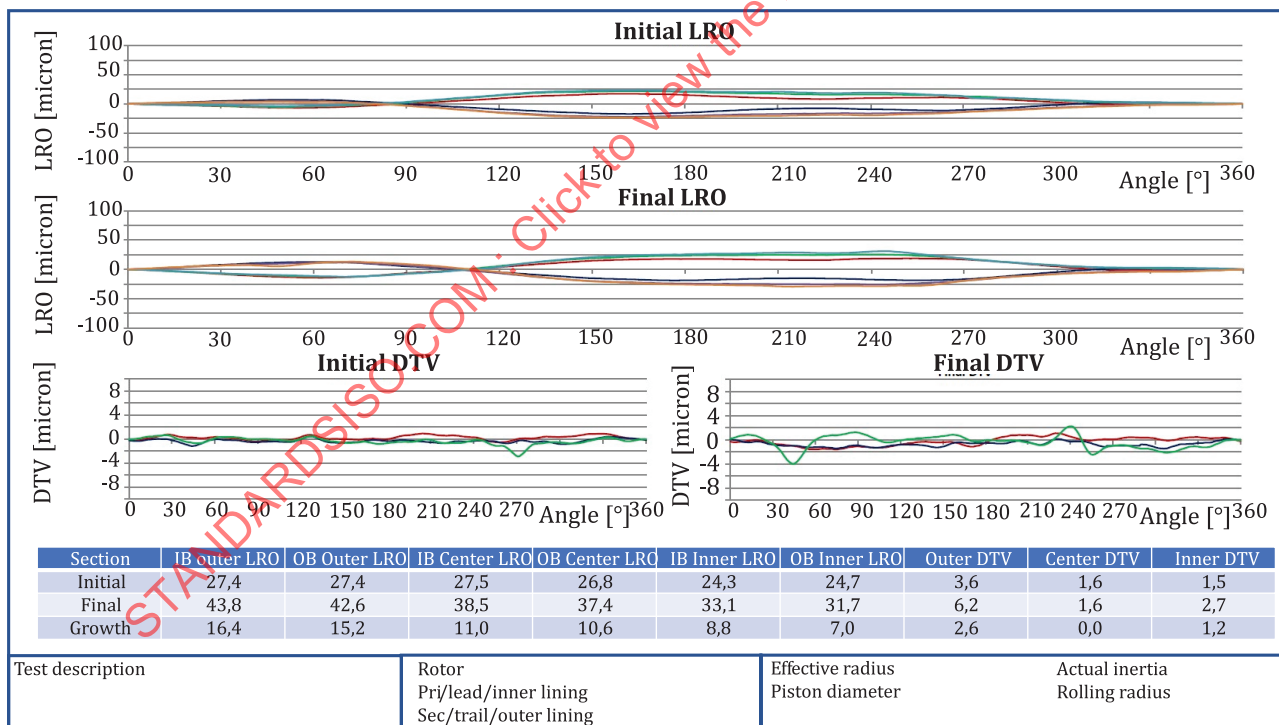


Figure B.3 — Proposal for general MPU test report — “LRO, DTV graph”

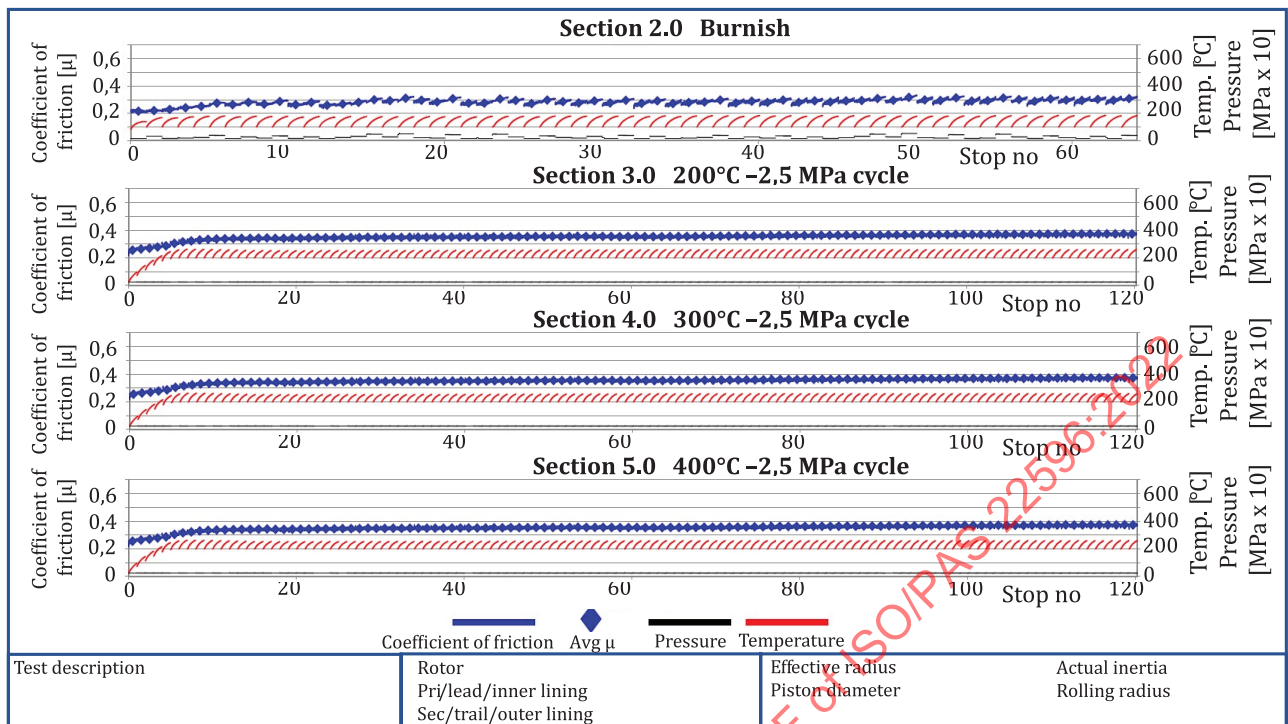


Figure B.4 — Proposal for general MPU test report — “burnish data plot”

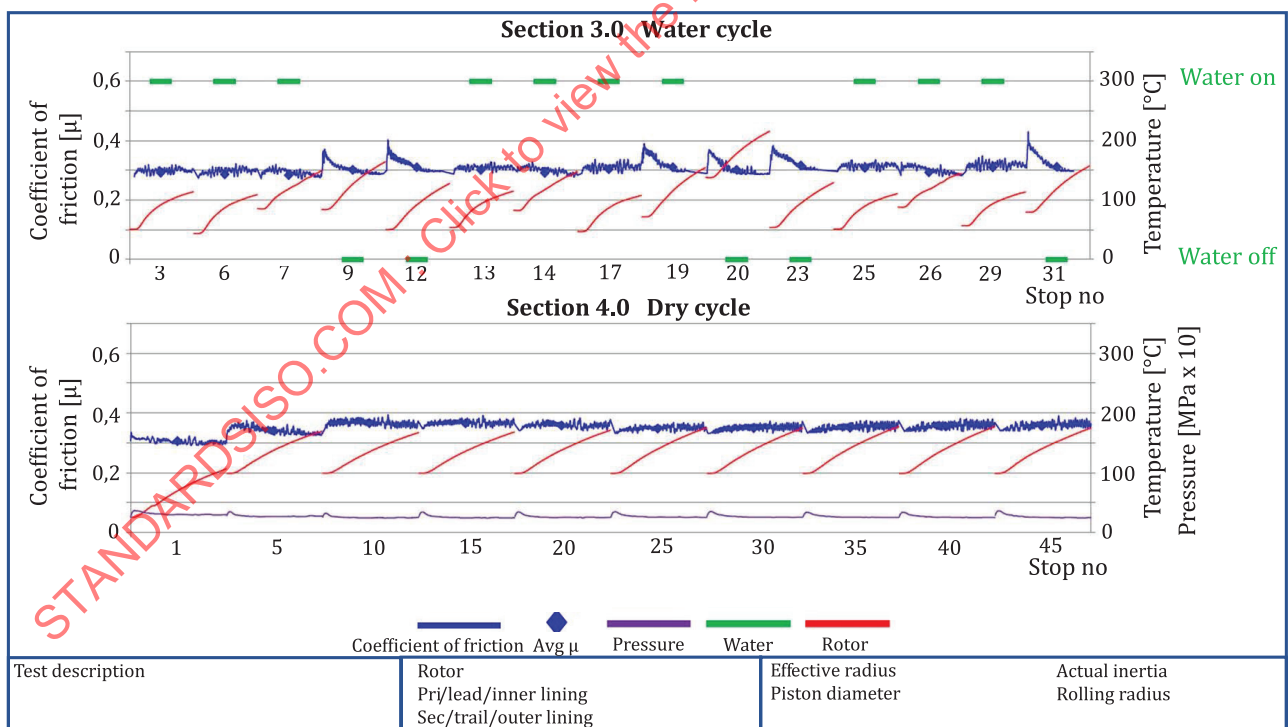


Figure B.5 — Proposal for the water and salt MPU test report — “in-stop data plot”

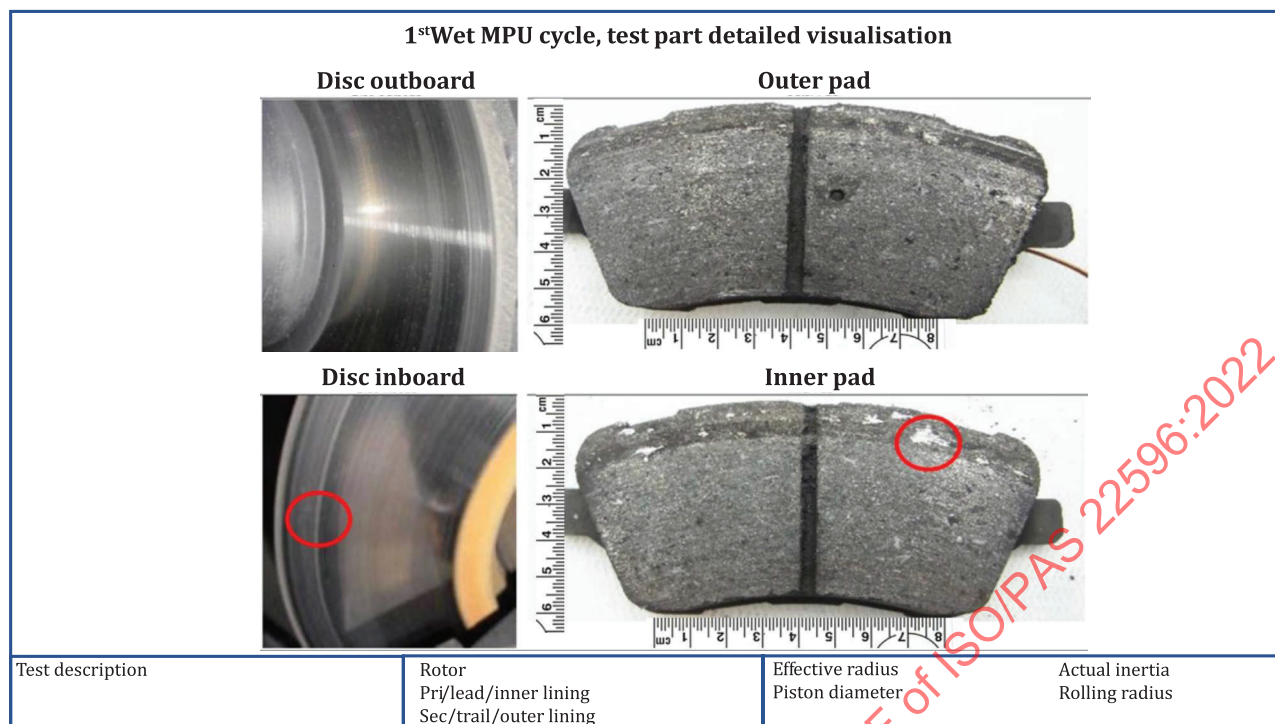


Figure B.6 — Proposal for the MPU test report — “detailed visualization of disc and pads”



Figure B.7 — Proposal for the water and salt MPU test report — “water and salt MPU evaluation”



Figure B.8 — Proposal for the wet MPU test report — “heat and pressure MPU evaluation”

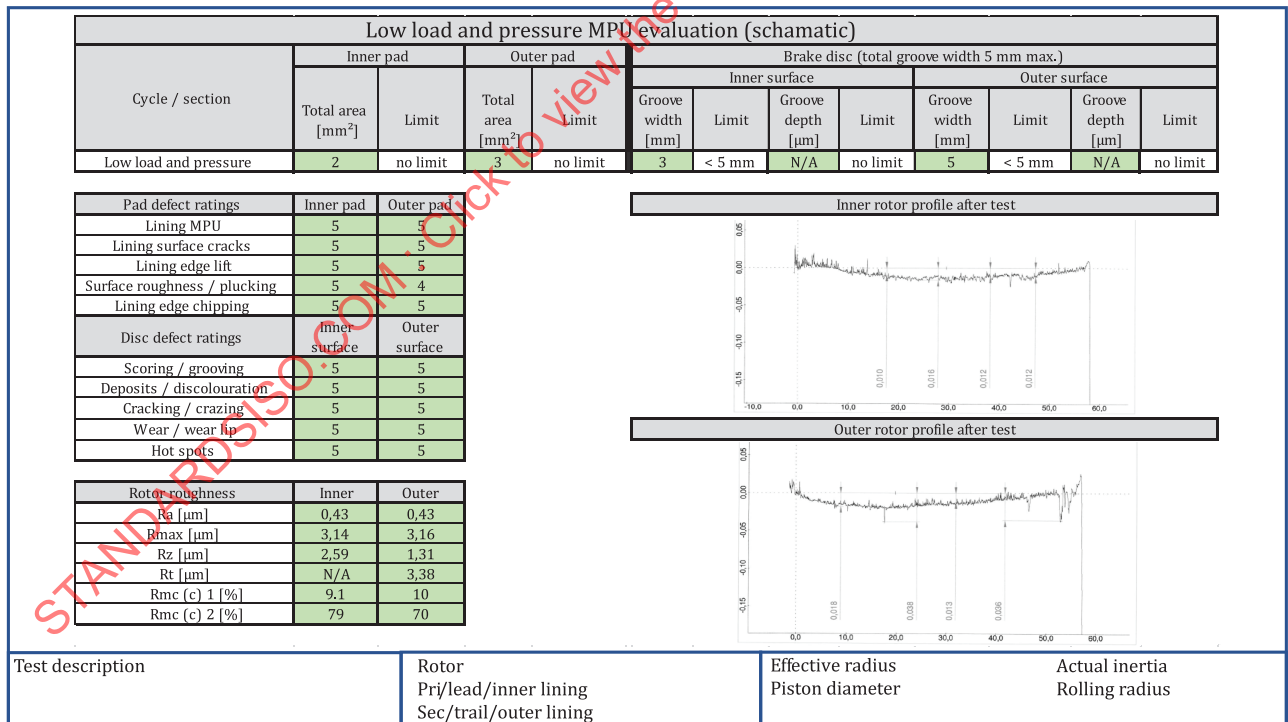


Figure B.9 — Proposal for the wet MPU test report — “low load and pressure MPU evaluation”