



BSI Standards Publication

Paints and varnishes – Overview of test methods on hardness and wear resistance of coatings

National foreword

This Published Document is the UK implementation of CEN ISO/TR 21555:2020. It is identical to ISO/TR 21555:2019. It supersedes PD ISO/TR 21555:2019, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee STI/10, Test methods for paints.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Published by BSI Standards Limited 2020

ISBN 978 0 539 14061 3

ICS 87.040

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 August 2019.

Amendments/corrigenda issued since publication

Date	Text affected
31 October 2020	This corrigendum renumbers PD ISO/TR 21555:2019 as PD CEN ISO/TR 21555:2020

English Version

Paints and varnishes - Overview of test methods on
hardness and wear resistance of coatings (ISO/TR
21555:2019)

Beschichtungsstoffe - Überblick zu Verfahren zur
Bestimmung von Härte und Verschleißfestigkeit von
Beschichtungen (ISO/TR 21555:2019)

This Technical Report was approved by CEN on 4 October 2020. It has been drawn up by the Technical Committee CEN/TC 139.

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European foreword

The text of ISO/TR 21555:2019 has been prepared by Technical Committee ISO/TC 35 "Paints and varnishes" of the International Organization for Standardization (ISO) and has been taken over as CEN ISO/TR 21555:2020 by Technical Committee CEN/TC 139 "Paints and varnishes" the secretariat of which is held by DIN.

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Endorsement notice

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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).

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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 35, *Paints and varnishes*, Subcommittee SC 9, *General test methods for paints and varnishes*.

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

The determination of the hardness and of the wear resistance is one of the most important preconditions for evaluating the resistance of coatings to mechanical stress.

The procedures and numerical data given in this document provide a rough overview; detailed information is found in the applicable standards.

For all of the methods for the evaluation of the hardness and of the wear resistance the visco-elastic properties have a wide influence on the test result. Consequently, the time between testing and evaluation are agreed and observed.

Mechanical properties of coatings depend on, among others, temperature and moisture content. Consequently, the tests should be carried out immediately after the conditioning phase.

The tests are preferably carried out in the climatic chamber.

Each method has its specific application. An unsuitable method may lead to false conclusions. All of the test methods require a certain expertise of the test person. For most of the test methods the test results depend on, among others, the film thickness of the coating to be tested.

Paints and varnishes - Overview of test methods on hardness and wear resistance of coatings

1 Scope

This document provides an overview for selecting the most suitable test method regarding the evaluation of the hardness and the wear resistance of coatings.

[Annex A](#) gives a summarized list of test methods for the evaluation of the hardness and of the wear resistance of coatings for different stresses.

Methods for testing cross-linking (wear test in connection with solvents) and abrasion tests with multiple impacts are not covered by this document.

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 4618, *Paints and varnishes — Terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4618 and the following apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

hardness

ability of a dry film or coat to resist indentation or penetration by a solid object

[SOURCE: ISO 4618:2014, 2.136]

3.2

wear

irreversible change of a coating which is caused by the mechanical impact of moved objects

3.3

stylus

scratching tool with specified geometry

[SOURCE: ISO 22557:2019, 3.1]

3.4

scratch

line-shaped damage of a coating which is caused by the impact of a loaded object being moved over the coating

3.5

mar

blemish on the surface of a coating, extending over a particular area of the coating and visible due to the difference in the light-reflection properties of the area affected compared with the light-reflection properties of adjacent areas

[SOURCE: ISO 4618:2014, 1.152]

3.6

abrasion

wear ([3.2](#)) which is caused by removal of coating material on a surface

3.7

repeatability conditions

conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time

[SOURCE: ISO 5725-1:1994, 3.14]

3.8

repeatability limit

r

the value less than or equal to which the absolute difference between two test results obtained under *repeatability conditions* ([3.7](#)) may be expected to be with a probability of 95 %

[SOURCE: ISO 5725-1:1994, 3.16]

3.9

reproducibility conditions

conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment

[SOURCE: ISO 5725-1:1994, 3.18]

3.10

reproducibility limit

R

the value less than or equal to which the absolute difference between two test results obtained under *reproducibility conditions* ([3.8](#)) may be expected to be with a probability of 95 %

[SOURCE: ISO 5725-1:1994, 3.20]

4 Hardness tests

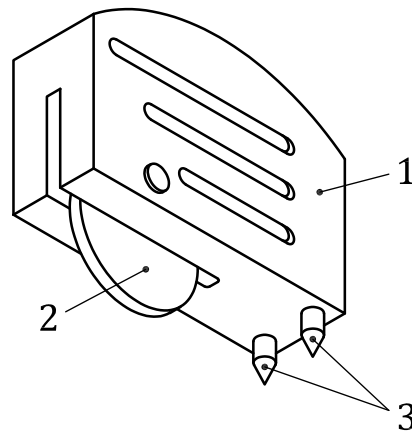
4.1 Indentation tests with resting indenter

4.1.1 Indentation test with Buchholz indenter

— Description

An indenter made of hardened steel, the shape and dimensions of which are specified in accordance with Buchholz, impacts the coating under a load (500 g, corresponding to 4,96 N) for 30 s and produces an indentation. After a resting time of 35 s the indentation length (mm) is determined under specified lighting conditions using a measuring microscope (×20 magnification).

[Figure 1](#) shows the test device and [Figure 2](#) shows the Buchholz indenter. [Figure 3](#) illustrates the microscopic measurement of the indentation.

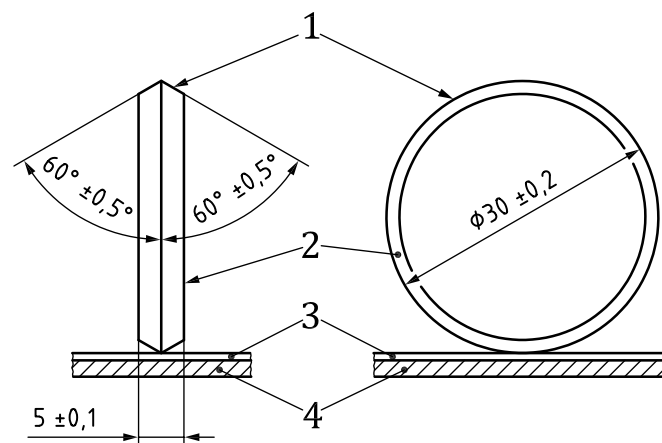


Key

- 1 steel block
- 2 indenter
- 3 tip

Figure 1 — Indentation tester in accordance with Buchholz

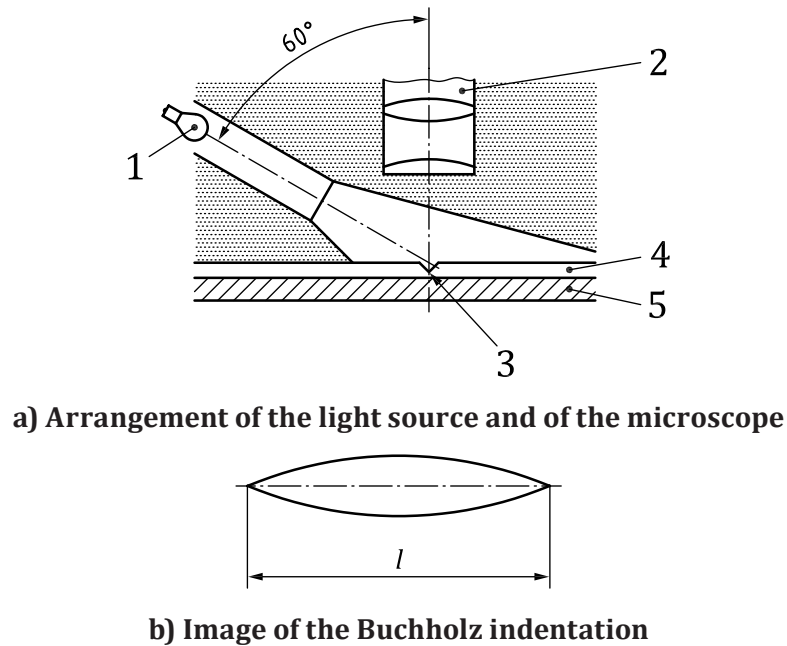
Dimensions in millimetres



Key

- 1 indentation edge
- 2 indenter
- 3 coating
- 4 substrate

Figure 2 — Buchholz indenter



Key

- 1 light source
- 2 microscope
- 3 indentation
- 4 coating
- 5 substrate
- l indentation length

Figure 3 — Measuring the Buchholz indentation

— **Application**

The indentation test with Buchholz indenter is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

- Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h)
- First, lower the tips of the test device onto the coating, and then carefully lower the indenter.
- Leave the loaded indenter on the coating for 30 s and remove in reverse order.
- 35 s after removal of the load determine the indentation length (mm) using a measuring microscope (see [Figure 3](#)).

— **Evaluation**

Test result is the indentation length (mm), as mean value of five determinations.

— **Precision**

The repeatability limit r is 0,23 mm.

The reproducibility limit R is 0,45 mm.

— Reference

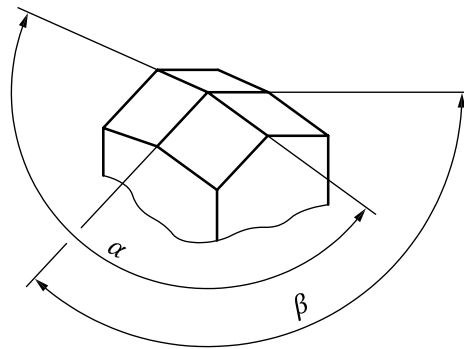
The indentation test with Buchholz indenter is specified in ISO 2815.

4.1.2 Indentation test with Knoop indenter

— Description

A diamond indenter, the shape and dimensions of which are specified in accordance with Knoop, impacts the coating under a load (25 g, corresponding to 0,245 N) for 18 s and produces an indentation. Immediately after removal of the load the length (mm) of the long diagonal of the indentation is determined using a measuring microscope. From this, the “Knoop Hardness Number” KHN (kg/mm^2) is calculated.

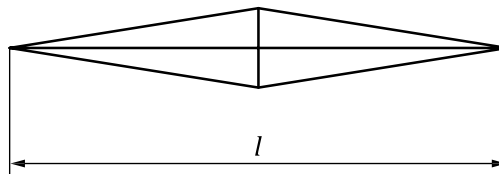
[Figure 4](#) shows the dimensions of the Knoop indenter. [Figure 5](#) shows the top view of the Knoop indentation.



Key

- α angle of the longitudinal edge ($172,5^\circ$)
- β angle of the transverse edge (130°)

Figure 4 — Dimensions of the Knoop indenter



Key

- l indentation length

Figure 5 — Top view of the Knoop indentation

— Application

The indentation test with Knoop indenter is generally applicable.

— Calibration

On a reference block the KHN value is determined and compared to the nominal value.

— Procedure

- Condition test panel (23°C / 50 % relative humidity / ≥ 24 h).
- Lower the test device onto the coating in a plane area.

- Lower the indenter and apply the specified test load.
- Leave the loaded indenter on the coating for 18 s.
- Immediately after the removal of the load, determine the indentation length l (mm) using a measuring microscope (see [Figure 5](#)).

— **Evaluation**

Calculate the KHN value using the measured length l : $KHN = 0,356 / l^2$. (Factor 0,356 results from the test load and the shape factor of the indenter.)

Test result is the KHN value (kg/mm), as mean value of n determinations. (The number n is agreed.)

NOTE In accordance with ISO 4545-1, the Knoop hardness is expressed in HK, which is different from the KHN used here.

— **Precision**

The repeatability (in accordance with ASTM D1474/D1474M) is 9 %.

The reproducibility (in accordance with ASTM D1474/D1474M) is 24 %.

— **Reference**

The indentation test with Knoop indenter is specified in ASTM D1474/D1474M-13, Method A: Knoop Indentation Hardness.

A general method for the determination of the Knoop hardness HK is specified in ISO 4545-1.

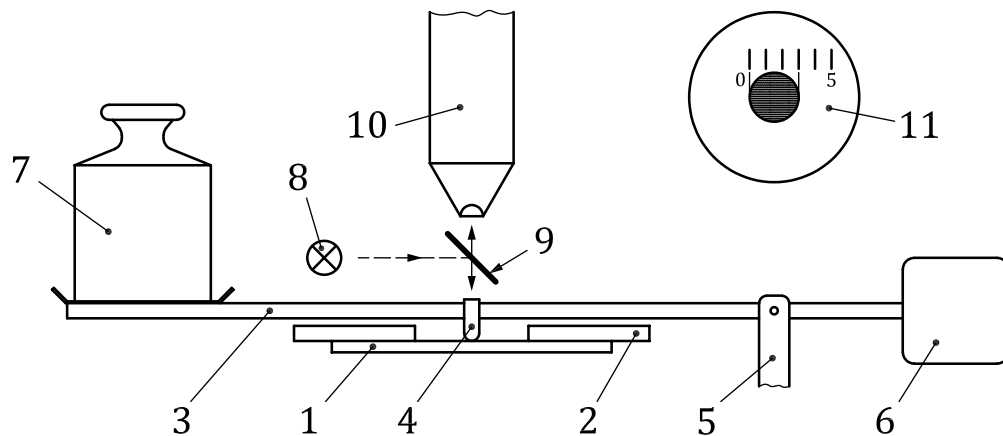
For testing automobile coatings, the method is also described in References [\[47\]](#) and [\[56\]](#).

4.1.3 Indentation test with Pfund indenter

— **Description**

A transparent quartz or sapphire indenter (hemisphere Ø 0,318 mm), the shape and dimensions of which are specified in accordance with Pfund, impacts the coating under load (1 kg, corresponding to 9,8 N) for 60 s and produces an indentation. Immediately after that the diameter (mm) of the indentation under load by the transparent indenter is determined using a measuring microscope. From this, the “Pfund Hardness Number” PHN (kg/mm²) is calculated.

[Figure 6](#) shows the principle of the indentation test with Pfund indenter.

**Key**

- 1 test panel
- 2 stop
- 3 load arm
- 4 transparent indenter
- 5 pivot
- 6 tare weight
- 7 load weight
- 8 light source
- 9 semi-transparent mirror
- 10 measuring microscope
- 11 microscopic image (Pfund indentation and scale)

Figure 6 — Principle of the indentation test**— Application**

The indentation test with Pfund indenter is generally applicable.

— Calibration

On a reference block the PHN value is determined and compared to the nominal value.

— Procedure

- Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).
- Lower the test device onto the coating in a plane area.
- Lower the indenter and apply the specified test load.
- Leave the loaded indenter on the coating for 60 s.
- After that, still loaded, determine diameter d (mm) of the indentation through the transparent indenter using a measuring microscope.

— Evaluation

Calculate the PHN value using the measured diameter d : $PHN = 1,27 / d^2$. (Factor 1,27 results from the test load and the shape factor of the indenter.)

Test result is the PHN value (kg/mm²), as mean value of at least 5 determinations.

— **Precision**

The repeatability (in accordance with ASTM D1474/D1474M) is 18 %.

The reproducibility (in accordance with ASTM D1474/D1474M) is 36 %.

— **Reference**

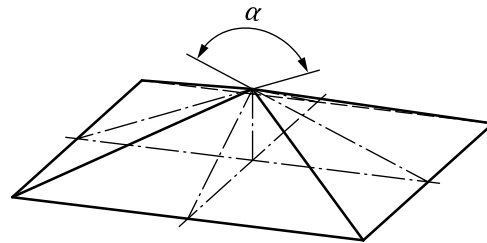
An indentation test with Pfund indenter is specified in ASTM D1474/D1474M-13, Method B: Pfund Indentation Hardness.

4.1.4 Indentation test with Vickers indenter

— **Description**

A diamond indenter, the shape and dimensions of which are specified in accordance with Vickers, is pressed into the coating under increasing, controlled load. The Martens hardness HM (N/mm^2) in dependence of the indentation depth is calculated from the measured indentation depth (μm) and the respective test load (N).

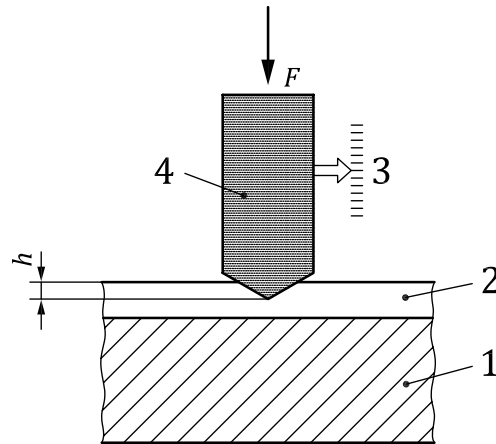
[Figure 7](#) shows the dimensions of the indenter and [Figure 8](#) shows the test principle.



Key

α pyramid angle (136°)

Figure 7 — Schematic diagram of the Vickers indenter

**Key**

- 1 substrate
- 2 coating
- 3 distance measuring device for the indentation depth
- 4 indenter with Vickers geometry
- h indentation depth
- F test load

Figure 8 — Principle of the indentation test with Vickers indenter

— **Application**

The indentation test with Vickers indenter is generally applicable.

— **Calibration**

On a certified calibration panel (e.g. glass of the BK 7 type) an indentation test with a specified load is carried out. From the load-indentation curve the HM value is determined and compared to the certified value.

— **Procedure**

- Agree the test parameters:
 - The number and the values of the test load levels (N) [the test load levels are normally selected proportionally $(\text{test load})^{1/2}$].
- Position the test panel in the test device and set the agreed test parameters.
- Start the test procedure and record the indentation depth h (μm) in dependence of test load F (N).

— **Evaluation**

Calculate the values for the Martens hardness $HM = F/26,43 h^2$ (N/mm^2) from the h -values and the corresponding F -values. (Factor 26,43 results from the shape factor of the indenter.)

Test result is the Martens hardness HM (N/mm^2) for an agreed indentation depth h (μm) and/or the hardness profile (HM as a function of h).

— **Precision**

No precision data are currently available.

— Reference

An indentation test with Vickers indenter is specified in ISO 14577-1 and ISO 14577-4.

For testing automobile coatings slightly deviating procedures are described in References [42] and [45].

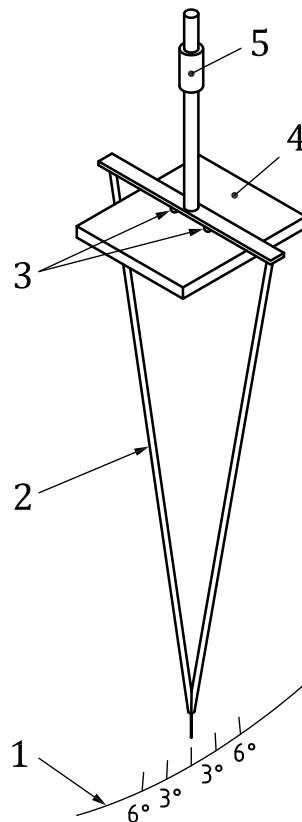
4.2 Indentation tests with oscillating indenter

4.2.1 Oscillation damping test with König pendulum

— Description

A pendulum, the shape, mass and dimensions of which are specified in accordance with König, together with its two integrated tungsten-carbide balls ($\varnothing$ 5 mm) is lowered on the coating, displaced by 6° , and released. The damping duration (s) of the pendulum swing until reaching the specified final displacement (3°) is determined.

[Figure 9](#) shows the test principle.



Key

- 1 angle scale
- 2 König pendulum
- 3 tungsten-carbide ball
- 4 test panel
- 5 adjusting weight

Figure 9 — Principle of the test with König pendulum

— **Application**

The oscillation damping test with König pendulum is generally applicable.

— **Calibration**

On a polished, plane glass panel the duration of a pendulum swing and the damping duration are determined and compared to the corresponding nominal values.

— **Procedure**

- Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).
- Position the test panel in the test device.
- Lower the pendulum with the integrated hard-metal balls onto the coating so that the tip of the pendulum is aligned with the zero point of the scale.
- Displace pendulum by 6° and release.
- Determine the damping duration (s) until reaching the final displacement (3°) by using a stop watch.

— **Evaluation**

Test result is the damping duration (s), as mean value of three determinations.

— **Precision**

The repeatability limit r is 7 s, corresponding to 5 swings.

The reproducibility limit R is 14 s, corresponding to 10 swings.

— **Reference**

The oscillation damping test with König pendulum is specified in ISO 1522 and ASTM D4366.

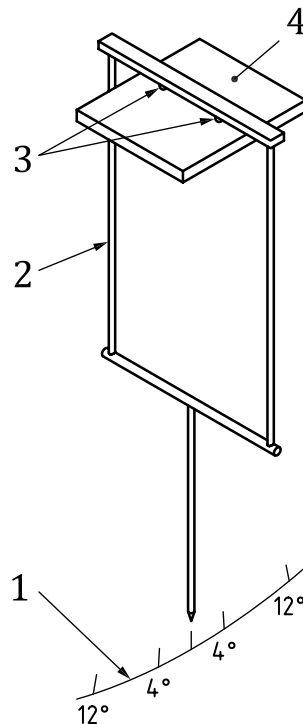
For testing automobile coatings a slightly deviating method is described in Reference [61].

4.2.2 Oscillation damping test with Persoz pendulum

— **Description**

A pendulum, the shape, mass and dimensions of which are specified in accordance with Persoz, together with its two integrated tungsten-carbide balls ($\varnothing$ 8 mm) is lowered on the coating, displaced by 12°, and released. The damping duration (s) of the pendulum swing until reaching the specified final displacement (4°) is determined.

[Figure 10](#) shows the principle.



Key

- 1 angle scale
- 2 Persoz pendulum
- 3 tungsten-carbide ball
- 4 test panel

Figure 10 — Principle of the test with Persoz pendulum

— **Application**

The oscillation damping test with Persoz pendulum is generally applicable.

— **Calibration**

On a polished, plane glass panel the duration of a pendulum swing and the damping duration are determined and compared to the corresponding nominal values.

— **Procedure**

- Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).
- Position the test panel in the test device.
- Lower the pendulum with the integrated hard-metal balls onto the coating so that the tip of the pendulum is aligned with the zero point of the scale.
- Displace pendulum by 12° and release.
- Determine the damping duration (s) until reaching the final displacement (4°) by using a stop watch.

— **Evaluation**

Test result is the damping duration (s), as mean value of three determinations.

— **Precision**

The repeatability limit r is 3 %.

The reproducibility limit R is 8 %.

— **Reference**

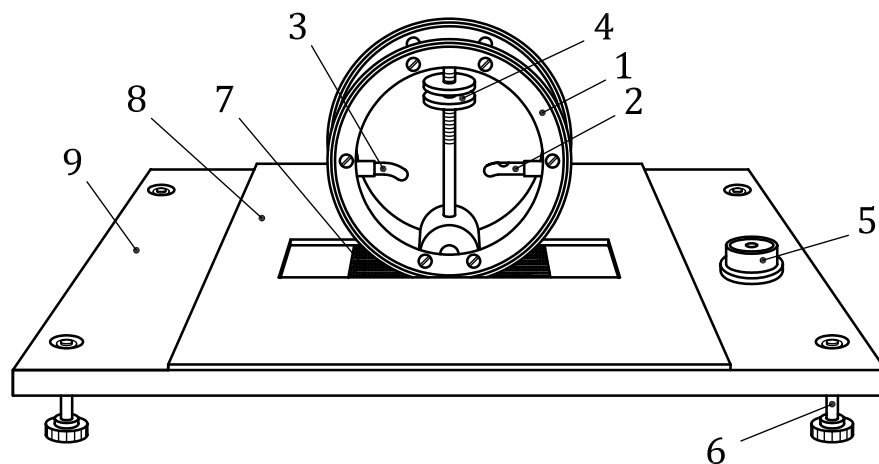
The oscillation damping test with Persoz pendulum is specified in ISO 1522 and ASTM D4366.

4.2.3 Oscillation damping test with rocker

— **Description**

A rocker, the shape, mass and dimensions of which are specified in accordance with Sward, together with its two races is lowered on the coating, displaced by 22° and released. The number of swings until reaching the specified final displacement (16°) is determined.

[Figure 11](#) shows the test arrangement.



Key

- 1 race
- 2 level for final displacement
- 3 level for initial displacement
- 4 adjustment apparatus
- 5 levelling level
- 6 adjustable foot
- 7 test panel
- 8 clamp mask
- 9 glass panel

Figure 11 — Arrangement of the oscillation damping test with rocker

— **Application**

The oscillation damping test with rocker is generally applicable.

— **Calibration**

On a glass panel the number of swings within a time period of 60 s is determined and compared to the nominal value.

— **Procedure**

- Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).
- Secure the test panel with the clamp mask on the levelled glass plate (see [Figure 11](#)).
- Lower the rocker with the two races onto the coating, displace by 22° and release.
- Determine the number of swings until reaching the final displacement (16°).

— **Evaluation**

Test result is the number of swings, multiplied by two, within the specified angle range, as mean value of four determinations.

— **Precision**

No precision data are currently available.

— **Reference**

The oscillation damping test with rocker is specified in ASTM D2134.

5 Wear resistance tests

5.1 Single-scratch tests

5.1.1 Scratch test with pencils

— **Description**

A pencil lead with specified geometry is pushed over the coating at an angle of 45° and a test load of 7,5 N. The hardness degree is gradually increased in the range of 9B to 9H until a damage of the coating is visible. The highest hardness degree is determined for which no damage is detected.

[Figure 12](#) shows the set-up of the device. [Figure 13](#) shows the shape of the pencil lead after using a special sharpener.

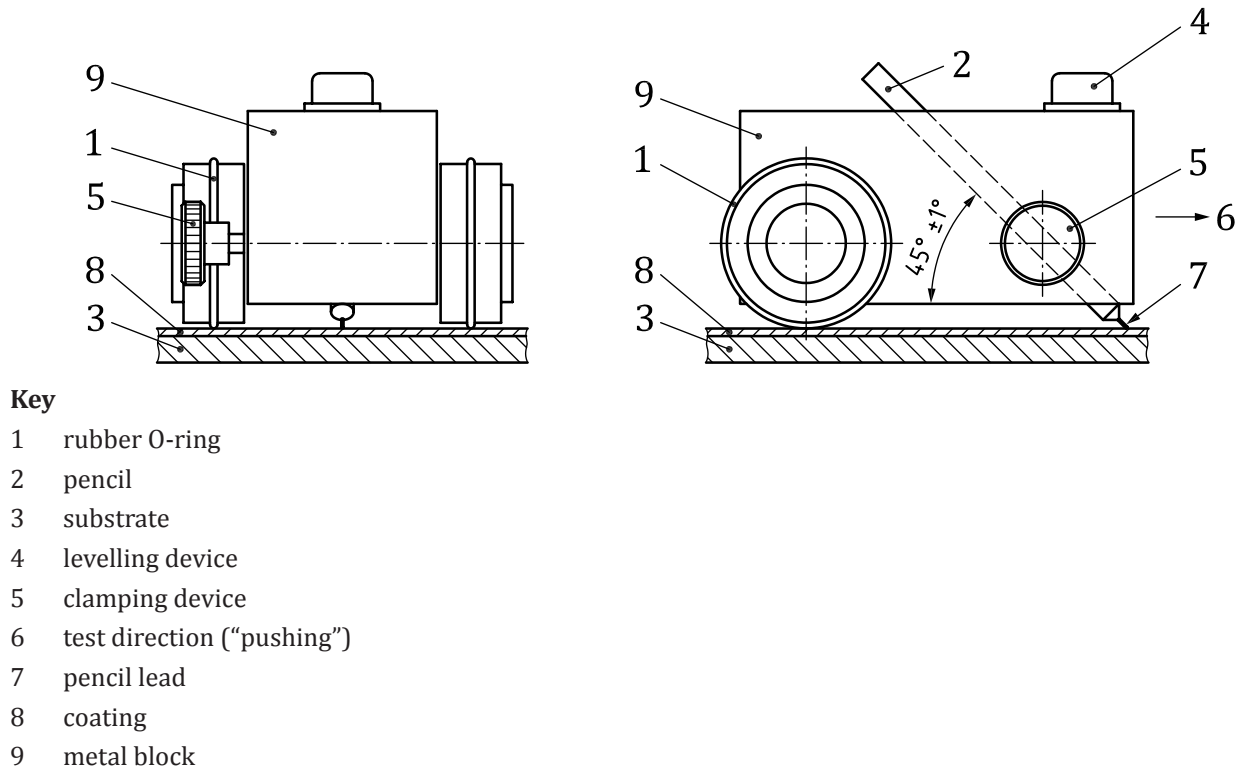
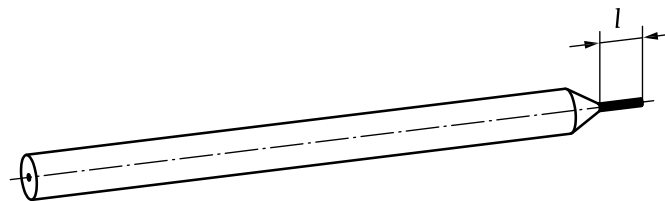


Figure 12 — Device for scratch test with pencils



Key

l lead length (5 mm to 6 mm)

Figure 13 — Pencil after sharpening

— **Application**

The scratch test with pencils is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

- Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).
- Prepare the pencils in accordance with [Figure 13](#) and sand the tips of the leads plane.
- Secure a pencil of a "medium" hardness degree in the horizontally aligned device in accordance with [Figure 12](#) and lower the device onto the coating.
- Push the loaded pencil lead over the coating with constant speed in the direction of arrow 6 in [Figure 12](#).

— After 30 s visually inspect the coating (if agreed, using a magnifier, magnification $\times 6$ to $\times 10$) for damages and, if applicable, determine the type of damage.

— Carry out further scratch tests with varied pencil hardness degrees until a damage of at least 3 mm length is detectable on the coating.

— Based on this, carry out scratch tests with decreasing pencil hardness degrees until the coating is not damaged any more.

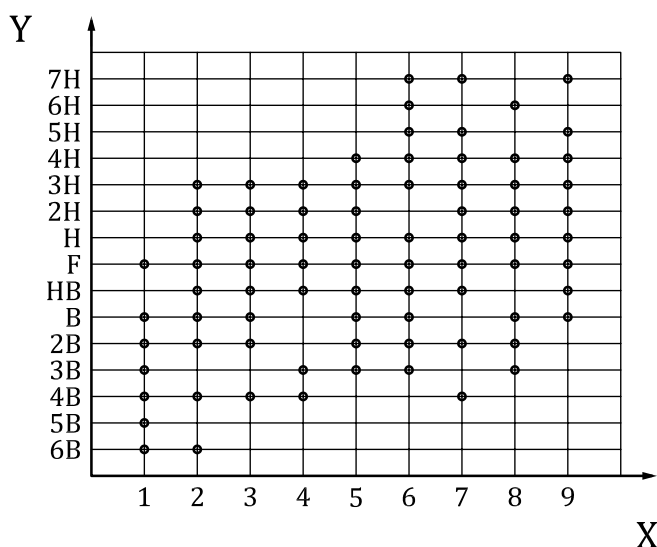
— Evaluation

Test result is the highest pencil hardness degree for which no damage, i.e. any visual deviation from the undamaged area, is detected on the coating.

— Precision

No precision data are currently available.

[Figure 14](#) graphically shows the results of scratch tests with pencils which have been carried out by different persons, on different coatings, and with different types of pencils:



Key

X identifications of coatings

Y hardness degrees of the leads

Figure 14 — Results of scratch tests with pencils

The results of the measurements in accordance with [Figure 14](#) suggest that the scratch test with pencils is not meaningful for the comparison of different coatings. It is more meaningful to carry out relative assessments within a range of test panels which show significant differences during the scratch test with pencils.

— Reference

A scratch test with pencils is specified in ISO 15184.

For testing coil coatings a slightly deviating method is described in EN 13523-4.

Further methods with higher test load are described in References [\[53\]](#) and [\[57\]](#).