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Paints and varnishes — Determination of film thickness

Peintures et vernis — Détermination de l'épaisseur du feuil

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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 2808 was prepared by Technical Committee ISO/TC 35, *Paints and varnishes*, Subcommittee SC 9, *General test methods for paints and varnishes*.

This fourth edition cancels and replaces the third edition (ISO 2808:1997), which has been technically revised. The main changes are as follows:

a)   The structure of the standard has been changed into four main clauses:

1)   determination of wet-film thickness;

2)   determination of dry-film thickness;

3)   determination of the thickness of uncured powder layers; and

4)   measurement of film thickness on rough surfaces.

b)   Methods using photothermal, radiological and acoustic techniques have been added.

c)   The split-beam method has been deleted as such instruments are no longer manufactured.

Introduction

Measurement of film thickness depends on the following steps:

a) calibration of the measurement instrument, typically performed by the manufacturer or by any qualified laboratory;

b) verification of the instrument (an accuracy check performed by the user at regular intervals, typically before each series of measurements);

c) subsequent adjustment, if necessary, of the instrument so that the thickness readings it gives match those of a specimen of known thickness. For a dry-film thickness gauge this would mean zeroing it on the uncoated surface, using devices of known thickness such as shims, or using a coated specimen of known film thickness;

d) measurement.

Paints and varnishes — Determination of film thickness

1   Scope

This International Standard describes a number of methods that are applicable to the measurement of the thickness of coatings applied to a substrate. Methods for determining wet-film thickness, dry-film thickness and the film thickness of uncured powder layers are described. Reference is made to individual standards where these exist. Otherwise the method is described in detail.

An overview on the methods is given in Annex A, in which the field of application, existing standards and the precision are specified for the individual methods.

This International Standard also defines terms concerning the determination of film thickness.

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 463, *Geometrical Product Specifications (GPS) — Dimensional measuring equipment — Design and metrological characteristics of mechanical dial gauges*

ISO 3611, *Micrometer callipers for external measurement*

ISO 4618:2006, *Paints and varnishes — Terms and definitions*

ISO 8503-1, *Preparation of steel substrates before application of paints and related products — Surface roughness characteristics of blast-cleaned steel substrates — Part 1: Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces*

3   Terms and definitions

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

3.1
substrate
surface to which a coating material is applied or is to be applied

[ISO 4618:2006]

3.2
coating
continuous layer formed from a single or multiple application of a coating material to a substrate

[ISO 4618:2006]

3.3
film thickness
distance between the surface of the film and the surface of the substrate

3.4
wet-film thickness
thickness of a freshly applied wet coating material, measured immediately after application

3.5
dry-film thickness
thickness of a coating remaining on the surface when the coating has hardened

3.6
thickness of uncured powder layer
thickness of a freshly applied coating material in powder form, measured immediately after application and before stoving

3.7
relevant surface area[1]
part of an article covered or to be covered by the coating and for which the coating is essential for serviceability and/or appearance

3.8
test area[1]
representative part of the relevant surface area within which an agreed number of single measurements is made as a spot-check

3.9
measurement area[1]
area over which a single measurement is made

3.10
minimum local film thickness[1]
lowest value of the local film thickness found on the relevant surface area of a particular test specimen

3.11
maximum local film thickness[1]
highest value of the local film thickness found on the relevant surface area of a particular test specimen

3.12
mean film thickness[1]
arithmetic mean of all the individual dry-film thicknesses in the test area or the result of a gravimetric determination of the thickness

3.13
calibration
controlled and documented process of measuring traceable calibration standards and verifying that the results are within the stated accuracy of the measurement instrument

NOTE   Initial calibration is typically performed by the instrument manufacturer or by a qualified laboratory in a controlled environment using a documented process. This initial calibration will normally be verified by the user at regular intervals. The standards used in the calibration are such that the combined uncertainties of the resultant measurement are less than the stated accuracy of the instrument.

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1) Measurement of this property is only required for the extended evaluation of film thickness measurements; see Clause 8 (test report), items k) and l).

3.14
verification
accuracy check performed by the user using reference standards

3.15
reference standard
specimen of known thickness against which a user can verify the accuracy of the measurement instrument

NOTE   Reference standards may be coated thickness standards, or shims. If agreed to by the contracting parties, a part of the test specimen may be used as a thickness standard for a particular job.

3.16
adjustment
act of aligning the measurement instrument's thickness readings to match those of a reference standard

NOTE   Most electronic measurement instruments can be adjusted on a thickness standard or on a shim, where the thickness of the coating or of the shim is known.

3.17
accuracy
consistency between a measured value and the true value of the thickness standard

4   Determination of wet-film thickness

4.1   General

Annex A gives an overview of the methods used for the determination of wet-film thickness.

4.2   Mechanical methods

4.2.1   Principle

In all mechanical methods the substrate surface is contacted by part of the measurement instrument through the coating, and the surface of the coating is contacted simultaneously (see Figure 1) or subsequently (see Figures 2 and 3) by another part of the instrument. The wet-film thickness is the height difference between these two points of contact, which can be read directly.

4.2.2   Field of application

The mechanical principle is suitable for all film-substrate combinations. The substrate has to be flat in at least one direction in the area where the measurement is conducted. Curvature of the surface in a single plane is permissible (e.g. internal or external surface of pipes).

4.2.3   General

Classification as a destructive or non-destructive method depends on:

a)   the rheological properties of the coating material;

b)   the nature of the wetting contact between the contact surfaces of the measurement instrument and the coating material;

c)   whether the thickness measurements will make the coating unsuitable for the purpose for which it is intended.

Since the possibility of pigment particles remaining between the gauge and the substrate cannot be excluded, all mechanical methods contain a systematic error: the film thickness displayed is smaller than the actual wet-film thickness by at least the mean diameter of the pigment particles.

In the case of a wheel gauge (method 1B, see 4.2.5), the wheel has to be wetted by the coating material. If not, this represents a further source of systematic error which can result in exaggerated readings and is a function of:

— the surface tension and the rheological properties of the coating material;

— the material of the wheel gauge;

— the speed at which the wheel is turned.

4.2.4 Method 1A — Comb gauge

4.2.4.1 Description of instrument

A comb gauge is a flat plate made of a corrosion-resistant material with teeth along its edges (see Figure 1). The reference teeth at the corners of the plate define a baseline along which the inner teeth are arranged to give a graduated series of gaps. Each tooth is labelled with the assigned gap value.

With commercially available comb gauges the maximum thickness which can be measured is typically 2 000 µm and the smallest increment is typically 5 µm.

Key
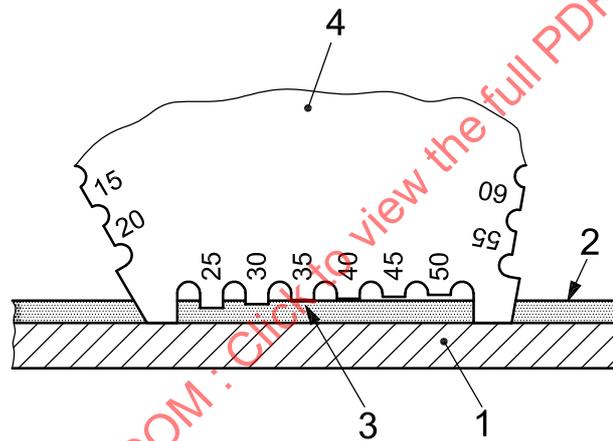
1 substrate
2 coating
3 point of wetting contact
4 comb gauge

Figure 1 — Example of a comb gauge

4.2.4.2 Procedure

Ensure that the teeth are clean and not worn or damaged. Place the comb gauge onto the flat specimen surface such that the teeth are normal to the plane of the surface. Allow sufficient time for the coating to wet the teeth prior to removing the gauge.

In the case of specimens curved in a single plane, the comb gauge shall be placed in position parallel to the axis of curvature.

The result of the thickness measurement depends on the time of measurement. The thickness should therefore be measured as soon as possible after application.

Note the greatest gap reading of the tooth wetted by the coating material as the wet-film thickness.

4.2.5   Method 1B — Wheel gauge

4.2.5.1   Description of instrument

A wheel gauge consists of a wheel, made of hardened and corrosion-resistant steel, with three projecting rims (see Figure 2).

Two rims are ground to the same diameter and are configured concentrically to the wheel axle. The third rim has a smaller diameter and is eccentrically ground. One of the outer rims has a scale from which the respective projection of the concentric rims relative to the eccentric rim can be read.

Two versions are available:

—   version 1 has the eccentric rim located between the concentric rims;

—   version 2 has the eccentric rim located outside the concentric rims and closely adjacent to one of them.

NOTE   Unlike version 1, the design of version 2 allows parallax-free reading of the wet-film thickness.

With commercially available wheel gauges, the maximum thickness which can be measured is typically 1 500 µm and the smallest increment is typically 2 µm.

Key
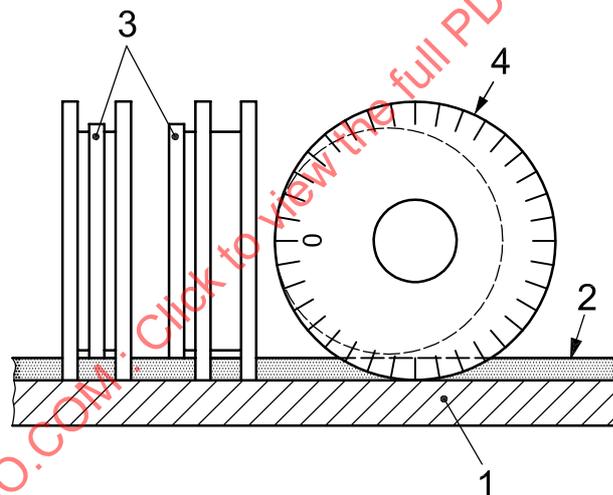
1   substrate
2   coating
3   eccentric rim
4   wheel gauge

Figure 2 — Example of a wheel gauge

4.2.5.2   Procedure

Grip the wheel gauge with the thumb and index finger by the wheel axle and press the concentric rims onto the surface at the point of the largest reading on the scale.

In the case of specimens curved in a single plane, the axis of curvature and the wheel gauge axle shall be parallel.

Roll the wheel gauge in one direction, lift it from the surface and read off the highest scale reading at which the eccentric rim is still wetted by the coating material. Clean the gauge and repeat in the other direction.

Calculate the wet-film thickness as the arithmetic mean of these readings.

The result of the thickness measurement depends on the time of measurement. The thickness should therefore be measured as soon as possible after application.

To minimize the effect of surface tension on the result, observe how the paint wets the eccentric rim and record the scale reading at the first point of contact. This is only possible with version 2 of the wheel gauge.

4.2.6   Method 1C — Dial gauge

4.2.6.1   Instrument and reference standards

4.2.6.1.1   **Dial gauge** (see Figure 3)

Mechanical dial gauges conforming to the requirements of ISO 463 and electronic dial gauges are typically capable of measuring to an accuracy of 5 μm (mechanical dial gauge) or 1 μm (electronic dial gauge), or better. The gauge can have an analogue or digital display.

The underside of the dial gauge has two contact pins of equal length located equidistant from the movable plunger and in a straight line with it. An adjusting screw is used to make fine adjustments to the position of the plunger in its guideway.

Key
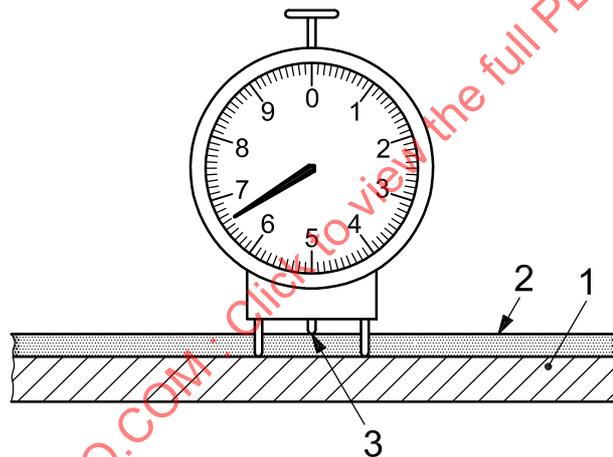
1   substrate
2   coating
3   plunger

Figure 3 — Example of a dial gauge

4.2.6.1.2   Reference standard for zeroing the gauge

A flat reference plate is required for zeroing the gauge. The reference plate shall consist of a flat glass plate whose flatness tolerance does not exceed 1 μm (see also ISO 1101 [1]).

4.2.6.2   Procedure

Zero the dial gauge on the reference plate with the measuring tip adjusted so that it is just touching the plate.

Screw the plunger back from the zeroing position. Place the contact pins of the dial gauge on the specimen so that they are normal to the surface of the substrate and carefully screw the plunger down until the measuring tip is just touching the coating material.

The result of the thickness measurement depends on the time of measurement. The thickness should therefore be measured as soon as possible after application.

Read the wet-film thickness directly from the gauge.

4.3 Gravimetric method

4.3.1 Principle

A coating is applied and the thickness is determined by dividing the mass of the coating by its density and by the coated surface area.

The wet-film thickness, t_w, in micrometres, is calculated from the equation

$$t_w = \frac{m - m_0}{A \cdot \rho} \tag{1}$$

where

m_0 is the mass of the uncoated specimen, in grams;

m is the mass of the coated specimen, in grams;

A is the coated surface area, in square metres;

ρ is the density of the liquid coating material applied, in grams per millilitre.

NOTE   The density of the liquid coating material applied can be determined in accordance with ISO 2811-1, ISO 2811-2, ISO 2811-3 or ISO 2811-4.

4.3.2 Field of application

The gravimetric principle is generally applicable, provided that the amount of highly volatile substances in the liquid coating material is low.

4.3.3 General

Determination using the gravimetric principle yields the mean value of the wet-film thickness over the entire coated surface area. With spray application in particular, the reverse side of the specimen shall be masked to prevent measurement errors resulting from partial coating of the reverse (overspray). Any masking of the reverse side shall be removed before weighing the coated specimen.

4.3.4 Method 2 — By difference in mass

4.3.4.1 Apparatus

Required are scales capable of weighing up to 500 g to the nearest 1 mg.

4.3.4.2 Procedure

Weigh the specimen first uncoated and then coated and calculate the wet-film thickness using Equation (1).

4.4 Photothermal method

4.4.1 Principle

The film thickness is determined from the difference between the time a thermal wave is radiated towards the coating and the time the re-emitted wave (either heat or ultrasonic) is detected (see Figure 4).

Irrespective of the type of excitation involved or the method of detection, all photothermal methods use the same principle: the periodic or pulsed introduction of energy in the form of heat into a specimen and the subsequent detection of the local temperature increase.

The time difference measured is compared against values obtained with the instrument for films of known thickness under fixed conditions (excitation energy, pulse length, excitation frequency, etc.) (see 4.4.2).
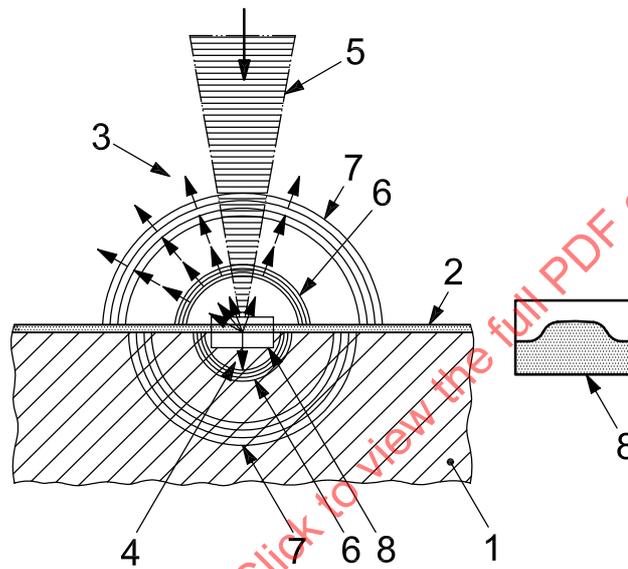
Key

1   substrate
2   coating
3   re-emitted thermal radiation
4   absorption of radiation by coating (depends on coating thickness and coating material)
5   thermal irradiation
6   thermal waves
7   ultrasonic waves
8   surface deformation

Figure 4 — Interaction of radiation with the specimen in photothermal thickness measurement, showing surface deformation

4.4.2 Field of application

The photothermal principle is basically suitable for all film-substrate combinations. It can also be used to determine the thicknesses of the individual layers in a multilayer coating, provided the layers are sufficiently distinct from each other with respect to their thermal conductivity and reflection properties.

The required minimum substrate thickness is a function of the measurement system used (see 4.4.4.1.1) and the film-substrate combination.

4.4.3 General

Classification of the method as destructive or non-destructive depends on the purpose of the coating. The thermal energy absorbed by the coating could have an impact on the coating owing to the local heating effect produced (see item 8 in Figure 4).

4.4.4 Method 3 — Determination using thermal properties

4.4.4.1 Instrument and reference standards

4.4.4.1.1 Measurement system

There are various methods for producing thermal waves in a coating material and for detecting the thermal effects induced at the heated location in the specimen (see EN 15042-2 [18]). Thermal radiation sources (e.g. laser sources, light-emitting diodes, incandescent light sources) are mainly used as the excitation system for paint coatings.

The following detection methods are used:

— detection of the re-emitted thermal radiation (photothermal radiometry);

— detection of the change in refractive index (in the heated air above the measurement area);

— pyroelectric detection (heat flow measurement).

4.4.4.1.2 Reference standards

Reference specimens with different absorption properties and a range of film thicknesses are required for calibration purposes (see EN 15042-2 [18]).

4.4.4.2 Calibration

Calibrate the measurement system with the reference specimens (see 4.4.4.1.2) for each film-substrate combination (in particular for each coating material).

4.4.4.3 Procedure

Operate the apparatus and measure the film thickness in accordance with the manufacturer's instructions.

5 Determination of dry-film thickness

5.1 General

Annex A gives an overview of the methods used for determination of dry-film thickness.

5.2 Mechanical methods

5.2.1 Principle

A micrometer or dial gauge (method 4A, see 5.2.4) is used to measure the film thickness as the difference between the total thickness (substrate + film) and the substrate thickness.

There are two ways of determining the film thickness:

a)   Measurements are made before and after coating removal (destructive)

The total thickness is first measured in a defined measurement area and then, after the coating has been removed in the measurement area, the substrate thickness is measured.

b)   Measurements are made before and after coating application (non-destructive)

The substrate thickness is first measured and then the total thickness is measured in the same measurement area after coating.

The film thickness is calculated from the difference between the two readings.

A depth gauge (method 4B, see 5.2.5) or a profilometer (method 4C, see 5.2.6) enable the film thickness to be determined directly as the difference in height between the surface of the film and the surface of the exposed substrate.

NOTE   Only the "coating removal" variant is possible with a depth gauge or profilometer (methods 4B and 4C).

5.2.2   Field of application

The mechanical principle is basically suitable for all film-substrate combinations. Where mechanical gauging is used, the substrate and coating shall be hard enough to prevent the reading from being falsified as a result of the measuring tip creating an indentation.

The micrometer or dial gauge (method 4A) is also suitable for measuring the film thickness of cylindrical specimens of circular cross-section (e.g. wires, pipes).

The profilometer (method 4C) is recognized as the referee method in the event of disputes.

5.2.3   General

In the "coating application" variant, a template with labelled holes is used to ensure that the determination of the substrate thickness and total thickness is carried out at exactly the same points.

NOTE 1   The "coating application" variant is preferred in the case of plastic substrates since in most cases the substrate cannot be exposed without causing damage.

In the "coating removal" variant, the measurement areas shall be circled and labelled. The coating shall be carefully and completely removed in the measurement areas without damaging the substrate mechanically or chemically. The substrate may be partly masked using adhesive tape before coating in order to obtain well-defined steps from one layer to the next.

In the case of the depth gauge and profilometer (methods 4B and 4C), the coating which is not removed in the region of the measurement area shall remain undamaged.

In the case of the profilometer (method 4C), the shoulder between the substrate and the film surface shall be sufficiently well defined.

With hard substrates (e.g. glass) the coating can be removed mechanically, but with less hard substrates (e.g. steel) the coating shall be removed chemically using a solvent or paint remover.

NOTE 2   In the case of less hard substrate materials such as steel, the film can be cut through with a core drill of 10 mm diameter and the disc of coating thus formed removed with a solvent or paint remover.

All surfaces (coating, substrate, reverse side of specimen) which are contacted or gauged shall be clean and free from film residues.

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5.2.4   Method 4A — By difference in thickness

5.2.4.1   Description of instrument

5.2.4.1.1   Micrometer

The micrometer shall be capable of measuring to the nearest 5 µm. It shall be fitted with a ratchet to limit the force exerted by the spindle on the test surface.

Version 1 — Fixed to a stand

A micrometer head with a plane measuring face is clamped to a rigid stand with a flat baseplate such that its height can be adjusted. The measuring face shall be aligned parallel to the top of the baseplate.

Version 2 — Hand-held (see Figure 5)

The usual term for this kind of instrument is an outside micrometer, although it is also known as micrometer callipers for exterrnal use (see ISO 3611). The micrometer shall conform to the requirements of ISO 3611. The measuring faces of the spindle and the anvil shall be plane and parallel to each other.
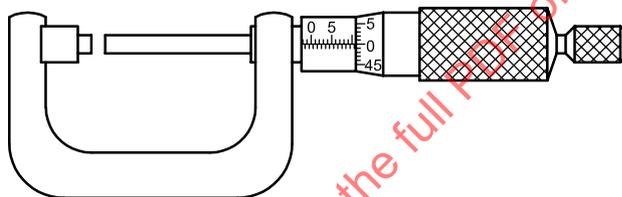
Figure 5 — Outside micrometer

5.2.4.1.2   Dial gauge

Mechanical dial gauges conforming to the requirements of ISO 463 and electronic dial gauges are typically capable of measuring to an accuracy of 5 µm (mechanical dial gauge) or 1 µm (electronic dial gauge), or better. The gauge shall be fitted with a device for lifting the measuring tip. The shape of the measuring tip shall be selected as a function of the hardness of the coating material whose thickness is to be measured (spherical for hard materials, plane for soft materials).

Version 1 — Fixed to a stand

The dial gauge is clamped to a stand as shown in Figure 6. If a plane stylus tip is used, the measurement surface shall be aligned parallel to the top of the baseplate.
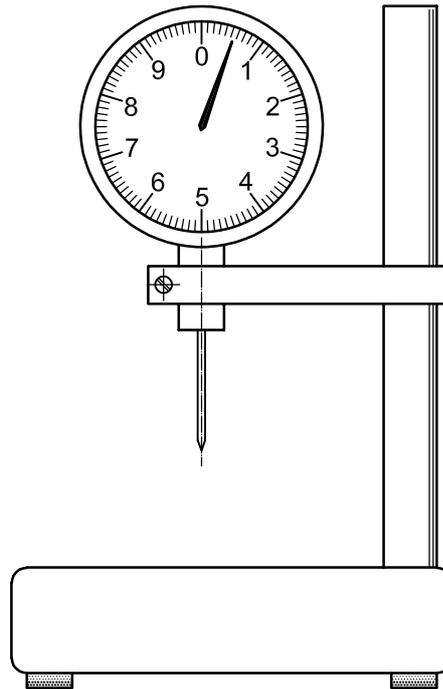
Figure 6 — Dial gauge fixed to a stand

Version 2 — Hand-held

This dial gauge is fitted with a hand grip. The device for lifting the plunger shall be configured such that the thickness gauge can be operated with one hand. The interchangeable tip of the anvil shall be located opposite the movable measuring tip. The shape of the measuring tip shall be selected as a function of the hardness of the material to be tested (spherical for hard materials, plane for soft materials).

If both the measuring tip and the anvil are of plane design (such as in the foil thickness gauge shown in Figure 7), the measurement surfaces shall be parallel to each other.
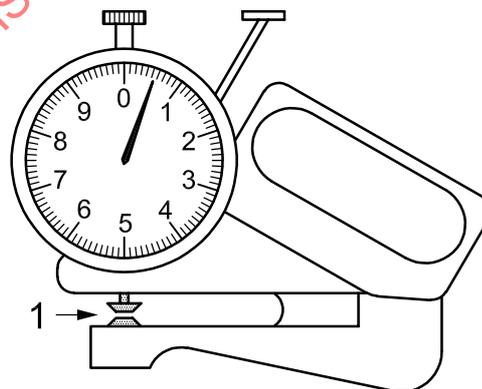
Key

1   gauge aperture

Figure 7 — Foil thickness gauge

5.2.4.2 Procedure

Prepare the specimen as specified in 5.2.3 for the "coating removal" and "coating application" variants (see 5.2.1).

Operate all instruments so that the coated side of the specimen or the side to be coated is facing the spindle (micrometer, see 5.2.4.1.1) or the contact element (dial gauge, see 5.2.4.1.2) in the "coating removal" and "coating application" variants, respectively.

When using an instrument clamped to a stand (5.2.4.1.1 and 5.2.4.1.2, version 1 in each case) place the specimen on the baseplate.

When using a hand-held type (5.2.4.1.1 and 5.2.4.1.2, version 2 in each case) hold the specimen against the fixed measuring tip.

NOTE   The grip of the instruments specified in 5.2.4.1.1 and 5.2.4.1.2, version 2 in each case, can be clamped to a stand to make operation easier.

Repeat the procedure for the second measurement after removing the film ("coating removal") or applying the film ("coating application").

Carry out each measurement such that:

— when using a micrometer as described in 5.2.4.1.1, the spindle is moved against the surface to be tested until the ratchet is activated;

— when using a dial gauge as described in 5.2.4.1.2, the surface is carefully contacted by the tip of the spring-loaded contact element.

The film thickness is the difference between the reading obtained for the total thickness and that obtained for the substrate thickness.

5.2.5 Method 4B — Depth gauging

5.2.5.1 Instrument and reference standards

5.2.5.1.1 Version 1 — Micrometer depth gauge (see Figure 8)

Micrometers of this type are typically capable of measuring to the nearest 5 μm, or better. The micrometer shall be fitted with a ratchet to limit the force exerted by the contact element on the substrate. It has a flat base or foot which is placed on the coating surface and acts as a reference plane.

Key
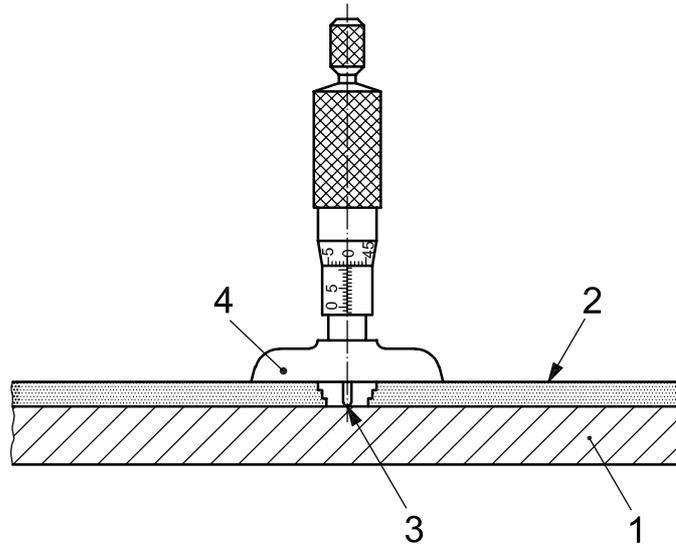
1   substrate
2   coating
3   contact element
4   flat base or foot

Figure 8 — Micrometer depth gauge

5.2.5.1.2   Version 2 — Dial depth gauge (see Figure 9)

Mechanical dial gauges conforming to the requirements of ISO 463 and electronic dial gauges are typically capable of measuring to an accuracy of 5 μm (mechanical dial gauge) or 1 μm (electronic dial gauge), or better. The gauge can have a flat base or foot which is placed on the coating surface and acts as a reference plane.

Key
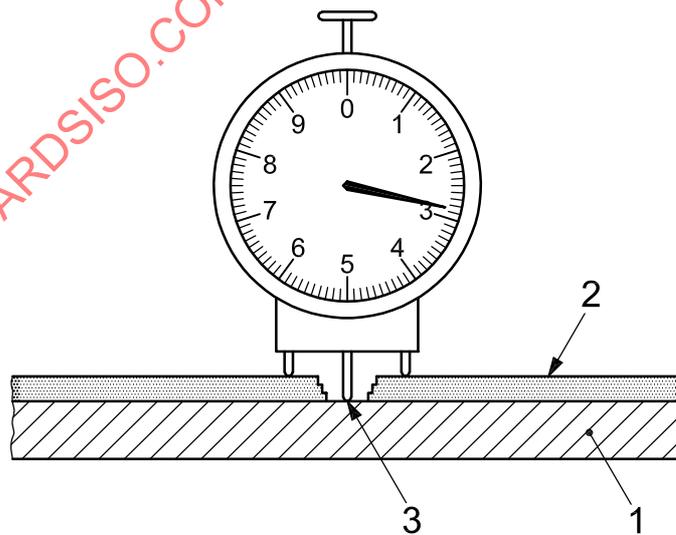
1   substrate
2   coating
3   contact element

Figure 9 — Dial depth gauge

5.2.5.1.3 Reference standard for zeroing the gauge

A flat reference plate is required for zeroing the gauge. The reference plate shall consist of a flat glass plate whose flatness tolerance does not exceed 1 μm (see also ISO 1101 [1]).

5.2.5.2 Procedure

Remove the coating from the measurement area. Zero the instrument by checking the zero point with the reference plate (5.2.5.1.3) and then:

a) when using a micrometer depth gauge, place the foot on the coating surface so that the spindle is above the exposed area and screw the spindle down until the tip touches the substrate and the ratchet is actuated;

b) when using a dial depth gauge, place the contact element on the exposed substrate and the foot (or contact pins) on the coating (if the gauge is of the type with contact pins, care shall be taken to ensure that they are normal to the specimen surface).

The film thickness can be read off directly as a depth reading (correcting, as necessary, for any zero error).

5.2.6 Method 4C — Surface profile scanning

5.2.6.1 Description of instrument

This instrument comprises a traversing stylus connected to suitable amplifying and recording equipment. For the purposes of film-thickness measurements, the instrument is used to record the profile of a shoulder formed between the substrate and the coating by removal of part of the coating (see Figure 10). Roughness or profile gauges with a freely moving stylus in which the radius of the stylus tip is selected to match the roughness of the substrate and film surface are the most suitable.

NOTE   Measurements can also be made optically or acoustically (i.e. without any contact with the specimen).

Key
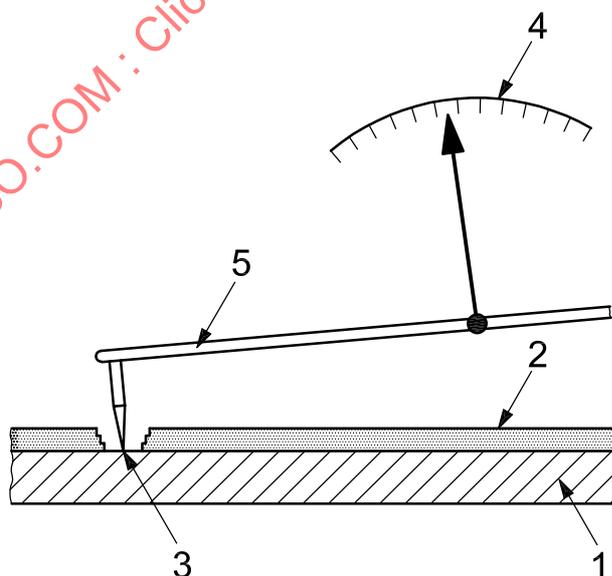
1   substrate
2   coating
3   stylus tip
4   scale
5   lever

Figure 10 — Surface profile scanner

5.2.6.2   Procedure

Prepare the specimen as specified in 5.2.3. Scan and record the surface profile in the measurement area using an appropriate monitor and plotter.

The following factors can adversely affect the readings:

⸺ inadequately cleaned surfaces;

⸺ vibrations in the gauging system;

⸺ the use of an unsuitable stylus tip.

Draw reference lines through the mean height of the trace recorded for the film surface (upper line) and through the trace recorded for the substrate (lower line). Measure the film thickness as the distance between the reference lines at the mid-point of the shoulder.

5.3   Gravimetric method

5.3.1   Principle

The dry-film thickness, t_d, in micrometres, is calculated from the difference between the mass of the uncoated specimen and that of the coated specimen using the following equation:

$$t_d = \frac{m - m_0}{A \cdot \rho_0}$$

(2)

where

m_0 is the mass of the uncoated specimen, in grams;

m is the mass of the coated specimen, in grams;

A is the coated surface area, in square metres;

ρ_0 is the density of the dry coating material applied, in grams per millilitre.

NOTE   The dry-film density of the coating material can be determined in accordance with ISO 3233.

5.3.2   Field of application

The gravimetric method has general applicability.

5.3.3   General

Using the gravimetric method yields the mean value of the dry-film thickness over the entire coated surface area. With spray application in particular, the reverse side of the specimen shall be masked to prevent measurement errors resulting from partial coating of the reverse (overspray).

5.3.4   Method 5 — By difference in mass

5.3.4.1   Apparatus

Required are scales capable of weighing up to 500 g to the nearest 1 mg.

5.3.4.2 Procedure

Weigh the clean uncoated specimen, coat it, dry it and reweigh. Calculate the dry-film thickness using Equation (2).

5.4 Optical methods

5.4.1 Principle

In the cross-sectioning method (method 6A, see 5.4.4) the specimen is ground/cut along a plane normal to the coating so that the film thickness can be measured directly using a microscope (see Figure 11).

Key
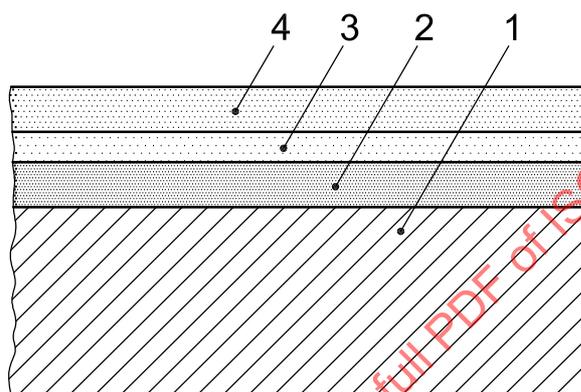
1   substrate
2   coating 1
3   coating 2
4   coating 3

Figure 11 — Cross-sectioned specimen

With the wedge cut method (method 6B, see 5.4.5) a cut of defined dimensions is made in the coating using a cutting tool at a specified angle to the surface (see Figure 12). The film thickness, t, is calculated using the equation

$$t = b \cdot \tan \alpha \tag{3}$$

where

b is the projected half-width of the cut (from the edge to the substrate), determined using a microscope;

α is the angle of cut.

Key

1   substrate
2   coating
3   symmetrical cut
4   conical bore
5   sloping cut

Figure 12 — Symmetrical cut, conical bore and sloping cut

The symmetrical wedge cut (No. 3 in Figure 12) can be made in the coating using a special blade, the conical bore (No. 4 in Figure 12) by a special borer and the sloping cut (No. 5 in Figure 12) with a milling tool.
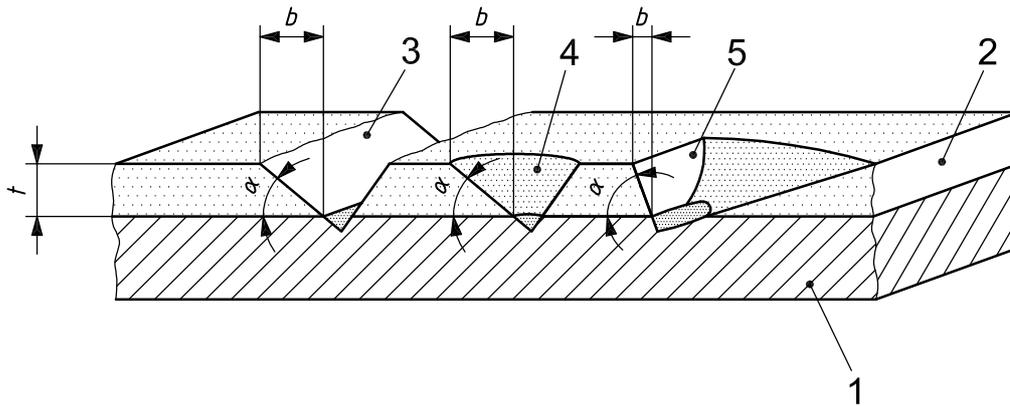
5.4.2   Field of application

The optical principle is basically suitable for all film-substrate combinations. The thicknesses of the individual layers in a multilayer coating can also be measured, provided the layers are sufficiently distinct from each other.

If the cross-sectioning or wedge cut method is used, the substrate will have to have the properties necessary for it to be sectioned, bored or cut.

In the event of a dispute, the cross-sectioning method (method 6A, see 5.4.4) is recognized as the referee method.

5.4.3   General

The specimen shall be flat for the wedge cut method (see, however, the Note to 5.4.5.2).

If the coating material is elastic, the cross-section/wedge cut can be so deformed that measurement gives invalid results. This effect may be reduced by cooling the specimen before making the cut.

In the event of a brittle and/or inadequately bonded coating, delamination of the film can make it difficult to determine the true interface between the coating and the substrate. There might, therefore, be an error in the readings.

5.4.4 Method 6A — Cross-sectioning

5.4.4.1 Version 1 — By grinding

5.4.4.1.1 Apparatus and materials

5.4.4.1.1.1 Grinding and polishing machine

Apparatus which is used for producing metallographic preparations is suitable.

5.4.4.1.1.2 Embedding medium

Use a cold-setting resin that has no deleterious effect on the paint coating and gives gap-free embedding.

5.4.4.1.1.3 Grinding and polishing media

Use waterproof abrasive paper, for example 280, 400 and 600 grit, or suitable grades of diamond paste or a similar paste.

5.4.4.1.1.4 Measuring microscope

Required is a microscope with a suitable illumination system giving optimum image contrast. The magnification shall be chosen such that the field of vision corresponds to 1,5 to 3 times the film thickness. The eyepiece or optoelectronic measurement device shall permit measurements to be made to an accuracy of at least 1 µm.

5.4.4.1.2 Procedure

Embed the specimen or a representative sample of the specimen in the resin (5.4.4.1.1.2). Wet-polish the specimen or sample using the grinding and polishing machine (5.4.4.1.1.1) along a plane normal to the coating surface. Repeat this process with an ever-finer grade of abrasive. Measure the thickness(es) of the exposed layer(s) using the microscope.

5.4.4.2 Version 2 — By cutting

5.4.4.2.1 Apparatus

5.4.4.2.1.1 Cutter

Required is a traversing or rotary microtome with carbide blades of suitable geometry and a holder for clamping the specimen in place.

5.4.4.2.1.2 Measuring microscope

Required is a microscope with a suitable illumination system giving optimum image contrast. The magnification shall be chosen such that the field of vision corresponds to 1,5 to 3 times the film thickness. The eyepiece or optoelectronic measurement device shall permit measurements to be made to an accuracy of at least 1 µm.

5.4.4.2.2 Procedure

Clamp the specimen or a representative sample taken from the specimen in the microtome specimen holder and cut along a plane normal to the coating surface. Measure the thicknesses of the exposed layers using the microscope.

5.4.5 Method 6B — Wedge cut

5.4.5.1 Apparatus

5.4.5.1.1 General

A cutter and a measuring microscope are required for the wedge cut method. These can both be incorporated in a single instrument.

5.4.5.1.2 Cutter

Required is a special instrument with a replaceable cutting tool for producing precise cuts at the specified angle.

The cutting tool (cutting blade, special paint borer or milling tool) shall

— be made of a carbide material;

— have precisely ground cutter flanks;

— be of suitable geometry to ensure accurate wedge cuts.

Standard cutting angles are in the range α = 5,7° (tanα = 0,1) to α = 45° (tanα = 1).

5.4.5.1.3 Measuring microscope

Required is a microscope with approximately ×50 magnification and an illumination device. The eyepiece shall permit measurements to be made to the nearest 20 μm.

5.4.5.2 Procedure

Mark the specimen with, for example, a felt-tip pen in a contrasting colour in the measurement area. Make the cut or bore through this mark. The cut or bore shall penetrate into the substrate. Using the mark to locate the cut or bore with the microscope, measure the projected half-width, b, and calculate the film thickness(es) using Equation (3) (see 5.4.1).

NOTE   Equation (3) cannot be used with curved surfaces. A modified calculation formula can be used for conical bores in curved surfaces, however.

5.5 Magnetic methods

5.5.1 General

With most magnetic-type dry-film thickness gauges, it is imperative that they are checked prior to readings being taken. Verification in accordance with the manufacturer's instructions shall be carried out within the range of thicknesses expected for the coating.

5.5.2 Principle

The film thickness is determined from the interaction between a magnetic field and the metallic substrate. The film thickness is determined from the force required to remove a magnet from the coating (method 7A, see 5.5.5), or from changes in the magnetic field (methods 7B, 7C and 7D, see 5.5.6, 5.5.7 and 5.5.8).

5.5.3 Field of application

Magnetic methods are suitable for coatings on metal substrates.

For methods 7A, 7B and 7C, the substrate must be ferromagnetic, and for method 7D non-ferromagnetic.

The properties of the coating shall be such that the reading is not rendered invalid when the instrument touches the coating surface.

5.5.4 General

The magnetic field produced by the instrument can be affected by the following factors:

— the geometry of the substrate (dimensions, curvature and thickness);

— the properties of the substrate material (e.g. permeability, conductivity and properties resulting from any pretreatment);

— the roughness of the substrate;

— other magnetic fields (residual magnetism of the substrate and external magnetic fields).

5.5.5 Method 7A — Magnetic pull-off gauge

5.5.5.1 Description of instrument

This instrument contains a magnet for determining the film thickness from the force of attraction between the magnet and the substrate [see Figures 13a) and 13b)].

NOTE   The instrument shown in Figure 13a) can be used in any position. The instrument shown in Figure 13b) is designed for use only in one orientation because of the effect of gravity.

a) Version 1   b) Version 2

Key
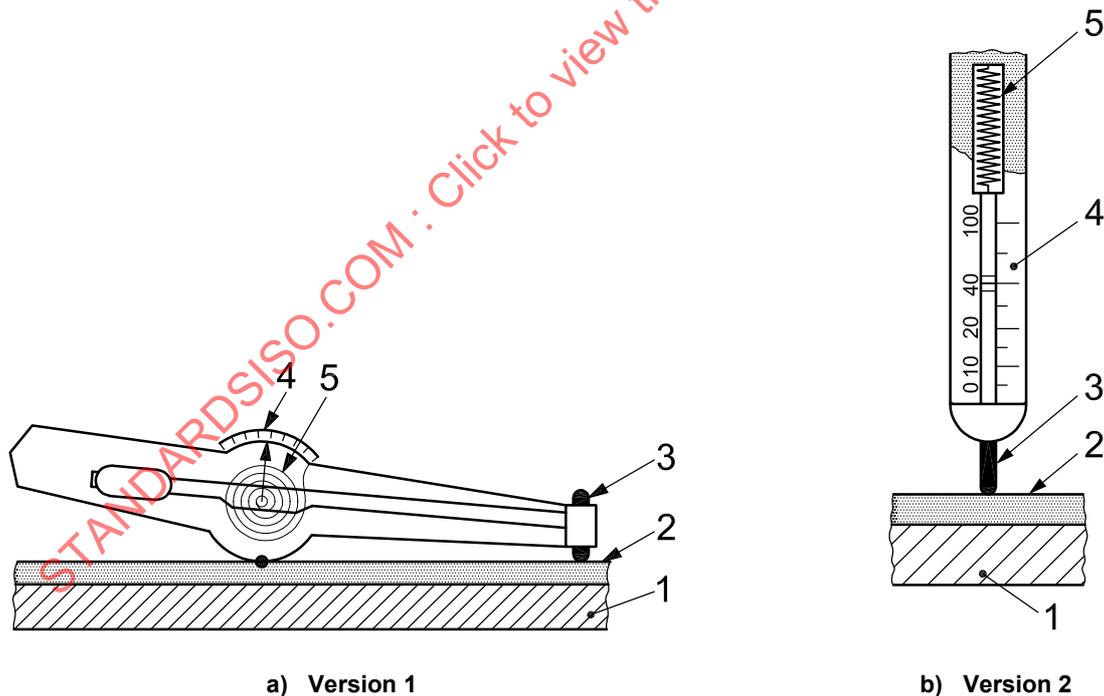
1 substrate
2 coating
3 magnet
4 scale
5 spring

Figure 13 — Magnetic pull-off gauge

5.5.5.2 Procedure

Place the instrument with the magnet against the coating. Lift the magnet away from the coating in a direction perpendicular to the coating surface. The film thickness is derived from the force required to remove the magnet from the specimen.

5.5.6 Method 7B — Magnetic-flux gauge

5.5.6.1 Description of instrument

This instrument contains a magnet for determining the film thickness from the change, caused by the substrate, in the magnetic field of the magnet. The magnetic field is measured with a Hall probe (see Figure 14).

Key
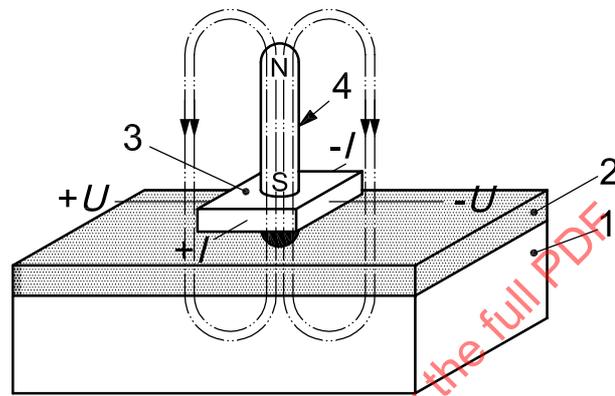
1 substrate
2 coating
3 Hall element
4 magnet
U Hall voltage
I control current

Figure 14 — Hall probe

5.5.6.2 Procedure

Place the instrument on the coating so that it is perpendicular to the coating. Read the thickness directly from the dial or calculate it in accordance with the manufacturer's instructions.

5.5.7 Method 7C — Magnetic-induction gauge

5.5.7.1 Description of instrument

This instrument contains an electromagnet for determining the film thickness from the change produced in the magnetic field when it approaches a ferromagnetic substrate (see Figure 15). A low-frequency (LF, e.g. 60 Hz to 400 Hz) alternating electromagnetic field is generated by the electromagnet (see ISO 2178 [3]).

Key

1   substrate
2   coating
3   ferromagnetic core
4   alternating magnetic field (LF)
5   measurement signal
6   current

Figure 15 — Principle of magnetic-induction gauge
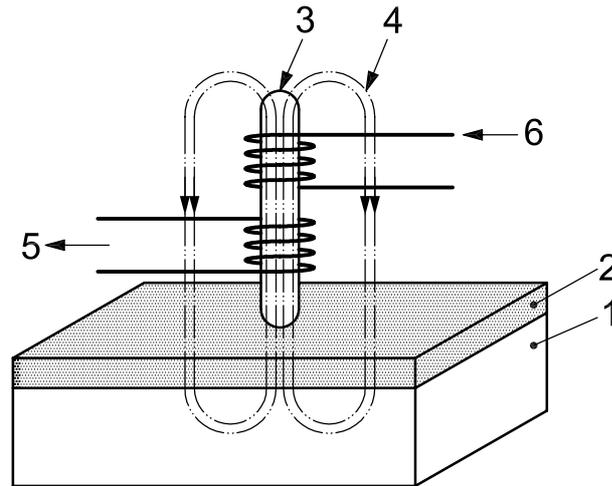
5.5.7.2   Procedure

Place the instrument on the coating so that it is perpendicular to the coating. Calculate the film thickness from the change in the magnetic flux.

5.5.8   Method 7D — Eddy-current gauge

5.5.8.1   Description of instrument

This instrument contains an electromagnet for determining the film thickness from the change in the magnetic field caused by eddy currents in the electrically conductive substrate (see Figure 16). A high-frequency (HF, e.g. 0,1 MHz to 30 MHz) alternating electromagnetic field is generated in the electromagnet (see ISO 2360 [4]).

Key

1   substrate
2   coating
3   ferrite core
4   alternating magnetic field (HF)
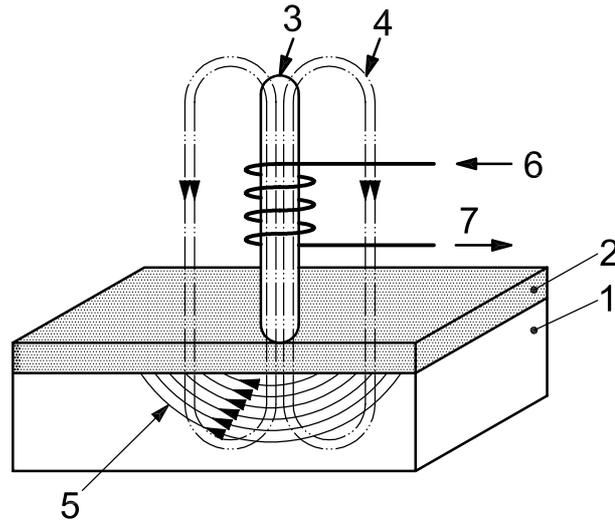5   eddy currents
6   current
7   measurement signal

Figure 16 — Principle of eddy-current gauge

5.5.8.2   Procedure

Place the instrument on the coating so that it is perpendicular to the coating.

5.6   Radiological method

5.6.1   Principle

The film thickness is derived from the interaction between ionizing radiation and the coating. A radioisotope is used as the radiation source.

5.6.2   Field of application

The radiological principle is suitable for any film-substrate combination, provided the difference between the atomic number of the coating material and that of the substrate is at least 5 (see ISO 3543 [10]).

5.6.3   General

Measurement of the film thickness can be affected by

— the geometry of the substrate (dimensions, curvature);

— impurities at the surface of the coating;

— variations in the coating density.

5.6.4   Method 8 — Beta backscatter method

5.6.4.1   Description of instrument

The beta backscatter apparatus (see Figure 17) consists of

— a radiation source (radioisotope) which emits mainly beta particles having an energy appropriate to the film thickness to be measured;

— a probe or measurement system with a range of apertures and containing a beta detector to count the number of backscattered beta particles (e.g. a Geiger counter);

— a data-processing and display system.

Key
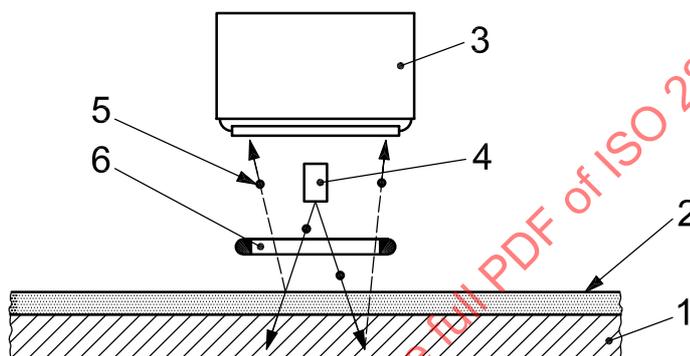
1   substrate
2   coating
3   counter
4   radioisotope
5   backscattered particles
6   aperture

Figure 17 — Beta backscatter method

5.6.4.2   Verification

Verify and, if necessary, adjust the instrument with standards having as far as possible a coating and substrate of the same composition as the specimen to be examined.
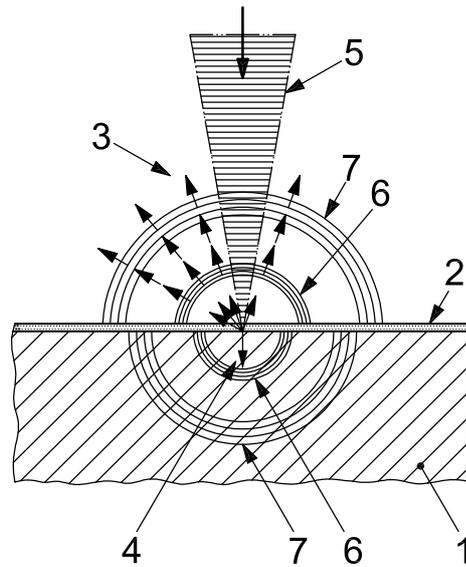
5.6.4.3   Procedure

Operate the instrument in accordance with the manufacturer's instructions.

5.7   Photothermal method

5.7.1   Principle

The film thickness is determined from the difference between the time a thermal wave is radiated towards the coating and the time the re-emitted wave (either heat or ultrasonic) is detected (see Figure 18).

Key

1   substrate
2   coating
3   re-emitted thermal radiation
4   absorption of radiation by coating (depends on coating thickness and coating material)
5   thermal irradiation
6   thermal waves
7   ultrasonic waves

Figure 18 — Interaction of radiation with the specimen in photothermal thickness measurement

Irrespective of the type of excitation involved or the method of detection, all photothermal methods use the same principle: the periodic or pulsed introduction of energy in the form of heat into a specimen and the subsequent detection of the local temperature increase.

The time difference measured is compared against values obtained with the instrument for films of known thickness under fixed conditions (excitation energy, pulse length, excitation frequency, etc.) (see 5.7.4.2).

5.7.2   Field of application

The photothermal principle is basically suitable for all film-substrate combinations. It can also be used to determine the thicknesses of the individual layers in a multilayer coating, provided the layers are sufficiently distinct from each other with respect to their thermal conductivity and reflection properties.

The required minimum substrate thickness is a function of the measurement system used (see 5.7.4.1.1) and the film-substrate combination.

5.7.3   General

Classification of the method as destructive or non-destructive depends on the purpose of the coating. The thermal energy absorbed by the coating could have an impact on the coating owing to the local heating effect produced.

5.7.4 Method 9 — Determination using thermal properties

5.7.4.1 Instrument and reference standards

5.7.4.1.1 Measurement system

There are various methods for producing thermal waves in a coating material and for detecting the thermal effects induced at the heated location in the specimen (see EN 15042-2 [18]). Thermal radiation sources (e.g. laser sources, light-emitting diodes, incandescent light sources) are mainly used as the excitation system for paint coatings.

The following detection methods are used:

— detection of the re-emitted thermal radiation (photothermal radiometry);

— detection of the change in refractive index (in the heated air above the measurement area);

— pyroelectric detection (heat flow measurement).

5.7.4.1.2 Reference standards

Reference specimens with different absorption properties and a range of film thicknesses are required for verification purposes (see EN 15042-2 [18]).

5.7.4.2 Verification

Verify and, if necessary, adjust the measurement system with the reference specimens (see 5.7.4.1.2) for each film-substrate combination (in particular for each coating material).

5.7.4.3 Procedure

Operate the instrument in accordance with the manufacturer's instructions. Read the thickness directly from the display or calculate it in accordance with the manufacturer's instructions.

5.8 Acoustic method

5.8.1 Principle

In the acoustic method, the film thickness is determined from the propagation time of an ultrasonic pulse through the coating.

5.8.2 Field of application

The acoustic principle is suitable for any film-substrate combination.

The sound velocity shall be uniform in the individual coats and shall differ markedly from the sound velocity in the adjacent coat and in the substrate.

NOTE   Inhomogeneities in the coating (e.g. the presence of aluminium flakes) and in the substrate (e.g. the grain in wood) can influence the result.
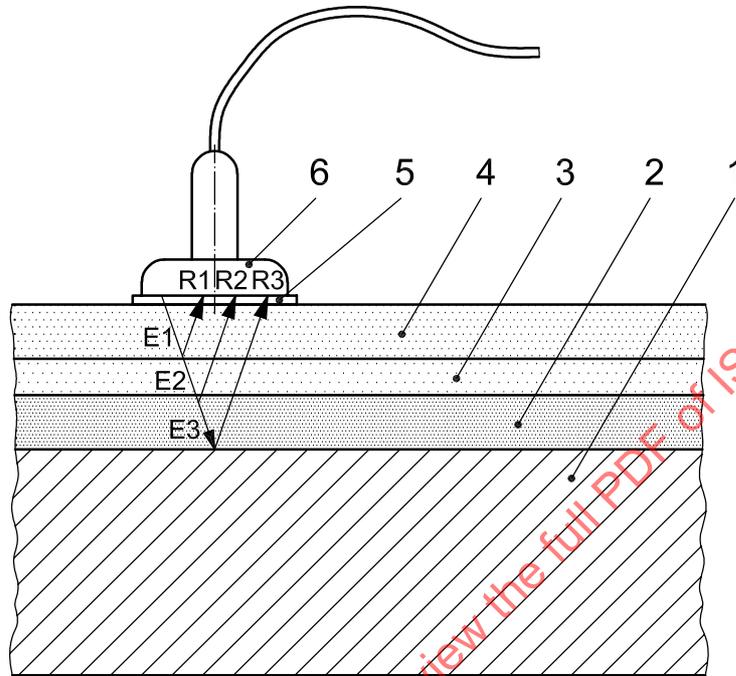
5.8.3 General

The acoustic field can be affected by the geometry of the substrate (dimensions, curvature and roughness).

5.8.4 Method 10 — Ultrasonic thickness gauge

5.8.4.1 Description of instrument

This instrument has an ultrasonic transmitter and a receiver for determining the film thickness from the sound propagation time (see Figure 19).

Key

1   substrate
2   coating 1
3   coating 2
4   coating 3
5   couplant
6   probe (transmitter and receiver)
E   pulse penetrating into coating
R   reflected pulses

Figure 19 — Ultrasonic thickness gauge

5.8.4.2 Procedure

Apply a couplant to the coating whose thickness is to be measured. Place the instrument with the probe face flat on the coating. Operate the instrument and determine the results in accordance with the manufacturer's instructions.

6   Determination of thickness of uncured powder layers

6.1   General

Annex A gives an overview of the methods used for determination of the thickness of uncured powder layers.

6.2 Gravimetric method

6.2.1 Principle

The film thickness of the uncured powder layer, t_p, in micrometres is calculated from the difference between the mass of the uncoated specimen and that of the coated specimen using the following equation:

$$t_p = \frac{m - m_0}{A \cdot \rho_p} \tag{4}$$

where

m_0 is the mass of the uncoated specimen, in grams;

m is the mass of the coated specimen, in grams;

A is the coated surface area, in square metres;

ρ_p is the density of the uncured powder coating material applied, in grams per millilitre.

NOTE   The density of the powder coating material can be determined in accordance with ISO 8130-2 or ISO 8130-3.

6.2.2 Field of application

The gravimetric method has general applicability.

6.2.3 General

Using the gravimetric method yields the mean value of the film thickness over the entire coated surface area. When applying the powder, the reverse side of the specimen shall be masked to prevent measurement errors resulting from partial coating of the reverse (overspray).

6.2.4 Method 11 — By difference in mass

6.2.4.1 Apparatus

Required are scales capable of weighing up to 500 g to the nearest 1 mg.

6.2.4.2 Procedure

Weigh the clean uncoated specimen, coat it and reweigh. Calculate the film thickness using Equation (4).

The second weighing shall be carried out immediately after powder application.

6.3 Magnetic methods

6.3.1 Principle

The film thickness is determined from the interaction between a magnetic field and the metallic substrate. The film thickness is derived from the change in the magnetic field.

6.3.2 Field of application

Magnetic methods are suitable for coated metal substrates.

For method 12A, the substrate must be ferromagnetic, and for method 12B non-ferromagnetic.

6.3.3 General

The magnetic field produced by the instrument can be affected by the following factors:

— the geometry of the substrate (dimensions, thickness);

— the properties of the substrate material (e.g. permeability, conductivity and properties resulting from any pretreatment);

— the roughness of the substrate;

— other magnetic fields (residual magnetism of the substrate and external magnetic fields).

Only measurements on flat surfaces are permissible.

6.3.4 Method 12A — Magnetic-induction gauge

6.3.4.1 Description of instrument

This instrument contains an electromagnet for determining the film thickness from the change produced in the magnetic field when it approaches a ferromagnetic substrate (see Figure 20). A low-frequency (LF, e.g. 60 Hz to 400 Hz) alternating electromagnetic field is generated by the electromagnet (see ISO 2178 [3]).

Key
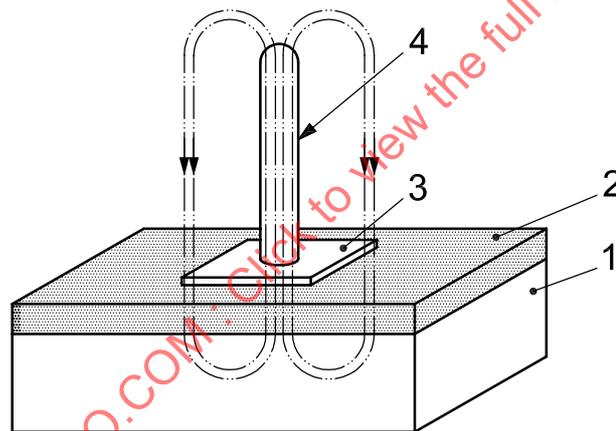
1   substrate
2   coating
3   baseplate
4   magnet or eddy current probe

Figure 20 — Probe of magnetic-induction gauge for powder coating thickness measurements

The influence of the probe on the thickness of the uncured powder layer shall be kept to a minimum when positioning the probe.

6.3.4.2 Procedure

Place the instrument on the coating so that it is perpendicular to the coating. Read the thickness directly from the display or calculate it in accordance with the manufacturer's instructions.