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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

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

This fifth edition cancels and replaces the fourth edition (ISO 2808:2007), which has been technically revised. The main changes compared to the previous edition are as follows:

— the terms and definitions have been updated to ISO 4618 and ISO/IEC Guide 99;

— the principle has been revised;

— white-light interferometer has been added as method 6C;

— the terahertz method has been added as method 11;

— the existing methods have been adapted to the current state of metrology;

— the characterisation of the methods and procedures in Annex A have been revised;

— information in Annex A on the precision of the individual methods has been adapted to current standards;

— the references to test standards and constructions standards in Annex A have been updated;

— former Clause 7 on measurement of the film thickness on rough surfaces has been moved to Annex B;

— Annex C, on factors which influence measuring accuracy when measurements are performed on wood has been added.

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

This document consistently enumerates the individual coatings applied in a multi-layer system by referring to the first coating applied on the substrate as coating 1. Some other standards referring to individual test methods enumerate in reverse order.

Paints and varnishes — Determination of film thickness

1 Scope

This document describes methods for measuring 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.

For each method described, this document provides an overview of the field of application, existing standards and the precision.

Information on measuring film thickness on rough surfaces is given in Annex B.

Information on measuring film thickness on wooden substrates is given in Annex C.

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 3611, *Geometrical product specifications (GPS) — Dimensional measuring equipment: Micrometers for external measurements — Design and metrological characteristics*

ISO 4618, *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.

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

3.2
wet-film thickness
thickness of a freshly applied wet coating material, measured immediately after application

3.3
dry-film thickness
thickness of a coating remaining on the surface when the coating has hardened

3.4
thickness of uncured powder layer
thickness of a freshly applied coating material in powder form, measured immediately after application and before stoving

3.5
relevant surface area
part of an object covered or to be covered by the coating and for which the coating is essential for serviceability and/or appearance

Note 1 to entry: Measurement of this property is only required for the extended evaluation of film thickness measurements; see Clause 7, k) and l).

3.6
test area
representative part of the relevant surface area within which an agreed number of single measurements is made as a spot-check

Note 1 to entry: Measurement of this property is only required for the extended evaluation of film thickness measurements; see Clause 7, k) and l).

3.7
measurement area
area over which a single measurement is made

Note 1 to entry: Measurement of this property is only required for the extended evaluation of film thickness measurements; see Clause 7, k) and l).

3.8
minimum local film thickness
lowest value of the local film thickness found on the relevant surface area of a particular test specimen

Note 1 to entry: Measurement of this property is only required for the extended evaluation of film thickness measurements; see Clause 7, k) and l).

3.9
maximum local film thickness
highest value of the local film thickness found on the relevant surface area of a particular test specimen

Note 1 to entry: Measurement of this property is only required for the extended evaluation of film thickness measurements; see Clause 7, k) and l).

3.10
mean film thickness
arithmetic mean of all the individual *dry-film thicknesses* (3.3) in the test area or the result of a gravimetric determination of the thickness

Note 1 to entry: Measurement of this property is only required for the extended evaluation of film thickness measurements; see Clause 7, k) and l).

3.11
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[SOURCE: ISO/IEC Guide 99:2007, 2.39]

3.12
verification
provision of objective evidence that a given item fulfils specified requirements

EXAMPLE 1   Confirmation that a given reference material as claimed is homogeneous for the quantity value and measurement procedure concerned, down to a measurement portion having a mass of 10 mg.

EXAMPLE 2   Confirmation that performance properties or legal requirements of a measuring system are achieved.

EXAMPLE 3   Confirmation that a target measurement uncertainty can be met.

Note 1 to entry: When applicable, measurement uncertainty should be taken into consideration.

Note 2 to entry: The item may be, e.g. a process, measurement procedure, material, compound, or measuring system.

Note 3 to entry: The specified requirements may be, e.g. that a manufacturer's specifications are met.

Note 4 to entry: Verification in legal metrology, as defined in VIML, and in conformity assessment in general, pertains to the examination and marking and/or issuing of a verification certificate for a measuring system.

Note 5 to entry: Verification should not be confused with calibration. Not every verification is a validation.

Note 6 to entry: In chemistry, verification of the identity of the entity involved, or of activity, requires a description of the structure or properties of that entity or activity.

[SOURCE: ISO/IEC Guide 99:2007, 2.44]

3.13
reference material
RM
material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties

Note 1 to entry: Examination of a nominal property provides a nominal property value and associated uncertainty. This uncertainty is not a measurement uncertainty.

Note 2 to entry: Reference materials with or without assigned quantity values can be used for measurement precision control whereas only reference materials with assigned quantity values can be used for calibration or measurement trueness control.

Note 3 to entry: "Reference material" comprises materials embodying quantities as well as nominal properties.

EXAMPLE 1   Examples of reference materials embodying quantities:

a)   water of stated purity, the dynamic viscosity of which is used to calibrate viscometers;

b)   human serum without an assigned quantity value for the amount-of-substance concentration of the inherent cholesterol, used only as a measurement precision control material;

c)   fish tissue containing a stated mass fraction of a dioxin, used as a calibrator.

EXAMPLE 2   Examples of reference materials embodying nominal properties:

a)   colour chart indicating one or more specified colours;

b)   DNA compound containing a specified nucleotide sequence;

c)   urine containing 19-androstenedione.

Note 4 to entry: A reference material is sometimes incorporated into a specially fabricated device.

EXAMPLE 3   Substance of known triple-point in a triple-point cell.

EXAMPLE 4   Glass of known optical density in a transmission filter holder.

EXAMPLE 5   Spheres of uniform size mounted on a microscope slide.

Note 5 to entry: Some reference materials have assigned quantity values that are metrologically traceable to a measurement unit outside a system of units. Such materials include vaccines to which International Units (IU) have been assigned by the World Health Organization.

Note 6 to entry: In a given measurement, a given reference material can only be used for either calibration or quality assurance.

Note 7 to entry: The specifications of a reference material should include its material traceability, indicating its origin and processing (Accred. Qual. Assur.:2006).

Note 8 to entry: ISO/REMCO has an analogous definition but uses the term "measurement process" to mean "examination" (ISO 15189:2007, 3.4), which covers both measurement of a quantity and examination of a nominal property.

Note 9 to entry: Reference materials 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.

[SOURCE: ISO/IEC Guide 99:2007, 5.13, modified — Note 9 to entry has been added.]

3.14
adjustment
adjustment of a measuring system
set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1 to entry: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment, and span adjustment (sometimes called gain adjustment).

Note 2 to entry: Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.

Note 3 to entry: After an adjustment of a measuring system, the measuring system must usually be recalibrated.

Note 4 to entry: Most digital 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.

[SOURCE: ISO/IEC Guide 99:2007, 3.11, modified — Note 4 to entry has been added and "adjustment" is used as the first preferred term.]

3.15
accuracy
measurement accuracy
accuracy of measurement
closeness of agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept "measurement accuracy" is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

Note 2 to entry: The term "measurement accuracy" should not be used for measurement trueness and the term measurement precision should not be used for 'measurement accuracy', which, however, is related to both these concepts.

Note 3 to entry: "Measurement accuracy" is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

[SOURCE: ISO/IEC Guide 99:2007, 2.13, modified — "accuracy" is used as the preferred term.]

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

With mechanical procedures, the measuring instrument (see Figures 1, 2 and 3, Key 4) passes through by the coating being placed on the surface of the substrate. The difference between the points of contact (substrate, see Figures 1, 2 and 3, Key 1) and the coating surface touched from the top of the measurement instrument (Figures 1, 2 and 3, Key 3) corresponds to the readable wet-film thickness.

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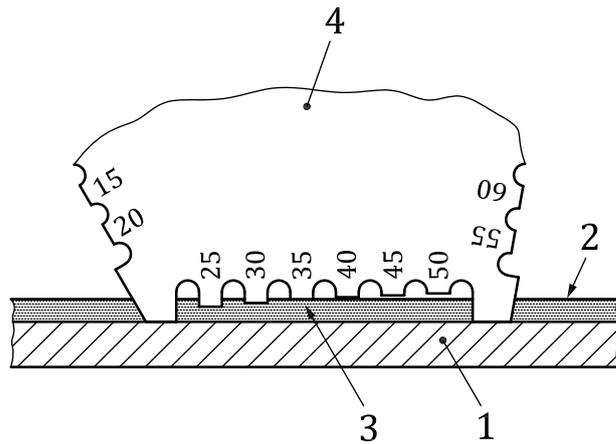
1   substrate
2   coating
3   point of wetting contact
4   comb gauge

Figure 1 — Example of a comb gauge

4.2.4.2   Procedure

Ensure that the teeth are clean and not worn out 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 thickness shall be measured directly after application since the result will be influenced, for example, by physical drying, curing or solvent loss.

Take 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 protrusion 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 systematically 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
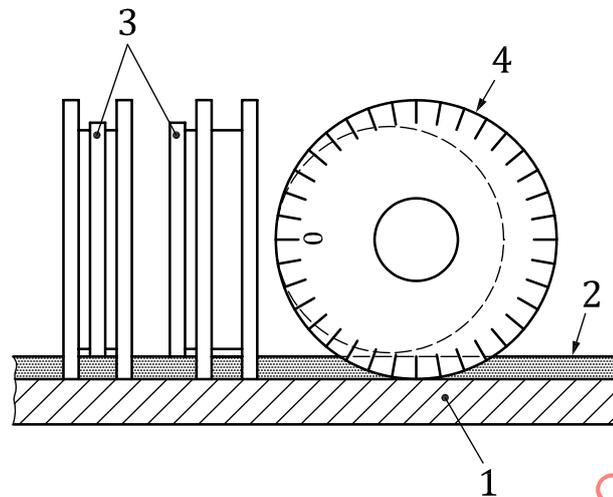
1   substrate
2   coating
3   eccentric rim
4   wheel gauge

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 thickness shall be measured directly after application since the result will be influenced, for example, by physical drying, curing or solvent loss.

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 materials (reference standard)

4.2.6.1.1   Dial gauge [see Figure 3 a) and b)]

Analogue dial gauges conforming to the requirements of ISO 463 and digital dial gauges are typically capable of measuring to an accuracy of 5 μm (analogue dial gauge) or 1 μm (digital 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 careful adjustments to the position of the plunger in its guideway.
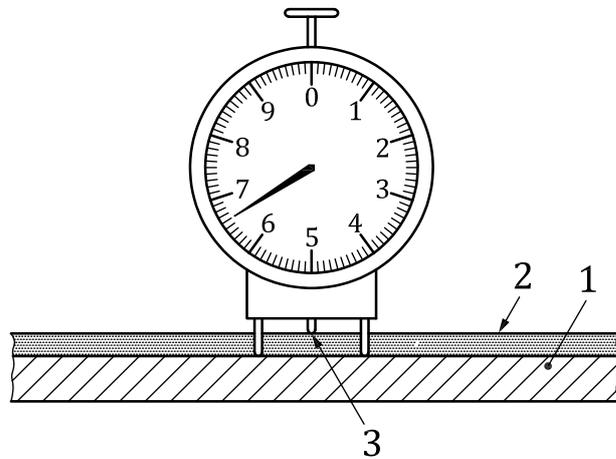
a) Example of an analogue dial gauge
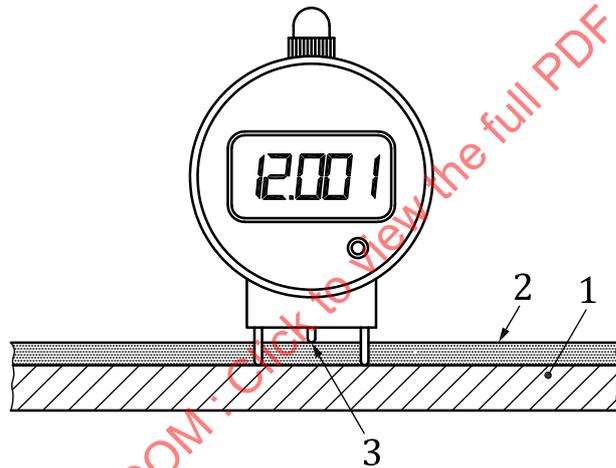
b) Example of a digital dial gauge

Key
1   substrate
2   coating
3   plunger

Figure 3 — Examples of an analogue and a digital dial gauge

4.2.6.1.2   Reference material for zeroing the gauge

A flat reference plate is required for zeroing the gauge. The reference plate shall be a polished glass plate.

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 perpendicular to the surface of the substrate and carefully lower the plunger down until the measuring tip is just touching the coating material.

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

The thickness shall be measured directly after application since the result will be influenced, for example, by physical drying, curing or solvent loss.

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 with Formula (1)

$$t_w = \frac{m - m_0}{A \cdot \rho}$$ (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 cubic centimetres.

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 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 Formula (1).

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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 4.4.4.2).

Key
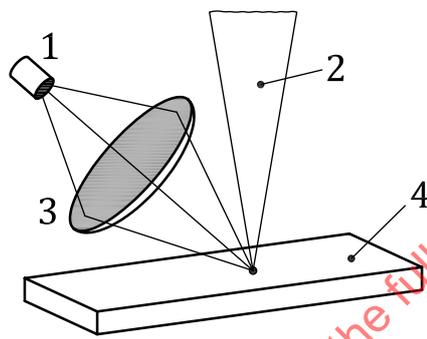
1   infrared detector
2   excitation beam
3   thermal radiation
4   specimen

Figure 4 — Representation of radiometric detection

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.

4.4.4 Method 3 — Determination using thermal properties

4.4.4.1 Instrument and reference materials (reference specimens)

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[28]). Thermal radiation sources (e.g. laser sources, light-emitting diodes, incandescent light sources) are mainly used as the excitation system for 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 material

Reference materials with different absorption properties and a range of film thicknesses are required for calibration purposes (see, for example, EN 15042-2[28]).

4.4.4.2 Calibration

Calibrate the measurement system with the reference materials (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 micrometre 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) enables 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 constituted so as to prevent the reading from being falsified as a result of the measuring tip creating an indentation.

The micrometre 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 a dispute.

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.

5.2.4   Method 4A — By difference in thickness

5.2.4.1   Description of instrument

5.2.4.1.1   Micrometre

5.2.4.1.1.1   General

The micrometre 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.

5.2.4.1.1.2 Version 1 — Fixed to a stand

A micrometre head with a plane measuring face is clamped to a stand with a flat measuring table surface such that its height can be adjusted. The measuring face shall be aligned parallel to the measuring table surface.

5.2.4.1.1.3 Version 2 — Hand-held (see Figure 5)

The usual term for this kind of instrument is an outside micrometre, although it is also known as micrometre callipers for external use. The micrometre 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.
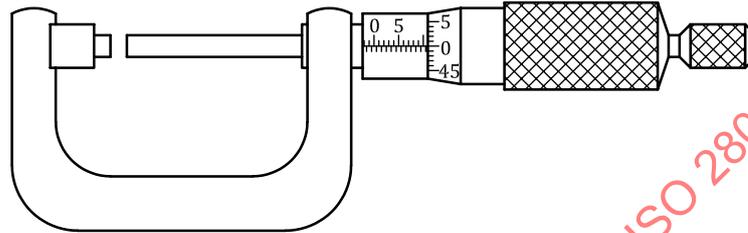
Figure 5 — Outside micrometre

5.2.4.1.2 Dial gauge

5.2.4.1.2.1 General

Analogue dial gauges conforming to the requirements of ISO 463 and digital dial gauges are typically capable of measuring to an accuracy of 5 μm (analogue dial gauge) or 1 μm (digital 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).

5.2.4.1.2.2 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 measuring table surface.
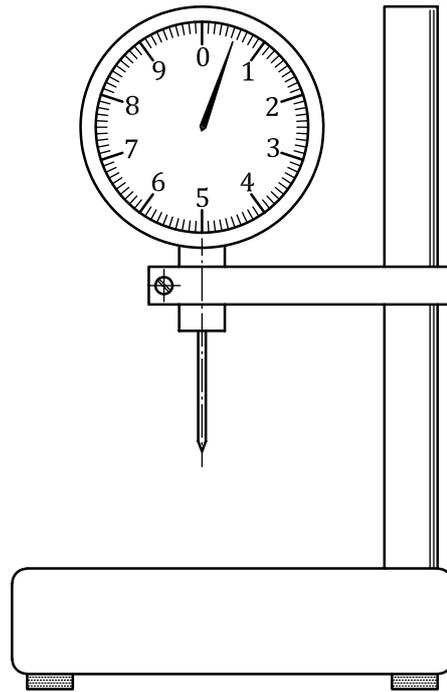
Figure 6 — Dial gauge fixed to a stand

5.2.4.1.2.3 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 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.
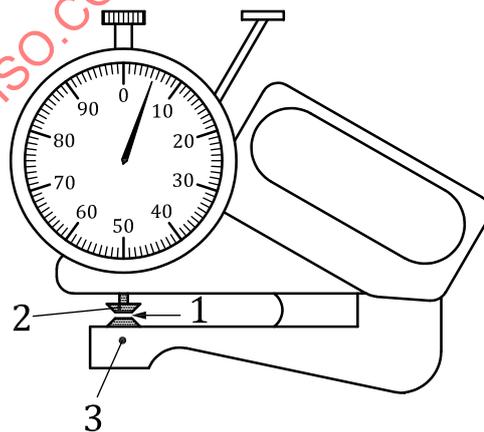
Key

1   gauge aperture
2   upper measuring tip
3   measuring plug

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 (micrometre, 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 measuring table surface.

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 micrometre 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   Instruments and reference materials (reference specimens)

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

Micrometres of this type are typically capable of measuring to the nearest 5 µm, or better. The micrometre 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
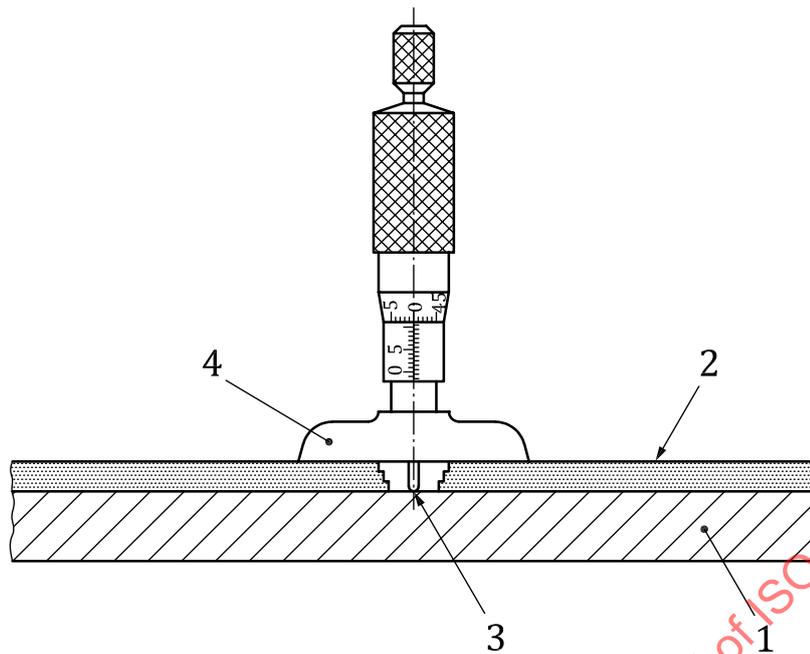
1   substrate

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)

Analogue dial gauges conforming to the requirements of ISO 463 and digital dial gauges are typically capable of measuring to an accuracy of 5 µm (analogue dial gauge) or 1 µm (digital dial gauge), or better. Instead of a flat measuring bridge, two contact pins of equal length can be fixed to the bottom side of the dial gauge. Both need to be arranged in equal distance and aligned to the movable contact element as shown in Figure 9. The gauge can have a flat base or foot which is placed on the coating surface and acts as a reference plane.

Key
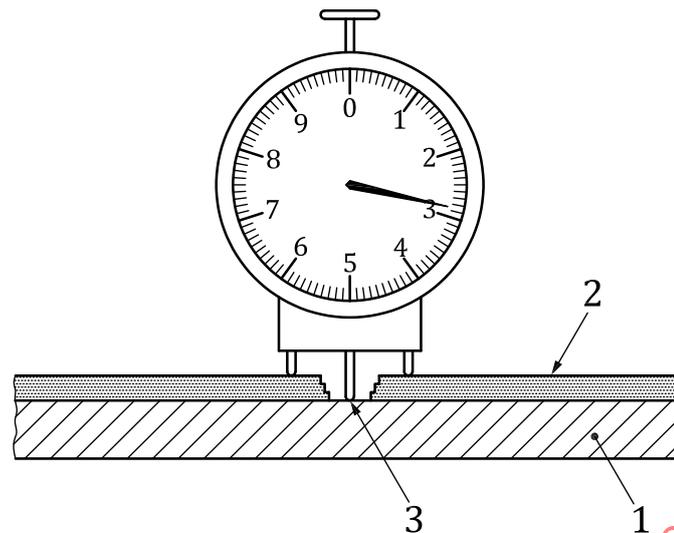
1   substrate
2   coating
3   contact element

Figure 9 — Dial depth gauge

5.2.5.1.3   Reference materials for zeroing the gauge

A flat reference plate is required for zeroing the gauge. The reference plate shall be a polished glass plate.

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 micrometric 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 perpendicular 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
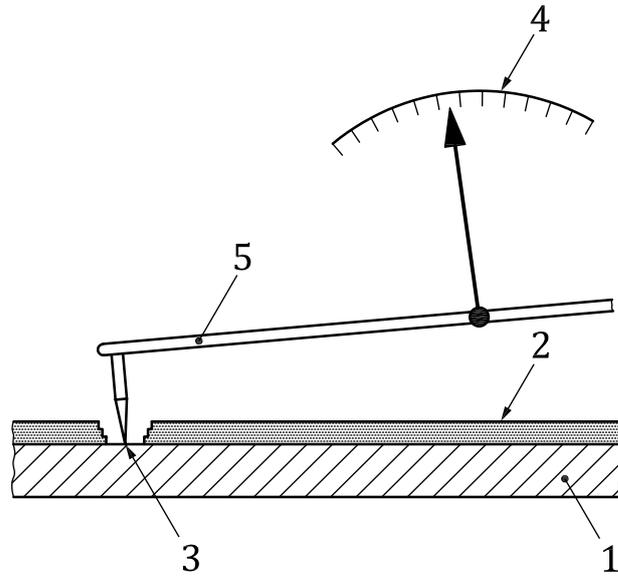
1   substrate
2   coating
3   stylus tip
4   scale
5   lever

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 Formula (2):

$$t_d = \frac{m - m_0}{A \cdot \rho_o} \tag{2}$$

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 cubic centimetre.

NOTE   The dry-film density of the coating material can be determined in accordance with ISO 3233-1, ISO 3233-2 or ISO 3233-3.

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.

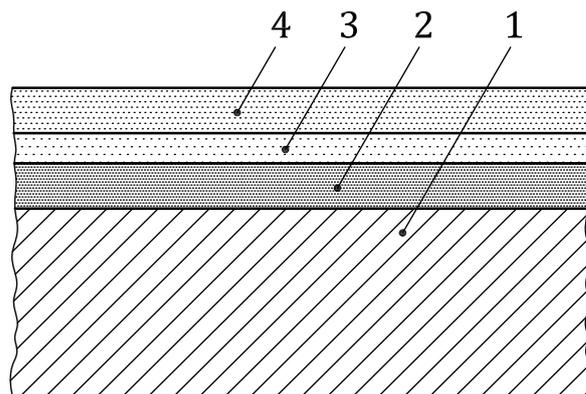#### 5.3.4.2   Procedure

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

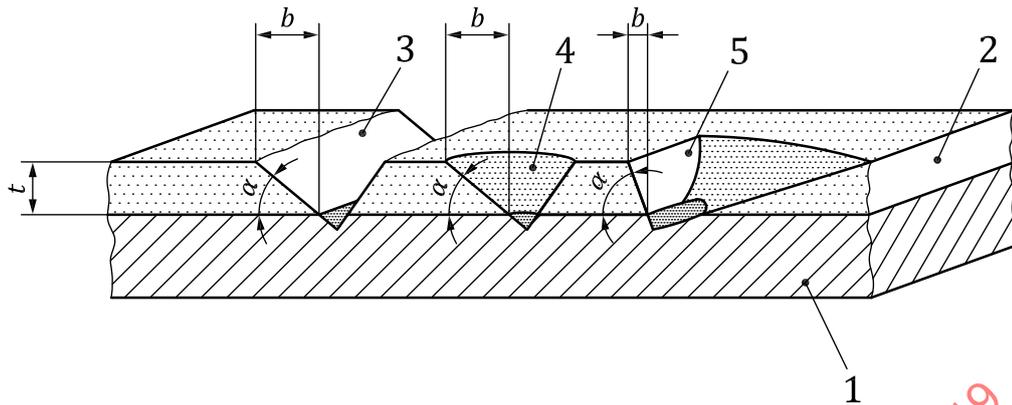With the wedge cut method (method 6B, see 5.4.5) a cut of defined dimensions is made in the coating using a cutting tool at a specified angle to the surface (see Figure 12). The film thickness, t, is calculated using Formula (3):

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

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 the cut.

Key

1   substrate

2   coating

3   symmetrical cut

4   conical bore

5   sloping cut

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

t film thickness

α angle of cut

Figure 12 — Symmetrical cut, conical bore and sloping cut

The symmetrical wedge cut (key 3 in Figure 12) can be made in the coating using a special blade, the conical bore (key 4 in Figure 12) by a special borer and the sloping cut (key 5 in Figure 12) with a milling tool.

With white-light interferometry (method 6C, see 5.4.6) the thickness is measured by means of interference with white light (see Figure 13). The measured interferences are compared with values which were previously determined on films with a known thickness through a secured method.

a) **Schematic beam path**   b) **Measurement diagram**
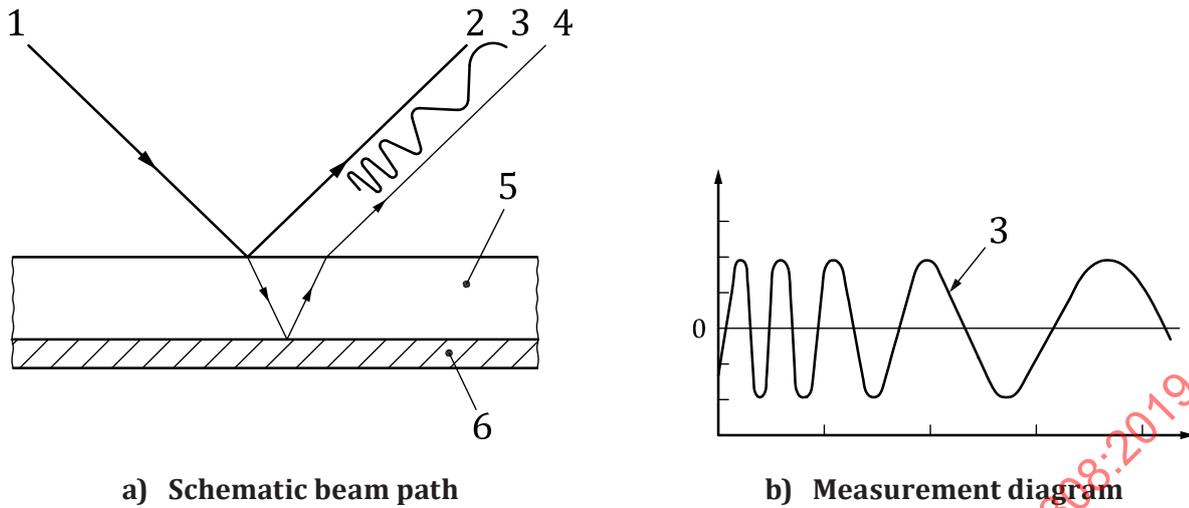
Key

1   ingressing light beam
2   reflected partial beam 1
3   interference
4   reflected partial beam 2
5   coating
6   substrate

Figure 13 — White-light interferometry

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 in contrast 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.

Film thickness measurement with the white light interferometer (method 6C, see 5.4.6) is applicable for optically transparent films.

5.4.3   General

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.

The measurement surface of the specimen shall be flat (in addition see the Note in 5.4.5.2).

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.

With white-light interferometry the light interference can be influenced by the geometry of the substrate, e.g. curvature and roughness.

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 coating and gives gap-free embedding.

5.4.4.1.1.3 Grinding and polishing media

Use waterproof abrasive paper, for example P280, P400 and P600 grit, or suitable grades of diamond paste or a similar paste.

5.4.4.1.1.4 Measuring microscope

A microscope with a suitable illumination system achieving optimum image contrast is required. 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 vertical 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 perpendicular 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 or digital measurement equipment

A microscope with approximately ×50 magnification and an illumination device is required. The eyepiece shall permit measurements to be made to the nearest 20 µm. Digital measurement equipment may be used as an alternative.

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 or the digital measurement equipment, measure the projected half-width, b, and calculate the film thickness(es) using Formula (3) (see 5.4.1).

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

5.4.6 Method 6C — White-light interferometry

5.4.6.1 Instrument and reference material

5.4.6.1.1 White-light interferometer

Commercial white-light interferometer.

5.4.6.1.2 Reference material

A reference material with a known thickness is required for calibration purposes.

5.4.6.2 Procedure

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

5.5 Magnetic methods

5.5.1 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 5.5.4), or from changes in the magnetic field (methods 7B.1, 7B.2 and 7C, see 5.5.5, 5.5.6 and 5.5.7).

5.5.2 Field of application

Magnetic methods are suitable for coatings on metal substrates.

For methods 7A, 7B.1 and 7B.2, the substrate shall be ferromagnetic, and for method 7C non-ferromagnetic.

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

5.5.3 General

The magnetic field produced by the instrument can be affected, among other things, 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).
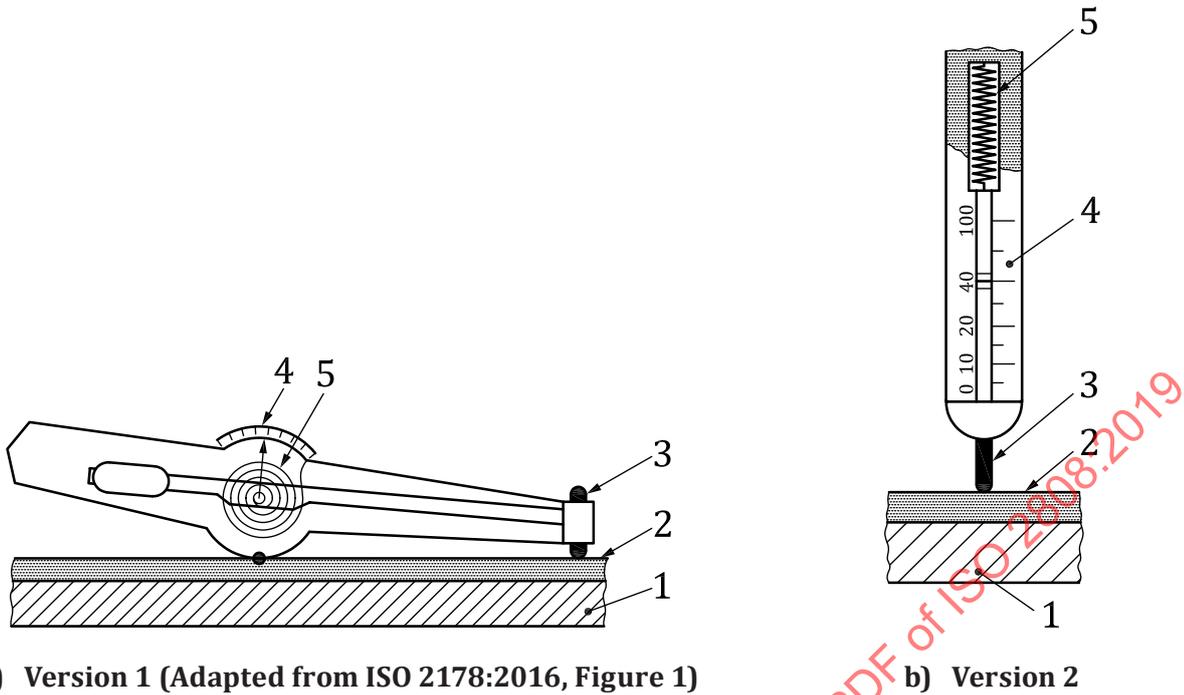
See ISO 2178[3] and ISO 2360[4] for further influencing factors.

5.5.4 Method 7A — Magnetic pull-off gauge

5.5.4.1 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 Figure 14).

NOTE   The instrument shown in Figure 14 a) can be used in any position. The instrument shown in Figure 14 b) is designed for use only in one orientation because of the effect of gravity.

a) Version 1 (Adapted from ISO 2178:2016, Figure 1)   b) Version 2

Key

1   substrate
2   coating
3   magnet
4   scale
5   spring

**Figure 14 — Magnetic pull-off gauge**

5.5.4.2   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.

5.5.5   Method 7B.1 — Magnetic-flux gauge

5.5.5.1   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 15).

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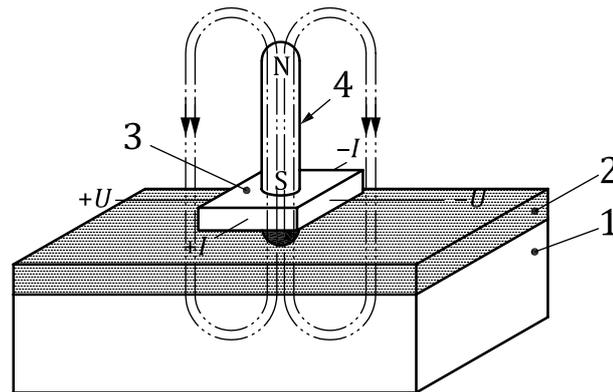
1 substrate
2 coating
3 hall element
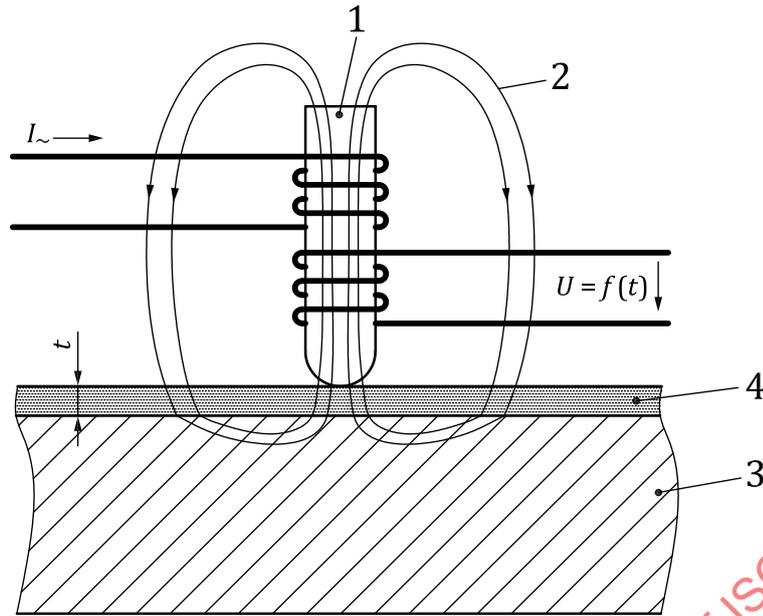4 magnet
U hall voltage
I control current

Figure 15 — Hall probe

5.5.5.2 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.

5.5.6 Method 7B.2 — Magnetic field change, magnetic-induction principle

5.5.6.1 Description of instrument

This instrument contains a coil system for determining the film thickness from the change produced in the magnetic field when it approaches a ferromagnetic substrate (see Figure 16). A low-frequency (<1 kHz) alternating electromagnetic field is generated by the coil system.

Key

1	ferromagnetic core of the probe	$I\sim$	excitation current
2	low-frequency alternating magnetic field	t	thickness
3	steel/iron substrate	$U = f(t)$	measurement signal
4	coating		

Figure 16 — Principle of magnetic-induction gauge (Adapted from ISO 2178:2016, Figure 2)

5.5.6.2 Procedure

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

5.5.7 Method 7C — Eddy-current gauge

5.5.7.1 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 17). A high-frequency (>1 kHz) alternating electromagnetic field is generated in the electromagnet.

Key
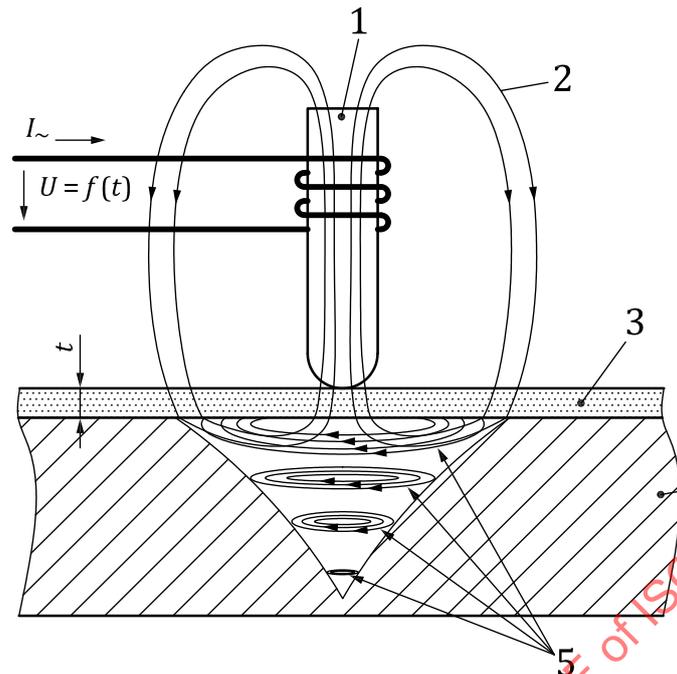
1	ferrite core of the probe	$I\sim$	excitation current
2	high-frequency electromagnetic field	$U = f(t)$	measurement signal
3	coating	t	thickness
4	base metal		
5	induced eddy current		

Figure 17 — Example for the eddy current method (Adapted from ISO 2360:2017, Figure 1)

5.5.7.2 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 determined 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[12]).

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 18) 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
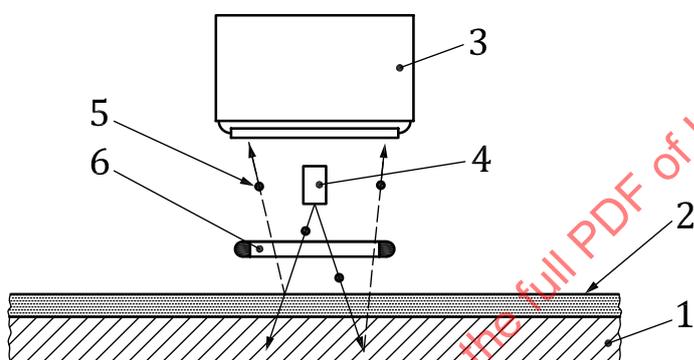
1 substrate
2 coating
3 counter
4 radioisotope
5 backscattered particles
6 aperture

Figure 18 — 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.
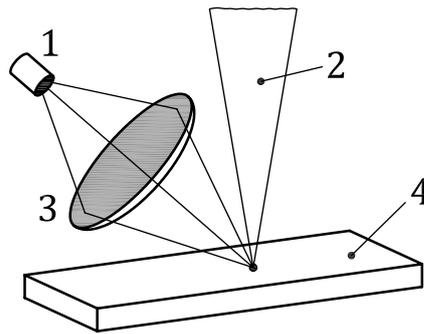
5.6.4.3   Procedure

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 19).

Key

1   infrared detector
2   excitation beam
3   thermal radiation
4   specimen

Figure 19 — Representation of radiometric detection

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   Instruments and reference materials (reference specimens)

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[28]). 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 materials

Reference materials with different absorption properties and a range of film thicknesses are required for verification purposes (see EN 15042-2[28]).

5.7.4.2 Verification

Verify and, if necessary, adjust the measurement system with the reference materials (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 individual film thicknesses are determined from the propagation times of a partially reflected ultrasonic pulse at the interfaces of the coating system. See ISO/TS 19397.

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 layers and shall differ significantly from the sound velocity in the adjacent layer 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 reflection

5.8.4.1 Description of instrument

This instrument has an ultrasonic transmitter and a receiver for calculating the film thickness on the basis of the time interval elapsed between entry and exit of the ultrasonic waves (see Figure 20).

Key
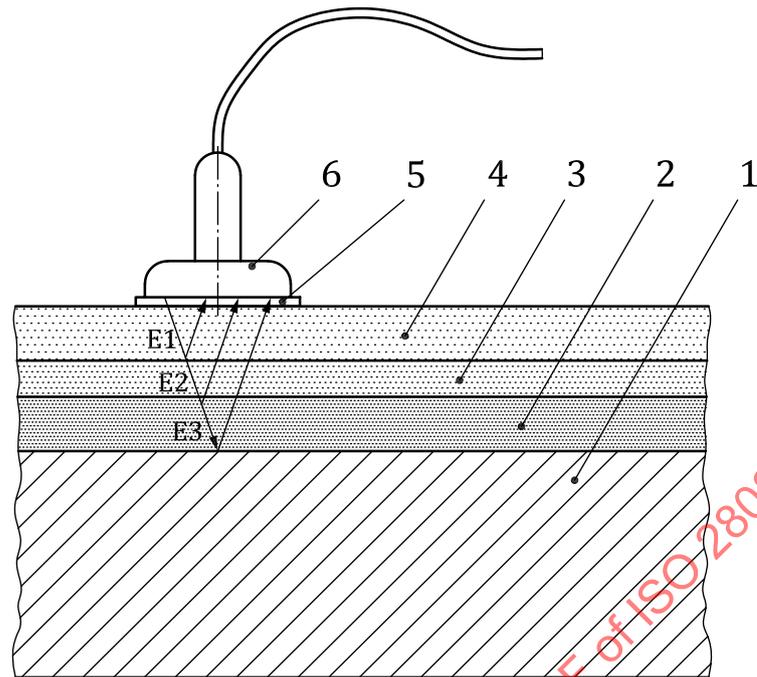
1   substrate
2   coating 1
3   coating 2
4   coating 3
5   couplant
6   ultrasonic probe (transmitter and receiver)
E   echo 1, 2, 3

Figure 20 — Ultrasonic method

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. The coating thickness is calculated from the time interval required by the ultrasound to travel through the coatings and back.

5.9   Electromagnetic method

5.9.1   Method 11 — Terahertz method

5.9.1.1   Description of instrument

An instrument having a terahertz transmitter and a terahertz receiver for determining the film thickness through the sum of the reflections (see Figure 21).
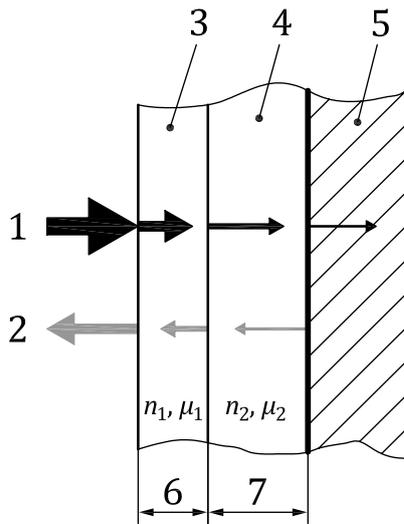
a) **Schematic beam path**
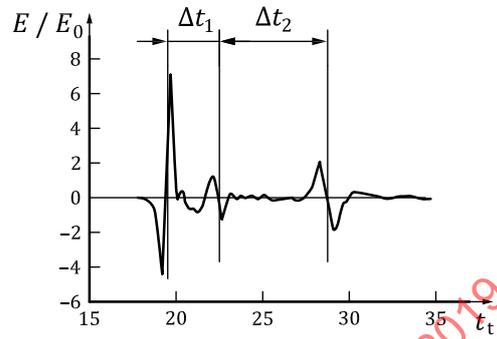
b) **Measurement diagram**

Key

1   ingressing terahertz radiation
2   sum of all reflected pulses
3   film 2
4   film 1
5   substrate
6   thickness of film 2
7   thickness of film 1
n_1, μ_1 refractive index and/or extinction coefficient of film 2 for the terahertz range used
n_2, μ_2 refractive index and/or extinction coefficient of film 1 for the terahertz range used
E/E_0 relative electrical field
t_t time, in picoseconds (ps)
Δt_1 double pulse propagation of the first reflex in film 2
Δt_2 double pulse propagation of the second reflex in film 1

Figure 21 — Principle of terahertz measurement

Introduce periodic terahertz radiation into the specimen and then detect the reflected portions of the pulse. The sum of all reflected pulses is detected and the thickness of the individual films calculated from this pulse curve. The prerequisite for this calculation is knowledge of the material constants n and μ of each film.

5.9.1.2   Field of application

The terahertz measurement principle is suitable for nearly all film-substrate combinations. However, pure layers of metal, e.g. galvanic coatings cannot be measured using this method. It can be used in particular in order to determine the thickness of individual films in a multilayer system if the material constants n und μ of the individual films sufficiently differ.

The detectable minimum thickness of a film is approximately 5 µm. This minimum film thickness and the maximum determinable film thickness depend on the material properties of the coating and the substrate and the measurement system used.

5.9.1.3 General

The terahertz method is a non-destructive method.

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 Formula (4):

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

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 side (overspray).

6.2.4 Method 12 — 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 Formula (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 determined from the change in the magnetic field.

6.3.2 Field of application

Magnetic methods are suitable for coated metal substrates.

For method 13A, the substrate shall be ferromagnetic, and for method 13B 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 13A — Magnetic-induction method

6.3.4.1 Description of instrument

This instrument contains a coil system for determining the film thickness from the change produced in the magnetic field when it approaches a ferromagnetic substrate (see Figure 22). A low-frequency (<1 kHz) alternating electromagnetic field is generated by the electromagnet.
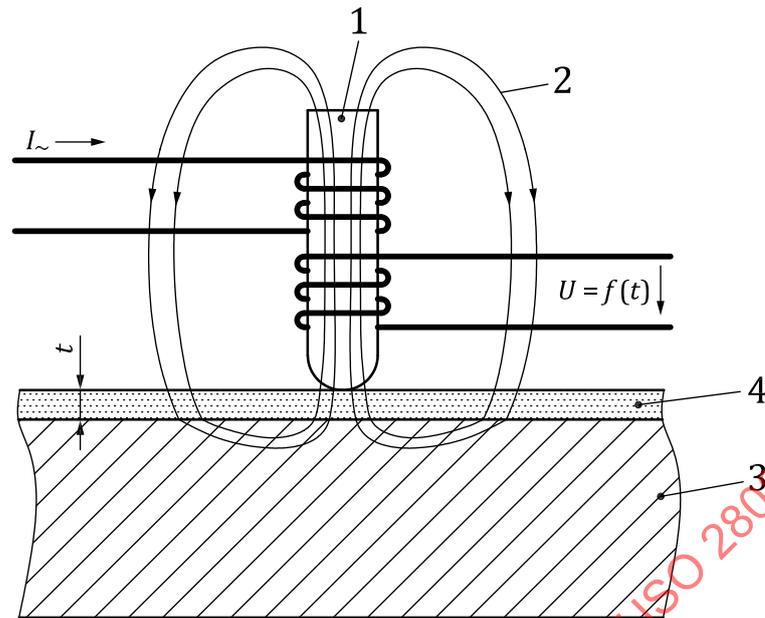
Key

1 ferromagnetic core of the probe

2 low-frequency alternating magnetic field

3 steel/iron substrate

4 coating

$I\sim$ excitation current

t thickness

$U = f(t)$ measurement signal

Figure 22 — Measurement of a powder coating illustrated with the example of a magnetic induction probe

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. The coating thickness is calculated from the change in the magnetic field or according to the manufacturer's instructions.

6.3.5 Method 13B — Eddy-current

6.3.5.1 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 23). A high-frequency (>1 kHz) alternating electromagnetic field is generated in the electromagnet.

Key
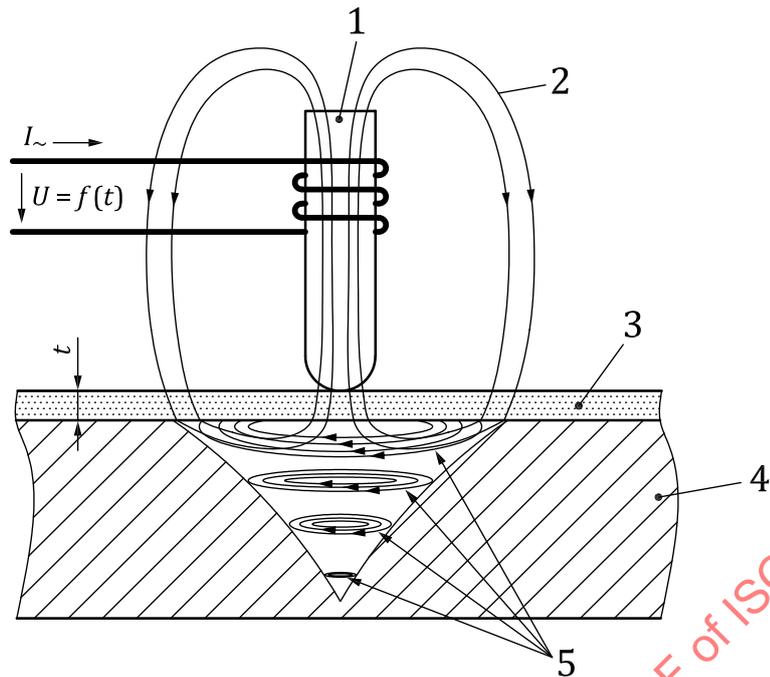
1	ferrite core of the probe	$I\sim$	excitation current
2	high-frequency electromagnetic field	$U = f(t)$	measurement signal
3	coating	t	thickness
4	substrate		
5	induced eddy current		

Figure 23 — Eddy current method

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

6.3.5.2   Procedure

Place the instrument on the coating so that it is perpendicular to the coating. The coating thickness is determined by the change of the magnetic field.

6.4   Photothermal method

6.4.1   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 is detected (see Figure 18).

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 to values obtained with the instrument for films of known thickness under fixed conditions (excitation energy, pulse length, excitation frequency, etc.) (see 6.4.4.2).