BS EN 16813:2016

BSI Standards Publication

Thermal spraying — Measurement of the electrical conductivity of thermal sprayed non-iron metal coatings by means of eddy current method

bsi.

National foreword

This British Standard is the UK implementation of EN 16813:2016.

The UK participation in its preparation was entrusted to Technical Committee STI/40, Thermal spraying and thermally sprayed coatings.

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

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2016

ISBN 978 0 580 88075 9

ICS 25.220.20

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2016.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 16813

November 2016

ICS 25.220.20

English Version

Thermal spraying - Measurement of the electrical conductivity of thermal sprayed non-iron metal coatings by means of eddy current method

Projection thermique - Mesurage de la conductivité électrique des revêtements métalliques non ferreux obtenus par projection thermique, à l'aide de la méthode par courants de Foucault

Thermisches Spritzen - Messung der elektrischen Leitfähigkeit thermisch gespritzter Nichteisenmetall-Schichten mittels Wirbelstromverfahren

This European Standard was approved by CEN on 24 September 2016.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 16813:2016 E

Contents

Page

European foreword 3
Introduction 4
1 Scope 5
2 Normative references 5
3 Terms and definitions 5
4 Measuring process 6
4.1 Measuring method 6
4.2 Calibration standard 7
4.3 Measuring frequency and penetration depth 8
4.4 Measuring instruments 8
4.5 Factors, which have effects on the uncertainty of the measurement 9
4.6 Limit of application 9
5 Procedure of the measurement 10
5.1 Calibration of the measuring instruments 10
5.2 Measurement 10
6 Measuring results and their assessment 10
7 Test report and documentation 11
Annex A (informative) Record for the applied Electrical Conductivity Measurement 12
A.1 General 12
A.2 Component/part 12
A.3 Surface preparation for spraying 12
A.4 Spraying procedure for component/part 12
A.5 Preparation of measurement 13
A.6 Measuring instrument 13
A.7 Result of the measured electrical conductivity 13
Bibliography 14

European foreword

This document (EN 16813:2016) has been prepared by Technical Committee CEN/TC 240 “Thermal spraying and thermally sprayed coatings”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2017, and conflicting national standards shall be withdrawn at the latest by May 2017.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

In many applications, the electrical conductivity is a relevant technical parameter. For testing of imperfections in components or technological material properties the eddy current method can be very well applied. It can be detected or determined, for example:

— defects in welds;

— imperfections or change in the structure of a component, for example, due to aging processes in structures made out of aluminium;

— change in structure caused by temperature effects;

— thickness;

— physical material properties such as the electrical conductivity.

Due to an interaction between high frequency magnetic fields, emitted from a measuring probe, and the eddy currents induced in the object to be measured the electrical conductivity can be determined, e.g. according to ASTM E 1004 or can be used for fast and contact less measurements of a coating thickness according to EN ISO 21968.

Due to the manufacturing process thermal sprayed coatings contain a layer orientated structure. Dependent on the material used, it can also contain oxides and/or inclusions as well as porosity created due to splat boundary effects during spraying.

Besides the structure with its grain boundaries, dislocations, internal stresses and impurities, e.g. oxide skins, the specific gravity of a material plays an important role for the level of the electrical conductivity. In order to produce the highest possible level of electrical conductivity in the coating, the influencing factors for the thermal spraying process should be minimized.

1 Scope

This European standard specifies the procedure of the measurement of the electrical conductivity of non-Ferro-magnetic thermal sprayed coatings. By this measurement the absolute value of the electrical conductivity in the coating sprayed on component can be determined as well as also deviations from the agreed rated value can be used to control a running production. With that, a remarkable contribution can be applied to process and quality assurance measures of a manufacture process.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 21968, *Non-magnetic metallic coatings on metallic and non-metallic basis materials - Measurement of coating thickness - Phase-sensitive eddy-current method (ISO 21968)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
electrical conductivity
σ
physical value, which shows the ability of a material – in this case of a thermal sprayed coating – to conduct the current

Note 1 to entry: It is defined to be the constant of proportionality between the current density and the electrical field intensity within the general Formula (1) of the ohmic law. σ is measured in S/m.

$$J = \sigma \times E \quad (1)$$

where

- J is the current density;
- σ is the electrical conductivity;
- E is the field intensity.

3.2
electrical resistance
R
value, which defines the electrical voltage, which is needed that a certain current can flow through an electrical conductor

Note 1 to entry: The unit is ohm (Ω).

3.3
specific electrical resistivity
property of material, which is the result of the electrical resistance in a homogenous part with a constant current intensity distribution across the constant cross-section and length of the conductor and an ohmic resistance

Note 1 to entry: The specific electrical resistance, see Formula (2), depends on the temperature of material and is the reciprocal value of the electrical conductivity ($\rho = 1/\sigma$). The unit is ohm metre ($\Omega \times m$).

$$\rho = R \times \frac{A}{L} \tag{2}$$

where

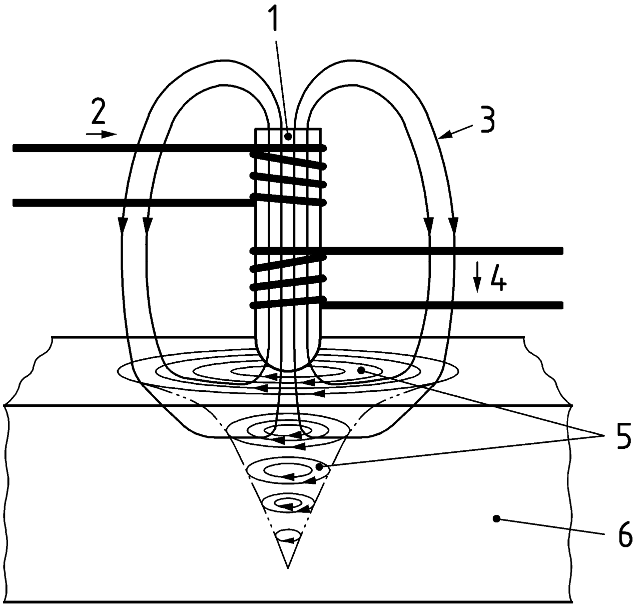
ρ	is the specific electrical resistivity in $\Omega \times m$;
R	is the ohmic resistance;
A	is the constant cross-section of the conductor;
L	is the length of the conductor.

4 Measuring process

4.1 Measuring method

Measuring of the absolute value of the electrical conductivity takes place usually by a current voltage measurement. However, this method is usually applied in laboratories only.

If the electrical conductivity shall be determined in a component on site, primarily eddy current processes are applied. To measure the electrical conductivity of non-magnetic metals, such as aluminium, copper, brass, titanium, chrome-nickel-steel, etc. Therefore, the phase-sensitive eddy current measurement procedure is very suitable. By that, the measuring probe fed from a generator with alternating current of a certain frequency is to be put to the object to be measured or to be brought into small distance to its surface. This exciter current generates a magnetic field of high frequency, which induces eddy currents in the material to be tested (in this case the coating respectively the base material), their intensity and penetration depth depend on its electrical conductivity. On the other hand the magnetic field induced by eddy currents overlaps the generating field. The generated resulting magnetic field is detected by a measuring coil. By that, the induced voltage is a function of the electrical conductivity of the object to be measured and can be used as a signal for its measuring. See Figure 1.



Key

1 ferrite core of the probe
2 exiting current
3 high frequency magnetic alternating field
4 measuring signal
5 eddy current induced
6 electrically conductive non-ferrous-alloy

Figure 1 — Phase-sensitive eddy current measuring method

Using the phase-sensitive eddy current measurement procedure the phase changing between exciter current and measuring signal is to be transferred into a conductivity value. This measuring value is independent from the distance between the probe and the coating surface for a certain arrangement, which depends on the type of the probe. By that, a non-contactable determination of the conductivity can be applied also using this method, for example, below a varnish or a synthetic material coat. Using an adequate measuring frequency the influence of the surface roughness remains low.

4.2 Calibration standard

Using the phase-sensitive eddy current measurement procedure the measuring value found in the component will be compared to the calibration standard as a reference standard, which conductivity is very well known. Standards for calibration of the measuring instrument are available for the whole conductivity range. Usually, they are also supplied from the measuring instrument producer.

Because the calibration standards are subject to changes in properties due to use they have to be recalibrated at regular time periods or to be replaced.

4.3 Measuring frequency and penetration depth

The penetration depth of the eddy current is defined by the conductivity σ and the measuring frequency *f*. Generally, the penetration depth σ_0 of the eddy current in a non-ferrous-alloy is given by:

$$\sigma_0 = \frac{503}{\sqrt{f \times \sigma \times \mu_R}} \tag{3}$$

where

σ_0	is the penetration depth of the eddy current in a non-ferrous-alloy;
f	is the measuring frequency in Hz;
σ	is the electrical conductivity in MS/m;
μ_R	is the permeability = 1 for non-magnetic materials.

The penetration depth of the eddy current is also decisive for the minimally permissible thickness of the object to be measured. In order to achieve complete saturation within the coating to be measured a penetration depth σ_S shall be taken:

$$\sigma_s = 2,5 - 3\sigma_0 \tag{4}$$

where

σ_S	is the penetration depth of the eddy current in the coating;
σ_0	is the penetration depth of the eddy current in a non-ferrous-alloyl.

Due to the usually low thickness of thermal sprayed coatings, a higher measuring frequency shall be taken, therefore. Usually, such measuring frequencies are in the range of 480 kHz to more than 1 MHz. They are available in commercial instruments.

Due to the increase of the skin effect with increasing frequency, however, the measuring frequency should not be selected unnecessary high, because the measuring result could not be representative for the coating then.

In the case of increasing measuring frequency the negative influence of surface roughness to the measuring result also increases. The higher the frequency the smoother should be the surface. Using the phase-sensitive eddy current measurement procedure the effect remains low.

4.4 Measuring instruments

Nowadays, instruments to measure the electrical conductivity are equipped as to be:

— independent instrument for control measurement in the laboratory;

— integrated instrument with an automatic measurement in installations for manufacture;

— hand-operated instrument for measurements in the work shop.

Usually, the attachment contains:

— collection of measuring data and connections to PC, printer and to have the capability of data storing;

— measuring range: e.g. 0,5 MS/m to 65 MS/m respectively 1 % to 112 % IACS (International Annealed Copper Standard).

Often a disturbing effect of distance variations can be suppressed when using a scanning probe. Therefore, measuring tasks can be served successfully, where a direct contact to the metallic surface is not possible or undesirable, such as for varnishes or moved measuring objects.

4.5 Factors, which have effects on the uncertainty of the measurement

Following influencing factors can lead to deviations of the measuring result:

— distance from the probe to the component surface, also called take-off effect, is too large or not sufficiently compensated or dirt particles are in between;

— distance from the probe to an edge is too small or not sufficiently compensated (necessary distance can be found experimentally or according to EN ISO 21968);

— curvature of the surface, e.g. if the curvature is too low related to the diameter of the probe;

— thickness of the measuring object (coating), when saturation thickness (see 4.3) cannot be kept);

— different measuring temperatures, usually temperature compensation is done by an internal or external temperature sensor with relation to the conductivity at +20 °C;

— surface roughness of the object to be measured. Rough surfaces can cause systematic as well as random errors. A reduction of defects by chance can be achieved using a greater number of measurements at different points. However, the roughness plays only a role using higher measuring frequencies;

— inhomogeneity of the measuring object within the recorded area, e.g. by accumulation of pores, voids, oxides, or by changing of the structure or the chemical composition within the coating.

Using a sufficient calibration of the measuring instrument the effects of distance of the probe to the surface, distance to edges, curvature and temperature effects can be eliminated to the greatest possible extent.

When manipulation and calibration of the measuring instrument is well done a measuring uncertainty of less than 5 % can be achieved.

4.6 Limit of application

A limit of application is given for the measuring method to measure the absolute value of the electrical conductivity of the coating, when:

— above mentioned factors of influence cannot be compensated by calibration of the measuring instrument or other measures;

— the coating thickness is too small, the necessary saturation depth cannot be achieved, so that the eddy currents penetrate the substrate material.

Limits of application of the measuring method can be given to serve for the manufacturing assurance of the spraying process, when:

— the difference in conductivity between the coating and the base metal is too less and the eddy currents penetrate the substrate material;

— a more and different mixing took place between the conductive coating and non-conductive substrate material at the interface and this zone will be reached by the eddy currents;

— the coating thickness is such small, that the portion for measurement of the substrate material extremely prevails despite highest measuring frequency.

The limits of the application are reached when the measurements of the base material and the coating are equal.

5 Procedure of the measurement

5.1 Calibration of the measuring instruments

Before use the measuring instrument shall be calibrated according to the instructions of the producer using two standards with different conductivity, where the surrounding air is used as one of the standards, normally. At the moment of the calibration the measuring instrument and calibration standard shall possess nearly the temperature of the objects to be measured. The calibration should be checked after a greater number or duration time of measurements according to the instructions of the producer.

The electrical conductivity of the coating shall be between the conductivity values of the two calibration standards.

If the curvature of the coated surface to be measured does not allow calibration on a flat surface, the standards used for the calibration shall contain the same curvature radius, such as the part to be inspected or a specific testing apparatus shall be applied, which compensates the influence of the curvature.

5.2 Measurement

The measuring instruments are to be calibrated and to be used according to the instructions of the producer.

Prior to the execution of the measurements any foreign substances (dirt, oil, grease, corrosive products, etc.) are to be removed from the surface of the calibration standard and the objects to be measured.

It shall be checked, that the measuring frequency and thus the penetration depth of the eddy current is in the scale of the coating thickness. This fact is important for the measurement of the absolute values.

To avoid faulty measuring the necessary distance from the probe to edges shall be kept and in the case of narrow curvatures of the component a probe with a smaller diameter or with adequate geometry is to be used after adequate calibration.

6 Measuring results and their assessment

The necessary number of measurements is given by the type of task. The number of measurement points should be chosen so that a mean value can be calculated from an area representative for a part.

Multiple measurements at different points are required, if the electrical conductivity and its homogeneousity in the coating are investigated.

When validating the reproducibility of a manufacturing process, the average of a number of readings is required in order to exclude non-homogenous coating variability on any one sample measured.

When such measurements are required from the customer number and position of the measuring points at the component should be agreed upon between the parties involved in this transaction.

7 Test report and documentation

The test report shall contain following items:

a) type of task, aim of the measurement;

b) any instructions for identifying the test specimen or of the part to be tested;

c) reference to this test standard;

d) frequency, as in A.6;

e) size of the surfaces to be tested on each part, e.g. in mm^2;

f) position of the measuring points on every part;

g) number of the measured test specimens/parts;

h) designation of the test instrument, the measuring probe, the used calibration standard;

i) results of the measurements, details of the conductivity values measured as single and mean values respectively differences to the rated value in the case of measurements for comparison;

j) name of the inspector;

k) deviations from the procedure observed and features during testing, which are expected to may have influence to the results and their validity;

l) date of testing.

Annex A
(informative)

Record for the applied Electrical Conductivity Measurement

(The user of this form is allowed to copy it.)

A.1 General

Manufacturer:.. Inspection body:...

Component designation:................................. Substrate material:..

Function of the coating:.................................. Chemical analysis:..

Procedure qualification:................................ Accompanying specimen.................................

A.2 Component/part

Component/part:………………………………..

Substrate material:……………………………... Diameter:……………….

Sketch of component/part (if applicable)

A.3 Surface preparation for spraying

Program No:...

Blasting procedure (manually/mechanized)………………………………………..

Type of grit:..Grain size:...............................

Blasting pressure:………… bar……………….Blasting distance/angle:......…...................................

Visual inspection: Cleanliness, uniformity, according to EN ISO 8501-1:...................................

Roughness, e.g. according to EN ISO 8503-1:...

Date/time of blasting and spraying:...

A.4 Spraying procedure for component/part

Spray procedure acc. to prEN ISO 14917:2015:……… Spray procedure specification (SPS):……………….

Spraying manually: yes / no Spraying mechanized: Spraying program No.:................. Rev. index:..........

Spraying material: Designation acc. to standard:..

Grain size / wire diameter:.....................................……………………………………

Chemical composition (main elements):.......................……………………………………

Preheating: yes / no Preheating temp.:..................°C Cooling: yes / no Medium:.......................................

Spraying distance:...............mm Surface speed ....m/min (relative speed between spray torch and part)

Auxiliary spray device, if applicable, No.:...

Coating thickness: as sprayed:......................... Roughness as sprayed: R_z.........................

Post treatment: grinding/polishing Final roughness: R_a/R_z [μm]……………

Number of specimens sprayed, if applicable:…………..........

Thermal sprayer/operator:...

A.5 Preparation of measurement

Measuring instrument calibrated: yes /no

Date of calibration: ………………………………

A.6 Measuring instrument

Measuring instrument: Type:……………………………… Designation No.: ………………

Independent instrument yes /no

Integrated instrument yes /no

Hand-operated instrument yes /no

Measuring frequency:……………....Hz

Condition: Ambient temperature:…………………………….. °C; Humidity:…………………….. %

A.7 Result of the measured electrical conductivity

Measuring frequency:											
	Rated value	**Location for measurement**							**Mean value**	**Results**	
Location No.	**—**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**Passed**	**Failed**
Measured value in MS/m											
Measured value in % IACS											

Date of issue:..

Verifying:

For inspection body: Name:.. Signature:...

For manufacturer: Name:...…… Signature:...

Bibliography

[1] EN 2004-1, *Aerospace series - Test methods for aluminium and aluminium alloy products - Part 1: Determination of electrical conductivity of wrought aluminium alloys*

[2] EN 12084, *Non-destructive testing — Eddy current testing — General principles and basic guidelines*

[3] EN ISO 8501-1, *Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness - Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings (ISO 8501-1)*

[4] EN 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 (ISO 8503-1)*

[5] EN ISO 12718, *Non-destructive testing - Eddy current testing - Vocabulary (ISO 12718:2008)*

[6] prEN ISO 14917:2015, *Thermal spraying — Terminology, classification*

[7] ASTM E 1004-09, *Standard Test Method for Determination Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method*

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Copyright in BSI publications

Storing and using standards

Standards purchased in soft copy format:

- A British Standard purchased in soft copy format is licensed to a sole named user for personal or internal company use only.
- The standard may be stored on more than 1 device provided that it is accessible by the sole named user only and that only 1 copy is accessed at any one time.
- A single paper copy may be printed for personal or internal company use only.

Standards purchased in hard copy format:

- A British Standard purchased in hard copy format is for personal or internal company use only.
- It may not be further reproduced – in any format – to create an additional copy. This includes scanning of the document.

If you need more than 1 copy of the document, or if you wish to share the document on an internal network, you can save money by choosing a subscription product (see 'Subscriptions').

Reproducing extracts

For permission to reproduce content from BSI publications contact the BSI Copyright & Licensing team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email subscriptions@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Useful Contacts

Customer Services
Tel: +44 345 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 345 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.