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Report 8 (2021)

Test procedure for condition assessment of building

Module "Non-destructive testing methods"

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Test procedure for condition assessment of building

Module "Non-destructive testing methods"

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Table of contents

Foreword **7**

Part 1 - Steel test methods **9**

1.1 Visual inspection 11
1.2 Endoscopy: Borescopes 115
1.3 Endoscopy: Fiberscopes 119
1.4 Endoscopy: Videoscopes 23
1.5 Tear-off attempt 27
1.6 Cross-cut test and cross-cut test 311
1.7 Wedge cut 11
1.8 Penetrant testing PT 11
1.9 Mobile hardness test HT rebound method according to Leeb 11
1.10 Mobile hardness test HT according to the UCI method 11
1.11 Mobile hardness testing HT using the TIV method 11
1.12 Mobile hardness test HT according to the Rockwell principle 12
1.13 Knock test 12
1.14 Acoustic emission test AT 12
1.15 Ultrasonic testing UT 12
1.16 Magnetic field change (layer thickness determination) 712
1.17 Magnetic particle testing MT 12
1.18 Eddy current test ET 12
1.19 Infrared thermography test TT 12
1.20 Radiographic testing RT 12
1.21 Optical emission spectroscopy OES 12
1.22 X-ray fluorescence analysis XRF 95

Part 2 - Concrete test methods **13**

2.1 Visual inspection 15
2.2 Endoscopy: Borescopes 15
2.3 Endoscopy: Fiberscopes 15
2.4 Endoscopy: Videoscopes 15
2.5 Stripping test 15
2.6 Tear-off attempt 15

2.7 Drill with automatic switch-off 15
2.8 Rebound hammer / Schmidt hammer 15
2.9 Knock test 15
2.10 Impact echo 15
2.11 Ultrasound: Echo (and transmission) 15
2.12 Low-strain method / hammer blow method 15
2.13 Magnetic DC field 15
2.14 Alternating magnetic field 16
2.15 Remanence magnetism / Magnetic stray field measurement 16
2.16 Radar 16
2.17 Active thermography 16
2.18 Radiographic testing / radiography 16
2.19 X-Ray Diffraction - XDF / X-ray diffraction 16
2.20 Neutron probe 16
2.21 Potential field measurement 16
2.22 Indicator method: Phenolphthalein 16
2.23 Salt analysis method 16
2.24 Laser-induced plasma spectroscopy LIPS 16
2.25 X-ray fluorescence analysis XRF 16
2.26 Energy dispersive X-ray analysis EDA 16

Part 3 - Test methods for masonry 18
3.1 Visual inspection 19
3.2 Endoscopy: Borescopes 19
3.3 Endoscopy: Fiberscopes 19
3.4 Endoscopy: Videoscopes 19
3.5 Knock test 219
3.6 Impact echo 219
3.7 Ultrasound: Echo (and transmission) 219
3.8 Microseismics 2219
3.9 Geoelectrics 224
3.10 Radar 19
3.11 Microwaves 19
3.12 Active thermography 19
3.13 Radiography 19
3.14 Salt analysis method 19

Foreword

Users on the part of infrastructure operators/developers are regularly faced with the problem that there is hardly any independent information available on condition assessment methods beyond the classic manual inspection/structure testing.

Since 1991 - initially as a loose-leaf collection and from 2004 as a web-based catalog - the former NDT Construction Compendium of the BAM Federal Institute for Materials Research and Testing closed this gap for the field of non-destructive testing methods in construction (NDT construction methods). Since the beginning of 2017, the NDT construction compendium is no longer available on the BAM website.

Under the leadership of the German Center for Rail Transport Research at the German Federal Railway Authority, the BMVI expert network Wissen Können Handeln has developed a new catalog of **test procedures for the inspection of construction sites**, the first module of which is now available. This module contains three main components:

- Structured presentation of practical test tasks
- Standardized descriptions of the relevant test methods
- Linking matrix between test tasks and procedures, which shows the suitability of the procedures for the respective test task

The work on non-destructive testing methods for testing tasks on bridges made of steel, concrete and masonry has been completed. A module describing destructive methods is currently being worked on. Further modules are planned.

This **module "Non-destructive testing methods" summarizes** the method descriptions developed in the research projects. For background information and the linking matrices, please refer to the publication series "Reports of the German Center for Rail Transport Research".

Report 6 (2021):

NDT construction process for steel engineering structures and implementation of a logic for the use and retrieval of data (steel)

Report 7 (2021):

Report 7 (2021): Recording, description, evaluation and linking of NDT construction methods and techniques for road and rail engineering structures (concrete and masonry)

Part 1 - Test method Steel

1.1 Visual inspection

As of 18.12.2019

Physical basis	Optical measuring principle
Procedure **Visual inspection** Visual Testing VT	Test task - Surface inhomogeneities: Surface cracks - Corrosion - Bulges/deformations

Brief description

Non-destructive testing to detect damage, defects and faults and to assess the condition of the test surface by visual inspection of a test surface with or without aids. - Surface method

Standard area of application (practical testing tasks)

- Locating and evaluating superficial mechanical and optical quality characteristics by perceiving, comparing, estimating, counting and measuring [1]
- Recognize from:
  - Corrosion and rust stains,
  - Defects in riveted and bolted joints,
  - Defects in welded joints (e.g. seam protrusion, root sag, penetration notches)
  - Cracks [2]
  - Strain changes [3]
- Determining and, if necessary, measuring dents and deformations
- Assessment of coating damage, e.g. degree of blistering, degree of rust, degree of cracking, in accordance with DIN EN ISO 4628-1...10
- Visual inspection as a basic test for further investigations

Application limits (technical, physical, economic)

- Accessibility
- Lighting conditions
- Recognizability on the surface
- Viewing distance or visual inspection grid
- Size and shape of the object to be located

Special applications (additional testing tasks)

- Use of aids such as mirrors, lenses, endoscopes and photo and video technology

On-site requirements

- Accessible test surface (if necessary by erecting scaffolding and platforms; distances to the test object less than 600 mm and at an angle of not less than 30° to the test surface for the local visual inspection, distances greater than 600 mm for the overview inspection in accordance with DIN EN 13018)
- Sufficient lighting conditions (if necessary, add lighting sources with at least 160 lx for the overview inspection and at least 500 lx for the local visual inspection in accordance with DIN EN 13018)
- Preparing the surface: if necessary, clean the surface for a low degree of surface soiling

Procedure description

Long description

According to [DIN EN 13018: 2016-06], visual inspection is divided into direct and indirect visual inspection:
- "[Direct] visual inspection with uninterrupted beam path between the eye of the inspector and the test surface. This test is carried out with or without aids, e.g. with a mirror, lens, endoscope or fiber optic device"
The indirect visual inspection is carried out if the direct inspection cannot be performed.
- "[Indirect] visual inspection with an interrupted beam path between the inspector's eye and the inspection surface. Indirect visual inspection includes the use of photo and video technology, automated systems and robots".

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Visual inspection without tools is quick, depending on accessibility,
- However, visual inspection without aids may not detect the features that can be detected with aids
- No detection of fine surface cracks compared to MT and PT
- No detection of faults below the surface

1.1 Visual inspection

1.1 Visual inspection

As of 18.12.2019

Measuring method

Measurement setup

Bulges on steel bridge
A. Taffe, HTW Berlin

Measuring devices

- If necessary, aids such as mirrors, lenses, endoscopes or photo and video technology

Measured variable and target variable

Specified characteristic(s): Surface inhomogeneities: surface cracks, corrosion, bulges/deformations
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Ensure sufficient accessibility to the test area, using aids such as mirrors, magnifying glasses and endoscopes if necessary
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Performance of the test *(taking into account 2.):* Direct visual inspection [DIN EN 13018: 2016-06]
- Distance to the test surface < 600 mm
- Viewing angle of ≥ 30° to the test surface
- for overview inspections: Distance of > 600 mm permissible
- Additional lighting if necessary: at least 500 lx for local visual inspection and at least 160 lx for general inspection

4. Documentation
- Marking (e.g. with chalk) of the defined feature (inhomogeneity, deformation) on the structure to assess the damaged area (crack growth, dent); indication of the test date for traceability
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary
- Proof of the tester's visual acuity (near vision and color vision)

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	1/5	1/5	3/5

Further information

Device manufacturer, software

-

Related methods/ measurement variants

- **Endoscopic procedures:**
 - Borescopes (rigid endoscopes)
 - Fiberscopes (flexible endoscopes)
 - Videoscopes (flexible video endoscopes)
- **Surface testing method:**

Mechanical processes
 - PT indentation test (for non-magnetic materials)

Magnetic processes
 - Magnetic particle testing MT (for ferromagnetic materials)

(- Eddy current test ET (for conductive materials))

→ Magnetic particle inspection and penetrant testing like visual inspection with visual evaluation; additionally: detection of fine surface cracks that are invisible to the human eye

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- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

- Visual inspection is one of the classic NDT methods and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out the visual inspection.

Non-destructive testing (ICS 19.100)

- DIN EN 13018, 2016-06: Non-destructive testing - Visual inspection - General principles.
- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

Welded joints (ICS 25.160.40)

- DIN EN ISO 5817, 2014-07: Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (without beam welding) - Assessment groups of irregularities.
- DIN EN ISO 10042, 2019-01: Welding - Arc-welded joints on aluminum and its alloys Assessment groups of irregularities.
- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.
- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of fusion-welded joints.

Coating materials (paints and varnishes) (ICS 87.040)
DIN EN ISO 4628-1, 2016-07: Paints and varnishes - Evaluation of coating defects - Coating damage assessment Evaluation of the amount and size of damage and the intensity of uniform changes in appearance Part 1: General introduction and evaluation system
Part 2: Assessment of the degree of
blistering Part 3: Assessment of the
degree of rusting Part 4:
Assessment of the degree of
cracking
Part 5: Assessment of the degree of flaking
Part 6: Assessment of the degree of chalking using the adhesive tape
method Part 7: Assessment of the degree of chalking using the velvet
method
Part 8: Assessment of delamination and corrosion from a scratch or other artificial injury
Part 10: Evaluation of filiform corrosion

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Other/ Notes/ Remarks/ Comment

Physical basis	Optical measuring principle
Procedure **Endoscopy: Borescopes (rigid endoscopes)** Endoscopy: Borescope Inspection	Test task - Surface inhomogeneities: Surface cracks - Corrosion - Bulges/deformations

Brief description

Non-destructive testing of an inaccessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of optical image transmission through a special lens system and an optical fiber for illumination. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)
- Examination of tendons with regard to grouting condition and turnbuckles (usually via borehole)
- Inspection of corresion conditions / pitting corresion (specifically via drill holes)

Application limits (technical, physical, economic)

- Accessibility or presence of straight openings
- Moisture (due to damage or wet drilling) and drilling dust (due to dry drilling)
- Distortion effects of the optics can make it difficult to interpret the images
- Rough estimates of sizes and dimensions (for simple devices)
- No digital storage of images (for simple devices)

Special applications (additional testing tasks)

- Insertion of instruments through shaft
- Use of prismatic attachments and swivel mirrors for different viewing directions
- Some manufacturers offer borescopes with memory function as well as photo and video function [4]
- Verification of suspected areas of prestressing steel breakage (if necessary using a drill with automatic switch-off)

On-site requirements

- Presence of openings and cavities
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity
- Straightforward access

Procedure description

Long description

The classic, lens-optical borescope consists of an eyepiece at one end, a tube with an image transmission system and an objective at the other end. The image transmission system consists of a special lens system that is rigidly arranged. Illumination is provided by light guides or a tiny light bulb integrated into the head. Depending on the design, the direction of view can be changed: forwards, sideways, diagonally forwards or backwards. The type of lens determines the aperture angle of the endoscope. The viewing direction and the opening angle together determine the field of view of the endoscope.

The interpretation of the circular images is complicated by the distortion effects of the optics and the unusual perspective and requires experience in interpreting the images.

There are now also more advanced borescopes with fiber optic bundles for image transmission.

In addition to rigid borescopes, there are also flexible fiberscopes and flexible videoscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ better optical quality than flexible endoscopes

+ Higher resolution due to larger camera design compared to other endoscopes

- not bendable

1.2 Endoscopy: Borescopes

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- Borescope (consisting of an eyepiece, a long tube with an image transmission system and an objective) with diameters from 1.6 to 8 mm and lengths from 50 to 650 mm [3]
- Tripod if necessary
- Drill and power connection for drill if necessary

Measured variable and target variable

Specified characteristic(s): Surface inhomogeneities: surface cracks, corrosion, bulges/deformations
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning
- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Performance of the examination (taking into account 2.): **Endoscopic examination with a borescope**

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec
- PCE Instruments

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
    (Special form: articulated arm endoscopes, rigid endoscopes with articulated arms in which deflecting prisms are installed)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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Welded joints (ICS 25.160.40)
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- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of fusion-welded joints.

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- DGZfP - OV 01, 2013-11: Leaflet on optical methods - Part 1: Selection and initial inspection of optical visual inspection devices; Part 2: Inspection of optical visual inspection devices by the user.

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Additional technical contract conditions and guidelines for civil engineering structures

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- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Guidelines for the implementation of federal construction tasks, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Physical basis	Optical measuring principle
Procedure **Endoscopy: Fiberscopes (flexible endoscopes)** Endoscopy: Fiberscope Inspection	Test task - Surface inhomogeneities: Surface cracks - Corrosion - Bulges/deformations

Brief description

Non-destructive testing of an inaccessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of image transmission via a bundle of optical fibers. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/ exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)
- Examination of tendons with regard to grouting condition and turnbuckles (usually via borehole)
- Inspection of corrosion conditions/pitting corrosion (targeted via drill holes)

Application limits (technical, physical, economic)

- Accessibility or presence of openings
- Moisture (due to damage or wet drilling) and drilling dust (due to dry drilling)
- Rough estimates of sizes and dimensions (for simple devices)
- Lower resolution with smaller diameters due to lower number of pixels

Special applications (additional testing tasks)

- Verification of suspected areas of prestressing steel breakage (if necessary using a drill with automatic switch-off)
- Use of special equipment for targeted examinations:
  - Connection of CCD cameras and photo cameras for documentation
  - Equipped with gripping tools for sampling
  - Connection of optical devices such as magnifying glasses or microscopes
  - Use of monocular measuring magnifiers to measure crack widths

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity

Procedure description

Long description

The fiberscope, also known as a fiber optic endoscope, consists of an image guidance system made of ordered glass fibers and a light guidance system. The image is transmitted from the objective to the eyepiece via the flexible glass fibers. The more glass fibers there are, the better the image resolution. The glass fiber bundle is also called an image guide bundle. Illumination takes place via an optical fiber bundle.
The interpretation of the circular images is made more difficult by the distortion effects of the optics, the unusual perspective and the limited image resolution (number of pixels) and requires experience in interpreting the images. In addition to flexible fiberscopes, there are also rigid borescopes and flexible videoscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ More flexible control than rigid endoscopes
+ Smaller device diameter than with videoscopes
- Lower optical image resolution than the borescope due to the raster image of the fiber optic bundles

1.3 Endoscopy: fiberscopes

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- Fiberscope with a diameter of 2.5 to 4.2 mm and a length of up to 1200 mm [3]
- Miniature fiberscope with a diameter of 0.35 to 2.0 mm if necessary [3].
- Drill and power connection for drill if necessary

Measured variable and target variable

Specified characteristic(s): Surface inhomogeneities: surface cracks, corrosion, bulges/deformations

- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task

- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning

- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Carrying out the examination *(taking into account 2.)* : **Endoscopic examination with a fiberscope**

- Fiber optic tubing must not be kinked, otherwise the image transmission fibers will break

4. Documentation

- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information

- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

- Visual inspection is one of the classic NDT procedures and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out the visual inspection.

Non-destructive testing (ICS 19.100)

- DIN EN 13018, 2016-06: Non-destructive testing - Visual inspection - General principles.
- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

Welded joints (ICS 25.160.40)

- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.
- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of fusion-welded joints.

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Guidelines for the implementation of federal construction projects
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Other/ Notes/ Remarks/ Comment

1.4 Endoscopy: videoscopes

As of 18.12.2019

Physical basis	Optical measuring principle
Procedure **Endoscopy: videoscopes (flexible video endoscopes)** Endoscopy: Videoscope Inspection	Test task - Surface inhomogeneities: Surface cracks - Corrosion - Bulges/deformations

Brief description

Non-destructive testing of an inaccessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of image transmission via an electrical cable with a CCD image converter chip for video recording and an optical fiber for illumination. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)
- Examination of tendons with regard to grouting condition and turnbuckles (usually via borehole)
- Inspection of corrosion conditions/pitting corrosion (targeted via drill holes)

Application limits (technical, physical, economic)

- Accessibility or presence of openings
- Moisture (due to damage or wet drilling) and drilling dust (due to dry drilling)

Special applications (additional testing tasks)

- "Freezing" images
- Measurement of defects
- Verification of suspected areas of prestressing steel breakage (if necessary using a drill with automatic switch-off)

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity

Procedure description

Long description

The videoscope consists of a flexible endoscope and a measuring probe with an integrated video chip (CCD). The data is generated and transmitted digitally, enabling subsequent digital image processing.
Due to the unusual perspective, interpreting the circular images requires a certain amount of experience.
In addition to flexible videoscopes, there are also rigid borescopes and flexible fiberscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Higher image resolution compared to rigid and flexible endoscopes
+ High resistance to breakage compared to fiberscopes with sensitive glass fibers
+ Storage of images and videos using digital technology
+ Highest image transmission length compared to rigid and flexible endoscopes

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- Videoscope with diameter 4 to 6mm and up to 8000mm working length [3]
- Drill and power connection for drill if necessary

Measured variable and target variable

Specified characteristic(s): Surface inhomogeneities: surface cracks, corrosion, bulges/deformations
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning
- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Carrying out the examination *(taking into account 2.)* : **Endoscopic examination with a videoscope**

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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[2] Endoscopy (2014). In: DBV leaflet: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets), p. 31-33
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- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

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- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

Welded joints (ICS 25.160.40)

- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.
- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of fusion-welded joints.

DGZfP leaflets

- DGZfP - B6, 1996: Leaflet on visual inspection and endoscopy as optical methods for non-destructive testing in the building industry
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Other/ Notes/ Remarks/ Comment

1.5 Tear-off test

As of 18.12.2019

Physical basis	Mechanical measuring principle

Procedure	Test task
Tear-off attempt Pull-off test	- Coating materials: Adhesive strength

Brief description

Non-destructive test to **determine** the adhesive strength of a coating on a component surface (steel substrate) **by measuring** the tensile force that has to be applied in order to apply a bonded, surface-wise defined test stamp from the test surface.

Standard area of application (practical testing tasks)

- Determination of the adhesive strength of single and multi-layer systems (for all layer thicknesses) on component surfaces

Application limits (technical, physical, economic)

- Minimum thickness of the component to be tested (steel substrate): 10 mm [ISO 16276-1].
- Influence on the test result by: mechanical properties of the system under test, type and preparation of the test surface of the component to be tested, by the application method, the drying/curing conditions of the coating, by temperature, humidity and other factors as well as the type of test equipment used [ISO 4624].

Special applications (additional testing tasks/techniques)

- Performance of the test on sample panels that have been produced simultaneously and in the same way as the coating on the building [DIN EN ISO 16276-1].
- Perform the test with a minimum component thickness (steel substrate) of < 10 mm [ISO 16276-1]:
  - Application of the sandwich technique (see ISO 4624)
  - Reinforcement of the component (e.g. double T-beam, base plate)
  - Testing according to ISO 16276-2

On-site requirements

- Minimum thickness of the component to be tested (steel substrate): 10 mm [ISO 16276-1].
- Preparation of the test surface [ISO 16276-1]:
  - Cleaning the surfaces of the test stamp and the coating system and thorough degreasing
  - Drying of the surface if necessary
- Monitoring and recording of weather conditions, surface temperature of the coated structure and condition of the surface (wet/dry) over a period of 24 h before the test [DIN EN ISO 16276-1].

Procedure description

Long description

In the tear-off test, the adhesive strength of a coating on a component surface (substrate) is tested mechanically. For this purpose, an adhesive is applied to the surface of a test stamp and this test stamp is applied to the coating to be tested. Once the adhesive has hardened, any excess adhesive is removed and the coating is cut along the test stamp up to the component surface (substrate).

The tensile tester is then used to pull off the test stamp at a constant speed within 90 seconds and measure the minimum tensile stress that must be applied to cause an adhesive fracture (between the coating and substrate) and/or cohesive fracture (in the coating) of the test assembly. Finally, the fracture patterns are evaluated according to the type of fracture.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Easy handling and therefore suitable for use on the construction site
+ Adhesive strength is measured in comparison to the grid and cross-cut test
- Influence of numerous parameters on the test result
- Repair work required by surface destruction test according to the specification of the coating system [ISO 16276-1].

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

Test accessories according to DIN EN ISO 4624 and DIN EN ISO 16276-1:
- Adhesive (with better cohesion and adhesion properties than the coating to be tested)
- Test stamp: metal cylinder (stainless steel or aluminum alloy) with a diameter of 20 mm
- Transportable tensile tester / pull-off tester with constant force increase speed of $\leq$ 1 MPa/s and with centering device to ensure coaxial alignment of the test arrangement
- Cutting device for separating the test surface from the rest of the coating system

Measured variable and target variable

- centric tensile strength or tear strength in [N/mm²]:
  (Tensile force until the stamp breaks off in [N]/area of the test stamp in [mm²])
- Documentation of the type of failure with proportions of cohesive and adhesive fracture, the failure forces and the surface tensile strength to be calculated from this [ISO 16276-1].

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system in accordance with DIN EN ISO 16276-1
  Measurement plan, inspection areas, minimum number of inspections depending on the size of the inspection area

3. Performance of the test (taking into account 2.) according to DIN EN ISO 4624: **Tear-off test**
- Measurement and recording of the following conditions during the test:
  Air temperature, relative humidity and surface temperature of the coated structure

4. Documentation
- Recording of the execution and the measurement result: Fracture pattern analysis with acceptance and rejection of the test in accordance with DIN EN ISO 16276-1
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

Further information

Device manufacturer, software

Related methods/ measurement variants

Overview of methods for determining the adhesive strength of coatings according to DIN SPEC 91063

1. Adhesion tests without scoring/cutting

1.1 Tests with mechanical layer stress

1.1.1 Pull-off test

1.1.2 Shear-off test (twist-off test)

1.1.3 Peel-off test

1.2 Tests with continuous sample deformation

1.2.1 Mandrel bending test with wedge-shaped conical mandrel

1.2.2 Mandrel bending test with conical mandrel

1.2.3 Mandrel bending test with cylindrical mandrel

1.2.4 Three-point bending process

1.2.5 T-bend test

1.2.6 Cupping test

1.3 Tests with impact stress

1.3.1 Single impact test

1.3.2 Ball impact test

1.3.3 Multi-impact test

1.3.4 Impact folding test

2. Adhesion tests with scoring/cutting

2.1 Tests with individual scoring

2.1.1 Scratch test

2.2 Tests with multiple scribing (without sample deformation)

2.2.1 Pressurized water jet test ("steam jet test")

2.2.2 Cross-cut test

2.2.3 Cross cut test

2.2.4 Scribe test with square-diagonal grid

2.2.5 Scribe test with diamond grid

2.3 Tests with multiple scribing (with sample deformation)

2.3.1 Cupping test

Bibliography I (technical literature)

Bibliography II (regulations: standards, guidelines, information sheets)

Terminology (ICS 01.040.19)

- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Coating materials (paints and varnishes) (87,040)

- DIN SPEC 91063, 2011-07: Adhesion strength of coatings.
- DIN EN ISO 4624, 2016-08: Paints and varnishes - Tear-off test for the determination of adhesion.
- DIN EN ISO 4628-1, 2016-07: Paints and varnishes - Evaluation of coating defects - Coating damage assessment Evaluation of the amount and size of damage and the intensity of uniform changes in appearance Part 1: General introduction and evaluation system
Part 2: Assessment of the degree of
blistering Part 3: Assessment of the
degree of rusting Part 4:
Assessment of the degree of
cracking
Part 5: Assessment of the degree of flaking
Part 6: Assessment of the degree of chalking using the adhesive tape
method Part 7: Assessment of the degree of chalking using the velvet
method
Part 8: Evaluation of delamination and corrosion from a scratch or other artificial injury
Part 10: Evaluation of filiform corrosion
- DIN EN ISO 16276-1, 2007-08: Corrosion protection of steel structures by coating systems - Evaluation of adhesion/cohesion of a coating and criteria for its acceptance - Part 1: Tear-off test.

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Other/ Notes/ Remarks/ Comment

"If the coated structure is made of high-strength steel, care must be taken to ensure that the steel surface is not damaged, as this can lead to component failure due to the effects of corrosion." [DIN EN ISO 16276-1]

1.6 Cross-cut test and cross-cut test

As of 18.12.2019

Physical basis	Mechanical measuring principle

Procedure	Test task
Cross-cut test and Cross cut test Cross-cut tape testing and X-cut tape testing	- Coating materials: Adhesive strength

Brief description

Non-destructive test to **assess** the adhesive strength of a coating on a component surface (steel substrate) **by qualitatively evaluating** the resistance of the coating system to detachment after the defined incision of the test surface.

Standard area of application (practical testing tasks)

- Assessment of the adhesive strength of single and multi-layer systems (for all layer thicknesses) on steel structures

Application limits (technical, physical, economic)

- Grid and cross-cut tests are not methods for determining the adhesive strength by *measurement* [ISO 2409; Method for determining the adhesive strength by measurement according to DIN EN ISO 4624: e.g. tear-off test]
- In the case of hard coatings, it may not be possible to use the cross-cut test. In such cases, the cross-cut test should be used. [DIN EN ISO 16276-2]
- for coatings with effect pigments, the cross-cut and cross-cut tests can be misleading. The coating material manufacturer should be consulted for recommendations [DIN EN ISO 16276-2]
- May be influenced by the age of the coating system
- The test result can be influenced by temperature, humidity and ventilation

Special applications (additional testing tasks)

- Carry out the test on sample plates that are applied simultaneously and in the same way as the coating on the building have been manufactured [DIN EN ISO 16276-2]

On-site requirements

- Preparation of the test surface: Test surface must be dry or dried (recorded in the test report) [DIN EN ISO 16276-2].
- Monitoring and recording of weather conditions, surface temperature of the coated structure and condition of the surface (wet/dry) over a period of 24 h before the test [DIN EN ISO 16276-2].

Procedure description

Long description

Two tests can be used to assess the resistance of coating systems to loss of adhesion/cohesion strength due to cutting:

- **Cross-cut test** (cuts at a 90° angle, cut length 20 mm, distances between the cuts depending on the coating thickness) in accordance with DIN EN ISO 2409 for

Layer thicknesses < 250 µm and according to ASTM D3359 for layer thicknesses < 125 µm:

"In the cross-cut **test,** the coating is evaluated with a grid of continuous cuts and then the damage caused. The cross-cut test is carried out as described in ISO 2409. The cuts can either be made individually with a single-cut device and a template for the correct cut spacing or with a multi-cut device with the correct number and spacing of cuts." [DIN EN ISO 16276-2]

"The cross-cut method consists of applying a grid of continuous cuts to the substrate in the coating so that uniform squares are created. The distance between the cuts and thus the size of the squares is determined by the thickness of the coating to be tested. Adhesive tape is applied with a certain force to remove the parts of the coating that adhere poorly after the cuts have been m a d e . The result of the test is given as a characteristic value corresponding to the damage found. For details of the method, see ISO 2409." [DIN EN ISO 16276-2]

- **Cross-cut test** (cuts at an angle between 30° and 45°, cut length 40 mm, adhesive tape length 75 mm) according to DIN EN ISO 16276-2 for all layer thicknesses (without limitation) or according to ASTM D3359 for layer thicknesses > 125 µm:

"In the **cross-cut test,** two cuts are made at such an angle that the cuts form an X. Adhesive tape is applied to the cuts with a specified force (e.g. by thumb pressure) and then removed at the specified angle. The cross-cut test is performed as described in ASTM D 3359-02, Method A, using Annex A of this document [DIN EN ISO 16276-2] for evaluation." [DIN EN ISO 16276-2]

"The cross-cutting process consists of making a cross-cut in the coating with a sharp cutting edge that goes right through to the substrate. Adhesive tape is applied with a certain force to remove the parts of the coating that adhere poorly after the cuts have been made. The result of the test is given as a characteristic value corresponding to the damage found. For the characteristic value scale, see Appendix A." [DIN EN ISO 16276-2]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Easy handling and therefore suitable for use on the construction site
- Repair work required by surface destruction test according to the specification of the coating system [DIN EN ISO 16276-2].

1.6 Cross-cut test and cross-cut test

As of 18.12.2019

Measuring method

Measurement setup

Cutter and template
J. Wiese, HTW Berlin

Measurement results

Cross-cut test on steel plate
J. Wiese, HTW Berlin

Measuring devices

- Cross-cut test: (preferably) single-cutting device and template for cutting guide and cutting distance or multi-cutting device with the correct number and distance of cutting edges [DIN EN ISO 16276-2]; details according to ISO 2409
- Cross-cut test: template (to achieve a straight cut edge), cutting device, transparent self-adhesive tape [DIN EN ISO 16276-2]; details according to ISO 2409

Measured variable and target variable

Either classification of the test results using scales with six levels of the corresponding standards:
- Cross-cut test according to DIN EN ISO 2409 (classification from 0 to 5) and ASTM D3359 (classification from 5B to 0B)
- Cross-cut test according to DIN EN ISO 16276-2 Annex A (classification from 0 to 5) and ASTM D3359 (classification from 5A
to 0A)

or assessment of the test results by yes/no test, pass/fail or acceptance or rejection (according to criteria for acceptance in [DIN EN ISO 16276-2]);
In the case of a multi-layer system: indication of the layers between which a separation has occurred

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system:
  Measurement plan, inspection areas, minimum number of inspections depending on the size of the inspection area
- Determination of the procedure to be carried out: cross-cut test or cross-cut test

3. Performance of the test (taking into account 2.) in accordance with DIN EN ISO 16276-2: **Grid and cross-cut test**
- Measurement and recording of the following conditions during the test:
  Air temperature, relative humidity and surface temperature of the coated structure

4. Documentation
- Recording of the implementation and the measurement result
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	2/5	1/5	3/5

32

Further information

Device manufacturer, software

- Tenth Testing Instruments

Related methods/ measurement variants

Overview of methods for determining the adhesive strength of coatings according to DIN SPEC 91063

1. Adhesion tests without scoring/cutting

1.1 Tests with mechanical layer stress

1.1.1 Pull-off test
1.1.2 Shear-off test (twist-off test)
1.1.3 Peel-off test

1.2 Tests with continuous sample deformation

1.2.1 Mandrel bending test with wedge-shaped conical mandrel
1.2.2 Mandrel bending test with conical mandrel
1.2.3 Mandrel bending test with cylindrical mandrel
1.2.4 Three-point bending process
1.2.5 T-bend test
1.2.6 Cupping test

1.3 Tests with impact stress

1.3.1 Single impact test
1.3.2 Ball impact test
1.3.3 Multi-impact test
1.3.4 Impact folding test

2. Adhesion tests with scoring/cutting

2.1 Tests with individual scoring

2.1.1 Scratch test

2.2 Tests with multiple scribing (without sample deformation)

2.2.1 Pressurized water jet test ("steam jet test")
2.2.2 Cross-cut test
2.2.3 Cross cut test
2.2.4 Scribe test with square-diagonal grid
2.2.5 Scribe test with diamond grid

2.3 Tests with multiple scribing (with sample deformation)

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Adhesives, adhesive bonds (83,180)

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Part 2: Assessment of the degree of
blistering Part 3: Assessment of the
degree of rusting Part 4:
Assessment of the degree of
cracking

Part 5: Assessment of the degree of flaking
Part 6: Assessment of the degree of chalking using the adhesive tape
method Part 7: Assessment of the degree of chalking using the velvet
method
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and corrosion
Part 10: Evaluation of filiform corrosion
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Other/ Notes/ Remarks/ Comment

1.7 Wedge cut

As of 18.12.2019

Physical basis	Mechanical measuring principle

Procedure	Test task
Wedge cut (scoring and drilling method) Wedge-cut method (scribe and drill method)	- Coating materials: Layer thickness (number of layers)

Brief description

Non-destructive testing to determine the layer thickness and number of layers of a coating on the component to be tested by means of a defined incision on the surface and subsequent microscopic evaluation.

Standard area of application (practical testing tasks)

- Determining the dry film thickness for almost all layer-substrate combinations [DIN EN ISO 19399].
- Determination of the individual layer thicknesses of coating systems [DIN EN ISO 19399].

Application limits (technical, physical, economic)

- Layer thicknesses greater than the depth of field of the measuring microscope [DIN EN ISO 19399].
- Prevention of the perception of recognizable cracks or recognizable drill holes by [ISO 19399]:
  - Coatings that are too soft and/or elastic
  - Substrates that are too hard (cannot be scribed/tapped) or too soft and/or elastic
  - Too little optical contrast between coating and substrate

Special applications (additional testing tasks)

On-site requirements

- Sample with a flat area at least twice the size of the base area of the wedge cut device [DIN EN ISO 19399].

Procedure description

Long description

In the wedge cut method, "a wedge cut with a known flank angle is produced in the coating [...] using a scribing tool or a drilling tool. The coating thickness is calculated from the width of the flank projection of the wedge cut obtained with a measuring microscope." [DIN EN ISO 19399]

The use of a scoring tool is referred to in the standard as method A, the use of a drilling tool as method B.

In the scribing method, the scribe is placed on the coating and the graver is slowly moved over the sample so that a scribe of at least 10 mm is obtained, which passes through the coating to the steel surface. The length of the wedge cut in the coating is then measured with the measuring microscope and converted into the dry film thickness using the wedge cut factor of the graver.

With the drilling method, the drilling device is placed on the coating and the rotating drilling attachment is lowered so that the drill spindle drills conically through the coating down to the steel surface. The length of the wedge cut in the coating is then measured with the measuring microscope and converted into the dry film thickness using the wedge cut factor of the drill. [DIN EN ISO 19399]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Quick and easy implementation and evaluation
- slightly destructive compared to magnetic methods and eddy current testing
- Touch-up work required by surface destructive testing according to the specification of the coating system

1.7 Wedge cut

As of 18.12.2019

Measuring method

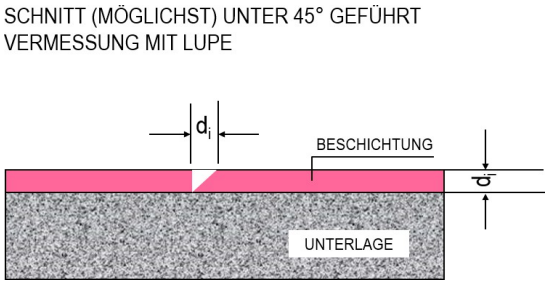
Measurement setup

Wedge cutter on steel plate

J. Wiese, HTW Berlin

Measurement results

Measurement of layer thickness with wedge cutter Haasis, haasis construction



Measuring devices

Device with cutting device according to DIN EN ISO 19399:

- Method A: Wedge-cut scriber with carbide wedge-cut graver (see image)
- Method B: Wedge-cutting drill with wedge-cutting carbide drill bit
- Measuring microscope (with illumination device, at least 40x magnification, a measuring range of at least 2 mm and a scale division of no more than 0.02 mm);

As an alternative to the measuring microscope: digital measuring device [DIN EN ISO 2808].

Measured variable and target variable

Target value:

- Dry film thickness t_d in [µm]; $t_d = l * \tan \alpha$

Measured variables:

- Wedge section base length l in [µm] (microscope reading)
- Wedge cut factor of the wedge cut tool used tan α; in the range from α = 5.7° (tan α = 0.1) to α = 45° (tan α = 1) [DIN EN ISO 2808]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task

- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (manufacturer, material, curvature, etc.)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning

- Specification of the test areas and a test system: Number of measurements (at least three scribes or holes per sample and two measurements of the wedge cut base length per scribe or hole) [DIN EN 19399].
- Determination of the procedure to be carried out: scoring or drilling method
- Sample preparation: Application of a two-dimensional contrast marking [DIN EN ISO 19399].

3. Carrying out the test (taking into account 2.) in accordance with DIN EN ISO 19399: **Wedge cut test**

4. Documentation

- Recording of the implementation and the measurement result
- Evaluation of the results in a test report

5. Further information

Process effort (from 1: low effort to 5: high effort)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	2/5

36

Further information

Device manufacturer, software

- TQC Sheen GmbH: TQC SP1100 SuperPIG (Process A)
[https://www.tqcsheen.com/rsrc/artikel_downloads/superpig-iii-destructive-paint-inspection-gauge-sp1100-m44-49-31.pdf]
- Elcometer: 141 Wedge cutter (PIG)
[https://www.elcometer.com/de/beschichtungskontrolle/trockenfilmdicke/zerstrend/elcometer-141-keilschnittgerat-pig.html]
- Erichsen:
  - Paint Inspection Gauge P.I.G. Model 455; mech.-opt. Coating thickness measurement, cutting (method A)
  - PAINT BORER 518; mech.-opt. Coating thickness measurement, drilling (method B)
  - Special version: PAINT BORER 518 USB with digital microscope and for connection to PC
[https://www.erichsen.de/de-de/produkte/oberflaechenpruefung/filmapplikation-und-schichtdicke/schichtdickenmessung-manuell-7/518-mc/technische-beschreibung-paint-borer-518-mc-pdf]

Related methods/ measurement variants

Overview of methods for non-destructive determination of dry film thickness [DIN EN ISO 2808 - Annex A, Table 2].

1. Gravimetric measuring principle
  1.1 Mass difference
2. Optical measuring principle
  2.1 Cross-section (destructive)
  2.2 Wedge cut (destructive)
  2.3 White light interferometry
3. Magnetic measuring principle
  3.1 Adhesive force
  3.2 Magnetic field change, method based on the Hall sensor principle
  3.3 Magnetic field change, magneto-inductive process
  3.4 Eddy current
4. Radiological measuring principle
  4.1 Beta backscattering process
5. Photothermal measuring principle
  5.1 Heat propagation
6. Acoustic measuring principle
  6.1 Ultrasonic reflection
7. Electromagnetic measuring principle
  7.1 Terahertz

Bibliography I (technical literature)

Bibliography II (regulations: standards, guidelines, information sheets)

Terminology (ICS 01.040.19)

- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Coating materials (paints and varnishes) (87,040)

- DIN EN ISO 2808, 2018-07: Paints and varnishes - Determination of coating thickness.
- DIN EN ISO 19399, 2018-02: Paints and varnishes - Determination of dry film thickness by the wedge cut method (scoring and drilling method).

Bibliography III (General regulations)

Protection of and in buildings in general (ICS 91.120.01)
- VDI 6200, 2010-02: Stability of buildings - Regular inspection.

Civil engineering in general (ICS 93.010)
- DIN 1076, 1999-11: Engineering structures in the course of roads and paths - monitoring and testing.

Additional technical contract conditions and guidelines for civil engineering structures
- ZTV-ING - Part 4 Steel construction, steel composite construction. In: Federal Highway Research Institute (ed.): Additional Technical Contract Conditions and Guidelines for Civil Engineering Structures.

Guidelines for the maintenance of engineering structures
- RI-ERH-KOR. Guidelines for the maintenance of the corrosion protection of steel structures. In: Federal Ministry of Transport, Building and Urban Development (ed.): RI-ERH-ING. Guidelines for the maintenance of engineering structures, pp. 1-38.

Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

1.8 Penetrant testing

As of 18.12.2019

Physical basis	Mechanical measuring principle

Procedure	Test task
Penetrant testing Penetrant Testing PT	- Surface inhomogeneities: Surface cracks - Connection Welded joints: Weld seam cracks

Brief description

Non-destructive testing for the detection of inhomogeneities open to the surface by applying a penetrant to the component surface to be tested and visualizing the inhomogeneity using a
Color contrast or luminance contrast on the test surface. - Surface method

Standard area of application (practical testing tasks)

- Surface inspection to indicate material separations open to the surface [1]
- Characterization and determination of defect position, defect length, defect depth
- Visualization of surface cracks and damage [2]
- Detection of defects such as cracks, overlaps, folds, pores and binding defects that are open to the surface of the material to be tested [DIN EN ISO 3452-1].
- Testing of welded joints [DIN EN ISO 23277]

Application limits (technical, physical, economic) [1]

- Use only for material separations that penetrate to the surface
- Error length can generally be estimated from the detected displays
- smallest measurable defects: between 0.1 µm (with a smooth surface) and approx. 1 mm opening size (with a defect depth of > 2 mm)
- rough surfaces run the risk of over-washing during intermediate cleaning
- Testing with fluorescent penetrant testing agents at darkened workstations with UV lamp
Pre-cleaning by sandblasting is unsuitable as cracks can be "slammed shut" [2]

Special applications (additional testing tasks)

- Testing of ceramics, plastics and glass possible [1]
- Testing at temperatures < 10 °C and > 50 °C in accordance with DIN EN ISO 3452-5/ -6

On-site requirements

- Component temperature between 10 °C and 50 °C due to the viscosity of the penetrant (outside these limits: use of a special product family) [1]
- Test surface: removal of corrosion protection and paint layers by careful sanding [1]
- Viewing conditions for the dye penetrant method [DIN EN ISO 3059]:
  - Uniform illumination of the test area, avoidance of glare and reflections
  - Illuminance > 500 lx during testing
- Viewing conditions fluorescent methods [DIN EN ISO 3059]:
  - Uniform irradiation (UV-A radiation) of the test surface
  - Ambient light < 20 lx during the test

Procedure description

Long description

In the first step of penetrant testing, a liquid, the penetrant, is applied to the test surface. Due to the capillary effect, the penetrant p e n e t r a t e s into defects that are open to the surface. In the second step, intermediate cleaning, the excess penetrant is washed off with an intermediate cleaner, whereby the penetrant must not b e washed out of the defects and defects must not be washed over. Therefore, intermediate cleaning must be carried out with great care. In the third step, a developer is applied by spraying, (dipping), pouring or brushing on, which either makes the penetrant appear as a contrasting background (dye penetrant method) or enhances the appearance of the penetrant (fluorescent method).
The error evaluation is carried out under the observation conditions required for the respective product family.
The dye penetrant method is also known as the "red-white method" because cracks are colored red on a white-colored surface. [1, DIN EN ISO 3452-1]

Procedure advantages and disadvantages (compared to procedures for the same test task)

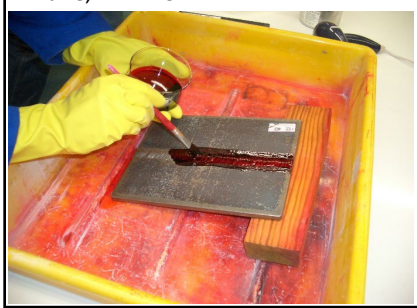
+ Low material costs, therefore cost-effective
+ Can also be used with non-magnetic materials
- Result depends on the tester and the surface preparation, material and accessibility
- Very careful processing of the surfaces
- Only locate displays/material separations that are open to the surface
- No reliable detection of cracks filled with corrosion products, in contrast to magnetic particle testing
- relatively time-consuming (0.5 h penetration; ≥ 0.5 h development) [6]
- Complex and error-prone

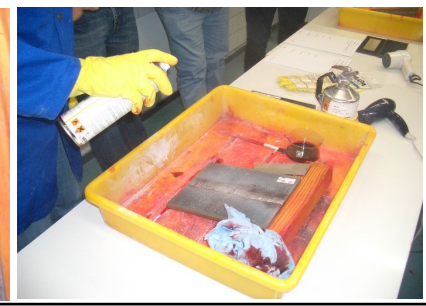
Measuring method

Measurement setup

Measurement results

(1) Weld seam penetrant, (2) Weld seam penetrant detail, (3) Weld seam developer
A. Taffe, HTW Berlin





Measuring devices

- Devices/processes for pre-cleaning and surface preparation in accordance with DIN EN ISO 3452-1
- Approved, sample-tested product family for penetration testing in accordance with DIN EN ISO 3452-2 consisting of
  - Penetrant (to increase the wetting capacity): Fluorescent and/or dye penetrants
  - Intermediate cleaner: water, lipophilic emulsifier, solvent, hydrophilic emulsifier or water and solvent
  - Developer (to improve contrast): Dry developer or wet developer
- White light lamp or UV(A) lamp with irradiance according to DIN EN ISO 3059
- Protective gloves and respiratory protection [6]

Measured variable and target variable

Specified characteristic(s) from test specification or test instruction: Displays/material separations that are open to the surface

- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Definition of the test areas and a test system

3. Carrying out the test (taking into account 2.) according to DIN EN ISO 3452: **Penetrant test**
- Preparation and pre-cleaning (with subsequent drying process): residue-free cleaning of the component surface and imperfections
- Penetration process: full-surface wetting of solid materials and penetration into defects due to the low surface tension (penetration time: between 5 and 60 minutes)
- Intermediate cleaning (with subsequent drying process): Removal of excess penetrant
- Development process: absorption of the rewetting penetrant by developer powder and formation of a contrast background (developer duration: always longer than the selected penetrant duration)
- If necessary, post-cleaning for further processing of the component and drying process

4. evaluation and documentation
- Start of the inspection with application of the developer
- Final ad evaluation after the specified developer period has expired:
  Searching for ads, classifying ads, interpreting ads, logging ads and evaluating ads [4]

5. Further information
- Special attention is paid to bogus advertisements
- Repeat the test if the result is inconclusive or another procedure is used

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	4/5	3/5	5/5

Further information

Device manufacturer, software

- MR Chemie GmbH [https://www.mr-chemie.de/eindringpruefung/produkte/eindringmittel/]
- Magnaflux GmbH [https://magnaflux.eu/de/Produkte/Eindringprufung]

Related methods/ measurement variants

- **Surface testing methods**

Mechanical processes

- Penetrant testing PT (for non-magnetic materials)

Magnetic methods

- Magnetic particle testing MT (for ferromagnetic materials)
- Eddy current test ET (for conductive materials)

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[1] **Penetrant testing (PT)** (2018). In: German Society for Non-Destructive Testing e.V. (ed.): **BC 3 M1 Basic course level 3. module 1. basic knowledge. Documents for the lessons. Penetration test.**

[2] Helmerich, Rosemarie (ed.) (2005): **Old steels and steel structures. Material investigations, fatigue tests on original bridge girders and measurements from 1990 to 2003**. Research report 271. BAM Federal Institute for Materials Research and Testing. Berlin.

[3] Fischer, Karl-Heinz; Schmeink, Helmut: **Non-destructive testing (NDT) and its evaluation in steel construction.** In: **Steel Construction Calendar 2006**, p. 549-596.

[4] Schiebold, Karlheinz (2014): **Non-destructive materials testing - Penetrant testing**. 1st edition with 122 images and 35 tables. Berlin, Heidelberg: Springer Berlin Heidelberg.

[5] **Testing for surface cracks using the indentation method** (1999). Volume 9, in collaboration with Volker Deutsch. In: Informationsschriften zur zerstörungsfreien Prüfung - ZfP - kompakt und verständlich, Vol. 9.

[6] Bauakademie Hessen-Thüringen E.V. (ed.) (2019): **Course on steel and steel composite bridges for engineers of the Building inspection** Documents for teaching

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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN ISO 12706, 2010-04: Non-destructive testing - Penetrant testing - Definitions.

Personnel management, vocational training (ICS 03.100.30)

- Penetrant testing is one of the classic NDT methods and is marked with the abbreviation "PT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out penetrant testing.

Non-destructive testing (ICS 19.100)

- DIN EN ISO 3059, 2013-03: Non-destructive testing - Penetrant testing and magnetic particle testing - Viewing conditions
- DIN EN ISO 3452-1, 2014-09: Non-destructive testing - Penetrant testing - Part 1: General principles
- DIN EN ISO 3452-2, 2014-03: Non-destructive testing - Penetrant testing - Part 2: Testing of penetrant testing equipment
- DIN EN ISO 3452-3, 2014-03: Non-destructive testing - Penetrant testing - Part 3: Control specimens
- DIN EN ISO 3452-4, 1999-02: Non-destructive testing - Penetrant testing - Part 4: Equipment
- DIN EN ISO 3452-5, 2009-04: Non-destructive testing - Penetrant testing - Part 5: Penetrant testing at temperatures above 50 °C
- DIN EN ISO 3452-6, 2009-04: Non-destructive testing - Penetrant testing - Part 6: Penetrant testing at temperatures below 10 °C

Welded joints (ICS 25.160.40)

- DIN EN ISO 5817, 2014-07: Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (without beam welding) - Assessment groups of irregularities.
- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.

- DIN EN ISO 23277 2015 06: Non-destructive testing of welded joints - Penetrant testing of welded joints - admissibility limits.

DGZfP regulations - guidelines and leaflets on surface crack detection (EM series)
- DGZfP-EM5, 2002-11: Information sheet on protective measures when handling electromagnetic fields in the non-destructive material testing.
- DGZfP-EM6, 2012-01: Leaflet on viewing stations for fluorescent testing with the magnetic particle and penetrant method - Equipment and protective measures for work with UV radiation.

[withdrawn: EM0, 2005: Guideline on the performance of magnetic particle tests
EM1, 2003: Guideline on the visual acuity of test personnel for NDT surface procedures EM2, 1988: Guideline on viewing conditions for magnetic particle and penetrant testing

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Other/ Notes/ Remarks/ Comment

1.9 Mobile hardness test HT rebound method according to Leeb

As of 18.12.2019

Physical basis	Mechanically excited measuring principle

Procedure	Test task
Mobile hardness testing with rebound method according to Leeb Leeb/ Rebound Hardness Testing HT	- (Change in) building material properties: Hardness

Brief description

Non-destructive test to determine a hardness (indirectly) by measuring the energy loss of an impactor on impact with the test object. [Dynamic testing]

Standard area of application (practical testing tasks)

- Dynamic hardness of all metallic materials [ISO 16859-1].
- in particular testing on coarse-grained steel of any shape

Application limits (technical, physical, economic)

- Application range: Hardness range from approx. 300 to 1000 HL [ISO 16859-1].
- Hardness test results are only consistent for one and the same test method if all test parameters are observed (the following specifications are required: definition of the hardness value, geometry and material of the indenter, type and size of the test load, duration of the test load in static test methods and condition of the specimen) [VDI/VDE 2616-1].
- Testing on curved surfaces with a radius of curvature < 50 mm or 30 mm (depending on the type of impact device) only with special stop flaps on the testing device [ISO 16859-1].
- (Electro-) magnetic fields (in the frequency range of a few kHz) influence the test result [DIN EN ISO 16859-1].

Special applications (additional testing tasks)

-

On-site requirements

- Minimum thickness and minimum mass of the sample depending on the type of impact device: Minimum thickness of 1.0 mm to 10.0 mm depending on the coupling and a minimum mass of 0.5 kg to 15 kg depending on the support;
(Observe the specifications of the device manufacturer, larger thicknesses or masses may be required) [ISO 16859-1].
- Sample surface: Removal of coatings, scale, impurities and surface irregularities as well as lubricants to achieve a specified average roughness depth according to [ISO 16859-1, Table 3]; metallic bright and ground in the test area [VDI/VDE 2616-1].
- Ambient temperature between 10 °C and 35 °C (better: narrow temperature range) [DIN EN ISO 16859-1].
- Ambient location must be free of (electro-) magnetic fields [DIN EN ISO 16859-1].

Procedure description

Long description

In hardness testing using the Leeb rebound method, "the hardness of the material is measured indirectly via the energy loss of an impact body on impact with the surface to be tested." [DGZfP MC 1]
"During the test, an impact body with a spherical indenter made of hard metal, ceramic or diamond strikes the test surface by spring force and rebounds. The impact and rebound speed are measured without contact [inductively]. The hardness value HL is calculated from these two measured values. The test indentation produced is not used to determine the hardness." [VDI/VDE 2616-1; Principle of the method]
The calculated hardness value must also be assigned to a material group in the tester in order to take the elastic properties of the material into account.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Testing in all positions, e.g. also overhead measurement, possible using correction factors [VDI/VDE 2616-1].
+ direct display of the hardness value
- Testing of samples of low thickness or low mass is problematic due to the impact force [VDI/VDE 2616-1].

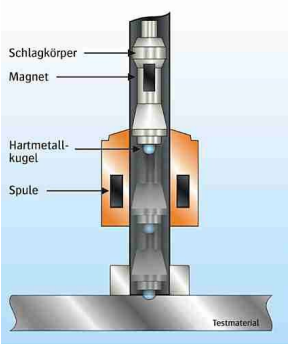
1.9 Mobile hardness test HT rebound method according to Leeb

As of 18.12.2019

Measuring method

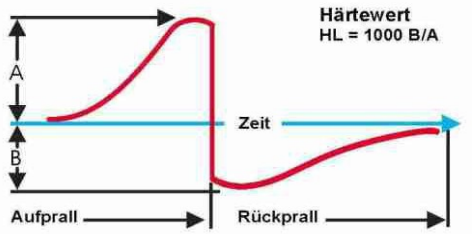
Measurement setup

Schematic structure of a rebound impact device according to Leeb [DGZfP - MC 01, 2008-04: Guideline for criteria for the selection of hardness testing methods with mobile devices, Figure 5].



Measurement results

Progression of the measured induced voltage during a hardness measurement [DGZfP - MC 01, 2008-04: Guideline for criteria for the selection of hardness testing methods with mobile devices, Figure 4].



Measuring devices

- Leeb hardness tester consisting of an impact device with indenter and an electronic measuring and display unit for determining the impact and rebound velocity of the impactor [in accordance with DIN EN ISO 16859-1, Annex D]:
  - spherical indenter made of hard metal (for samples up to a Vickers hardness of 800 HV 30) or
  - spherical indenter made of ceramic or synthetic diamond (for samples up to 1200 HV 30)
- Testing device according to ISO 16859-2 requirements

Measured variable and target variable

- Target value: Leeb hardness HL [dimensionless] [seven different Leeb scales based on seven different types of impact device; the letter after the "HL" represents the type of impact device [DIN EN ISO 16859-1]]
- Measured variable: Impact velocity v_a and rebound velocity v_r of the impactor
- HL = 1000 * (v /v)$_{ra}$
- Conversion of dynamic hardness values into hardness values of static methods according to DIN EN ISO 18265 and
- Conversion of hardness values into tensile strength values in accordance with DIN EN ISO 18265, taking uncertainties into account
- Each hardness test result must be specified with a measurement uncertainty [VDI/VDE 2616-1].

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Definition of the test areas and a test system: Compliance with minimum distances between test indentations and to the edge of the sample according to DIN EN ISO 16859-1 - Implementation [VDI/VDE 2616-1].
- Information on the test device (impact device type)

3. Performance of the audit (taking into account 2.)
- The impact device must be held perpendicular to the sample surface. [DIN EN ISO 16859-1]
- Correction of the hardness values if necessary: "If the test is not performed in the direction of gravity, the direction of the test and the correction must be recorded and the corrected hardness value must be stated as the result of the Leeb hardness." according to DIN EN ISO 16859-1, Annex A

4. evaluation
- Determination of the Leeb hardness: Calculation of the arithmetic mean value from at least three measured values.

If the range of three measured values is greater than 5 % of the arithmetic mean, additional measurements must be carried out to form an average of at least 10 measured values.

5. Documentation
- Recording of the performance "with all essential details of the test which are not specified in ISO 16859 or which were applied optionally, e.g. type of coupling, test area on the sample, direction of the impact in relation to gravity" [DIN EN ISO 16859-1].
- Logging of the measurement result and the number of underlying individual values
- Logging of all incidents or special features that could have influenced the measurement result
- Evaluation of the results in a test report

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	2/5	3/5	3/5

1.9 Mobile hardness test HT rebound method according to Leeb

Further information

Device manufacturer, software

- Proceq AG: Equotip 550 Leeb
- GE Inspection: DynaMIC

Related methods/ measurement variants // Methods with the same test task

Mobile hardness test (with indenter) [DGZfP MC 1]

Dynamic testing

a) Parallel to the surface:
- Scoring

b) Perpendicular to the surface:
- **Leeb/rebound method** (dynamic-elastic-plastic) [e.g. DynaMic from GE Inspection, Equotip from Proceq].
- Shore/rebound method: Drop hammer (scleroscope) or pendulum hammer (duroscope)
- Poldi hammer, shear force, Baumann hammer (dynamic-plastic)

Static testing

a) Frequency shift:
- **UCI method** [e.g. Microdur MIC 10 from GE Inspection]

b) Electrical resistance:
- Force-resistance measurement [e.g. Esatest from Cisam-Ernst]

c) Penetration depth:
- **Rockwell principle** with high test force [e.g. Dynatest from Cisam-Ernst].
- Rockwell principle with low test force [e.g. Computest from Cisam-Ernst, Equostat from Proceq].

d) Lateral position
- **TIV method** (length measurement under load) [e.g. TIV from GE Inspection].
- Test clamps (length measurement after unloading)

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Mechanical testing of metals (77.040.10)

- DIN EN ISO 16859-1/ -2/ -3, 2016-02: Metallic materials - Leeb hardness test.
- DIN EN ISO 18265, 2014-02: Metallic materials - Conversion of hardness values.
- ASTM E140 - 12B, 2019: Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness.
- VDI/VDE 2616-1, 2012-08: Hardness testing of metallic materials. [TIV method not described]

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Other/ Notes/ Remarks/ Comment

Note on the term non-destructive testing from DGZfP Guideline MC 1

"Mobile hardness testing can be classified as non-destructive testing if the functionality of the component is not impaired by the indentation [of the indenter]."

Note on portable hardness testers in DIN 50159-1:2015-01 - Introduction

"Portable hardness testers allow hardness tests to be carried out on samples that are too large or too heavy to be tested on stationary hardness testing machines. As the classic hardness test methods such as Rockwell, Vickers, Brinell and others are difficult or impossible to implement in portable devices, various manufacturers have developed new test methods based on the classic methods, which can also be used in portable devices. However, the development of each new test method also means, in principle, the introduction of a new hardness scale. If these devices are to indicate the measured hardness values in the common scales such as Rockwell, Vickers or Brinell, they must carry out a conversion at one point in their measuring chain. Such hardness values are then not true Rockwell, Vickers or Brinell values because they are not determined using the standardized Rockwell, Vickers or Brinell methods.
have been made."

1.10 Mobile hardness test HT according to the UCI method

As of 18.12.2019

Physical basis	Mechanically excited measuring principle
Procedure **Mobile hardness testing according to the UCI procedure** Ultrasonic Contact Impedance Hardness Testing HT	Test task - (Change in) building material properties: Hardness

Brief description

Non-destructive test to determine the hardness (indirectly) by measuring the frequency shift of a pyramid imprint left by the indenter (Vickerdiamond) after applying a defined test force. [Quasi-static test]

Standard area of application (practical testing tasks)

- quasi-static hardness of metallic materials [DIN 50159-1]
- in particular testing on fine-grained steel, non-ferrous metals and hard metal [DIN 50159-1].
- typical applications depending on the applied test force [DIN 50159-1]:
  - high test force: weld seams, heat-affected zones, small forged parts
  - Low test force: thin layers with polished surface

Application limits (technical, physical, economic)

- Application range: Hardness range from approx. 20 to 1740 HV [DGZfP MC 1].
- Hardness test results are only consistent for one and the same test method if all test parameters are observed (the following specifications are required: definition of the hardness value, geometry and material of the indenter, type and size of the test load, duration of the test load for static test methods and condition of the specimen) [DIN 50157-1].
- Correction of hardness values determined on curved test surfaces [1]
- Vibrations and strong magnetic fields influence the measurement result [DIN 50159-1]

Special applications (additional testing tasks)

- Measurement of the hardness of metal layers with the probe positioned vertically on the test surface, taking into account the penetration depth h of the Vickers indenter [DIN 50159-1].

On-site requirements

- Minimum thickness and minimum mass of the sample: Consideration of a minimum thickness (typical value: 3 mm) and a minimum mass (typical value: 300 g) in order to minimize the influence of the natural vibrations of the sample or additional measures such as coupling or substructure of the sample [1, DIN 50159-1].
- Sample surface: Removal of scale, foreign bodies and surface irregularities as well as lubricants [1, DIN 50159-1].
- Specimen surface: Observe the specifications for the maximum permissible surface roughness Ra as a function of the test load in accordance with DIN 50 159-1 [1, DIN 50159-1].
- Ambient temperature between 10 °C and 35 °C [DIN 50159-1].
- The surrounding area must be free from vibrations and strong magnetic fields [DIN 50159-1].

Procedure description

Long description

In hardness testing using the UCI measurement method, a vibrating rod vibrating at an ultrasonic frequency with a Vickers indenter at its lower end is pressed onto the sample with a defined test force. Its resonance frequency increases as soon as it is brought into contact with the sample when the indentation is created. The resonant frequency shift Δf is determined under test force. It depends on the size of the contact surface and the modulus of elasticity of the overall system, consisting of the specimen and the vibrating rod. With the aid of samples of known hardness (e.g. hardness reference plates), the resonance frequency shift Δf is assigned to the corresponding Vickers hardness via an appropriate device adjustment." [DIN 50159-1]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Testing in all positions, e.g. overhead measurement also possible [1]
+ direct display of the hardness value [1]
+ Hardness measurement in hard-to-reach areas [1]
- Testing of samples of low thickness or low mass must be coupled [1]
- Dependence on the modulus of elasticity [1]
- for small test indentations, the hardness depends on the type of test surface preparation [1]

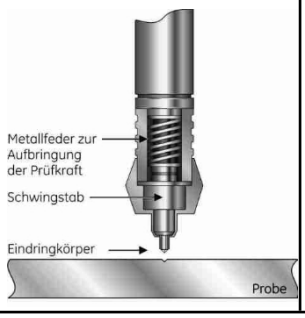
1.10 Mobile hardness test HT according to the UCI method

As of 18.12.2019

Measuring method

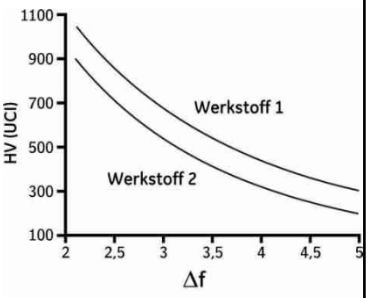
Measurement setup

Schematic structure of a UCI probe [DGZfP - MC 01, 2008-04: Guideline for criteria for the selection of hardness testing methods with mobile devices, Figure 6].



Measurement results

Frequency shift of a UCI probe as a function of hardness for two different materials [DGZfP - MC 01, 2008-04: Guideline for criteria for the selection of hardness testing methods with mobile devices, Figure 7].



Measuring devices

UCI hardness tester consisting of [1]: - Probe (different geometries) with receiving transducer, vibrating rod, transmitting transducer and Vickers diamond (indenter according to Vickers)
- Electronic measuring and display unit
- Test force between 1 N and 98 N depending on the test task
- Test device according to the requirements of DIN 50159-2

Measured variable and target variable

- Measured variable: Resonant frequency shift Δf under test load [1]
- Assignment of the resonant frequency shift Δf to a corresponding Vickers hardness [1]
- Target value: Hardness HV (UCI) [1]
- Conversion of hardness scales in accordance with DIN EN ISO 18265 and
- Conversion of hardness values into tensile strength values in accordance with DIN EN ISO 18265, taking uncertainties into account

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Definition of the test areas and a test system: Compliance with minimum distances between test indentations and to the edge of the specimen in accordance with DIN 50159-1 - Implementation: Distance of the center of each test indentation from the edge of the specimen: at least 5 mm; distance between the centers of two adjacent test indentations for the material steel: at least 1 mm
- Information on the test device (test force)
- Before starting a series of measurements: Ensure that the device displays the calibrated hardness value by testing it on a hardness reference block
- Information on the reference material

3. Carrying out the test (taking into account 2.) in accordance with DIN 50159-1
- The test is performed perpendicular to the test surface
- Ensure that the sample does not move during the test procedure (if necessary, use a suitable holding device)
- Application of the test force: continuously increasing, shock-free and along the vibrating rod
- Avoidance of vibrations of the sample or probe during the UCI hardness test

4. evaluation
- Determination of the UCI hardness: Determination of the arithmetic mean of at least three measured values

5. Documentation
- Recording of the execution with "all essential details of the test which are not specified in DIN 50159-1 or which were applied optionally, e.g. type of coupling, test location on the sample" [3].
- Recording of the measurement result, the number of underlying individual values and the measurement uncertainty of the hardness values
- Logging of all incidents or special features that could have influenced the measurement result
- Evaluation of the results in a test report

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

1.10 Mobile hardness test HT according to the UCI method

48

Further information

Device manufacturer, software

- Proceq AG: Equotip 550 UCI
- GE Inspection Technologies: Microdur MIC 10

Related methods/ measurement variants // Methods with the same test task

Mobile hardness test (with indenter) [DGZfP MC 1]

Dynamic testing

a) Parallel to the surface:
- Scoring

b) Perpendicular to the surface:
- **Leeb/rebound method** (dynamic-elastic-plastic) [e.g. DynaMic from GE Inspection, Equotip from Proceq].
- Shore/rebound method: Drop hammer (scleroscope) or pendulum hammer (duroscope)
- Poldi hammer, shear force, Baumann hammer (dynamic-plastic)

Static testing

a) Frequency shift:
- **UCI method** [e.g. Microdur MIC 10 from GE Inspection]

b) Electrical resistance:
- Force-resistance measurement [e.g. Esatest from Cisam-Ernst]

c) Penetration depth:
- **Rockwell principle** with high test force [e.g. Dynatest from Cisam-Ernst].
- Rockwell principle with low test force [e.g. Computest from Cisam-Ernst, Equostat from Proceq].

d) Lateral position
- **TIV method** (length measurement under load) [e.g. TIV from GE Inspection].
- Test clamps (length measurement after unloading)

Bibliography I (technical literature)

Bibliography II (regulations: standards, guidelines, information sheets)

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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

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- DIN 50159-2, 2015-01: Metallic materials - Hardness testing by the UCI method - Part 2: Testing and calibration of hardness testers.
- DIN EN ISO 18265, 2014-02: Metallic materials - Conversion of hardness values.
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Other/ Notes/ Remarks/ Comment

Note on the term non-destructive testing from DGZfP Guideline MC 1

"Mobile hardness testing can be classified as non-destructive testing if the functionality of the component is not impaired by the indentation [of the indenter]."

Note on portable hardness testers in DIN 50159-1:2015-01 - Introduction

"Portable hardness testers allow hardness tests to be carried out on samples that are too large or too heavy to be tested on stationary hardness testing machines. As the classic hardness test methods such as Rockwell, Vickers, Brinell and others are difficult or impossible to implement in portable devices, various manufacturers have developed new test methods based on the classic methods, which can also be used in portable devices. However, the development of each new test method also means, in principle, the introduction of a new hardness scale. If these devices are to indicate the measured hardness values in the common scales such as Rockwell, Vickers or Brinell, they must carry out a conversion at one point in their measuring chain. Such hardness values are then not true Rockwell, Vickers or Brinell values because they have not been determined using the standardized Rockwell, Vickers or Brinell methods."

1.11 Mobile hardness test HT according to the TIV method

As of 18.12.2019

Physical basis	Mechanically excited measuring principle

Procedure	Test task
Mobile hardness testing according to the TIV method Through Indenter Viewing Hardness Testing TIV	- (Change in) building material properties: Hardness

Brief description

Non-destructive test to determine a hardness (indirectly) by optical measurement of the diagonal lengths of a pyramid impression left behind *through the indenter* (Vickers diamond) when a defined test force is reached. [Conforms to the Vickers hardness test; static test]

Standard area of application (practical testing tasks)

- Static hardness of metallic materials (including hard metals) [ISO 6507-1].
- Testing of thin-walled sheet metal [DGZfP MC 1]
- Possible applications: thin layers, weld seams, heat-affected zone [GE]

Application limits (technical, physical, economic)

- Application range: Hardness range from approx. 30 to 1000 HV [DGZfP MC 1].
- Correction of hardness values determined on curved surfaces [ISO 6507-1].
- Hardness test results are only consistent for one and the same test method if all test parameters are observed (the following specifications are required: definition of the hardness value, geometry and material of the indenter, type and size of the test load, duration of the test load for static test methods and condition of the specimen) [DIN 50157-1].

Special applications (additional testing tasks)

On-site requirements

- Sample surface: Removal of scale, foreign matter and lubricants to achieve a surface that allows accurate measurement of the indentation diagonals [DIN EN ISO 6507-1].
- for hard metals: Surface layer removal of at least 0.2 mm
- Ambient temperature between 10 °C and 35 °C (better: narrower temperature range of 23 ± 5 °C) [DIN EN ISO 65071].
- Minimum thickness of the test piece: 1.5 times the diagonal length of the indentation [ISO 6507-1].

Procedure description

Long description

In hardness testing using the TIV method, an indenter (Vickers diamond, pyramid-shaped) is pressed into the surface of the component to be tested with a defined test force. The TIV tester is equipped with an optical system consisting of a microscope and CCD camera and the diamond is transparent. As the test force is applied, the growing, pyramid-shaped test impression of the Vickers diamond in the test surface can be followed through the diamond in real time and the impression image can be digitally evaluated and saved using software integrated in the device. This software determines the perimeter of the indentation and calculates the lengths of the diagonals from the intersections of the perimeter of the indentation and the edges (at a 136° roof angle) of the diamond. The mean value of the diagonals is used for conversion into hardness values according to the Vickers definition:
"The Vickers hardness is proportional to the quotient of the test force [F in N] and the inclined surface of the indentation, which is assumed to be a straight pyramid with a square base and the same angle [α = 136 °] as the indenter." [ISO 6507-1]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Test independent of direction [1]
+ Test independent of material; can be used on different materials without calibration [1]
+ immediate assessment of the quality of the measurement through real-time imaging of the pyramid impression of the diamond [1]

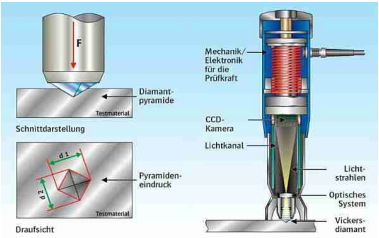
1.11 Mobile hardness test HT according to the TIV method

As of 18.12.2019

Measuring method

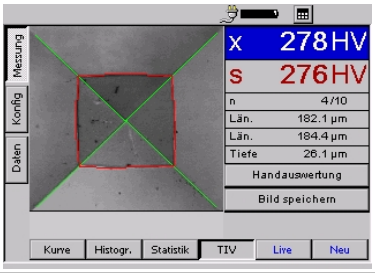
Measurement setup

Hardness test using the Vickers method and schematic structure of a TIV probe
[DGZfP - MC 01, 2008-04: Guideline for criteria for the selection of hardness testing methods with mobile devices, Figure 8].



Measurement results

TIV - Hardness impression with measurement result
[DGZfP - MC 01, 2008-04: Guideline for criteria for the selection of hardness testing methods with mobile devices, Figure 9].



Measuring devices

TIV hardness tester consisting of [DGZfP MC 1]:
- Probe (height approx. 215mm) with Vickers diamonds, optical system, CCD camera and mechanics/electronics for applying the test force
- Electronic measuring and display unit

Measured variable and target variable

- Measured variable: Length of the two diagonals d_1 and d_2 in [mm] of the Vickers diamond pyramid imprint in plan view
- Conversion of the arithmetic mean value d of the diagonals, the test force F and the mean angle α between opposing surfaces of the pyramid-shaped indenter (nominal 136°) into hardness values [ISO 6507-1]
- Target value: Vickers hardness HV (measuring range: 30 to at least 1000 HV) [DGZfP MC 1].
- Conversion of dynamic hardness values into hardness values of static methods according to DIN EN ISO 18265 and
- Conversion of hardness values into tensile strength values in accordance with DIN EN ISO 18265, taking uncertainties into account

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Definition of test areas and a test system: Compliance with minimum distances between adjacent test indentations in accordance with DIN EN ISO 6507-1
- Information on the tester

3. conducting the audit (taking into account 2.)
- Correction of the hardness values if necessary

4. evaluation
- Determination of hardness according to TIV: Automatic evaluation according to DIN EN ISO 6507-4: Tables for determining hardness values

5. Documentation
- Logging of the implementation
- Logging of the measurement result and the number of underlying individual values
- Logging of all incidents or special features that could have influenced the measurement result
- Evaluation of the results in a test report

6. further information

Process effort (from 1: low effort to 5: high effort)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

1.11 Mobile hardness test HT according to the TIV method

52

Further information

Device manufacturer, software

- GE Inspection Technologies: TIV

Related methods/ measurement variants

Mobile hardness test (with indenter) [DGZfP MC 1]

Dynamic testing

a) Parallel to the surface:
- Scoring

b) Perpendicular to the surface:
- **Leeb/rebound method** (dynamic-elastic-plastic) [e.g. DynaMic from GE Inspection, Equotip from Proceq].
- Shore/rebound method: Drop hammer (scleroscope) or pendulum hammer (duroscope)
- Poldi hammer, shear force, Baumann hammer (dynamic-plastic)

Static testing

a) Frequency shift:
- **UCI method** [e.g. Microdur MIC 10 from GE Inspection]

b) Electrical resistance:
- Force-resistance measurement [e.g. Esatest from Cisam-Ernst]

c) Penetration depth:
- **Rockwell principle** with high test force [e.g. Dynatest from Cisam-Ernst].
- Rockwell principle with low test force [e.g. Computest from Cisam-Ernst, Equostat from Proceq].

d) Lateral position
- **TIV method** (length measurement under load) [e.g. TIV from GE Inspection].
- Test clamps (length measurement after unloading)

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- DIN EN ISO 6507-1, 2018-07: Metallic materials - Vickers hardness test - Part 2: Verification and calibration of testing machines
- DIN EN ISO 6507-1, 2018-07: Metallic materials - Vickers hardness test - Part 3: Calibration of hardness reference blocks
- DIN EN ISO 6507-1, 2018-07: Metallic materials - Vickers hardness test - Part 4: Tables for the determination of hardness values
- DIN EN ISO 18265, 2014-02: Metallic materials - Conversion of hardness values.
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Other/ Notes/ Remarks/ Comment

Note on the term non-destructive testing from DGZfP Guideline MC 1

"Mobile hardness testing can be classified as non-destructive testing if the functionality of the component is not impaired by the indentation [of the indenter]."

Note on portable hardness testers in DIN 50159-1:2015-01 - Introduction

"Portable hardness testers allow hardness tests to be carried out on samples that are too large or too heavy to be tested on stationary hardness testing machines. As the classic hardness test methods such as Rockwell, Vickers, Brinell and others are difficult or impossible to implement in portable devices, various manufacturers have developed new test methods based on the classic methods, which can also be used in portable devices. However, the development of each new test method also means, in principle, the introduction of a new hardness scale. If these devices are to indicate the measured hardness values in the common scales such as Rockwell, Vickers or Brinell, they must carry out a conversion at one point in their measuring chain. Such hardness values are then not true Rockwell, Vickers or Brinell values because they are not determined using the standardized Rockwell, Vickers or Brinell methods.
have been made."

1.12 Mobile hardness test HT according to the Rockwell principle

As of 18.12.2019

Physical basis	Mechanically excited measuring principle

Procedure	Test task
Mobile hardness testing according to the Rockwell principle Portable Rockwell Hardness Testing	- (Change in) building material properties: Hardness

Brief description

Non-destructive test to determine the hardness (indirectly) by measuring the difference between the indentation depth of the indenter (diamond) with test pre-load before applying the test load and the indentation depth with test pre-load after removing the test load. [analog
the Rockwell method; static testing]

Standard area of application (practical testing tasks)

- Static hardness test on metallic materials [DIN 50157-1].
- for scratch-sensitive, polished and thin parts [Proceq]
- ideal for thin or light samples [Flyer Proceq]

Application limits (technical, physical, economic)

- Application range: Hardness range from approx. 20 HRC to 70 HRC; depth range from 0 to 300 µm [DIN 50157-1].
- Hardness test results are only consistent for one and the same test method if all test parameters are complied with (the following specifications are required: definition of the hardness value, geometry and material of the indenter, type and size of the test load, duration of the test load for static test methods and condition of the specimen) [DIN 50157-1].
- Correction of hardness values determined on curved test surfaces [50157-1]
- Influence of additional operating errors due to individually hand-held hardness testers [DIN EN 50157-1].

Special applications (additional testing tasks)

On-site requirements

- Minimum thickness: At least ten times the penetration depth for conical indenters and 15 times the penetration depth for spherical indenters [DIN 50157-1].
- Sample surface: smooth surface; free of scale, foreign bodies and in particular free of lubricants [DIN 50157-1].
- Ambient temperature between 10 °C and 35 °C (better: narrow temperature range) [DIN 50157-1].

Procedure description

Long description

In mobile hardness testing according to the Rockwell principle, the test is carried out in the same way as the Rockwell method. "The devices work according to the Rockwell principle, i.e. a test pre-force F_0 is applied, then an additional test force F_1 is applied, held and withdrawn so that the test pre-force acts again. An indenter [...] is pressed vertically into the surface of a sample by hand or by a mechanism built into the measuring head with constantly increasing force up to a maximum value, whereby the indentation depth is measured after reaching a fixed test pre-force during the application of the force and also after the withdrawal of the additional test force. The hardness is determined by the device via a calibration curve from the difference between the indentation depths of the two measurements." [DIN 50157-1]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Measurement on horizontal, vertical or inclined surfaces without correction factors [DIN 50157-1].
- Calibration of the mobile hardness testers is only valid for the material of the hardness reference blocks used
- Hardness values can only be compared if indenters, initial test forces and total test forces are the same
- Possible additional operating errors with portable hardness testers due to individual use and experience of the tester [DIN 50157-1].

1.12 Mobile hardness test HT according to the Rockwell principle

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- Test device consisting of [1,3]:
  - mechanical measuring head with indenter according to DIN EN ISO 6508-2:
    - Standard: Diamond cone with cone angle 120° and tip radius 0.2 mm or
    - Brinell ball made of carbide with a diameter of 1.5875 mm
  - electronic measuring and display unit
- Test force
  - Test preload F_0 : 10 N to 100 N
  - Total test force F: 50 N to 981 N

Measured variable and target variable

- Measured variable: Diamond penetration depth Δ in [µm]; $\Delta = d_2 - d_1$ with d_1 : Penetration depth of the indenter with test load before application of the test load and d_2 : Penetration depth of the indenter with test load after removal of the test load [1]
- Target value: modified Rockwell hardness HMMRC by converting the indentation depth into hardness values using a calibration curve (stored in the device) [1]
- Conversion of hardness scales in accordance with DIN EN ISO 18265 and
- Conversion of hardness values into tensile strength values in accordance with DIN EN ISO 18265, taking uncertainties into account

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Definition of the test areas and a test system: Compliance with minimum distances between test indentations and to the edge of the sample in accordance with DIN 50 157-1
- Information on indenters, test forces and test times

3. conducting the audit (taking into account 2.)
- It must be ensured that the sample cannot move during the measurement. If necessary, use a suitable holding device for this purpose. Any movement of the sample distorts the measurement and can cause damage to the indenter. [DIN 50157-1]

4. evaluation
- Determination of the modified Rockwell hardness by converting the indentation depth of the indenter into hardness values using a calibration curve

5. Documentation
- Recording of the performance "with all essential details of the test which are not specified in DIN 50157 or which can be applied optionally
- Logging of the measurement result and its measurement uncertainty
- Logging of all incidents or special features that could have influenced the measurement result
- Evaluation of the results in a test report

6. further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

1.12 Mobile hardness test HT according to the Rockwell principle

56

1.12 Mobile hardness test HT according to the Rockwell principle

Further information

Device manufacturer, software

- Proceq AG: Equotip 550 Portable Rockwell
- Cisam-Ernst: Dynatest

Related methods/ measurement variants // Methods with the same test task

Mobile hardness test (with indenter) [DGZfP MC 1]

Dynamic testing

a) Parallel to the surface:
- Scoring

b) Perpendicular to the surface:
- **Leeb/rebound method** (dynamic-elastic-plastic) [e.g. DynaMic from GE Inspection, Equotip from Proceq].
- Shore/rebound method: Drop hammer (scleroscope) or pendulum hammer (duroscope)
- Poldi hammer, shear force, Baumann hammer (dynamic-plastic)

Static testing

a) Frequency shift:
- **UCI method** [e.g. Microdur MIC 10 from GE Inspection]

b) Electrical resistance:
- Force-resistance measurement [e.g. Esatest from Cisam-Ernst].

c) Penetration depth:
- **Rockwell principle** with high test force [e.g. Dynatest from Cisam-Ernst, Equotip from Proceq].
- Rockwell principle with low test force [e.g. Computest from Cisam-Ernst, Equostat from Proceq].

d) Lateral position
- **TIV method** (length measurement under load) [e.g. TIV from GE Inspection].
- Test clamps (length measurement after unloading)

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Mechanical testing of metals (77.040.10)

- DIN 50157-1/ -2, 2008-04: Metallic materials - Hardness testing with portable hardness testers using mechanical indentation depth measurement.
- DIN EN ISO 6508-1, 2016-12: Metallic materials - Rockwell hardness test - Part 1: Test method.
- DIN EN ISO 6508-2, 2015-06: Metallic materials - Rockwell hardness testing - Part 2: Verification and calibration of testing machines and indenters.
- DIN EN ISO 6508-3, 2015-06: Metallic materials - Rockwell hardness testing - Part 3: Calibration of hardness reference blocks.
- DIN EN ISO 18265, 2014-02: Metallic materials - Conversion of hardness values.
- ASTM E140 - 12B, 2019: Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness.
- VDI/VDE 2616-1, 2012-08: Hardness testing of metallic materials. [TIV method not described]

DGZfP leaflets

- DGZfP MC 01, 2008-04: Guideline for criteria for the selection of hardness testing methods with mobile devices.

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Other/ Notes/ Remarks/ Comment

Note on the term non-destructive testing from DGZfP Guideline MC 1

"Mobile hardness testing can be classified as non-destructive testing if the functionality of the component is not impaired by the indentation [of the indenter]."

Note on portable hardness testers in DIN 50159-1:2015-01 - Introduction

"Portable hardness testers allow hardness tests to be carried out on samples that are too large or too heavy to be tested on stationary hardness testing machines. As the classic hardness test methods such as Rockwell, Vickers, Brinell and others are difficult or impossible to implement in portable devices, various manufacturers have developed new test methods based on the classic methods, which can also be used in portable devices. However, the development of each new test method also means, in principle, the introduction of a new hardness scale. If these devices are to indicate the measured hardness values in the common scales such as Rockwell, Vickers or Brinell, they must carry out a conversion at one point in their measuring chain. Such hardness values are then not true Rockwell, Vickers or Brinell values because they have not been determined using the standardized Rockwell, Vickers or Brinell methods."

Physical basis Mechanically excited measuring principle

Procedure

Tapping test/ tapping with a hammer

Tap Testing/ Hammer Tapping test

Test tasks

- (Change in) building material properties
- Corrosion
- Connection of riveted joints
- Connection Screw connections

Brief description

Non-destructive testing to assess the condition of the area near the surface of a test surface and to assess fasteners by tapping them with fingers, knuckles, fists or hammers to generate a sound.

Standard area of application (practical testing tasks)

- Determining the change in building material properties
- Detection of undermining rust on coated sheet steel [1]
- Inspection of riveted joints in steel structures [1]
- Checking bolted connections of steel structures
- Tapping test as a basic test for further examinations

Application limits (technical, physical, economic)

- Experience and assessment skills of the examiners
- Dependence of the sound:
  - the stress state, elasticity and vibration capacity of the material (robustness of the test surface)
  - from the component geometry, in particular component thickness
- Influence of noise sources

Special applications (additional testing tasks)

On-site requirements

- Elimination of disturbing influences from noise sources in the test environment
- Accessibility
- Sufficient robustness of the test surface

Procedure description

Long description

The tapping test is used to assess the condition of an area near the surface of a test surface or the fit of fasteners such as rivets and screws. Tapping is usually carried out with the aid of a hammer.
To assess the surface quality, the component surface is tapped, causing shock waves to penetrate the component. The audible sound can be differentiated as bright or dull or high and low frequency. A bright sound and clearly perceptible rebound of the hammer indicate an intact steel sheet; a dull sound, on the other hand, indicates an under-rusted steel sheet. [1]
To assess the rivet, touch the edge of the rivet head and the surrounding construction material at the same time with the index finger of one hand; with the other hand, strike each rivet head twice with a hammer at approximately right angles to each other. Loose rivets can be recognized by very small movements between the rivet head and the rolled material and their difference in sound compared to tight-fitting rivets. [3]
To better distinguish the sound, it is advisable to tap different areas several times.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ quick first impression
- only near-surface evaluation
- subjective evaluation of the results depending on the experience of the tester
- The following investigations are necessary for clarification

1.13 Knock test

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- Hammer
- Light locksmith's hammer with a weight < 300 g for striking rivets [2,3]

Measured variable

- Frequency content of the audibly reflected sound

Measurement implementation, measurement strategy (what, when, where, how often?)

1. **Information on the test task**
   - Definition of the test task and objective of the test
   - Inspection of test specifications/recommendations (standards, data sheets)
   - Information on the test object (ambient conditions, application limits, on-site requirements)
   - Procurement of information, if necessary by reviewing old and existing documents
2. **Test planning**
   - Definition of the test areas and a test system
3. **Performance of the audit** (taking into account 2.)
   - Tapping in a regular grid
   - Marking of suspicious areas if necessary
4. **Evaluation**
   - Subjective evaluation of the reflected sound
5. **Documentation**
   - Logging of the implementation
   - Logging of suspected locations in a register
   - Evaluation of the results in a test report
6. **Further information**
   - Further examinations, with ultrasound if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	1/5	1/5	2/5

Further information

Device manufacturer, software

- Mitsui Woodpecker: WP-632AM (Tapping Exfoliation Detector)

Related methods/ measurement variants

-Refined method for assessing the tight fit of rivets: Piezoelectric impulse hammer [2]

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[1] Kastner, Richard H. (2004): Altbauten - Beurteilen, Bewerten. Stuttgart: Fraunhofer-IRB-Verl., **Proceedings 7: Tapping**, p. 16-22
[2] Mertens, Martin; Gunkel, Oliver (2014): **Structural testing according to DIN 1076: Archaic tapping or modern technology?** Lecture 4. in: Symposium Building Diagnosis 2014: DGZfP, German Society for Non-Destructive Testing e.V (symposium on building diagnosis).
[3] Helmerich, Rosemarie (ed.) (2005): **Old steels and steel structures. Material investigations, fatigue tests on original bridge girders and measurements from 1990 to 2003**. Research report 271. BAM Federal Institute for Materials Research and Testing. Berlin.

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Other/ Notes/ Remarks/ Comment

Physical basis	Mechanically excited measuring principle
Procedure **Acoustic emission test** Acoustic Emission Testing AT (AET)	Test task - Surface inhomogeneities: Surface cracks - Volume inhomogeneities: Cross-section cracks - Construction elements: Material thickness/ sheet thickness - Connection Welded joints: Weld seam cracks

Brief description

Non-destructive testing for the detection of **active** cracks and inhomogeneities through the **passive** detection of Emission signals caused by structural changes in the material, e.g. under load.

Standard area of application (practical testing tasks)

- Detection of crack formation, crack propagation, crack surface friction, delamination and dislocation movement [1]
- Identification of areas that are critical or conspicuous under load [7]
- Hollow box sections, wire breaks in prestressed concrete and wire breaks in stay cables [1,7]
- as a basic test for further, detailed testing, e.g. with ultrasound [7]

Application limits (technical, physical, economic)

- No evidence of dormant, non-growing or non-moving inhomogeneities [1]: Prerequisite: external stress that leads to the occurrence/activity or change of defects [7]
- No statements about already broken prestressing wires before monitoring [1]
- Influence of background and operating noise and other external disturbing noise [DIN EN 13554]: Prerequisite: Localization of the noise emission sources to differentiate between noise emissions caused by internal damage and noise sources
- Influence on the measurement result due to correct acoustic coupling, mechanical mounting, frequency selection and adapted cabling [DIN EN 13554].
- Influenced by the evenness of the surface for mounting the sensors and for adequate and repeatable transmission of sound emission waves [DIN EN 13554].

Special applications (additional testing tasks)

- Permanent monitoring of areas that are critical or conspicuous under load [1,7].
- Comprehensive analysis possible through integration of additional sensor data (strain, vibrations, etc.) [7]
- Estimation of the effectiveness of repair measures and damage progression over time [4]
- Detection and localization of the formation of corrosion products possible in theory [10]

(On-site) requirements

- Comprehensive visual inspection before carrying out the acoustic emission test [DIN EN 13554].
- suitable excitation of the component to generate mechanical stresses or use of the operating loads
- Avoidance of operating noise and other external disturbing noises [DIN EN 13554].

Procedure description

Long description

In the acoustic emission test, elastic waves are recorded from damage caused in a component by loads, for example.
"The application of loads to a material or harsh environmental conditions cause internal structural changes such as localized plastic deformation, crack growth, corrosion, erosion and phase transitions. Acoustic emission sources also arise from impact loading, leakage (turbulent flow), cavitation, electrical discharge and friction. All these mechanisms and processes are generally accompanied by the generation of elastic waves that propagate in materials [...]. The waves therefore contain information about the changes in the material and/or the structure inside.
The waves are recorded using suitable sensors that convert the particle movement on the surface of the material into electrical signals. These signals can occur as single signals (bursts) or as continuous signals and are recorded and processed using suitable measurement technology in order to detect, characterize and locate the sound emission sources." [DIN EN 13554]
The number of sensors to be used depends, among other things, on the required localization accuracy and the size of the object to be monitored. If three-dimensional localization is required, at least four sensors must be used. [9]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ active use of traffic on bridges for noise emission for measurement [7]
- No verification of static defects, e.g. static cracks [DIN EN 13554, 1].
- no arbitrary repeatability of the test by measuring sound waves generated by the defect [6]
- Installing the sensors can be very time-consuming

1.14 Acoustic emission test AT

Measuring method

Measurement setup

Wireless SEA measurements at FMPA ramp
C. Grosse, TU Munich

Measuring devices

Test accessories according to [DIN EN 13554, 1]:
- Acoustic emission sensors (piezoelectric sensors)
- Sensor mounting: Magnetic holders or tapes, clamps, adhesives, etc. for acoustic coupling
- Coupling agent: silicone grease, oil, adhesive, wax, water-soluble paste or solvent-based paste
- Signal amplifier and frequency filter
- Control unit (PC software) with recording and evaluation unit

Measured variable and target variable

[DIN EN 13554, 1]:
- Transient sound emission signal (threshold crossing of the sound emission; so-called "hit"): Signal with a temporally recognizable beginning and end (this signal can also be a noise)
- Arrival time: Time when a transient signal exceeds the detection threshold for the first time
- Number of signals or signal rate per time unit
- further transient sound emission signals (so-called "bursts"): Maximum amplitude, signal energy, rise time, signal duration, number of overshoots
- Recording of waveforms and evaluation of the power spectrum (peak frequency, median frequency, etc.)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Carrying out a comprehensive visual inspection
- Definition of the test areas and a test system: Creation of test instructions
- Checking background noise
- Preparation of the test surface: Surface preparation

3. Performance of the test (taking into account 2.): Acoustic emission test according to DIN EN 13554
- Preparation: Verification of the sensor coupling, measuring chain and proper functioning of all measuring devices
- Load application to test object: generation of mechanical stress
- Release of elastic energy in the component due to inhomogeneity and wave propagation
- Detection of the mechanical shaft using sensors
- Follow-up: Verification of the sensitivity of each acoustic emission channel and verification of the functionality of the acoustic emission system

4. Evaluation and documentation
- Post-test data analysis for source evaluation and classification: parameter-based or signal-based acoustic emission analysis [9]
- Measurement data acquisition and visualization
- Recording of the implementation and the measurement result
- Presentation of the results in a test report

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
x/5	x/5	x/5	x/5

Further information

Device manufacturer, software

- Elsys AG [https://www.elsys-instruments.com/de/index.php]
- Embedded Real Time KERT [http://www.kert.u-boehm.de/k.html]
- Vallen Systeme GmbH [https://www.vallen.de/sensors/]
- Mistras Group: Physical Acoustics Group [https://www.physicalacoustics.com/sensors/]
- Hexagon Digital Wave [https://www.digitalwavecorp.com/]

Related methods/ measurement variants

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- DIN EN 1330-9, 2017-10: Non-destructive testing - Terminology - Part 9: Terms used in acoustic emission testing

Personnel management, vocational training (03.100.30)

- Acoustic emission testing is one of the classic NDT methods and is marked with the abbreviation "AT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out acoustic emission testing.

Non-destructive testing (ICS 19.100)

DIN EN 13477-1, 2013-11: Non-destructive testing - Acoustic emission testing - Characterization of test equipment - Part 1: Equipment description.
DIN EN 13477-2, 2013-04: Non-destructive testing - Acoustic emission testing - Characterization of test equipment - Part 2: Verification of performance characteristics.
DIN EN 13554, 2011-04: Non-destructive testing - Acoustic emission testing - General principles.

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Other/ Notes/ Remarks/ Comment

- DGZfP (German Society for Non-Destructive Testing): Acoustic emission colloquium [https://www.dgzfp.de/Fachaussch%C3%BCsse/Schallemissionspr%C3%BCfverf]
- EWGAE (European Working Group on Acoustic Emission): European Conference on Acoustic Emission [http://www.ewgae.eu/conf.html]
- ISAE International Society on Acoustic Emission: World Conference on Acoustic Emission [http://www.wcacousticemission.org.cn/whats_new.php]

Physical basis: Mechanically excited measuring principle

Procedure

Ultrasonic testing - Pulse-echo technique

Ultrasonic Testing UT

Test task
- Surface inhomogeneities: Surface cracks
- Volume inhomogeneities: cross-section and material cracks
- Construction element: 'Material thickness/ sheet thickness
- Coating materials: Layer thickness
- Ropes and tension elements: external/ internal wire breaks

Brief description

Non-destructive testing for the detection of relevant indications by generating mechanically excited pulses (piezoelectric) in the test head and their propagation and influence (e.g. reflection at the crack) according to the laws of elastic waves in the material to be tested.
Component [Active emission of signals] - Volume method

Standard area of application (practical testing tasks)

- Location and size of inhomogeneities in the component cross-section [2,7]
- Component/wall thickness [2.7]
- Elastic material properties [2,7]
- Determination of the thickness of coatings [ISO/TS 193979]
- Testing of welded joints [4]

Application limits (technical, physical, economic)

- Influencing parameters: Device gain/sensitivity adjustment [3], component dimensions, fault orientation, frequency-dependent sound attenuation [8]
- Defect type, defect position and orientation must be known before testing, because testing for all possible defect positions and orientations would be too time-consuming and costly [8]
- Detectability of defects in the order of magnitude of the wavelength: d ~ λ [8]
- Defect size: crack width cannot be quantified, crack depth is possible in principle
- Changing one parameter can prevent an entire UT inspection (seam elevation, coupling, welding process, …)
- Detection of defects depending on the crack orientation, the selected probe and the angle of incidence of the probe: [8]
  - **Cracks** that run vertically from the surface into the material cannot be detected with a beam angle of 60° or 30° (common beam angles in steel: 35°, 45°, 60°, 70° and 80°) [8]
  - **Weld seam cracks** must be examined with angle beam probes, as vertical probes cannot be mounted directly due to the weld seam superelevation [8]
  - **Inclusions** that are spherical or bubble-shaped and without a pronounced orientation can be detected with perpendicular and angle probes
  - **Planar defects** that are not surface cracks must be struck almost vertically for the verification [8]
  - **Wall thickness measurement**: Use of shock wave probes; for low wall thicknesses: Pre-travel section attachment [8]

Special applications (additional testing tasks)

-

On-site requirements

- Surface preparation: Test surfaces must be free of dirt, loose scale and welding spatter etc. and have a sufficiently uniform contour and smoothness [DIN EN ISO 16810].
- one-sided accessibility to the test surface [2]

Procedure description

Long description

In ultrasonic testing, "[...] ultrasonic waves are sent through the test object [...], whereby either the transmitted signal (called the transmission technique) or the signal reflected or scattered by a boundary surface or inhomogeneity (called the pulse-echo technique) is observed.
Both techniques can use a single probe that serves as both transmitter and receiver, a probe with separate transmit and receive transducers, or separate probes for transmitting and receiving. Similarly, both techniques can include inter-reflections from one or more surfaces of the test object." [DIN EN ISO 16810; Fundamentals of ultrasonic testing]
The **pulse-echo technique** "uses signals that are reflected or scattered at any interface of interest within the test object. These signals are described by their amplitude and their position on the time axis; the latter is a measure of the distance between the reflector and the probe. The position of the reflector is determined by its distance, by the direction of propagation of the sound and by the position of the probe.
It is recommended to measure the signal amplitude by referring to either:
a) one or more reference lines (DAC curves) recorded on artificial reflectors (cross holes, flat bottom holes, grooves, etc.) on one or more reference bodies;
b) an equivalent reflector diagram (AVG system);
c) Echoes from suitable grooves; or
d) Echoes from large reflectors oriented at right angles to the sound beam axis (e.g. a rear wall echo). These methods are described in ISO 16811.
Other techniques may be used to obtain additional information about the shape and size of reflectors. Such techniques are based, for example, on the change in signal amplitude during probe movement, time-of-flight measurements or frequency analysis." [DIN EN ISO 16810]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Detection of inhomogeneities on the surface and in the cross-section [4]
+/- Examination of surface cracks with ultrasound only on inaccessible component surfaces and weld seams; otherwise better with surface testing methods (penetrant testing, magnetic particle testing) [8]
- Defect type, defect position and orientation must be known before the test, because the test must cover all possible defect positions and orientations.
would be time-consuming and costly [8]

Measuring method

Measurement setup

Thickness control on test specimens

A. Taffe, HTW Berlin

Measurement results

Thickness control on test specimens: Evaluation

A. Taffe, HTW Berlin

Measuring devices

Test equipment according to DIN EN ISO 16810:
- Ultrasonic testing device according to EN 12668-1:
  - with an exciting frequency range between 1 and 10 MHz [9] (cf. concrete: 20 - 100 kHz),
  - high frequency: + resolution, but - penetration depth; low frequency: + penetration depth, but - resolution
- Ultrasonic probe according to EN 12668-2: Vertical probe, angle probe
- Coupling agent
- Calibration body
- Reference body

Measured variable and target variable

- Specified characteristic(s) from test specification or test instruction:
  - Test task: e.g. inhomogeneity: crack by measuring the amplitude A in [%SH] [2]
    - qualitative: detected or not detected
    - quantitative: e.g. estimation of the error size
  - Test task: e.g. coating thickness or wall thickness d in [µm; mm] by measuring the transit time t in [µs] [2]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Definition of the test areas and a test system
- Selection of the probe (vertical probe or angle beam probe) and the beam angle depending on: Test task, coupling technique, defect type, position and orientation, component dimensions, expected defect size [8]
- Setting the device: Distance adjustment, gain [DIN EN ISO 16810]
- Selection of the test frequency by preliminary test or trial and error [8]
- Preparation of the test surface: Surface preparation [DIN EN ISO 16810]

3. Performance of the test (taking into account 2.): Ultrasonic testing
- Measurement by moving the ultrasonic test sensor in a specific grid

4. Evaluation and documentation
- Measurement data acquisition and visualization: e.g. reconstruction of raw data with SAFT evaluation
- Evaluation of the display through source classification
- Recording of the implementation and the measurement result
- Presentation of the results in a test report

5. further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
4/5	4/5	4/5	4/5

Further information

Device manufacturer, software

- Karl Deutsch Prüf- und Messgerätebau GmbH + Co KG: Echograph series [http://www.karldeutsch.de/KD_ECHOGRAPH_Contents_Digital_DE_M1.html]
- Elcometer: NDT ultrasound product range [https://www.elcometer.com/de/ndt-ultraschall.html]:
 e.g. Elcometer: 456 coating thickness gauge [https://www.elcometer.com/de/beschichtungskontrolle/trockenfilmdicke/digital/elcometer-456-coatingthicknessgauge.html]
- GE Sensing & Inspection Technologies GmbH: Mentor UT, USM 36 Portable, USM Go + Portable [https://www.industrial.ai/inspection-technologies/ultrasound-portables]

Related methods/ measurement variants

- Ultrasound variants:

- Ultrasonic reflection/ transceiver method/ pulse-echo technology:
one-sided measurement with a single, combined transmitter and receiver probe
- Ultrasonic transmission/transmission technology according to DIN EN ISO 16823:
Two-sided transit time measurement on the component = sonication of the component with transmitter and receiver probe on opposite or offset surfaces of the test specimen

- Overview of methods for non-destructive determination of dry film thickness [DIN EN ISO 2808 - Annex A, Table 2].

1. Gravimetric measuring principle
 1.1 Mass difference
2. Optical measuring principle
 2.1 Cross-section (destructive)
 2.2 Wedge cut (destructive)
 2.3 White light interferometry
3. Magnetic measuring principle
 3.1 Adhesive force
 3.2 Magnetic field change, method based on the Hall sensor principle
 3.3 Magnetic field change, magneto-inductive process
 3.4 Eddy current
4. Radiological measuring principle
 4.1 Beta backscattering process
5. Photothermal measuring principle
 5.1 Heat propagation
6. Acoustic measuring principle
 6.1 **Ultrasonic reflection**

7 Electromagnetic measuring principle

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[1] **Ultrasound.** Mechanically excited methods (2014). In: **DBV leaflet**: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Merkblätter), pp. 12-15.

[2] **Ultrasonic testing (UT)** (2018). In: German Society for Non-Destructive Testing e.V. (ed.): BC 3 M1 Basic Course Level 3. Module 1. Basic knowledge. Documents for teaching.

[3] Fischer, Karl-Heinz; Schmeink, Helmut: **Non-destructive testing (NDT) and its evaluation in steel construction.** In: **Steel Construction Calendar 2006**, p. 549-596.

[4] Steinhausen, Ralf; Pientschke, Christoph; Strauß, Alexander: **Modern ultrasonic imaging methods for non-destructive testing of weld seams in steel construction.** In: **Steel Construction Calendar 2017**, pp. 271-312.

[5] Schiebold, Karlheinz (2015): **Non-destructive material testing - ultrasonic testing**. 1st edition with 441 images and 100 tables. Berlin: Springer-Verlag.

[6] **Ultrasonic testing. Volume 1** (1999). In collaboration with Volker Deutsch. In: Informationsschriften zur zerstörungsfreien Prüfung - ZfP - kompakt und verständlich, Vol. 1.

[7] **Measurement technology with ultrasound. Volume 2** (2002). In collaboration with Volker Deutsch. In: Informationsschriften zur zerstörungsfreien Prüfung - ZfP - kompakt und verständlich, Vol. 2.

[8] Karl Deutsch Prüf- und Messgerätebau GmbH + Co KG: **The agony of choice: Which probe for which application?** Special print: SD 1/51. Information leaflet, compiled by V. Schuster, M. Lach, M. Platte. In: DACH Annual Conference 2004, p. 1-19. Available online at https://www.karldeutsch.de/PDF/Sonderdrucke/SD_1_51%20Welcher%20Pr%C3%BCfkopf%20f%C3%BCr%20welchen

%20Einsatz.pdf.
[9] Bauakademie Hessen-Thüringen E.V. (ed.) (2019): **Course on steel and steel composite bridges for engineers of the Building inspection** Documents for teaching

Bibliography II (regulations: standards, guidelines, information sheets)

Terminology (ICS 01.040.19)

- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN ISO 5577:2017-05: Non-destructive testing - Ultrasonic testing - Terminology.

Personnel management, vocational training (03.100.30)

- Ultrasonic testing is one of the classic NDT methods and is identified by the abbreviation "UT". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out ultrasonic testing.

Non-destructive testing (ICS 19.100)

- DIN EN 12668, 2010-05: Non-destructive testing - Characterization and verification of ultrasonic testing equipment Teil 1: Testing equipment
- DIN EN 12668, 2010-06: Non-destructive testing - Characterization and verification of ultrasonic testing equipment Teil 2: Probes
- DIN EN 12668, 2014-02: Non-destructive testing - Characterization and verification of ultrasonic testing equipment Teil 3: Complete testing equipment
- DIN EN ISO 2400:2013-01: Non-destructive testing - Ultrasonic testing - Description of calibration block No. 1
- DIN EN ISO 7963:2010-12: Non-destructive testing - Ultrasonic testing - Description of the calibration block No. 2
- DIN EN ISO 16809, 2018-12: Non-destructive testing - Thickness measurement by ultrasonic. [Draft]
- DIN EN ISO 16810, 2014-07: Non-destructive testing - Ultrasonic testing - General principles.
- DIN EN ISO 16811, 2014-06: Non-destructive testing - Ultrasonic testing - Sensitivity and distance adjustment.
- DIN EN ISO 16823, 2014-07: Non-destructive testing - Ultrasonic testing - Transmission technique
- DIN EN ISO 16826, 2014-06: Non-destructive testing - Ultrasonic testing - Testing for inhomogeneities perpendicular to the surface.
- DIN EN ISO 16827, 2014-06: Non-destructive testing - Ultrasonic testing - Description and sizing of inhomogeneities.
- DIN EN ISO 16828:2014-06: Non-destructive testing - Ultrasonic testing - Diffraction time-of-flight technique, a technique for detecting and measuring inhomogeneities
- DIN EN ISO 16946:2017-07: Non-destructive testing - Ultrasonic testing - Description of the stepped wedge calibration block
- DIN EN ISO 18563: Non-destructive testing - Characterization and verification of ultrasonic testing equipment with phased arrays

Welded joints (ICS 25.160.40)

- DIN EN ISO 5817, 2014-07: Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (without beam welding) - Assessment groups of irregularities.
- DIN EN ISO 10042, 2019-01: Welding - Arc welded joints on aluminum and its alloys - Assessment groups of irregularities.
- DIN EN ISO 10863, 2011-12: Non-destructive testing of welded joints - Ultrasonic testing - Application of the time-of-flight diffraction technique (TOFD).
- DIN EN ISO 11666, 2018-05: Non-destructive testing of welded joints - Ultrasonic testing - Acceptance limits.
- DIN EN ISO 13588, 2013-11: Non-destructive testing of welded joints - Ultrasonic testing - Application of automated phased array technology.
- DIN EN ISO 15626, 2018-11: Non-destructive testing of welded joints - Time-of-flight diffraction (TOFD) technique - Acceptance limits.
- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.
- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of fusion-welded joints.
- DIN EN ISO 17640, 2019-02: Non-destructive testing of welded joints - Ultrasonic testing - Techniques, test classes and evaluation.
- DIN EN ISO 19285, 2017-12: Non-destructive testing of welded joints - Ultrasonic testing with phased arrays (PAUT) - Acceptance limits.
- DIN EN ISO 20601, 2019-04: Non-destructive testing of welded joints - Ultrasonic testing - Use of automated phased array technology for thin-walled steel components
- DIN EN ISO 22825, 2018-02: Non-destructive testing of welded joints - Ultrasonic testing - Testing of Welded joints in austenitic steels and nickel alloys

- DIN EN ISO 23279:2017-12: Non-destructive testing of welded joints - Ultrasonic testing - Characterization of indications in welds

Coating materials (paints and varnishes) (87,040)
- DIN EN ISO 2808, 2018-07: Paints and varnishes - Determination of coating thickness.
- DIN CEN ISO/TS 19397, 2018-05: Determination of the thickness of coatings by ultrasonic measurement.

DGZfP leaflets
- German Society for Non-Destructive Testing e.V. (in completion): Leaflet on ultrasonic methods for non-destructive testing in construction. revised version. Berlin: DGZfP, Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (DGZfP German Society for Non-Destructive Testing - Leaflets, B 04).

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Guidelines for the maintenance of engineering structures
- RI-ERH-KOR. Guidelines for the maintenance of the corrosion protection of steel structures. In: Federal Ministry of Transport, Building and Urban Development (ed.): RI-ERH-ING. Guidelines for the maintenance of engineering structures, pp. 1-38.

Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Guidelines for the implementation of federal construction tasks, pp. 1-13.

Other/ Notes/ Remarks/ Comment

1.16 Magnetic field change (layer thickness determination)

As of 18.12.2019

Physical basis	Magnetic measuring principle
Procedure **Magnetic process: Magnetic field change** (coating thickness measurement) Magnetic method (Measurement of coating thickness)	Test task - Coating materials: Layer thickness

Brief description

Non-destructive testing to determine the layer thickness of a non-magnetic coating on a magnetic base metal to be tested by changing the magnetic field.

Standard area of application (practical testing tasks)

- Coating thickness measurements of non-magnetic coatings on magnetic base metal [ISO 2178]

Application limits (technical, physical, economic)

- Influence of coating thickness, magnetic properties of the base metal (permeability), electrical properties of the coatings, thickness of the base metal, edge effect (geometry of the base metal), surface curvature, surface roughness, lift-off effect (cleanliness of the probe tip), probe contact pressure, probe inclination, temperature effects, external electromagnetic fields [ISO 2178].

Special applications (additional testing tasks)

The magnetic induction process and the magnetic flux meter "[...] can also be combined to form a process and the The same probe can be combined with another method, e.g. with the eddy current method according to ISO 2360 or ISO 21968." [ISO 2178]

On-site requirements

- the component (substrate) to be tested must be ferromagnetic
- Calibration and measurement on the same material

Procedure description

Long description

In coating thickness measurement with magnetic field change "[...] the coating thickness is determined using the magnetic flux density. Depending on the method used, the strength of the magnetic flux density is converted into corresponding electrical currents, electrical voltages or mechanical forces." [ISO 2178] "The magnetic flux density in the vicinity of a magnetic field (permanent magnet or electromagnet) depends on the distance to a magnetizable base metal. This phenomenon is used to determine the thickness of a non-magnetic layer deposited on a base metal." [ISO 2178]

The magnetic pull-off force method, the magnetic inductive method and the magnetic flux measuring device, which is designed as a Hall sensor or magnetoresistive sensor, can be used as methods.

In the **magnetic pull-off force method,** the device with integrated magnet is placed vertically on the coating and the coating thickness is derived from the mechanical force required to pull the magnet off the surface. [ISO 2808]

In the **magnetic induction method,** the device with integrated coil system, in which an electromagnetic alternating field of low frequency (< 1 kHz) is generated, is placed vertically on the coating and the coating thickness is derived from the change in the magnetic field. [ISO 2808]

When **using the Hall sensor principle,** the device with integrated Hall sensor is placed vertically on the coating and the coating thickness is derived from the change in the magnetic field. [ISO 2808]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Quick result and simple implementation
- Many influencing factors

1.16 Magnetic field change (layer thickness determination)

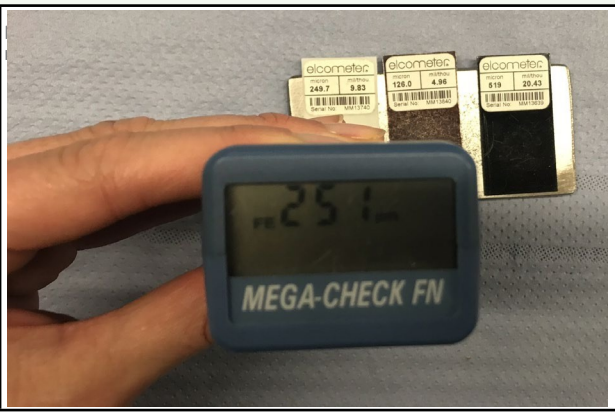
As of 18.12.2019

Measuring method

Measurement setup

Coating thickness gauge on calibration foils

J. Wiese, HTW Berlin



Measuring devices

[ISO 2178, ISO 2808]:
- Coating thickness gauge with magnetic holding force consisting of: Permanent magnet, pull-off device with continuously increasing pull-off force and display/scale for the coating thickness
- Coating thickness gauge using the magnetic induction measuring method consisting of: Electromagnet (for magnetic induction) and coil system (for measurement)
- Coating thickness gauge based on the Hall sensor principle consisting of: Electromagnet or permanent magnet (for magnetic induction) and Hall sensor as magnetic flux detector (for measurement)

Calibration foils Coating thickness standards Zero plates

Measured variable and target variable

[ISO 2178, ISO 2808]:
- Target value: layer thickness t in [µm]
- Measured variable: Magnetic flux density B or force F (principle of mechanical attraction/pull-off force)
- Measured variable: Magnetic flux density B or voltage U = f(t) (magnetic field change principle)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Determination of the procedure to be carried out

3. Performance of the test (taking into account 2.) according to [ISO 2178].
- Calibration
- Regularly check the probe tip for cleanliness to prevent lift-off effect

4. evaluation and documentation
- Determination of the coating thickness as the arithmetic mean of several individual values measured in a defined reference area of the coating and specification of the standard deviation
- Recording of the implementation and the measurement result
- Evaluation of the results in a test report

5. further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
8/5	2/5	2/5	3/5

1.16 Magnetic field change (layer thickness determination)

1.16 Magnetic field change (layer thickness determination)

Further information

Device manufacturer, software

- Electro Physics: MicroTest *(adhesive force method)*
  [https://www.checkline.de/prod/schichtdickenmessgeraet/mikrotest]
- Automation Dr. Nix GmbH & Co. KG: Qnix series *(magnetic-inductive processes and processes based on the Hall principle)*
[https://www.q-nix.com/de/schichtdickenmessgeraete/]
- List-Magnetik GmbH: Top-Check series *(magnetic induction methods)*
[https://www.list- magnetik.com/schichtdickenmessgeraete]

Related methods/ measurement variants

Overview of methods for non-destructive determination of dry film thickness [DIN EN ISO 2808 - Annex A, Table 2].

1. Gravimetric measuring principle
   1.1 Mass difference
2. Optical measuring principle
   2.1 Cross-section (destructive)
   2.2 Wedge cut (destructive)
   2.3 White light interferometry
3. Magnetic measuring principle
   3.1 Adhesive force
   3.2 Magnetic field change, method based on the Hall sensor principle
   3.3 Magnetic field change, magneto-inductive process
   3.4 Eddy current
4. Radiological measuring principle
   4.1 Beta backscattering process
5. Photothermal measuring principle
   5.1 Heat propagation
6. Acoustic measuring principle
   6.1 Ultrasonic reflection
7. Electromagnetic measuring principle
   7.1 Terahertz

Bibliography I (technical literature)

Bibliography II (regulations: standards, guidelines, information sheets)

Terminology (ICS 01.040.19)

- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Surface finish (17.040.20)

- DIN EN ISO 2178, 2016-11: Non-magnetic coatings on magnetic base metals - Measurement of coating thickness Magnetic process.

Coating materials (paints and varnishes) (87,040)

- DIN EN ISO 2808, 2018-07: Paints and varnishes - Determination of coating thickness.

1.16 Magnetic field change (layer thickness determination)

1.16 Magnetic field change (layer thickness determination)

Bibliography III (General regulations)

Protection of and in buildings in general (ICS 91.120.01)

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Additional technical contract conditions and guidelines for civil engineering structures

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- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

1.17 Magnetic particle testing
MT

Physical basis: Magnetic measuring principle

Procedure

Magnetic particle testing

Magnetic Particle Testing MT

Test task
- Surface inhomogeneities: Surface cracks
- Connection Welded joints: Weld seam cracks

Brief description

Non-destructive testing for the detection of surface inhomogeneities by magnetizing the component to be tested, creating a disturbed magnetic field at the crack flanks and visualizing the inhomogeneity by an accumulation of magnetic powder particles on the test surface. -
Surface treatment

Standard area of application (practical testing tasks)

- Visualization of surface inhomogeneities (especially cracks) in all ferromagnetic materials [2, DIN EN ISO 9934-1].
- Detection of gap-like material separations (depth t < 0.2 mm) [1]
- Visualization of cracks in the upper material layer under rivet heads from their emergence [2]
- Crack control on incorrectly drilled holes that were subsequently filled with hot material [2]
- Quality control for the execution of "stop-holes" to stop fatigue crack growth [2].
- Testing of welded joints [DIN EN ISO 17638, DIN EN ISO 23278]

Application limits (technical, physical, economic)

- Application only for ferromagnetic materials [DIN EN ISO 9934-1]; materials with permeability μ_r > 100 [7]
- Magnetization direction: alignment of the magnetic field must be perpendicular to the crack direction in order to produce optimum leakage flux and optimum crack indication; parallelism of defect course and magnetic flux does not produce leakage flux, magnetic field runs past the defect without significant influence [3]; maximum 30 ° deviation [7]
- Sensitivity when detecting inhomogeneities close to the surface decreases rapidly with increasing depth [ISO 9934-1].
- Application only for cracks that penetrate to the surface, whereby the defect does not have to be open
- No reduction in detection sensitivity for non-ferromagnetic coatings up to a thickness of approx. 50 µm (such as non-destroyed coatings), smoothly adhering paint layers) [DIN EN ISO 9934-1].
- Magnetization field strength: too low magnetization leads to weak crack indication, too strong magnetization leads to false indications [3]; magnetic field strength H < 2 kA/m [7]
- Scoring, surface roughness or other deformations can lead to apparent crack indications [1,3]
- No error depth evaluation possible [6]
- Do not use in direct sunlight
- Carrying out photographic documentation without flash [2]

On-site requirements

- Surface free of rust, scale, grease and oil [1, DIN EN ISO 9934-1].
- Remove paint and corrosion protection layers from the surface by brushing or careful sanding [2]
- Removal of paint coats and zinc coatings with thicknesses > 50 µm; coating thicknesses for bridges are generally > 320 µm [7]
- Shading of the area to be examined [2]
- Illuminance > 500 lx when testing with magnetic powder [1]
- Viewing conditions for non-fluorescent magnetic particle testing [DIN EN ISO 3059] (when used in the light range):
  - Uniform illumination of the test area, avoidance of glare and reflections
  - Illuminance > 500 lx during testing
- Viewing conditions for fluorescent methods [DIN EN ISO 3059] (for use in dark areas; enclosure if necessary) :
  - Uniform irradiation (UV-A radiation) of the test surface
  - Ambient light < 20 lx during the test
  - Protective measures against UV radiation

Procedure description

Long description

In magnetic particle testing, a localized area of the test surface is magnetized using a hand magnet [yoke magnetization] and sprayed with a suspension consisting of fine powder particles (iron particles) in a carrier liquid. With non-fluorescent m a g n e t i c p o w d e r , inhomogeneities become visible through a color contrast; with fluorescent magnetic powder, inhomogeneities become visible when irradiated with ultraviolet light according to the magnetic field of the aligned fluorescent iron filings. [2]
These iron filings follow the course of the magnetic field lines. At points where the pemeability (magnetizability) of the material changes significantly, e.g. at cracks, the field lines change direction or field lines emerge from the surface. The magnetic field that forms as a result is the magnetic leakage flux or the magnetic leakage field. This field is greater than the field of the defect, which has a favorable effect o n detectability. [1,3]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ most accurate results/ highest sensitivity for the detection of surface cracks [8]
+ low material expenditure [8]
- Processing and subsequent new protection of the surface [8]
- only ferromagnetic/magnetizable materials can be tested [8]
- No detection of hidden cracks [8]
- Method unsuitable for high brightness in the examined area [8]

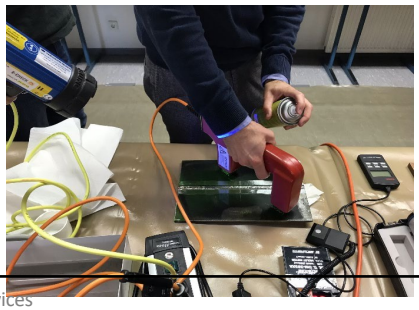
1.17 Magnetic particle testing
MT

As of 18.12.2019

Measuring method

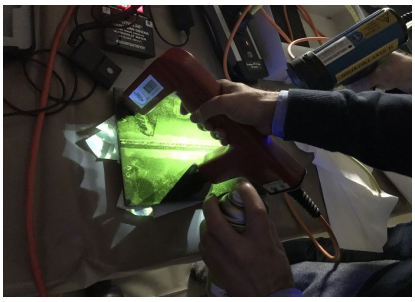
Measurement setup

Magnetic particle testing on steel plate
J. Wiese, HTW Berlin



Measurement results

Magnetic particle testing on steel plate: Display
J. Wiese, HTW Berlin



Measuring devices

- Surface cleaning devices: rotating wire brush, sandblasting
- Magnetization technique according to DIN EN ISO 9934-1: generally yoke magnetization by hand electromagnet (230 N) [1].
- Magnetic particle suspension
- Ultraviolet radiation source for fluorescent processes

Measured variable and target variable

- Magnetic particle display: Accumulation of magnetic particle over the crack [1]
- Specified feature(s): Cracks
  - qualitative: detected or not detected
  - Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids

Measurement implementation, measurement strategy (what, when, where, how often?) [7]

1. **Information on the test task**
   - Definition of the test task and objective of the test
   - Inspection of test specifications/recommendations (standards, guidelines, data sheets)
   - Information on the test object (ambient conditions, application limits, on-site requirements)
   - Procurement of information, if necessary by reviewing old and existing documents
2. **test planning** [7]
   - Definition of the test areas and a test system: Detail area (approx. 20 cm)
   - Preparation of the test surface: Surface preparation
   - Checking the viewing conditions: Illuminance, irradiance
   - Control of magnetization by size and direction: flux density and field strength
   - Checking the test equipment: Sensitivity using reference block according to DIN EN ISO 9934-2
3. **conducting the audit** (taking into account 2.)
   - Local magnetization and application of the test medium
   - Display assessment: Detection of the magnetic particle display by visually scanning the surface
   - Demagnetization
4. **Evaluation and documentation** [7]
   - Documentation of length, width, orientation, position, shape, arrangement of the displays
   - Recording of the implementation and the measurement result
   - Evaluation of the results in a test report
5. **More** [7]
   - Particular attention should be paid to bogus advertisements, which usually have a "washed-out" appearance
   - Repeat the test if the result is inconclusive or another procedure is used

Process effort (from 1: low effort to 5: high effort)

Technology	Time	Costs	Specialist knowledge
3/5	4/5	3/5	4/5

1.17 Magnetic particle testing MT

76

Further information

Device manufacturer, software

- MR Chemie GmbH [https://www.mr-chemie.de/magnetpulverpruefung/produkte/pruefmittel/]
- Magnaflux GmbH [https://magnaflux.eu/de/Produkte/Magnetpulverprufung]

Related methods/ measurement variants

- Stray flux test with magnetic field sensors according to DIN 54136:1988 [6]
- **Surface testing method:**

Mechanical processes

- Penetrant testing PT (for non-magnetic materials)

Magnetic methods

- Magnetic particle testing MT (for ferromagnetic materials)
- Eddy current test ET (for conductive materials)

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- DIN EN ISO 12707, 2016-08: Non-destructive testing - Magnetic particle testing - Vocabulary. [Replacement for DIN EN 1330-7]

Personnel management, vocational training (03.100.30)

- Magnetic particle testing is one of the classic NDT methods and is marked with the abbreviation "MT". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out magnetic particle testing.

Non-destructive testing (ICS 19.100)

- DIN EN ISO 3059, 2013-03: Non-destructive testing - Penetrant testing and magnetic particle inspection Viewing conditions.
- DIN EN ISO 9934-1 2017-03: Non-destructive testing - Magnetic particle testing - Part 1: General principles
- DIN EN ISO 9934-2, 2015-12: Non-destructive testing - Magnetic particle testing - Part 2: Test equipment
- DIN EN ISO 9934-3, 2015-12: Non-destructive testing - Magnetic particle inspection - Part 3: Equipment

Welded joints (ICS 25.160.40)

- DIN EN ISO 5817, 2014-07: Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (without beam welding) - Assessment groups of irregularities.
- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.
- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of welded joints

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[withdrawn: EM0, 2005: Guideline on the performance of magnetic particle tests
EM1, 2003: Guideline on the visual acuity of test personnel for NDT surface procedures EM2, 1988: Guideline on viewing conditions for magnetic particle and penetrant testing EM3, 1994: Guideline on the control of test parameters for magnetic particle testing

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Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Guidelines for the implementation of federal construction tasks, pp. 1-13.

Other/ Notes/ Remarks/ Comment

1.18 Eddy current test ET

As of 18.12.2019

Physical basis	Magnetic measuring principle
Procedure **Eddy current testing** Eddy Current Testing ET	Test task - Surface inhomogeneities: Surface cracks - Coating materials: Layer thickness - Connection Welded joints: Weld seam cracks

Brief description

Non-destructive testing for the detection of inhomogeneities by induction of electric current in conductive material and the measurement of the change in eddy current density in the area of the inhomogeneity. Surface method

Standard area of application (practical testing tasks)

- Detection of inhomogeneities (cracks, pores) [DIN EN ISO 15549].
- Measuring the thickness of coatings and layers [DIN EN ISO 15549].
- Testing of welded joints
- "Visualization of cracks or notches in rivet holes using a rotating probe"[1]
- Inspection/ condition assessment of rivet holes for cracks and notches (when removing old rivets and the planned use of new pretensioned screws) [1]
- Detection of surface defects in railroad tracks [5,6]

Application limits (technical, physical, economic)

- Use only with electrically conductive materials
- limited test depth due to decreasing eddy currents in depth direction [DIN EN ISO 15549].
- Influence of the measurement result by: Conductivity of the material, permeability of the material; size and geometry of the test material and geometry between the eddy current sensor and the test material [DIN EN ISO 15549].
- Influenced by: Surface quality [DIN EN ISO 15549]
- Crack depth evaluation possible within certain limits with the aid of calibration on artificial reference faults [3,4]
- Knowing the expected errors for comparative determination

Special applications (additional testing tasks)

- Undercutting of rivet holes: Determination of the element of a steel plate package in a composite cross-section in which a crack has occurred using a rotating probe [1]

"A prefabricated rotating eddy current probe would be a prerequisite for a high level of accuracy. This means that the probe must be adapted to the diameter of the rivet hole. Only by using an adapted probe would all notches or cracks be visible on the oscilloscope at the same time. This initially means high investment costs. Ready-made eddy current probes were not available for the test in this initial feasibility study." [1]

On-site requirements

- Removal of dirt; scale; non-conductive layers, especially if their thickness varies; other electrically conductive surface layers; welding spatter and oil, grease or water [DIN EN ISO 15549].

Procedure description

Long description

In eddy current testing, "the surface of the test material [...] is exposed to a magnetic (alternating) field, which generates an electrical voltage in the test object.

Driven by this electrical voltage, electrical currents can flow in the test material, which are called eddy currents due to their ring-like shape. These eddy currents propagate in the test material and also generate magnetic fields that can be measured from the outside. Conclusions about the properties and condition of the test object can be drawn from the signals obtained when measuring these magnetic fields." [2]

Defects and inhomogeneities in the test object can be detected by the change in the propagation of the eddy currents and the associated change in the measurement voltage. These changes form the basis for the defined comparative errors during evaluation. For the defined comparative errors, comparative measurements must be carried out on test specimens with defined defects and inhomogeneities (reference specimens). Eddy current testing is therefore a **comparative error method**. [7]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ In contrast to magnetic particle and penetrant testing, application also possible with coating
+ Contactless application possible [DIN EN ISO 15549]
+ no coupling agent required [DIN EN ISO 15549]
+ fast application/ high throughput speeds [DIN EN ISO 15549]
+ very sensitive
- Conclusion on errors by means of comparative measurements, expected errors must be known

1.18 Eddy current test ET

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

Testing device according to DIN EN ISO 15549:
- Eddy current device
- Sensors/ probes
- Connection cable
- Reference bodies with defined defects ("to set up the test system for functional tests, to verify the effectiveness of the test and to determine calibration curves")
- Power supply: Batteries or local AC mains voltage according to DIN EN ISO 15548-1

Measured variable

- Target value: Deviations from the normal value (measurement of absolute values is irrelevant) and inference of errors by means of comparative measurements [2]
- Measured variable: Change in voltage U and phase ϕ or current I and phase ϕ (at constant frequency and guidance of the coil with uniform speed and constant distance to the surface over the workpiece) [2]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of test range or non-testable range; scanning direction; type and size of the sensor; test speed and track width of the sensor according to DIN EN ISO 15549
- Preparation of the test area

3. Performance of the audit (taking into account 2.)
- Verification procedure according to the three stages of DIN EN ISO 15549

4. Evaluation and documentation
- Recording of the implementation and the measurement result
- Assessment of advertisements within the agreed admissibility limits
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	2/5	3/5	4/5

Further information

Device manufacturer, software

- Rohmann GmbH: Elotest series, e.g. M2 V3 or M3 [https://www.rohmann.com/produkte/?category=handgeraete]

Related methods/ measurement variants

- **Surface testing methods**

Mechanical processes

- Penetrant testing PT (for non-magnetic materials)

Magnetic methods

- Magnetic particle testing MT (for ferromagnetic materials)
- Eddy current test ET (for conductive materials)

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- DIN EN ISO 12718, 2018-07: Non-destructive testing - Eddy current testing - Terminology.

Personnel management, vocational training (03.100.30)

- Eddy current testing is one of the classic NDT methods and is marked with the abbreviation "ET". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out eddy current testing.

Non-destructive testing (ICS 19.100)

- DIN 54140-3, 1989-01: Non-destructive testing - Inductive methods - Representation and general characteristics of coil systems. *[Part 1 and 2 are withdrawn]*
- DIN EN ISO 15548-1:2014-03: Non-destructive testing - Technical equipment for eddy current testing - Part 1: Characteristics of test equipment and their verification
- DIN EN ISO 15548-2:2014-03: Non-destructive testing - Technical equipment for eddy current testing - Part 2: Characteristics of sensors and their verification
- DIN EN ISO 15548-3:2009-01: Non-destructive testing - Technical equipment for eddy current testing - Part 3: Characteristics of the system and their verification
- DIN EN ISO 15549, 2018-07: Non-destructive testing - Eddy current testing - General principles.
- DIN EN ISO 20339, 2017-08: Non-destructive testing - Technical equipment for eddy current testing Characteristics of sensor arrays and their verification.

Welded joints (ICS 25.160.40)

- DIN EN ISO 5817, 2014-07: Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (without beam welding) - Assessment groups of irregularities.
- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.
- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of fusion-welded joints.
- DIN EN ISO 17643, 2015-12: Non-destructive testing of welded joints - Eddy current testing of welded joints by vector evaluation.

Coating materials (paints and varnishes) (87,040)

- DIN EN ISO 2808, 2018-07: Paints and varnishes - Determination of coating thickness.

DGZfP regulations - guidelines and leaflets on surface crack detection (EM series)

- DGZfP-EM5, 2002-11: Leaflet on protective measures when handling electromagnetic fields in non-destructive materials testing.
- DGZfP-EM6, 2012-01: Leaflet on viewing stations for fluorescent testing with the magnetic particle and penetrant method - Equipment and protective measures for work with UV radiation.

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EM1, 2003: Guideline on the visual acuity of test personnel for NDT surface procedures EM2, 1988: Guideline on viewing conditions for magnetic particle and penetrant testing EM3, 1994: Guideline on the control of test parameters for magnetic particle testing

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Other/ Notes/ Remarks/ Comment

Physical basis	Electromagnetic measuring principle
Procedure **Infrared thermography test** Infrared Thermographic Testing TT	Test task - surface inhomogeneities, - corrosion - Construction elements: Material thickness - Coating materials: Layer thickness - Connection of riveted joints: Seat of the rivet - Connection Welded joints: Weld seam cracks

Brief description

Non-destructive testing for the imaging detection of inhomogeneities in the near-surface area of a component by means of an artificially generated, deliberately variable heat flow and local temperature differences in the component. - Surface treatment

Standard area of application (practical testing tasks)

- Detection of irregularities (e.g. cavities, **cracks**, inclusions, delamination) [DIN EN 17119].
- Determination of the thickness of a layer or component [DIN EN 17119].
- Testing of weld seams
- Testing of riveted joints [10]
- Detection of corrosion (under layers of paint) [4]
- Typical applications differentiated by excitation source according to DIN EN 17119, Annex A:
  - Flashlight: Detection of layer detachment near the surface and volume defects
  - Laser: Detection of cracks perpendicular to the surface and layer detachment
  - Mechanical excitation (e.g. ultrasound): Detection of cracks on and below the surface
  - Induction: Detection of surface defects

Application limits (technical, physical, economic)

- Cracks that run perpendicular to the test surface cannot be detected with surface excitation using *classic* active thermography [1]; laser thermography detects cracks perpendicular to the surface
- Laser thermography (flying spot thermography): Detection of surface cracks in steel with widths in the range of approx. 200 µm down to the sub-µm range and with depths of only about 10 µm [6]
- Inductively excited thermography can only be used on electrically conductive test objects [DIN 54183].

Special applications (additional testing tasks)

On-site requirements

- Surface accessible from one side

Procedure description

Long description

In thermography, a distinction is made between active and passive thermography.
Passive thermography is used in building physics and uses the building's own heat for thermographic measurements to locate cold or thermal bridges.
In active thermography, on the other hand, the object is specifically heated using thermal excitation techniques t h a t are selected according to the application and requirements. This creates an artificially generated, temporally and/or spatially variable heat flow (transient heat transfer through heating or cooling processes), which generates a temperature gradient to the surface and/or environment. The temperature gradient is caused by the fact that "in the case of external heating, the heat accumulates in front of defects in the component if the defects have a lower heat penetration coefficient b [also: effusivity] than the surrounding material". [3] These targeted heating or subsequent cooling processes are analyzed thermographically.
According to the current state of practice and research, the following process variants are differentiated according to the type of temporal stimulation:
- Lock-in thermography (LT): Excitation by continuous sinusoidal signals of a defined frequency (periodic thermal oscillations) and evaluation by measuring the time delay (phase) and the amplitude of the response signal for the corresponding frequency (may not be practical for the building industry due to long recording times), DIN 54185
- Impulse thermography (IT): Excitation by a thermal impulse with a large number of different frequencies and evaluation in the time domain via the temperature difference, DIN 54184
- Pulse phase thermography (PPT): a further development of pulse thermography, excitation as in IT by a thermal pulse, evaluation by thermogram series in order to record the phase delay of the local heat propagation in the image by means of a Fourier transformation

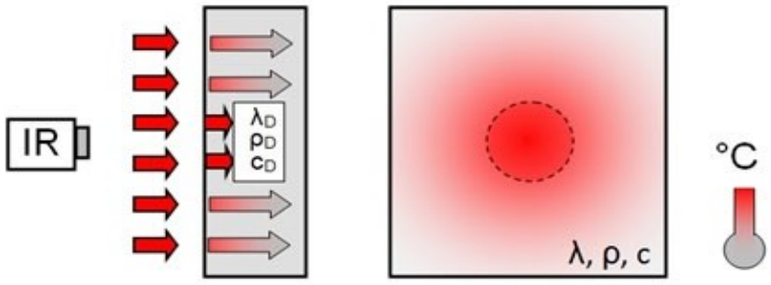
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ contactless [1]
+ no consumables [1], no use of chemical additives compared to MT and PT
+ no surface preparation [3]
+ Testing large areas in one step
+ Compared to radiographic testing, only one test side needs to be accessible and the test is performed without ionizing radiation

Measuring method

Measurement setup

Active thermography: Scheme
A. Taffe, HTW Berlin [11]



Measurement results

Measuring devices

- Infrared camera (IR camera) with accessories such as memory card and tripod
- Computer for digital recording
- Temperature and humidity meter
- Power connection and cable drum if necessary
- Thermal excitation source according to DIN EN 17119:
  - Absorption of optical radiation (solar radiation, infrared radiators, halogen lamps, flash lamps, lasers) and/or microwaves
  - Convection (fan heater, heat gun, building dryer, blower door)
  - Heat conduction (heating mats, cooling pads)
  - electromagnetic induction and/or electric current
  - Conversion of mechanical waves (e.g. ultrasound)

Measured variable and target variable

- Temperature-time curve: Course of the temperature T in [°C] over the time t in [s]
- Temperature contrasts in the recorded thermograms as a qualitative evaluation
- IT: Evaluation over time with temperature-time curves (transients as quantitative information)
- PPT: Evaluation via frequency space with amplitude and phase images

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Selection of the test system: Determination of the thermal excitation source and a suitable IR camera
- Definition of the test areas, the test system and the positioning of the test system
- Definition of the required accuracy of the results (the more complex PPT for very subtle signals or high result quality; the less complex IT for normal cases)
- Determination of the type of temporal excitation (pulse duration) and spatial excitation

3. performance of the test (taking into account 2.): thermographic test
- Recording the thermograms

4. evaluation and documentation
- Logging of the implementation and description of the environmental conditions
- Acquisition of a sequence of thermograms
- Evaluation of complete thermal sequences, individual thermograms or transients
- Evaluation of the results in a test report

5. further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	2/5	4/5	5/5

Further information

Device manufacturer, software

- InfraTec GmbH [https://www.infratec.de/thermografie/anwendungsgebiete/aktive-thermografie/]
- edevis GmbH [https://www.edevis.com/content/de/active_thermography.php]
- Flir Systems, Inc [https://www.flir.de/instruments/science/ndt-materials-testing/]

Related methods/ measurement variants

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Personnel management, vocational training (03.100.30)

- Infrared thermography testing is one of the classic NDT methods and is marked with the abbreviation "TT".

According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel***, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out infrared thermography testing.

Non-destructive testing (ICS 19.100)

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- DIN EN 16714-3, 2016-11: Non-destructive testing - Thermographic testing - Part 3: Definitions
- DIN EN 17119, 2018-10: Non-destructive testing - Thermographic testing - Active thermography.
- DIN 54183, 2018-02: Non-destructive testing - Thermographic testing - Inductively excited thermography.
- DIN 54184, 2017-10: Non-destructive testing - Pulse thermography with optical excitation.
- DIN 54185, 2018-10: Non-destructive testing - Thermographic testing - Lock-in thermography with optical

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Additional technical contract conditions and guidelines for civil engineering structures

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Federal Ministry of Transport, Building and Urban Affairs (ed.): Guidelines for the implementation of federal construction projects, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Physical basis	Electromagnetic measuring principle
Procedure **Radiographic testing** Radiography/ Radiographic Testing	Test task - Volume inhomogeneities - Corrosion - Connection Welded joints: Weld seam cracks - Ropes and tension elements

Brief description

Non-destructive testing to determine the internal structure of the component to be tested by different attenuation (absorption) of ionizing primary radiation due to differences in density, thickness and material in the component. - Volume method

Standard area of application (practical testing tasks)

- Detection of internal defects in the test object [3]
- Detection of cracks in concealed components [2]
- Observation of crack growth during fatigue tests [2]
- Testing of welded joints (pores and slag inclusions) [DIN EN ISO 17635,DIN EN ISO 17636-1/ -2].
- Wall thickness measurement and residual wall thickness measurement [DIN EN ISO 20769-1/ -2].
- Testing when ultrasonic testing can only be performed to a limited extent

Application limits (technical, physical, economic)

- Quality of the test depends on: Ability and experience of the test personnel (human factor) [2]
- Irradiation from several directions improves the detectability or deviation of the angle of incidence of only 20 % to the crack surface impairs the detectability of the crack tip [2].
- The image quality of the recording depends on the following influencing parameters:
  - Contrast: radiant energy, blackening (film technology)
  - Blur: Shooting arrangement,
  - Image graininess (film technology): Film type/ signal-to-noise ratio (digital technology)
- Range of application depending on the energy or isotope: up to 150 mm thickness [1, DIN EN ISO 20769-1].
- Use of digital imaging plates shortens the exposure time [2]

Special applications (additional testing tasks)

On-site requirements

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Dangerous goods regulations for the transportation of radionuclides
- Closing off the test area
- Access to the component from both sides (for radiation source and film)

Procedure description

Long description

In radiographic testing, a radiation source, X-ray tube or radioactive radiation source in the gamma range, is set up on one side of the component to be tested. The outgoing ionizing radiation is attenuated differently due to differences in density, thickness and material. The internal structure of the component is shown in an imaging image in different shades of gray. The steel is shown in lighter shades of gray due to its higher density and greater absorption; hollow areas (pores, cracks, blowholes), on the other hand, are shown in dark gray due to their lower density.
On the opposite side of the component, this attenuated primary radiation is detected and recorded using X-ray films, imaging plates, fluoroscopes, image intensifiers or flat panel detectors. [1, DBV leaflet]

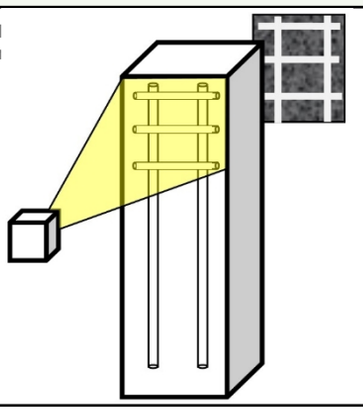
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ no surface preparation [2]
+ permanent documentation on films [2]
+ Radiographic testing for testing internal surfaces that are not accessible for magnetic particle and penetrant testing [2]
- Isolation of the test area according to the radiation intensity of the radiation source [2]
- Testing carried out exclusively by authorized bodies [2]
- Traffic restriction during the test due to radiation protection [2]
- Transportation of dangerous goods [2]
- high costs for procurement of equipment and radiation source as well as radiation protection [2]

Measuring method

Measurement setup

Radiography: Principle sketch
A. Taffe, HTW Berlin
[6]



Measuring devices

- Radiation source:
  - X-ray tube (with remote control)
  - Radionuclides (iridium, cobalt)
- Control unit for setting the tube current, tube voltage and exposure time
- Recording technology: films, digitizing imaging plates or detectors
- Software for image processing on the PC, if necessary
- Power connection
- Determination of the transmission time as a function of the geometric dimensions, age and distance of the radiation source to the carrier [2]

Measured variable and target variable

- Reconstruction and visualization of the different radiation intensities in imaging form
- Specified feature(s): e.g. cracks, internal defects
  - qualitative: detected or not detected
  - Quantitative: e.g. dimensions and position of a damaged area, crack width, etc.

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning [3]
- Choice of radiation energy and radiation source as well as imaging technology (e.g. X-ray film, digital imaging plates)
- Determination of the test areas and a test system: Recording arrangement
- Determining the exposure time
- Determination of the area to be cordoned off on the basis of the Radiation Protection Ordinance

3. Performance of the test (taking into account 2.): Radiographic testing
- Analog film technology: film processing (developing, intermediate rinsing, fixing, final rinsing, wetting agent balance, drying)
- Attaching the image quality test

4. Evaluation and documentation [3]
- Logging of the implementation
- Checking the contrast achieved using an image quality test body
- If necessary, image processing of the scanned radiographic films with the aid of special image processing systems improves the informative value
- Evaluation of the results in a test report

5 Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	5/5	5/5	5/5

Further information

Device manufacturer, software

- Yxlon International GmbH: Evo series [https://www.yxlon-portables.com/products]
- X-RAY WorX GmbH [https://www.x-ray-worx.com/x-ray-worx/index.php]
- Graetz Strahlungsmeßtechnik GmbH: Measuring devices for personal radiation protection, e.g. ED150 [http://www.graetz.com/produkte.html]

Related methods/ measurement variants

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[1] Radiographic testing (RT) (2018). In: German Society for Non-Destructive Testing e.V. (ed.): BC 3 M1 Basic Course Level 3. Module 1. Basic knowledge. Documents for teaching.

[2] Helmerich, Rosemarie (ed.) (2005): **Old steels and steel structures. Material investigations, fatigue tests on original bridge girders and measurements from 1990 to 2003**. Research report 271. BAM Federal Institute for Materials Research and Testing. Berlin.

[3] Fischer, Karl-Heinz; Schmeink, Helmut: **Non-destructive testing (NDT) and its evaluation in steel construction.** In: **Steel Construction Calendar 2006**, p. 549-596.

[4] Schiebold, Karlheinz (2015): **Non-destructive material testing - radiographic testing**. 1st edition with 252 images and 66 tables. Berlin, Heidelberg: Springer Berlin Heidelberg.

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- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN 1330-3, 1997-10: Non-destructive testing - Terminology - Part 3: Terms used in industrial radiographic testing.

Personnel management, vocational training (03.100.30)

- Radiographic testing is one of the classic NDT methods and is marked with the abbreviation "RT". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out radiographic testing.

Non-destructive testing (ICS 19.100)

- DIN EN 14784-1, 2005-11: Non-destructive testing - Industrial computed radiography with phosphor imaging plates - Part 1: Classification of systems. [Part 2: Withdrawn]
- DIN EN 16016-01, 2011-12: Non-destructive testing - Radiographic methods - Computed tomography - Part 1: Terminology
- DIN EN 16016-2, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 2: Principles, equipment and specimens
- DIN EN 16016-03, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 3: Execution and evaluation
- DIN EN 16016-04, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 4: Qualification
- DIN EN 13068-1, 2000-02: Non-destructive testing - Radioscopic testing - Part 1: Quantitative measurement of imaging properties
- DIN EN 13068-2,2000-02: Non-destructive testing - Radioscopic testing - Part 2: Testing of long-term stability of imaging systems
- EN 13068-3, 2001-12: Non-destructive testing - Radioscopic testing - Part 3: General principles for radioscopic testing of metallic materials using X-rays and gamma rays
- DIN EN 25580, Non-destructive testing - Viewing devices for industrial radiography - Minimum requirements
- DIN EN ISO 15708-1, Non-destructive testing - Radiographic methods - Computed tomography - Part 1: Terminology [draft]
- DIN EN ISO 15708-2, Non-destructive testing - Radiographic methods - Computed tomography - Part 2: Principles, equipment and specimens
- DIN EN ISO 15708-3 Non-destructive testing - Radiographic techniques - Computed tomography - Part 3: Performance and

Evaluation

- DIN EN ISO 15708-4, Non-destructive testing - Radiographic methods - Computed tomography - Part 4: Qualification
- DIN EN ISO 10675-1, 2017-04: Non-destructive testing of welded joints - Acceptance limits for radiographic testing - Part 1: Steel, nickel, titanium and their alloys. [Part 2: Aluminum]
- DIN EN ISO 19232-1, Non-destructive testing - Image quality of radiographic images - Part 1: Image quality test pieces (wire web) - Determination of the image quality index
- DIN EN ISO 19232-2, Non-destructive testing - Image quality of radiographic images - Part 2: Image quality test pieces (step/hole type) - Determination of the image quality index
- DIN EN ISO 19232-4, Non-destructive testing - Image quality of radiographic images - Part 4: Experimental determination of image quality indices and image quality tables
- DIN EN ISO 20769-1, 2018-12: Non-destructive testing - Radiographic testing for corrosion and deposits in pipes using X-rays and gamma rays - Part 1: Tangential radiographic testing.
- DIN EN ISO 20769-2, 2018-12: Non-destructive testing - Radiographic testing for corrosion and deposits in pipes using X-rays and gamma rays - Part 2: Double-wall radiographic testing.

Welded joints (ICS 25.160.40)

- DIN EN ISO 17635, 2017-04: Non-destructive testing of welded joints - General rules for metallic materials.
- DIN EN ISO 17636-1, Non-destructive testing of welded joints - Radiographic testing - Part 1: X-ray and gamma-ray techniques using films
- DIN EN ISO 17636-2, Non-destructive testing of welded joints - Radiographic testing - Part 2: X-ray and gamma-ray techniques with digital detectors
- DIN EN ISO 17637, 2017-04: Non-destructive testing of welded joints - Visual inspection of fusion-welded joints.

X-ray films (37.040.25)

- DIN EN ISO 11699-1, Non-destructive testing - Industrial films for radiographic testing - Part 1: Classification of film systems for industrial radiographic testing [Replacement for DIN EN 584-1:1994-10]
- DIN EN ISO 11699-2, Non-destructive testing - Industrial films for radiographic testing - Part 2: Control of film processing using reference values
- DIN EN 14096-1, 2003-08: Non-destructive testing - Qualification of X-ray film digitizing systems Part 1: Definitions; quantitative measurement of image quality parameters; standard reference film and quality assurance
- DIN EN 14096-2,2003-08: Non-destructive testing - Qualification of X-ray film digitizing systems - Part 2: Minimum requirements

Non-destructive testing of metals (77.040.20)

- DIN EN ISO 5579, 2014-04: Non-destructive testing - Radiographic testing of metallic materials using film and X-rays or gamma rays - Fundamentals.

DGZfP regulations - D-series guidelines

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Other/ Notes/ Remarks/ Comment

1.21 Optical emission spectroscopy OES

As of 18.12.2019

Physical basis	Chemical measuring principle

Procedure	Test task
Optical emission spectroscopy/ Emission spectrometry OES Optical Emission Spectroscopy/ Spectrometry	- Element composition: Element content

Brief description

Non-destructive testing to determine the elements by exciting a sample via an external energy supply, *z. For example, via a flame, an electric spark, an electric arc, a laser or an* ***inductively coupled plasma (ICP-OES)***, whereby the sample itself emits a characteristic electromagnetic radiation, the spectrum of which is analyzed in a spectrometer. (Atomic emission spectroscopy AES method)

Standard area of application (practical testing tasks)

- Qualitative and quantitative determination of the alloy of metallic materials
- Application for "multi-element determination" [DIN10351]
- Analysis of unalloyed and low-alloy steels using optical ICP emission spectrometry - Determination of Mn, P, Cu, Ni, Cr, Mo, V, Co, Al (total) and Sn according to DIN EN 10351
- Analysis of unalloyed and low-alloy steels using optical ICP emission spectrometry - Determination of Si, Mn, P, Cu, Ni, Cr, Mo and Sn in accordance with DIN EN 10355

Application limits (technical, physical, economic)

- Applicable to the elements listed in the standard and specified ranges of a certain mass fraction [DIN EN 10351, DIN EN 10355].
- Analysis of unalloyed and low-alloy steels with an iron content of at least 95% [DIN EN 10351, DIN EN 10355]

Special applications (additional testing tasks)

- Application also possible if other elements are included. However, these elements and their mass fractions should be carefully checked for each ICP emission spectrometer and for each wavelength, taking into account possible interferences, sensitivity, resolution and linearity criteria [DIN EN 10351]
- Use of liquid samples (conversion into an aerosol and injection into the plasma) or use of solid samples (direct analysis if a vaporizing agent is available, e.g. Laser ablation (LA-ICP-OES) or electrothermal vaporization (ETV)) [https://www.spectro.de/icp-oes-prinzip]

On-site requirements/ preparations

- Removal of coatings and creation of a metallic bright surface of the sampling point
- Sampling from the component (hole: approx. 1 mm diameter, sample quantity: a few milligrams)

Procedure description

Long description

In optical emission spectrometry with plasma excitation, plasma is used as an excitation source to emit characteristic radiant energy from a sample.
In the so-called plasma torch, consisting of three concentric quartz tubes, the sample is introduced from the inner tube through an atomizer unit as an aerosol, vapour or fine powder with the aid of an argon stream via the middle tube into the hot argon plasma, which is located in the outer tube. The argon plasma is an ionized gas that contains electrons and ions as well as atoms. Temperatures of 6000 to 8000 °C prevail in the plasma, causing the sample to dry and evaporate. In the process, the atoms are transferred to an energetically excited state. When the atom returns to its ground state, it emits the released energy in the form of light (polychromatic radiation). The polychromatic radiation is broken down spectrally by a grating and the elements contained are identified via the wavelengths. The intensity of the emitted light is used to determine the element content. For this purpose, the device is calibrated with synthetic solutions of known content. [1,2]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Quick determination of the elements contained
- Laboratory method

92

1.21 Optical emission spectroscopy OES

As of 18.12.2019

Measuring method

Measurement setup

Laboratory device ICP-OES
T. Schwarze, HTW Berlin/
KIWA Berlin

Measuring equipment (measuring devices and test equipment)

-Power connection for laboratory equipment
- prepared sample

Emission spectrometry with plasma excitation ICP-OES in a simultaneous spectrometer [1]

- Plasma torch (high-frequency generator) with atomizer unit as excitation source with inductively coupled high-frequency plasma ICP
- holographic grating and polychromator for spectral decomposition and simultaneous focusing of the radiation
- Photomultiplier as detection unit

Measured variable and target variable

- Splitting the radiation into wavelengths
- Representation of the total spectrum with spectral lines of the various elements in diagram: wavelength in [nm] on x-axis; intensity in [w.e.] on y-axis [1]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)

2. Test planning
- Determination of the test areas or sampling point

3. Performance of the test (taking into account 2.): Chemical analysis of ferrous materials using optical emission spectrometry with inductively coupled plasma [DIN EN 10351, DIN EN 10355].
- Sample preparation: Dissolving the sample
- Performing the analysis in the laboratory device

4. Documentation and evaluation
- Evaluating the spectra and determining the elements
- Documentation of the results in a test report

5. Further information
- Further examinations if necessary
- Proof of the tester's visual acuity (near vision and color vision)

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	4/5	4/5	5/5

Further information

Device manufacturer, software

- Spectro Analytical Instruments GmbH [https://www.spectro.de/produkte/icp-oes-aes-spektrometer]
- Thermo Fischer Scientific: iCAP-Series [https://www.thermofisher.com/de/de/home/industrial/spectroscopy-elemental-isotope-analysis/trace-elemental-analysis/inductively-coupled-plasma-optical-emission-spectrometry-icp-oes.html]

Related methods/ measurement variants

Overview of atomic spectrometric methods [1]

1. Atomic absorption spectrometry AAS
2. Atomic emission spectrometry AES *differentiated according to the type of excitation in:*
   - Flame Atomic Emission Spectrometry (F-AES)
   - Optical emission spectrometry with inductively coupled plasma (ICP-OES)
3. x-ray fluorescence spectrometry XRF/XRFS (X-ray fluorescence spectroscopy)

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[2] Skoog D.A., Leary J.J. (1996): **Emission spectroscopy based on plasma, arc and spark atomization**. In: Instrumental analysis. Springer textbook. Springer, Berlin, Heidelberg
[3] **Optical emission spectrometry**. Volume 11 in: Informationsschriften zur zerstörungsfreien Prüfung - ZfP - kompakt und verständlich, Vol. 11.

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Chemical analysis of metals (77.040.30)

- DIN EN 10351, 2011-05: Chemical analysis of ferrous materials - Analysis of non-alloy and low-alloy steels by inductively coupled plasma optical emission spectrometry - Determination of Mn, P, Cu, Ni, Cr, Mo, V, Co, Al (total) and Sn.
- DIN EN 10355, 2013-11: Chemical analysis of ferrous materials - Analysis of non-alloy and low-alloy steels by inductively coupled plasma optical emission spectrometry - Determination of Si, Mn, P, Cu, Ni, Cr, Mo and Sn after dissolution in nitric and sulphuric acid.
- DIN EN ISO 14284, 2003-02: Iron and steel - Sampling and preparation of samples for the determination of the chemical composition

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Other/ Notes/ Remarks/ Comment

94

1.22 X-ray fluorescence analysis XRF

As of 18.12.2019

Physical basis	Chemical measuring principle
Procedure **X-ray fluorescence analysis XRF/** **X-ray fluorescence spectroscopy RFS** X-Ray Fluorescence Spectroscopy XRF	Test task - Element composition: Element content

Brief description

Non-destructive testing to determine the elements by exciting a sample with primary X-rays from an X-ray tube, whereby the sample itself emits a secondary, fluorescent X-ray, the spectrum is examined in an X-ray spectrometer. (X-ray emission spectroscopy)

Standard area of application (practical testing tasks)

- "Identification of the chemical elements contained in a substance and
- to determine their quantity or
- for determining the thickness of coatings" [DIN 51418-1].

Application limits (technical, physical, economic)

- Detection of elements lighter than boron (atomic number Z=5) not possible [DIN 51418-2] ; detection with reliable analysis values from fluorine (Z = 9) [DIN 51418-1], good values from sodium (Z=11) , possible up to uranium (Z=92)

Special applications (additional testing tasks)

On-site requirements/ preparations

- either optically accessible examination surface with portable device (handheld spectrometer) in situ or sampling of the component to be examined for the laboratory
- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Sample must have at least one flat surface from which the X-rays can be reflected

Procedure description

Long description

X-ray fluorescence is based on the photoelectric effect. A material sample is excited by polychromatic X-rays. In the process, electrons close to the nucleus are lifted from the inner shells of the atom to those further out. This allows electrons from higher energy levels further away from the nucleus to fall back and fill the empty space near the nucleus in the atom. The energy released in this process is emitted in the form of element-specific, characteristic X-ray fluorescence radiation (fluorescence = spontaneous emission of light shortly after excitation of a material by electronic transitions). The spectrum of this fluorescence radiation can be analyzed by a radiation detector. The measured signal of this specific energy indicates the atomic number Z of the detected elements.
A distinction is made between two different types with regard to evaluation:
- Energy-dispersive X-ray fluorescence analysis ED-XRF: "Spectrometer in which the decomposition of the sample radiation according to its energy is carried out by the detector by electronic means" [DIN 51418-1].
The energy dispersive measurement can be carried out with a hand-held spectrometer, which enables in situ analysis. [DIN 51418-2]
- *Wavelength-dispersive X-ray fluorescence analysis WD-XRF: "X-ray spectrometer in which the dispersion of the sample radiation by diffraction from a crystal" [DIN 51418-1].*

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ with portable device, only optical accessibility to the surface to be examined must be guaranteed
+ No sample change due to on-site application
+ Results immediately available (less than 1 minute pure measuring time)
+ No danger to operators due to design and no environmentally hazardous chemicals
+ Low interference (occurrence and overlapping of fluorescence lines of different elements are rare, lines can be clearly assigned)
+ Determination of several chemical elements in one analysis step on the same specimen
- Laboratory: Preparation of the sample for the analyzer, such as creating the necessary geometry and a flat surface. Measuring surface

1.22 X-ray fluorescence analysis XRF

As of 18.12.2019

Measuring method

Measurement setup

XRF laboratory device
T. Schwarze, HTW Berlin/
KIWA Berlin

Measuring equipment (measuring devices and test equipment)

- Laboratory: **X-ray fluorescence spectrometer** consisting of:
  - Primary radiation source: X-ray tube (old. radioactive nuclides, synchrotron radiation source)
  - Detection unit
  - Sample to be analyzed (prepared if necessary)
  - Power connection for laboratory equipment
- In situ: **ED-XRF** handheld spectrometer (handheld spectrometer)

Measured variable and target variable

- EDRFA: Energy in [keV] and intensity in [w.E.], measurement of all energies in energy-proportional voltage pulses
- *WDRFA: Wavelength in [nm] and intensity in [w.e.], splitting the radiation into wavelengths*
- Representation of the overall spectrum with spectral lines of the various elements in a diagram: energy *or wavelength* on x-axis; intensity on y-axis

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)

2. Test planning
- Determination of the test areas (or sampling point for laboratory tests)
- Compliance with radiation protection regulations

3. Performance of the audit (taking into account 2.)

- Insitu:
  - Attaching the handheld spectrometer and automatic measurement within seconds
- Laboratory:
  - Sampling from the component to be tested
  - Sample preparation: Creating the geometry required for the measuring device and creating a flat measuring surface
  - Preparation of the test: Aligning and focusing the X-ray beam on the sample
  - Carrying out the analysis: bombardment and sample procedure

4. Documentation and evaluation
- Evaluation of the spectra
- Output of the identified metals and their quantity
- Documentation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
4/5	3/5	5/5	5/5

Further information

Device manufacturer, software

- Helmut Fischer GmbH: XAN 500 [Link: http://www.helmut-fischer.de/fileadmin/documents/broc/DE/BROC_X- RAY_Product_line_951-008_en.pdf]
- Spectro Analytical Instruments GmbH: Handheld product family SPECTRO xSORT [https://www.spectro.de/produkte/rfa-spektrometer]

Related methods/ measurement variants

- X-ray fluorescence analysis (= excitation with X-rays, emission of characteristic X-rays) works according to a similar physical principle as X-ray analysis = excitation with electron beam, emission of characteristic X-rays
- Special applications: Micro-XRF, total reflection XRF [DIN 51418]

Overview of atomic spectrometric methods [1]

1. Atomic absorption spectrometry AAS
2. Atomic emission spectrometry AES *differentiated according to the type of excitation in:*
   - Flame Atomic Emission Spectrometry (F-AES)
   - Optical emission spectrometry with inductively coupled plasma (ICP-OES)
3. x-ray fluorescence spectrometry XRF/XRFS (X-ray fluorescence spectroscopy)

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- DIN EN 10315, 2006-10: Standard method for the analysis of high-alloy steel by X-ray fluorescence spectroscopy (XRF) using a comparative correction method.

Physicochemical analysis methods/instrumental analysis (71.040.50)

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- DIN IEC 62495, VDE 0412-20: Radiation measuring instruments - Portable X-ray fluorescence analyzers with miniature X-ray tube (IEC 62495:2011) Date of issue: 2011-12-00

Oxides (71.060.20)

- DIN 51001, 2003-08: Testing of oxidic raw materials and materials - General principles of X-ray fluorescence analysis (XRF).
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- DIN 1076, 1999-11: Engineering structures in the course of roads and paths - monitoring and testing.

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Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Guidelines for the implementation of federal construction tasks, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Part 2 - Test method Concrete

2.1 Visual inspection

Physical basis	Optical measuring principle
Procedure **Visual inspection** Visual Testing	Test task - Surface inhomogeneities: Surface cracks - Moisture distribution - Corrosion

Brief description

Non-destructive testing to detect damage, defects and faults and to assess the condition of the test surface by visual inspection of a test surface with or without aids. - Surface method

Standard area of application (practical testing tasks)

- Locating and evaluating superficial quality characteristics by perceiving, comparing, estimating, counting and Measure [1]
- Gravel pockets, pore accumulations, accumulations of cement slurry, leaking tongues in construction joints, edge chipping and color differences due to reduced strength [2]
- Cracks [2]
- Sanding [2]
- Efflorescence due to salinization [2]: Assessment of the moisture distribution if residues of salts are visible on the concrete surface
- Lime crusts in the area of construction joints, gravel pockets and cracks [2]
- Rust stains on the concrete surface due to corrosion of the reinforcement (binding wire, formwork nails) [2]: Detectability of corrosion if it is advanced carbonation-induced corrosion
- Concrete spalling over reinforcement due to the increase in volume associated with corrosion [2]
- Cracks along the reinforcing steel/ tendon axis [2]: Detectability of prestressing steel fractures if cracks are visible that mark the course of the tendon
- Visual inspection as a basic test for further investigations

Application limits (technical, physical, economic)

- Accessibility
- Lighting conditions
- Recognizability on the surface
- Viewing distance or visual inspection grid
- Size and shape of the object to be located

Special applications (additional testing tasks)

- Use of aids such as mirrors, lenses, endoscopes and photo and video technology

On-site requirements

- Accessible test surface (if necessary by erecting scaffolding and platforms; distances to the test object less than 600 mm and at an angle of not less than 30° to the test surface for the local visual inspection, distances greater than 600 mm for the overview inspection in accordance with DIN EN 13018)
- Sufficient lighting conditions (if necessary, add lighting sources with at least 160 lx for the overview inspection and at least 500 lx for the local visual inspection in accordance with DIN EN 13018)
- Preparing the surface: if necessary, clean the surface for a low degree of surface soiling

Procedure description

Long description

According to [DIN EN 13018: 2016-06], visual inspection is divided into direct and indirect visual inspection:
- "[Direct] visual inspection with an uninterrupted beam path between the inspector's eye and the test surface. This test is performed with or without aids, e.g. with a mirror, lens, endoscope or fiber optic device." Indirect visual inspection is performed when direct visual inspection cannot be performed.
- "[Indirect] visual inspection with an interrupted beam path between the inspector's eye and the inspection surface. Indirect visual inspection includes the use of photo and video technology, automated systems and robots".

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Visual inspection without tools is quick, depending on accessibility,
- Visual inspection without aids may not detect the features that can be detected with aids

2.1 Visual inspection

Measuring method

Measurement setup

Visual inspection of the box girder of a concrete bridge
M. Friese, BASt

Measuring devices

- If necessary, aids such as mirrors, lenses, endoscopes or photo and video technology

Measured variable and target variable

Specified feature(s): e.g. surface cracks
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Ensure sufficient accessibility to the test area, using aids such as mirrors, magnifying glasses and endoscopes if necessary
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Performance of the test *(taking into account 2.):* Direct visual inspection [DIN EN 13018: 2016-06]
- Distance to the test surface < 600 mm
- Viewing angle of ≥ 30° to the test surface
- for overview inspections: Distance of > 600 mm permissible
- Additional lighting if necessary: at least 500 lx for local visual inspection and at least 160 lx for general inspection

4. Documentation
- Marking (e.g. with chalk) of the defined characteristic (inhomogeneity) on the structure to assess the damaged area (crack growth); indication of the test date for traceability
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary
- Proof of the tester's visual acuity (near vision and color vision)

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	1/5	1/5	3/5

Further information

Device manufacturer, software

-

Related methods/ measurement variants

- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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[1] Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (ed.): **BC 3 M1 Basic Course Level 3. Documents for teaching. Visual inspection (VT) - V1 Basics of visual inspection**.
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Bibliography II (regulations: standards, guidelines, information sheets)

Terminology (ICS 01.040.19)
- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)
- Visual inspection is one of the classic NDT procedures and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out the visual inspection.

Non-destructive testing (ICS 19.100)
- DIN EN 13018, 2016-06: Non-destructive testing - Visual inspection - General principles.
- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

DGZfP leaflets
- DGZfP - B6, 1996: Leaflet on visual inspection and endoscopy as optical methods for non-destructive testing in the construction industry
- DGZfP - OV 01, 2013-11: Leaflet on optical methods - Part 1: Selection and initial inspection of optical visual inspection devices; Part 2: Inspection of optical visual inspection devices by the user.

Bibliography III (General regulations)

Protection of and in buildings in general (ICS 91.120.01)
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Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Further information about the DGZfP (German Society for Non-Destructive Testing):
- 2nd specialist seminar on optical testing and measuring methods 2011
- 3rd specialist seminar on optical testing and measurement methods 2013
- 4th specialist seminar on optical testing and measuring methods 2015
- 5th specialist seminar on optical testing and measurement methods 2017

Physical basis	Optical measuring principle
Procedure **Endoscopy: Borescopes (rigid endoscopes)** Endoscopy: Borescope Inspection	Test task - Surface inhomogeneities: Surface cracks - Moisture distribution - Corrosion

Brief description

Non-destructive testing of a non-accessible surface or cavity via an opening for exploration of the internal structure of the component to be inspected by means of optical image transmission through a special lens system and an optical fiber for illumination. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/ exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)
- Examination of tendons with regard to grouting condition and turnbuckles (usually via borehole)
- Inspection of corrosion conditions/pitting corrosion (targeted via drill holes)

Application limits (technical, physical, economic)

- Accessibility or presence of openings
- Moisture (due to damage or wet drilling) and drilling dust (due to dry drilling)
- Rough estimates of sizes and dimensions (for simple devices)
- No digital storage of images (for simple devices)
- Distortion effects of the optics can make it difficult to interpret the images

Special applications (additional testing tasks)

- Insertion of instruments through shaft
- Use of prismatic attachments and swivel mirrors for different viewing directions
- Some manufacturers offer borescopes with memory function as well as photo and video function [6]
- Verification of suspected areas of prestressing steel breakage (if necessary using a drill with automatic switch-off)
- Endoscopy is physically possible to assess the moisture distribution if the appropriate Drilling depth intensive moisture penetration becomes visible through cracks

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity (if necessary, use a drill with automatic switch-off)

Procedure description

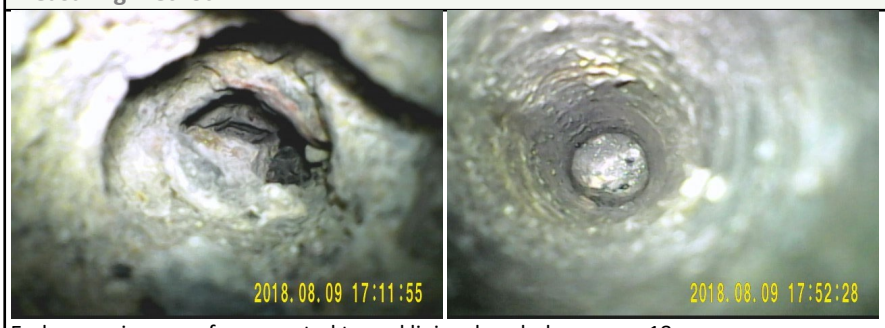
Long description

The classic, lens-optical borescope consists of an eyepiece at one end, a tube with an image transmission system and an objective lens at the other end. The image transmission system consists of a special lens system that is rigidly arranged. Illumination is provided by light guides or a tiny light bulb integrated into the head. Depending on the design, the viewing direction can be changed: forwards, sideways, diagonally forwards or backwards. The interpretation of the circular images is made difficult by the distortion effects of the optics and the unusual perspective and requires experience in interpreting the images.
There are now also more advanced borescopes with fiber optic bundles for image transmission.
In addition to rigid borescopes, there are also flexible fiberscopes and flexible videoscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ better optical quality than flexible endoscopes
+ Higher resolution due to larger camera design compared to other endoscopes
- not bendable

Measuring method



Endoscopy images of a concreted tunnel lining, borehole approx. 18 mm
Left: Cavities and washouts; right: compact gallery concrete without damage
Dr. Gabriele Patitz

Measuring devices

- Borescope (consisting of an eyepiece, a long tube with an image transmission system and an objective) with diameters of 1.6 to 8 mm and lengths of 50 to 650 mm [3]
- Drill, if necessary
- Power connection for drill, if necessary

Measured variable and target variable

Specified characteristic(s): Surface inhomogeneities: Corrosion
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning
- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Performance of the examination (taking into account 2.): **Endoscopic examination with a borescope**

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec
- PCE Instruments

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
    (Special form: articulated arm endoscopes, rigid endoscopes with articulated arms in which deflecting prisms are installed)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

- Visual inspection is one of the classic NDT procedures and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out the visual inspection.

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Other/ Notes/ Remarks/ Comment

Further information about the DGZfP (German Society for Non-Destructive Testing):

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- 3rd specialist seminar on optical testing and measuring methods - Lecture 01_2013-03
- 3rd specialist seminar on optical testing and measuring methods - Lecture 07_2013-03
- 4th specialist seminar on optical testing and measuring methods - Lecture 04_2015-03
- 5th specialist seminar on optical testing and measurement methods - Lecture 13_2017-03

Physical basis	Optical measuring principle
Procedure **Endoscopy: Fiberscopes (flexible endoscopes)** Endoscopy: Fiberscope Inspection	Test task - Surface inhomogeneities: Surface cracks - Moisture distribution - Corrosion

Brief description

Non-destructive testing of an inaccessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of image transmission via a bundle of optical fibers. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)
- Examination of tendons with regard to grouting condition and turnbuckles (usually via borehole)
- Inspection of corrosion conditions/pitting corrosion (targeted via drill holes)

Application limits (technical, physical, economic)

- Accessibility or presence of openings
- Rough estimates of sizes and dimensions (for simple devices)
- Lower resolution with smaller diameters due to lower number of pixels

Special applications (additional testing tasks)

- Verification of suspected locations of a prestressing steel fracture
- Endoscopy is physically possible to assess the moisture distribution if intensive moisture penetration through cracks is visible due to the corresponding drilling depth
- Use of special equipment for targeted examinations:
  - Connection of CCD cameras and photo cameras for documentation
  - Equipped with gripping tools for sampling
  - Connection of optical devices such as magnifying glasses or microscopes
  - Use of monocular measuring magnifiers to measure crack widths

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity (if necessary, use a drill with automatic shut-off)

Procedure description

Long description

The fiberscope, also known as a fiber optic endoscope, consists of an image guidance system made of ordered glass fibers and a light guidance system. The image is transmitted from the objective to the eyepiece via the flexible glass fibers. The more glass fibers there are, the better the image resolution. The glass fiber bundle is also called an image guide bundle. Illumination takes place via an optical fiber bundle.
The interpretation of the circular images is made more difficult by the distortion effects of the optics, the unusual perspective and the limited image resolution (number of pixels) and requires experience in interpreting the images.
In addition to flexible fiberscopes, there are also rigid borescopes and flexible videoscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,3, DGZfP B6]

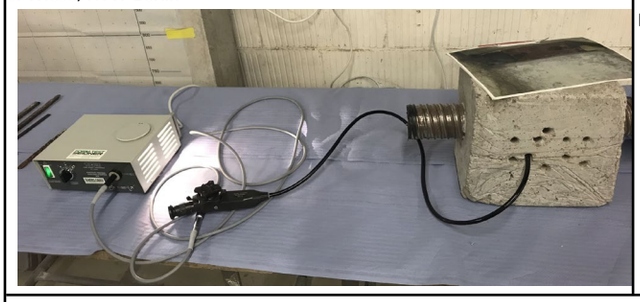
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ More flexible control than rigid endoscopes
+ Smaller device diameter than with videoscopes

Measuring method

Measurement setup

Fiberscopy on concrete test specimen
J. Wiese, HTW Berlin



Measurement results

Endoscopic image of a concreted tunnel lining, borehole approx. 18 mm: Cavities and washouts
Dr. Gabriele Patitz

Measuring devices

- Fiberscope with a diameter of 2.5 to 4.2 mm and a length of up to 1200 mm [3]
- Miniature fiberscope with a diameter of 0.35 to 2.0 mm if necessary [3].
- Drill, if necessary
- Power connection for drill, if necessary

Measured variable and target variable

Specified characteristic(s): Corrosion
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning
- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Carrying out the examination *(taking into account 2.)* : **Endoscopic examination with a fiberscope**
- Fiber optic tubing must not be kinked, otherwise the image transmission fibers will break

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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[1] Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (ed.): **BC 3 M1 Basic Course Level 3. Documents for teaching. Visual inspection (VT) - V2 Introduction to endoscopy**.
[2] **Endoscopy** (2014). In: DBV leaflet: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets), p. 31-33
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[4] Hanel, A.: **Chapter of Photogrammetry (PAK) 2013 SS - Techniques of Endoscopy**

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- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

- Visual inspection is one of the classic NDT procedures and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out the visual inspection.

Non-destructive testing (ICS 19.100)

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- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

DGZfP leaflets

- DGZfP - B6, 1996: Leaflet on visual inspection and endoscopy as optical methods for non-destructive testing in the construction industry
- DGZfP - OV 01, 2013-11: Code of Practice on Optical Procedures - Part 1: Selection and initial testing of optical Visual inspection equipment; Part 2: Inspection of visual inspection equipment by the user.

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Other/ Notes/ Remarks/ Comment

Further information about the DGZfP (German Society for Non-Destructive Testing):

- 2nd specialist seminar on optical testing and measuring methods - Lecture 02_2011-12
- 3rd specialist seminar on optical testing and measuring methods - Lecture 01_2013-03
- 3rd specialist seminar on optical testing and measuring methods - Lecture 07_2013-03
- 4th specialist seminar on optical testing and measuring methods - Lecture 04_2015-03
- 5th specialist seminar on optical testing and measurement methods - Lecture 13_2017-03

Physical basis	Optical measuring principle
Procedure **Endoscopy: videoscopes (flexible video endoscopes)** Endoscopy: Videoscope Inspection	Test task - Surface inhomogeneities: Surface cracks - Moisture distribution - Corrosion

Brief description

Non-destructive testing of a non-accessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of image transmission via an electrical cable with a CCD image converter chip for video recording and an optical fiber for illumination. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)
- Examination of tendons with regard to grouting condition and turnbuckles (usually via borehole)
- Inspection of corrosion conditions/pitting corrosion (targeted via drill holes)

Application limits (technical, physical, economic)

- Accessibility or presence of openings

Special applications (additional testing tasks)

- "Freezing" images
- Measurement of defects [4]
- Verification of suspected locations of a prestressing steel fracture
- Endoscopy is physically possible to assess the moisture distribution if intensive moisture penetration through cracks is visible due to the corresponding drilling depth

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity (if necessary, use a drill with automatic switch-off)

Procedure description

Long description

The videoscope consists of a flexible endoscope and a measuring probe with an integrated video chip (CCD). The data is generated and transmitted digitally, enabling subsequent digital image processing.
Due to the unusual perspective, interpreting the circular images requires a certain amount of experience.
In addition to flexible videoscopes, there are also rigid borescopes and flexible fiberscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Higher image resolution compared to rigid and flexible endoscopes
+ High resistance to breakage compared to fiberscopes with sensitive optical fibers
+ Storage of images and videos using digital technology
+ Highest image transmission length compared to rigid and flexible endoscopes

Measuring method

Measurement setup

Measurement results

Endoscopy images of a concreted tunnel lining, borehole approx. 18 mm
Left: Cavities and washouts; right: compact gallery concrete without damage
Dr. Gabriele Patitz

Measuring devices

- Videoscope with diameter 4 to 6mm and up to 8000mm working length [3]
- Drill, if necessary
- Power connection for drill, if necessary

Measured variable and target variable

Specified characteristic(s): Surface inhomogeneities: surface cracks, corrosion
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. **Information on the test task**
   - Definition of the test task and objective of the test
   - Inspection of test specifications/recommendations (standards, data sheets)
   - Information on the test object (ambient conditions, application limits, on-site requirements)
   - Procurement of information, if necessary by reviewing old and existing documents
   - Selection and inspection of a visual inspection device according to DGZfP - OV 01
2. **Test planning**
   - Definition of the test areas and a test system
   - Establish sufficient accessibility to the test area: use of an existing opening or Production of a borehole opening
   - Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Carrying out the examination *(taking into account 2.)* : **Endoscopic examination with a videoscope**

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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[1] Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (ed.): **BC 3 M1 Basic Course Level 3. Documents for teaching. Visual inspection (VT) - V2 Introduction to endoscopy**.
[2] **Endoscopy** (2014). In: DBV leaflet: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets), p. 31-33
[3] Karl Storz NDTec: **VTec C compact system**
https://www.karlstorzndtec.com/fileadmin/user_upload/produkte/Produktdatenblaetter/96191074_KSNDTec-SE-3-D.pdf
[4] Hanel, A.: **Chapter of Photogrammetry (PAK) 2013 SS - Techniques of Endoscopy**

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- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

- Visual inspection is one of the classic NDT procedures and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be acquired in order to carry out the visual inspection.

Non-destructive testing (ICS 19.100)

- DIN EN 13018, 2016-06: Non-destructive testing - Visual inspection - General principles.
- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

DGZfP leaflets

- DGZfP - B6, 1996: Leaflet on visual inspection and endoscopy as optical methods for non-destructive testing in the building industry
- DGZfP - OV 01, 2013-11: Code of Practice on Optical Procedures - Part 1: Selection and initial testing of optical Visual inspection equipment; Part 2: Inspection of visual inspection equipment by the user.

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- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Further information about the DGZfP (German Society for Non-Destructive Testing):

- 2nd specialist seminar on optical testing and measuring methods - Lecture 02_2011-12
- 3rd specialist seminar on optical testing and measuring methods - Lecture 01_2013-03
- 3rd specialist seminar on optical testing and measuring methods - Lecture 07_2013-03
- 4th specialist seminar on optical testing and measuring methods - Lecture 04_2015-03
- 5th specialist seminar on optical testing and measurement methods - Lecture 13_2017-03

2.5 Pull-out test

As of 18.12.2019

Physical basis	Mechanical measuring principle

Procedure	Test task
Stripping test Cut-And-Pull-Out test (CAPO test for short)	- Compressive strength

Brief description

Non-destructive test to determine the compressive strength by measuring the tensile force that must be applied to pull a steel bar, which is placed in a pre-drilled hole with a metal ring defined by its surface area, out of the concrete to be tested

Standard area of application (practical testing tasks)

- Determination of the compressive strength of an existing component

Application limits (technical, physical, economic)

- the larger the maximum grain size, the greater the scatter [1]

Special applications (additional testing tasks)

On-site requirements

- required substrate temperature of more than 0 °C [DIN EN 12504-3:2005-07].
- Minimum thickness of the concrete to be tested: 100 mm [DIN EN 12504-3:2005-07].
- Test should not be carried out in the immediate vicinity of existing reinforcement [DIN EN 12504-3:2005-07].

Procedure description

Long description

In the pull-out test, a hole is drilled perpendicular to the concrete surface, the lower area of the drill hole is widened by milling and a steel tension rod is inserted into the hole. An expansion ring is attached to the end of the rod, which anchors the rod in the concrete like a dowel. This ring, which is the actual pull-out part, is held in place by a cone screwed onto the tension rod. By screwing the tension rod to a marked point, the expansion ring is pushed through the spacer onto the cone and thus expanded. At the end of this process, it lies snugly on the groove of the cone. The experimental unit is now connected to a mechanical or hydraulic pull-off device and a counter pressure ring. When the extraction force is applied, compression struts form, creating a crater-shaped fracture surface. The force to be applied is measured and divided by the fracture surface. The break-out strength determined in this way is correlated with the required compressive strength, which can be read off using special calibration curves.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ simply suitable for use on the construction site
+ Time and cost savings thanks to immediate test results without specimen production
+ reasonably accurate result with general correlation curve
+ Curing of the concrete has almost no influence on the quality of the results [1]
- only assessment of the areas near the surface

116

2.5 Pull-out test

As of 18.12.2019

Measuring method

Measurement setup

Pull-out test on test specimen
C. Dauberschmidt/ M. Eger, Munich University of Applied Sciences

Measurement results

Measuring devices

Testing devices according to [DIN EN 12504-3:2005-07]:
- Drill
- Power connection for drill
- Washer (diameter 25 ± 0.1 mm)
- Shank (diameter < 0.6 of the pulley diameter; length equal to the pulley diameter, measured from the concrete surface to the nearest side of the pulley)
- Support ring (inner diameter 55 ± 0.1mm; outer diameter 70 ± 1mm)
- Pull-off device with constant loading speed of 0 5 + 0 2 kN/s

Measured variable and target variable

- Measurement of the extraction force in [N]
- Calculation of the fracture surface A in [mm²]
- Calculation of the pull-out strength fp in [N/ mm²]
- Conversion of pull-out strength to compressive strength using correlation curves [DIN EN 12504-3:2005-07].

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of test areas and a test system as well as test frequency [DIN EN 12504-3:2005-07]: depending on concrete composition, test purpose and required accuracy
- Distance between the centers of the test points: min. 200mm
- Distance of the center points from the concrete edge: at least 100mm
- Distance to reinforcement: expected fracture cone + at least the distance of one reinforcement diameter or the largest grain (larger value decisive)
- Description of the concrete to be tested: Age, moisture, etc.

3. Performance of the test (taking into account 2.): Pull-out test
- Drill hole: diameter 18 mm to a depth of 5 cm
- Milling: Widen the drill hole to a depth of 25 mm to a diameter of 25 mm
- Inserting tension rod with spreader ring
- Attaching the trigger device
- Measurement of the applied maximum load that led to the break: Specified to 0.05kN

4. Documentation
- Recording of the execution and the measurement result: correlation of the pull-out strength with the required compressive strength using special calibration curves
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	4/5	3/5	3/5

Further information

Device manufacturer, software

- Germann Instruments: CAPO test [Link: http://germann.org/products-by-application/category-1/capo-test]

Related methods/ measurement variants

- Locomotive test: same procedure as CAPO test, but for new buildings in which the steel bar with top plate is directly embedded in concrete/ installation before concreting

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[2] Latte Bovio, F.; Latte Bovio, G.; Brencich, A.; Cassini, G.; Pera, D.; Riotto, G.: **A New Pull-Out Technique for In-Place Estimation of Concrete Compressive Strength**. In: Advances in Materials Science and Engineering 2014 (6), pp. 1-8.

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Concrete. Precast concrete parts (91.100.30)

DIN EN 12504-3:2005-07: Testing of concrete in structures - Part 3: Determination of the pull-out force [This standard describes the determination of the pull-out force for components made of fresh and hardened concrete].

- ASTM C 900 - 15, 2015: Standard Test Method for Pullout Strength of Hardened Concrete
- BS 1881 - 207: 1992: Testing concrete. Recommendations for the assessment of concrete strength by near-to-surface tests

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- NT BUILD 211: 1984-05: Concrete, hardened Pullout strength

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Other/ Notes/ Remarks/ Comment

2.6 Tear-off test

As of 18.12.2019

Physical basis	Mechanical measuring principle

Procedure	Test task
Tear-off attempt Pull-off test	- Surface and adhesive tensile strength

Brief description

Non-destructive testing to **determine** the adhesive strength of a coating on a component surface concrete substrate or coating on concrete substrate) **by measuring** the tensile force that must be applied to tear off a bonded, surface-defined test stamp from the test surface.

Standard area of application (practical testing tasks)

- Determination of the surface tensile strength of a concrete surface (cohesion within a material)
- Determination of the adhesive tensile strength between the concrete replacement system and a concrete surface (adhesion between two layers)

Application limits (technical, physical, economic)

- Test method susceptible to test influences such as curing, carbonation, concrete moisture or substrate preparation

- For special test conditions such as testing on ceilings or walls, the determination of the surface tensile strength on drill cores may have to be considered as an alternative.

Special applications (additional testing tasks)

On-site requirements

- Required substrate temperature of at least 5 °C
- Even concrete surface (substrate preparation by milling and blasting)
- Dry concrete surface

Procedure description

Long description

The tear-off test is carried out with a stamp applied to the test surface and a tensile tester that measures the force until the bonded test stamp is torn off.
The test surface is either the concrete surface or the surface of the concrete replacement system on a concrete surface. Before the test stamp is removed, the adhesive must be completely hardened, which can take 15 minutes to 19 hours depending on the manufacturer, otherwise the measurement result may be falsified. The specifications for the test stamp such as material, thickness and dimensions as well as the pre-drilling of an annular groove vary depending on the regulations. The test result is the tensile stress that must be applied to cause a fracture in the interface (adhesive fracture) or a fracture in the concrete (cohesive fracture). The speed of the increase in force varies in the regulations depending on the application. The test frequency also varies depending on the regulations and test object; it is between three and nine test points.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ easy handling
+ simply suitable for use on the construction site
- Test result influenced by numerous test influences
- only assessment of the areas near the surface

Measuring method

Measurement setup

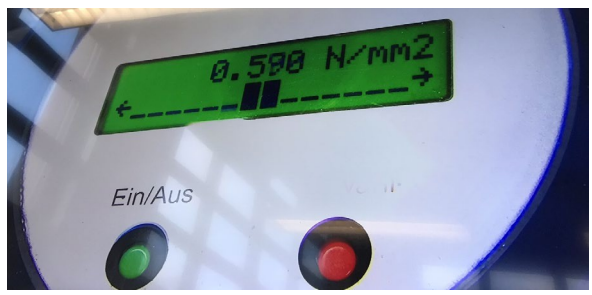
Transportable tester

J. Wiese, HTW Berlin

Measurement results

Tear-off strength display

J. Wiese, HTW Berlin



Measuring devices and accessories

Test accessories according to DIN EN ISO 4624:

- Adhesive: Adhesive based on epoxy resin (EP), polymethyl methacrylate (PMMA) or polyurethane (PU)
- circular punch made of steel (diameter 50 ± 0.5 mm; steel with thickness 20 mm)
- Transportable tester with up to 40 kN tensile force and constant force increase speed
- Thermometer for measuring the substrate temperature of the test surface

Measured variable and target variable

- centric tensile strength or tear strength in [N/mm²]:
  (Tensile force until the stamp breaks off in [N]/area of the test stamp in [mm²])
- Required strengths for normal concrete: minimum value 1.0 N/mm² and average value 1.5 N/mm² (Rili SIB)
- Documentation of the type of failure with proportions of cohesive and adhesive fracture, the failure forces and the surface tensile strength to be calculated from this (see form B1.3.2 ZTV- ING)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task

- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning

- Determination of the set of rules to be used for testing
- Definition of the test areas and a test system
  Measurement plan, inspection areas, minimum number of inspections depending on the size of the inspection area
- Determination of the type of adhesive; observation of the different strength developments

3. Performance of the test (taking into account 2.): Tear-off test (according to DIN EN ISO 4624)

- Measurement and recording of the following conditions during the test:
  Air temperature, relative humidity and surface temperature of the coated structure
- Preparing the test surface and the test stamp: Flat, grease-free and dry surface
- Pre-drilling an annular groove: Determination of a defined load surface
- Applying the stamp: Place the test stamp vertically on the test surface and stick it over the entire surface with an adhesive thickness of approx. 1 mm (for walls and ceilings, fix the stamp until the adhesive has hardened).
- Setting up the tester for the pull-off test: The tester must be set up centrally above the punch and secured in position to ensure centered tensile force
- Application of the load/load speed: The load must be increased constantly, preferably using an automatic tester

4. Documentation

- Recording of the execution and the measurement result: fracture pattern analysis with acceptance and rejection of the test (according to form B 1.3.2 ZTV- ING)
- Determining the type of failure: differentiating between adhesive and cohesive fractures

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	4/5	4/5	3/5

Further information

Device manufacturer, software

- Proceq: Automatic tensile adhesion testers DY-206, DY-216, DY-225 [Link: https://www.proceq.com/de/vergleichen/haftzugpruefung/]
- Proceq Webinar: Pull-off testing according to standards with Proceq DY-2 [Link: https://www.youtube.com/watch?v=Qze6FtfZIsA]; status 2016, referring to DIN EN 1542

Related methods/ measurement variants/ alternative methods

- Pull-out test, rebound hammer, tensile test on drill cores [2]

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[2] Momber, Andreas; Schulz, Rolf-Rainer (2006): **Handbuch der Oberflächenbearbeitung Beton. Processing, properties, testing**. Basel, Boston: Birkhäuser Verlag (BauHandbuch)

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Coating materials (paints and varnishes) (87,040)

- DIN SPEC 91063, 2011-07: Adhesion strength of coatings.
- DIN EN ISO 4624, 2016-08: Paints and varnishes - Tear-off test for the determination of adhesion.

Concrete construction (91.080.40)

- DIN EN 1542: 1999-07: Products and systems for the protection and repair of concrete structures - Test method - Measurement of bond strength in the pull-off test

Cement. Gypsum. Lime. Mortar (91.100.10)

- DIN EN 13892-8:2003-02: Test methods for screed mortars and floor screeds - Part 8: Determination of tensile bond strength

Other building materials (91.100.99)

- DIN EN 13408: 2002-06: Test method for hydraulically hardening floor levelling compounds - Determination of tensile bond strength

ZTV-ING

- ZTV- ING, Part 1, Section 3: 2007-12: Inspections during construction work
- ZTV- ING, Part 3, Section 4: 2007-12: Protection and repair of concrete components

German Committee for Reinforced Concrete

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Other/ Notes/ Remarks/ Comment

2.7 Drill with automatic switch-off

As of 18.12.2019

Physical basis	Mechanical/ electrical measuring principle
Procedure **Drilling machine with automatic Shutdown**	Test task - Reinforcement (reinforced concrete) - Tendons/ ducts (prestressed concrete)

Brief description

Non-destructive testing to locate reinforcement or cladding pipes in concrete using a special drilling machine that switches off automatically in the event of metallic contact to prevent damage

Standard area of application (practical testing tasks)

- Damage-free detection of reinforced and prestressed concrete structures:
  Reinforcement layer, tendons/ ducts, corrosion
- Basis for further endoscopic examinations through targeted drilling, but not drilling through

Application limits (technical, physical, economic)

Special applications (additional testing tasks)

- Procedure for preliminary investigation and as a safety measure for core drillings if these are to be carried out in the immediate vicinity of cladding pipes/reinforcement [2]

On-site requirements

A closed circuit between the reinforcement, the machine, the tool and the automatic switch-off system must be established to switch off the machine if the reinforcement is hit at the same time. [3]

Procedure description

Long description

This process is differentiated according to the mechanical and electrical principle[1]:
a) Mechanical principle: The change in drilling resistance when drilling into iron triggers the switch-off.
b) Electrical principle: An electrical connection is established between the clamping channel contacted at another point and the drill. Any contact between the drill bit and the clamping channel then triggers a shutdown.

The cladding tube can then be opened manually and the grout removed without damaging the prestressing steel.
In all cases, it must be strictly ensured that the opened areas are properly sealed again.

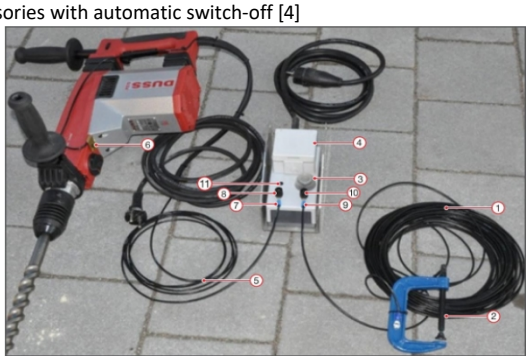
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ easy handling
- limited non-destructive by exposing a reinforcement point
- Risk of damage to reinforcement and cladding pipes

Measuring method

Measurement setup

Drill accessories with automatic switch-off [4]



Measurement results

Connection and use of the drill [3]

Measuring devices

Drill with automatic switch-off [4] (diameter from 5 mm)

1 Cable, reinforcement side (length 25 m)
2 Screw clamp (clamping range 0 - 75 mm)
3 Reset button
4 Power connection for machine connection (voltage 230 V)
5 Cable, machine side (length 4 m)
6 Earth contact, connection on machine side, metallic contact
7 Cable lug
8 Pole clamp
9 Cable lug
10 Pole clamp
11 LED

Measured variable and target variable

- Automatic switch-off

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. test planning
- Definition of the test areas and a test system
- Exposing a reinforcement point

3. Carrying out the audit (taking into account 2.):

Commissioning: Connection and connection of drilling machine, automatic switch-off and reinforcement point

"The machine-side cable (5) must be metallically connected to the machine with the earth contact (6) soldered to the end of the cable (metal housing or similar). The other end must be connected to the automatic switch-off ASA with the cable lug (7) under the pole terminal (8).

The cable (1) on the reinforcement side must be connected with the cable lug (9) to the second pole terminal (10) of the ASA automatic switch-off device, the screw clamp (2) must be brought into metallic contact with the existing reinforcement on the building side. Before attaching the screw clamp (2), the metallic surfaces must be polished to ensure secure contact." [4] Carry out a functional check:

"With the machine switched on, briefly touch the screw clamp (2). If installed correctly, the machine must switch off immediately when the screw clamp is touched. The LED (11) of the automatic switch-off ASA lights up red. Press the reset button (3) to reactivate the machine. The red LED (11) goes out. Make sure that the machine switch lever is not pressed and that the machine switch lock (if present) is not locked. Risk of injury!" [4]

Drilling and professional closing of the opened reinforcement points

4. Documentation
- Recording of the implementation and the measurement result
- Evaluation of the results in a test report

5. further information
- Further endoscopic examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	2/5

Further information

Device manufacturer, software

Friedrich Duss offers the automatic s w i t c h - o f f f u n c t i o n under the designation ASA; this function can be used in conjunction with any Duss rotary hammer drill. (To the best of our knowledge, Friedrich Duss is currently the only company on the market to offer the drill with automatic switch-off; as of September 2018)

Related methods/ measurement variants

Bibliography (technical literature, data sheets, regulations, standards, codes of practice, references)

[1] Bundesanstalt für Materialforschung und -prüfung BAM; ZfPBau- Kompendium: Drilling machine with automatic shut-off, 2004

[2] Guidelines for the retrofitting of bridges using external prestressing, 2013

[3] Friedrich Duss Maschinenfabrik GmbH & Co KG (ed.) (2013): ASA automatic switch-off product sheet.
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Other/ Notes/ Remarks/ Comment

The tool manufacturer Metabo had a drill with automatic switch-off called "KHE 26 Contact" in its range of hammers until 2010; there are currently no longer any such machines in the range. (as of August 2018)
The tool manufacturers Bosch, Hilti and Makita do not have any drills with automatic switch-off in their range. (as of August 2018)

2.8 Rebound hammer / Schmidt hammer

As of 18.12.2019

Physical basis	Mechanically excited measuring principle
Procedure **Rebound hammer (Schmidt-Hammer)** (Schmidt) Rebound Hammers	Test task - (Change in) building material properties: Compressive strength

Brief description

Measurement of the rebound distance of a mass (R-value) or measurement of the energy or velocity difference before and after the impact of a mass (Q-value) by placing and triggering the rebound hammer with integrated impact pin on the concrete test surface and converting the measured values into compressive strengths.

Standard area of application (practical testing tasks)

- Estimation of the concrete compressive strength of normal concretes in the near-surface area
- Proof of the uniformity of the strength properties of the concrete
- Locating areas with poor concrete quality

Application limits (technical, physical, economic)

- Statements only about areas close to the surface (not about the entire component cross-section)
- Carbonation leads to overestimation of the determined compressive strength: only permissible up to < 5mm carbonation depth without drill core samples
- Use of the rebound hammer without core removal and evaluation of cube compressive strengths only permitted in Germany
- not applicable for surfaces with changes due to corrosive influences, fire, frost or chemical influences [3]
- Not applicable for exposed aggregate concrete surfaces

Special applications (additional testing tasks)

- Evaluation of concrete compressive strength by means of rebound hammer test according to **DIN EN 13791 National Annex** [3]:
  - *< 5mm carbonation depth without correlation with drill core strength*
  - ≥ 5mm carbonation depth either (1) set up your own conversion curve or (2) shift the conversion curve of the standard (conversion curve only exists for the R value)
- Method in accordance with DIN EN 13791/A20: 2017-02 also permitted for lightweight concretes and for high-strength concretes

On-site requirements

- Carbonation depth: ≤ 5 mm (for estimation of compressive strength without drill cores in Germany) [1]
- Component thickness > 100 mm [1]
- Surface condition of the measuring point: free of pores, blowholes and porosity [1]
- Measuring point: approx. 300 x 300 mm [1]

Procedure description

Long description

The rebound hammer consists of a spring, a mass and a striker. When the rebound hammer is placed on the point to be tested and triggered, the mass is accelerated by the tensioned spring, the momentum of which is transferred to a striker, which strikes the test specimen with its round end and rebounds. The harder the material, the less energy the material absorbs and the further the mass rebounds.

The hammer measures either the rebound distance, the rebound value R, i.e. the mechanical distance covered by the mass during rebound, or the velocity ratio, the rebound quotient Q, from the velocity shortly after and before the impact of the mass.

The R-value is used for the original rebound hammers; the direction of impact must be taken into account here. The Q value is used for more advanced devices; here the measuring principle is independent of the direction of impact. The R or Q value, which is a measure of hardness, is displayed on the scale of the rebound hammer. Tables can be used to estimate the compressive strength. As concrete is a heterogeneous building material, a series of measurements is required to obtain a reliable result.

Procedure advantages and disadvantages (compared to procedures for the same test task)

- Compressive strength determined by the rebound hammer is generally lower than the compressive strength determined on the drill core, i.e. drill cores must always be taken for static recalculations
- Excessively high R or Q values can indicate rock grain hits; these outliers in a measurement series are not critical as long as the "outlier criterion" is met
- the measured values scatter very strongly on rough surfaces

126

Measuring method

Measurement setup

Rebound hammer on test body,
J. Wiese, HTW Berlin

Measurement results

Rebound hammer on test body: Q value,
J. Wiese, HTW Berlin

Measuring devices

- Rebound hammer
- Calibration anvil/ test anvil (weighing 16 kg)
- Grinding stone to prepare weathered surface for testing

Measured variable and target variable

- Measured variable: R or Q value as hardness [0...100 scale divisions; unitless]
- Target value: Conversion to characteristic concrete compressive strength $f_{c,is}$ or concrete compressive strength classes according to DIN EN 206-1/ DIN 1045-2

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Determination of the carbonation depth
- Carbonation depth: < 5 mm (for estimating the compressive strength without drill cores in Germany)
- Test temperature: 0 to 50°C
- Function check on the calibration anvil

3. Carrying out the audit (taking into account 2.):
- when using the table and approach 2 (shifting the standard curve): at least 9 measurements per measuring point and at least 9 measuring points, measuring points must be in an inspection area with concrete from the same population
- when applying approach 1 (own curve): 18 measuring points
- General: at least 2.5 cm distance between the measuring points and to the edge
- Final function check on the calibration anvil

4. Documentation
- Logging of the implementation
- Measurement result: The measurement result of a measuring point must be discarded if > 20% of the values deviate by > 30% of the median. The median should not be confused with the arithmetic mean. The median of a series of numbers is the value that is in the middle (central) position when the values are sorted by size - central value. In contrast, the arithmetic mean is the sum of the series of numbers divided by their number - mean value.
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	1/5	2/5	3/5

Further information

Device manufacturer, software

- Proceq: Schmidt rebound hammer [Cf. Proceq: SilverSchmidt or Original Schmidt; https://www.proceq.com/de/vergleichen/schmidt-ruckprallhammer/]

Related methods/ measurement variants // Methods with the same test task

- Pendulum hammer: for testing softer materials such as lightweight concrete and fresh concrete [Cf. Proceq: Schmidt OS- 120; https://www.proceq.com/de/vergleichen/schmidt-ruckprallhammer/]

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Guidelines for the implementation of federal construction projects

- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

The recalculation guideline for the recalculation of existing road bridges does not permit the sole use of the rebound hammer; it also requires that drill cores be taken and used to determine the concrete compressive strength.

128

Physical basis Mechanically excited measuring principle

Procedure

Tapping test/ tapping with a hammer

Tap Testing/ Hammer Tapping test

Test tasks

- (Change in) building material properties
- Surface inhomogeneities

Brief description

Non-destructive testing to assess the condition of the area near the surface of a test surface by tapping with fingers, knuckles, fist or hammer by generating a sound.

Standard area of application (practical testing tasks)

- Locating cavities near the surface of concrete components
- Determining the change in building material properties
- Tapping test as a basic test for further examinations

Application limits (technical, physical, economic)

- Experience and assessment skills of the examiners
- Dependence of the sound:
  - the stress state, elasticity and vibration capacity of the material (robustness of the test surface)
  - from the component geometry, in particular component thickness
- Influence of noise sources
- Areas with dense reinforcement influence the audible sound [2]

Special applications (additional testing tasks)

On-site requirements

- Avoidance of disturbing influences from noise sources in the test environment
- Accessibility
- Sufficient robustness of the test surface

Procedure description

Long description

In the tapping test, the condition of an area near the surface of a test surface is assessed. Tapping is usually carried out with the aid of a hammer.

The intensity of the tapping determines whether the layers close to the surface or the deeper component layers are made to vibrate. With weak tapping, the shock waves penetrate less deeply; with strong tapping, the shock waves penetrate deeper. When assessing the sound, it is important to differentiate between bright and muffled or high and low frequency sound: a bright sound and a clearly noticeable rebound of the hammer indicate good concrete. To better differentiate the sound, it is advisable to tap different areas several times.

The sound depends on the air content inside the component, caused by the porosity of the material or by cavities, as well as on the state of tension, elasticity and vibration capacity of the material.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ quick first impression of possible cavities (suspected locations)

- subjective evaluation of the results depending on the experience of the tester

- The following investigations are necessary for clarification

- does not provide absolute values compared to impact echo

Measuring method

Measurement setup

Hollow box tapping test
Beto Bridge
M. Friese, BASt

Measuring devices

- Light steel hammer

Measured variable

- Frequency content of the audibly reflected sound

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system

3. Performance of the test (taking into account 2.): Tapping test
- Tapping in a regular grid
- Marking of suspicious areas if necessary

4. Evaluation
- Subjective evaluation of the reflected sound

5. Documentation
- Logging of the implementation
- Logging of suspected locations in a register
- Evaluation of the results in a test report

5. further information
- Further examinations, e.g. with ultrasound

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	1/5	1/5	3/5

Further information

Device manufacturer, software

Related methods/ measurement variants

- Impact echo
- **DHD method (digital cavity detection)**
  >> Hillemeier, B.; Walther, Andrei (2008): Rapid and large-scale structural condition assessment of prestressed concrete bridges, screeds and ceiling systems. 3. detection of gypsum plaster detachments with the DHD method (digital cavity detection). Lecture 15. in: Symposium on Structural Diagnosis 2008: DGZfP, Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V (Symposium on Structural Diagnosis).
- **Chain Drag Test/ Chain Dragging/ Chain Drag Technique**
  >> ASTM D 4580, 2012: Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding.
  >> Kashif Ur Rehman, Sardar; Ibrahim, Zainah; Memon, Shazim Ali; Jameel, Mohammed (2016): Nondestructive test methods for concrete bridges: A review. 2.1.2 Chain drag. In: Construction and Building Materials 107, pp. 61-62. DOI: 10.1016/j.conbuildmat.2015.12.011.

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- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

2.10 Impact echo

As of 18.12.2019

Physical basis	Mechanically excited measuring principle
Procedure **Impact echo** Impact Echo	Test task - Surface inhomogeneities - Delaminations - Back wall

Brief description

Non-destructive testing by means of excitation of elastic waves by a short mechanical impulse (impact with impactor), the impact, and measurement of the resonance frequency.
[One-sided measurement on the component with impactor and sensor]

Standard area of application (practical testing tasks)

- Determination of the geometry/ component thickness in the range from 5 to 80 cm (especially in densely reinforced components) [1]
- Detection of localized or extensive bond defects or delamination
- Localization of hollow points; - Localization of ducts/ tendons
- Examination of the uniformity of the component by calibration via ultrasonic speed

Application limits (technical, physical, economic)

- Determination of *thin* component thicknesses from 5 cm and of *large* component thicknesses up to 80 cm [1]
- Determination of component thickness for multi-layer components only up to the top layer of the first acoustic separating layer
- less suitable for searching for small objects (defects, clamping channels) with a small cross-section
- No information behind air layer, but information behind steel

Special applications (additional testing tasks)

- Testing of component thicknesses > 1.00 m only in individual cases
- Localization of grouting faults only possible with large-area non-grouted cladding pipes [6]

On-site requirements

- For the thickness measurement, the propagation velocity must be known (determination of the speed of sound at a point of known thickness in the same component)
- Measurement on floor panels is best at a distance of at least twice the panel thickness from the edge

Procedure description

Long description

In the impact echo method, the elastic waves are excited with a short manual impact on the component surface using an impactor, usually a sphere. The diameter of the impactor determines the contact time and the frequency content introduced. The wave generated is a Lamb wave. The measurement is carried out in a grid along defined lines or a surface. To measure the generated waves and the resonance frequencies, a sensor is pressed onto the component surface near the excitation point. No couplant is required for this. The distance of the reflector or the layer boundary from the concrete surface can be determined from the read frequencies if the propagation speed is known.
Total reflection occurs at the interface with air in the case of an impact echo. This means that no information can be obtained behind a layer of air.

Procedure advantages and disadvantages (compared to procedures for the same test task)

- Lower resolution and therefore less accurate than ultrasonic echo
- no line scans [7]
- No exactly uniform energy input due to manual excitation [7]

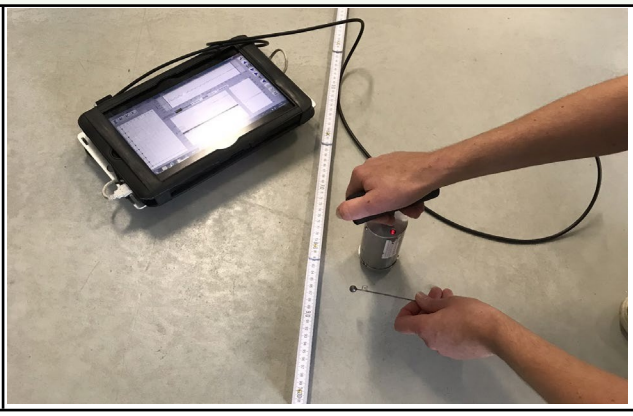
132

Measuring method

Measurement setup

Impact echo on concrete test body

J. Wiese, HTW Berlin



Measuring devices

-Spherical impactor with small diameter (high frequency components) : small thicknesses and small objects at close range

- Impactor with large diameter (for low frequency ranges) : larger thicknesses
- Suitable selection of impactors (3 to 30 mm ball diameter) for a large depth spectrum

Measured variable and target variable

Knowledge: Speed of sound v in [m/s] for concrete v= ~ 4000 m/s

Measured variable: Frequency f in [Hz] in the upper audible and lower ultrasonic range between 2 and 40 kHz Target variable: Component thickness d in [m],

Calculation of the target value: d = v/(2*f)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task

- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning [1]

- Definition of the test areas and a test system
- Selection of a suitable impactor
- Determination of the propagation velocity preferably at a location with known thickness

3. Performance of the test (taking into account 2.): Impact echo

4. Evaluation [1]

- Shift of the resonance frequency for adjacent materials with high impedances such as steel
- even with good quality of the actual measurement signal, interfering reflections can occur on boundary surfaces or internal objects (side walls, joints, reinforcement bundles, pipes)

5. Documentation

- Logging of the implementation
- Logging of suspected locations in a register
- Evaluation of the results in a test report

5. further information

- Further examinations, e.g. with ultrasound

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	4/5

Further information

Device manufacturer, software

- Germann Instruments: Mirador [Link: http://germann.org/products-by-application/flaw-detection/mirador]

Related methods/ measurement variants

- Contactless measurement through the use of microphones [6]

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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Other/ Notes/ Remarks/ Comment

- In Germany, the impact echo method is used for quality assurance in the production of tunnel inner shells and is part of the ZTV-ING with the RI-ZFP_TU. This requires a personnel qualification at the BASt. [8]
- In the USA, the impact echo method is primarily used to locate delaminations on concrete roadways.

Physical basis	Mechanically excited measuring principle
Procedure **Ultrasonic echo/ Reflected sound method** Ultrasonic Echo	Test task - Surface inhomogeneities: Surface cracks - Back wall - Reinforcement (reinforced concrete) - Tendons (prestressed concrete)

Brief description

Non-destructive testing for the detection of inhomogeneities by generating mechanically excited pulses in the test probe and their propagation and influence (e.g. reflection at the crack) according to the laws of elastic waves in the component to be tested [active emission of signals].
[One-sided measurement on the component with transmitter and receiver = reflection; also: transmit-receive method]

Standard area of application (practical testing tasks)

- Determination of component thickness
- Locating cavities and compaction defects (only if the rear wall is visible)
- Location of individual tendons in densely reinforced areas and localization of deep-seated reinforcement [3]

Application limits (technical, physical, economic)

- Measurement for components from 4 cm and up to 50 cm thick
- No specification of reinforcement diameters or geometric shapes
- no information behind air layers (applies to air layers in the submillimeter range), but behind
- No statement on the bonding of two layers
- Unsuitable for coatings and rough surfaces

Special applications (additional testing tasks)

- Locating grouting faults in tendons only in conjunction with phase evaluation [2]
- Testing of (densely reinforced) component thicknesses of up to 5 m with special arrangement of probes (LAUS-System - Large Aperture UltraSound) [10]
- with advanced devices, it is possible to measure the concrete cover [9]

On-site requirements

- for thickness measurement, propagation velocity must be known (determination of the speed of sound at a point of known thickness in the same component at an intact point)
- Surface coatings and seals must be removed
- Strong scattering effects due to aggregate with d_{Gr} > 16 mm

Procedure description

Long description

The ultrasonic echo method on concrete uses point-contact probes to generate ultrasonic pulses in the frequency range between 30 and 100 kHz. Several transmitters and receivers are arranged next to each other at fixed distances in the testing device - so-called array probes. The pulses generated are **transverse waves**. For the measurement, the test device must be pressed onto the concrete surface and moved in a grid. The grid is determined by the size of the objects to be detected. The elastic waves are reflected at layer boundaries or backscattered by reflectors such as reinforcing bars and cladding pipes. In the case of ultrasound, almost total reflection occurs at the interface with air. This means that no information can be obtained behind an air layer. The distance and extent of the detected objects can then be determined from the transit time of the reflected pulses.
A reconstruction of the raw data with SAFT evaluation provides an improved imaging representation of the results. [8]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Investigation of young concretes possible (in contrast to the radar method)
- blind in the near-surface area
+ Non-destructive, non-contact
- No exploration of areas behind cavities in contrast to radar

2.11 Ultrasound: echo (and transmission)

As of 18.12.2019

Measuring method

Measurement setup

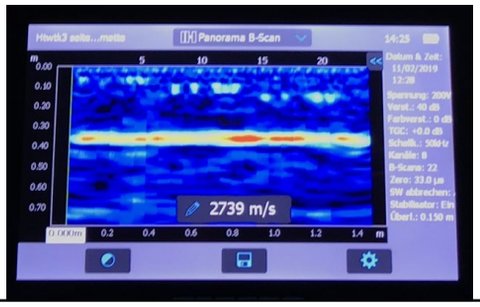
Ultrasound on concrete test specimens

J. Wiese, HTW Berlin

Measurement results

Ultrasound on concrete test specimens: evaluation

J. Wiese, HTW Berlin



Measuring devices

- Ultrasonic testing device with an exciting frequency range between 20 and 100 kHz *(compared to steel: 1 to 10 MHz)*
  - High frequency: lower penetration depth, higher resolution
  - Low frequency: higher penetration depth, lower resolution
- Control unit

Measured variable and target variable

Knowledge or calculation: Speed of sound v in [m/s] for concrete v_{Trans} = ~ 2500 m/s Measured variable: Running time t in [µs]

Target value: component thickness d in [m]

Calculation of the target value: d= v * t/2 (if necessary: v= λ * f)

Reflection coefficients: R= -1 boundary layer concrete/air (total reflection), R= + 0.5 ... 0.6 Concrete/steel boundary layer

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Determination of the propagation velocity

3. Performance of the test (taking into account 2.): Ultrasonic testing
- Measurement by moving the ultrasonic test sensor in a specific grid

4. Evaluation and documentation
- Measurement data acquisition and visualization: e.g. reconstruction of raw data with SAFT evaluation
- Recording of the implementation and the measurement result
- Presentation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

136

Further information

Device manufacturer, software

- Proceq (product range: Pundit)

Related methods/ measurement variants

Ultrasound variants:

- Ultrasonic reflection/ transceiver method/ pulse-echo technology:

one-sided measurement with a single, combined transmitter and receiver probe

- Ultrasonic transmission/transmission technology according to DIN EN ISO 16823:

Two-sided transit time measurement on the component = sonication of the component with transmitter and receiver probes on opposite or offset surfaces of the test specimen; test tasks: (change in) concrete compressive strength, solidification process of fresh concrete or homogeneity check

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- DIN EN ISO 5577:2017-05: Non-destructive testing - Ultrasonic testing - Terminology.

Personnel management, vocational training (03.100.30)

- Ultrasonic testing is one of the classic NDT methods and is identified by the abbreviation "UT". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out ultrasonic testing.

Non-destructive testing (ICS 19.100)
- DIN EN 12668, 2010-05: Non-destructive testing - Characterization and verification of ultrasonic testing equipment__ Part 1: Testing equipment
- DIN EN 12668, 2010-06: Non-destructive testing - Characterization and verification of ultrasonic testing equipment__ Part 2: Probes
- DIN EN 12668, 2014-02: Non-destructive testing - Characterization and verification of ultrasonic testing equipment - Part 3: Complete testing equipment
- DIN EN ISO 2400:2013-01: Non-destructive testing - Ultrasonic testing - Description of calibration block No. 1
- DIN EN ISO 7963:2010-12: Non-destructive testing - Ultrasonic testing - Description of the calibration block No. 2
- DIN EN ISO 16809, 2018-12: Non-destructive testing - Thickness measurement by ultrasonic. [Draft]
- DIN EN ISO 16810, 2014-07: Non-destructive testing - Ultrasonic testing - General principles.
- DIN EN ISO 16811, 2014-06: Non-destructive testing - Ultrasonic testing - Sensitivity and distance adjustment.
- DIN EN ISO 16823, 2014-07: Non-destructive testing - Ultrasonic testing - Transmission technique
- DIN EN ISO 16826, 2014-06: Non-destructive testing - Ultrasonic testing - Testing for inhomogeneities perpendicular to the surface.
- DIN EN ISO 16827, 2014-06: Non-destructive testing - Ultrasonic testing - Description and sizing of inhomogeneities.
- DIN EN ISO 16828:2014-06: Non-destructive testing - Ultrasonic testing - Diffraction time-of-flight technique, a technique for detecting and measuring inhomogeneities
- DIN EN ISO 16946:2017-07: Non-destructive testing - Ultrasonic testing - Description of the stepped wedge calibration block
- DIN EN ISO 18563: Non-destructive testing - Characterization and verification of ultrasonic testing equipment with phased arrays

DGZfP leaflets
- German Society for Non-Destructive Testing e.V. (in completion): Leaflet on ultrasonic methods for non-destructive testing in the building industry. revised version. Berlin: DGZfP, Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (DGZfP German Society for Non-Destructive Testing - Leaflets, B 04).

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Other/ Notes/ Remarks/ Comment

- Note on verifying the minimum concrete cover: DBV Code of Practice: **Concrete cover and reinforcement. Ensuring the concrete cover when designing, producing and installing reinforcement and concrete in accordance with Eurocode 2** (2015). Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets).

- Further literature references on **concrete cover**:
  - Brameshuber, Wolfgang; Schmidt, Hubert; Schröder, Petra; Fingerloos, Frank (2004): **Measurement of concrete cover - evaluation and acceptance**. In: Beton- und Stahlbetonbau 99 (3), pp. 169-175. DOI: 10.1002/best.200490112.
- Schmidt, Hubert: **Evaluation of right-skewed measurements. Approximation methods for parameter estimation of the Neville distribution**. In: zfv - Zeitschrift für Geodäsie, Geoinformation und Landmanagement, 2/2006 131. vol. p. 72-80.

2.12 Low-strain method / hammer blow method

As of 18.12.2019

Physical basis	Mechanically excited measuring principle
Procedure **Low-strain process/** **Hammer blow method** Low Strain Integrity Test/ Pile Integrity Test (PIT)	Test task - Surface inhomogeneities - Back panel

Brief description

Time of flight measurement after mechanical excitation of elastic waves on the pile head by a mechanical impulse (hammer blow) and the reflection caused by impedance jumps in the pile or the pile/subsoil interface.

Standard area of application (practical testing tasks)

- Integrity (intactness) of the pile
- Pile length: 5 to 20 m; pile length/diameter < 30:1

Application limits (technical, physical, economic)

- Damage just below the pile head is overlooked [1]
- small defects are not detected due to the long wavelengths [1]

Special applications (additional testing tasks)

On-site requirements

- Accessible pile head; alternative for inaccessible pile head: notching of the pile; further alternative: application of the sensor close to the pile shaft after prior uncovering [3].
- Removal of loose particles and cement-rich layers near the surface, spraying of the pile head surface if necessary [1,3].
- dry concrete surface, preferably ground at the coupling point of the sensor [1,3]
- Calibration of the shaft velocity v [1,3]
- Marginal information such as ground investigation, knowledge of pile construction methods and special incidents for pile production to assign the cause of the fault [1,3]

Procedure description

Long description

In the low-strain method, a sensor (geophone or piezo accelerometer) is attached to the pile head with plasticine, glue or similar. A hammer blow, the impact, on the pile head near the sensor causes a mechanical impulse that triggers an elastic wave. These waves are **strain waves**. This wave passes through the pile, is reflected at the base of the pile and recorded at the pile head with the aid of the sensor. The transit time determined in this way is then converted into the pile length using an equation. Impedance jumps in the pile, e.g. due to cross-sectional constrictions or bulges, cause reflections in addition to the base signal, which can be used to reconstruct this change in cross-section and determine the integrity of the pile.

If the reflection points in the same direction as the signal at the pile head, it is a constriction. If it points in the other direction, it is an increase in the cross-section. Accordingly, a distinction can be made in the footing signal as to whether the pile is embedded in normal soil or in rock. [1,3]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Quick assessment to distinguish between good piles and suspected cases
+/- large depth range but lower resolution of the process
- Length measurement method is subject to large scatter, as neither the actual pile length nor the shaft speed are known
- Method is not analytical: i.e. as a rule, no clear cause can be assigned to a signal (no clear differentiation between changes in cross-section, changes in concrete quality/raw density and the storage conditions of the subsoil)

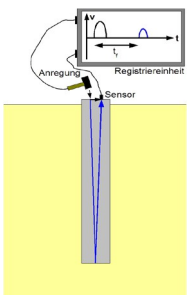
Measuring method

Measurement setup

Pile testing

A. Taffe, HTW Berlin

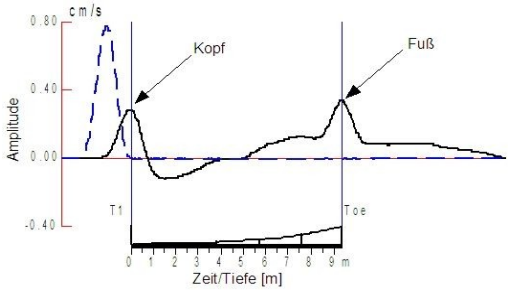
[2]



Measurement results

Result graphic: Pile test

A. Taffe, HTW Berlin [2]



- Hammer with steel or plastic cap [6]
- Piezo accelerometer/ acceleration sensor/ geophone [6]
- Computer control/measuring device for transit time measurement and recording of time signals (transit time curves) [6]

Measured variable and target variable

- Assumption: Speed of sound v in [m/s] for concrete piles v_{Dehn} = ~ 3500..4200 m/s (often as an estimate, as the actual length of piles or a reference pile is not known) [2]
- Measured variable: Running time t in [µs]
- Target values: Pile length/depth of an impedance discontinuity L in [m] and pile integrity (inference inv.) [2]
- Calculation of the target values: - L= v * t/ 2
  - v= 2 * L/ t

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system

3. Carrying out the audit (taking into account 2.):
- Prepare the pile head and attach the sensor to the pile head or to the side of the pile shaft with a force fit
- Hammer blow on pile head
- Measuring the runtime

4. Documentation
- Logging of the implementation
- Evaluation of the pile quality according to [5]
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	2/5	2/5	3/5

Further information

Device manufacturer, software

- Pile Dynamics Inc.: manufacturer of measurement technology, hardware and software for pile testing;
in Germany represented by GSP Gesellschaft für Schwingungsuntersuchungen und dynamische Prüfmethoden mbH

Related methods/ measurement variants

- Alternative to length measurement: parallel seismic method [3]

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Other/ Notes/ Remarks/ Comment

- Further information on piles can be found on the website of the **Deutsche Gesellschaft für Geotechnik e.v. DGGT in the** specialist section earthworks and foundation engineering in the working group AK 2.1.
[https://www.dggt.de/index.php?option=com_content&view=article&id=46&Itemid=59]

- Other names for the procedure are Sonic Echo / Impulse Response / Pulse Echo Testing

Physical basis	Magnetic measuring principle
Procedure **Magnetic DC field** Direct Current Field Measurement (DC)	Test task - Reinforcement (reinforced concrete)

Brief description

Non-destructive testing by magnetizing the electrically conductive reinforcement with an external permanent magnetic field using a permanent magnet = DC field magnetization.

Standard area of application (practical testing tasks)

- Locating ferromagnetic reinforcement close to the surface [5]
-Magnt. Attraction force: Statement of compliance with or shortfall of a specified concrete cover [5]
- Magnt. Flux leakage effect: Specification of the concrete cover and specification of the diameter if the concrete cover is known [5]

Application limits (technical, physical, economic)

- Mutual influence of neighboring reinforcing bars
- The pole strength of the magnets used must be sufficiently large to magnetize the reinforcement to the appropriate depth
- Magnt. Flux leakage effect: for the exact specification of the concrete cover, it is necessary to know the reinforcement diameter, which must be specified in the measuring device

Special applications (additional testing tasks)

On-site requirements

Procedure description

Long description

The magnetic methods are based on the physical principles of magnetizability and the electrical conductivity of the reinforcement. A distinction is made between two measurement principles in the magnetic DC field methods: magnetic attraction and magnetic flux leakage effect.
With the principle of **magnetic attraction,** the inspector guides a permanent magnet by hand over the concrete surface to magnetize the reinforcement and subjectively measures the force of attraction between the magnet and the reinforcement to locate the reinforcement. This method is hardly used today due to its subjectivity. With the principle of the **magnetic flux leakage effect,** the reinforcement is also magnetized with a permanent magnet, the magnetic field is scattered through the reinforcement and the measurement is carried out with a Hall probe.
However, only the location with the maximum display is recorded. For a quantitative statement on the concrete cover or the reinforcement diameter, comparative measurements must first be carried out on a calibration specimen with a known concrete cover and a known reinforcement diameter.

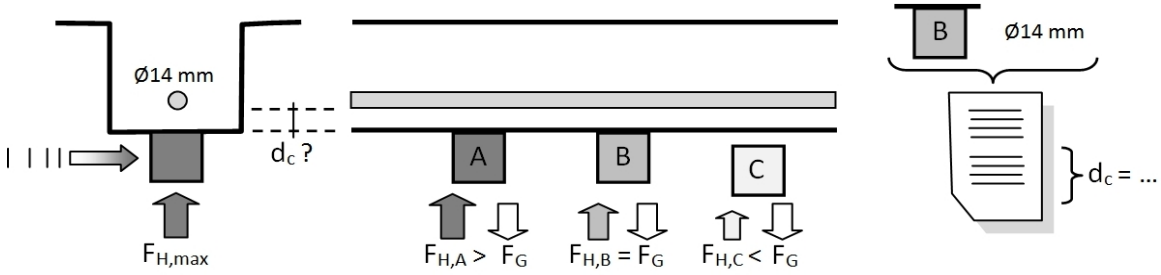
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ easy handling
+ In contrast to the alternating-field method, the chemical composition and the microstructure of the tested reinforcing steel only depend to a small extent on the chemical composition and the microstructure of the tested reinforcing steel
- No use of conventional magnetic methods for reinforcement made of carbon fibers or aramid [1]

Measuring method

Measurement setup

Magnetic DC field: Principle sketch
A. Taffe, HTW Berlin [5]



Measurement results

Measuring devices

- Magnt. Attraction force: Set of test magnets
- Magnt. Leakage flux: Permanent magnet/ Hall probe

Measured variable

- Magnt. Attraction: Magnetic attraction
- Magnt. Stray flux: Voltage change of a Hall probe

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system

3. Performance of the audit (taking into account 2.)

Procedure Magnetic attraction: [5]

1. Finding a bar position at the point of maximum perceptible force (subjective)
2. Try out magnets of different strengths A, B, C, …
3. Magnet B ("just sticks") + knowledge Ø -> calibration table
4. Concrete cover dc (or more)

Procedure Magnetic flux leakage effect:

Testing the surface with a permanent magnet and integrated Hall probe, which registers the change in the magnetic field and thus measures the concrete cover

4. Documentation
- Logging of the implementation
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	1/5	3/5

Further information

Device manufacturer, software

Related methods/ measurement variants

Bibliography I (technical literature)

[1] German Society for Non-Destructive Testing e.V. (2014): **Leaflet on non-destructive concrete cover measurement and reinforcement location on reinforced and prestressed concrete components**. revised edition April 2014. Berlin: DGZfP, Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (DGZfP German Society for Non-Destructive Testing - **Leaflets, B 02**).

[2] **Magnetic constant field**. Magnetic methods (2014). In: DBV leaflet: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Merkblätter), pp. 24-26.

[3] Flohrer, C. (2004): Method for measuring the concrete cover. In: Erich Cziesielski (ed.): **Bauphysik-Kalender 2004**. Berlin: Ernst & Sohn, pp. 370-371.

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Traffic safety, durability. Cologne: Rudolf Müller.

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Other/ Notes/ Remarks/ Comment

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- Further literature references on **concrete cover**:
  - Brameshuber, Wolfgang; Schmidt, Hubert; Schröder, Petra; Fingerloos, Frank (2004): **Measurement of concrete cover - evaluation and acceptance**. In: Beton- und Stahlbetonbau 99 (3), pp. 169-175. DOI: 10.1002/best.200490112.
- Schmidt, Hubert: **Evaluation of right skewed measured values. Approximation method for parameter estimation of the**
Neville distribution. In: zfv - Zeitschrift für Geodäsie, Geoinformation und Landmanagement, 2/2006 131. vol. p. 72-80.

144

Physical basis	Magnetic measuring principle
Procedure **Alternating magnetic field** Alternating Current Field Measurement (AC)	Test task - Reinforcement (reinforced concrete)

Brief description

Non-destructive testing by magnetizing the electrically conductive reinforcement by constantly reversing the polarity of an externally applied magnetic field using coils = alternating field magnetization. (Inductive method)

Standard area of application (practical testing tasks)

- Locating near-surface reinforcement
- Determination of the reinforcement diameter usually up to 28 mm diameter
- Determination of the concrete cover under normal boundary conditions between 60 - 70 mm cover with precise knowledge of the reinforcement diameter (accuracy +/- 1..2 mm)

Application limits (technical, physical, economic)

- Due to the shadowing effect, objects located deeper and behind another object are not detected
- Measurement result of the concrete cover depending on the set diameter of the reinforcing bar
- Non-standardized and older steels may have different magnetic permeability, which can influence the measurement; new and standardized steels have approximately constant permeability
- Mutual influence of neighboring reinforcing bars
- Alternating field flux leakage method: ferritic components in the concrete can strongly influence the measurement result or make it impossible
- Eddy current method: conductive components in the concrete can strongly influence the measurement result or make it impossible

Special applications (additional testing tasks)

On-site requirements

- Alternating field flux leakage method: Test object (reinforcing steel, prestressing steel) must be ferromagnetic
- Eddy current method: Test object (copper, stainless steel, reinforcing steel) must be conductive
- Precise knowledge of the reinforcement diameter for a concrete cover measurement with an accuracy of +/- 1..2 mm

Procedure description

Long description

The magnetic methods are based on the physical principles of magnetizability and the electrical conductivity of the reinforcement. [2] In the alternating magnetic field method, a distinction is made between the **ferromagnetic method** (alternating field flux leakage method, low frequency) and the **eddy current method** (high frequency) depending on the frequency:

In the **ferromagnetic method (AC field leakage test),** a low-frequency magnetic field of between 1 kHz and a few kilohertz is generated by a primary coil. If a ferromagnetic material, such as rebar, is present, the magnetic field is distorted. This distortion, which corresponds to a concentration of magnetic field lines, is detected and evaluated by a magnetic field sensor in the form of a secondary coil. The primary and secondary fields run in the same direction, which is why the magnetic field increases overall. Only ferromagnetic metals can be detected using the alternating field flux leakage method.

In the **eddy current test,** a high-frequency magnetic field with frequencies from around 10 kHz is generated by a primary coil. If electrically conductive metals are present in the area of this field, the magnetic field causes (induces) a closed current flow (eddy current, circular current). These eddy currents generate a secondary magnetic field that is directed in the opposite direction to the magnetic field of the coil. In contrast to the low-frequency magnetic field, the excited and induced quantities act against each other. This results in a weakening of the coil's magnetic field, which is measured as a change in the alternating current resistance (impedance). The eddy current method can also be used to detect conductive, non-ferromagnetic metals such as copper, brass and non-magnetic stainless steels. However, the concrete cover can only be measured accurately for steel bars.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ No surface preparation or post-treatment
+ contactless
+ independent of building moisture
+ very precise
- Magnetization state only includes areas close to the surface
- Mutual influence of neighboring bars
- No use of conventional magnetic methods for reinforcement made of carbon fibers or aramid [1]

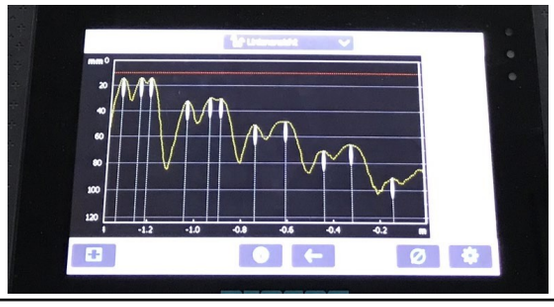
Measuring method

Measurement setup

Magnetic inductive measurement on concrete test specimens,
J. Wiese, HTW Berlin

Measurement results

Magnetic inductive measurement on concrete test specimens: evaluation,
J. Wiese, HTW Berlin



Measuring devices

- Measuring devices with and without recording of data along the measuring section with built-in
  - transmitting coil, which generates the primary field with applied AC voltage, and
  - Receiving coil that receives the sum of the voltages from the primary and secondary fields

Measured variable

- Voltage change due to inductance of the coil (Electrical parameters of the resulting magnetic field are determined depending on the test task: Position of the reinforcement, concrete cover or reinforcement diameter)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Device settings [5]:
  - Selection of measurement modes: Locating, line scan, multiple line scan, area scan, cross line scan
  - Presetting bar diameter
  - Neighboring rod correction if necessary
- Correct marking of the bar position:
  - Check the position of the measuring center point in the device
  - Recommendation: at least three measuring points to determine the bar axis

3. Performance of the audit (taking into account 2.)
- Traverse the test surface with the test device (perpendicular to the bar axis)
- Save the measurement data if necessary

4. Documentation
- Logging of the implementation
- Result: e.g. verification of the minimum concrete cover
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	2/5	3/5	4/5

Further information

Device manufacturer, software

- Hilti: Ferroscan PS200/250 (principle: ferromagnetic method) and PS35 (principle: eddy current method; no longer available online) [as of October 2018]
- Proceq: Profometer and Profoscope (eddy current principle) [as of October 2018]
- Würth: BDM 1 - also called: "Lithoscope" [as of December 2012]

Related methods/ measurement variants

- alternative procedure: Radiography/ radiographic examination

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- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN ISO 12718, 2018-07: Non-destructive testing - Eddy current testing - Terminology.

Personnel management, vocational training (03.100.30)

- Eddy current testing is one of the classic NDT methods and is m a r k e d with the abbreviation "ET". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out eddy current testing.

Non-destructive testing (ICS 19.100)

- DIN 54140-3, 1989-01: Non-destructive testing - Inductive methods - Representation and general characteristics of coil systems. *[Part 1 and 2 are withdrawn]*
- DIN EN ISO 15548-1:2014-03: Non-destructive testing - Technical equipment for eddy current testing - Part 1: Characteristics of test equipment and their verification
- DIN EN ISO 15548-2:2014-03: Non-destructive testing - Technical equipment for eddy current testing - Part 2: Characteristics of sensors and their verification
- DIN EN ISO 15548-3:2009-01: Non-destructive testing - Technical equipment for eddy current testing - Part 3: Characteristics of the system and their verification
- DIN EN ISO 15549, 2018-07: Non-destructive testing - Eddy current testing - General principles.
- DIN EN ISO 20339, 2017-08: Non-destructive testing - Technical equipment for eddy current testing - Characteristics of sensor arrays and their verification

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- DIN 1076, 1999-11: Engineering structures in the course of roads and paths - monitoring and testing.

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Other/ Notes/ Remarks/ Comment

- Note on verifying the minimum concrete cover: DBV Code of Practice: **Concrete cover and reinforcement. Ensuring the concrete cover when designing, producing and installing reinforcement and concrete in accordance with Eurocode 2** (2015). Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets).

Further literature references on **concrete cover**:

- Brameshuber, Wolfgang; Schmidt, Hubert; Schröder, Petra; Fingerloos, Frank (2004): **Measurement of concrete cover - evaluation and acceptance**. In: Beton- und Stahlbetonbau 99 (3), pp. 169-175. DOI: 10.1002/best.200490112.
- Schmidt, Hubert: **Evaluation of right-skewed measurements. Approximation methods for parameter estimation of the Neville distribution**. In: zfv - Zeitschrift für Geodäsie, Geoinformation und Landmanagement, 2/2006 131. vol. p. 72-80.

2.15 Remanence magnetism / magnetic stray field measurement

As of 18.12.2019

Physical basis	Magnetic measuring principle
Procedure **Magnetic stray field measurement (active)/ Remanence magnetism (passive)** Magnetic Leakage Field Method/ Remanent Magnetism	Test task - Tendons/ ducts - Prestressing steel fracture

Brief description

Non-destructive testing by measuring the magnetic stray field on the concrete surface caused by a prestressing wire break in the tendon using a magnetic field sensor after magnetization of the prestressing steel

Standard area of application (practical testing tasks)

- Detection of prestressing wire breaks in prestressed concrete with immediate and subsequent bonding
- Also detection of individual broken prestressing wires in a bundle of intact prestressing wires

Application limits (technical, physical, economic)

- Limits of the method depending on: bar spacing of the stirrup reinforcement and the proportion of broken wires

- No statement about the corrosion process that led to the breakage
- the tendon to be tested must not be located behind another tendon when viewed from the component surface to be tested
- Tendons made of a wire with a large cross-sectional area A > 50 mm², constant spacing of reinforced concrete reinforcement, fracture detection possible up to 30 cm concrete cover [2]
- Tendons made of several wires with a small cross-sectional area A = 20 mm², dense reinforced concrete reinforcement, fracture detection only possible up to a maximum of 10 cm concrete cover [2]

Special applications (additional testing tasks)

On-site requirements

- Accessibility to the concrete surface

Procedure description

Long description

In the remanent magnetism method, the tendons are magnetized in a defined manner from the concrete surface using electromagnets. When the electromagnet is removed, the magnetic field remains = remanent magnetism (remanent = remaining). The magnetized tendon then behaves like a bar magnet, i.e. the prestressing steel forms its own magnetic field with a magnetic north and south pole. This creates new dipoles at break points, as the north and south poles are then directly opposite each other. This creates a magnetic stray field, which can be measured with magnetic field probes on the concrete surface. A characteristic fracture signal can be recorded at the fracture point. The amplitude of this signal provides information about the degree of cross-sectional weakening.
Localization of the prestressing steel break and evaluation of the measurement results depending on: Concrete cover, cross-sectional area of the prestressing wires, number of wires in the tendon, number of broken wires in a cross-sectional area, bond between prestressing steel wires and the grout (breaking width), interference signals generated by ferromagnetic components such as reinforced concrete reinforcement and magnetic and magnetoelastic material properties of the prestressing steel type.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+/- only method for locating stress fractures
+ Prestressing steel and slack reinforcement can be differentiated in the signal evaluation
- Additional examinations with radar and ultrasound are usually necessary

2.15 Remanence magnetism / magnetic stray field measurement

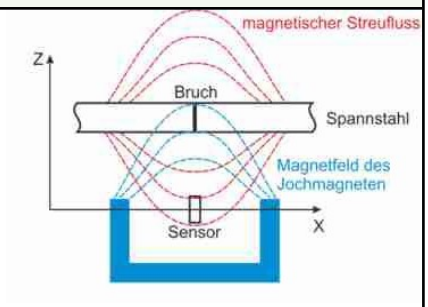
As of 18.12.2019

Measuring method

Measurement setup

Investigation of transverse tendons in the roadway slab [Ingenieure für Bauwesen - Prof. Hillemeier & Knapp GmbH, Berlin/DGZfP-VNB 89/28.08.17]

Measurement results



Typical break signals when measuring the axial or transverse component of the magnetic field strength
[Materials Testing Institute, University of Stuttgart/DGZfP-VNB 88/28.08.17]

Measuring devices

- Magnetizing unit (yoke magnet) [4]
- Magnetic field sensor (Hall probe or squids) [4]
- Power connection
- for large-area measurements of transverse tendons: self-propelled magnetic carriage with sensor unit [4]

Measured variable

- Measured variables:
  - Distance in [cm]
  - Transverse component of the magnetic flux density in [-]
- Target variable: Identification of a characteristic break signal of the transverse component/ peak-peak amplitude A_{PP} or break signal increase (BSA) [2]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Measuring the course of the tendon (e.g. using the radar method)

3. Performance of the test (taking into account 2.) [4]
- Magnetization of the tendon from the concrete surface
- Displacement-dependent measurement of the magnetic flux density at the component surface along the tendon
- Continuation of magnetization and measuring process until a sufficient number of different magnetic states of the tendon and its surroundings are available for a statement on prestressing wire breaks

4. Documentation
- Logging of the implementation
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	2/5	4/5	5/5

2.15 Remanence magnetism / magnetic stray field measurement

As of 18.12.2019

Further information

Device manufacturer, software

- MobiRem measuring units (developed at the TU Berlin) for large-area measurements
[Link: https://zerstoerungsfreie-pruefungen.de/messtechnik.html]

Related methods/ measurement variants

The following alternatives to remanence magnetism are given in [8]:
- Gradual magnetization of the prestressing steel [9]
- Measurement in the active magnetic field [10]

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e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Merkblätter), p. 29-31.
[2] Scheel, H.; Hillemeier, B. (2004): Remanence magnetism method for locating prestressing steel fractures. In: Erich Cziesielski (ed.): **Bauphysik-Kalender 2004**. Berlin: Ernst & Sohn, pp. 365-370.
[3] Walther, Andrei; Hasenstab, Andreas (2012): Non-destructive testing methods for the determination of material parameters in reinforced and prestressed concrete construction. In: Nabil A. Fouad (ed.): **Bauphysik-Kalender 2012**, vol. 18. Weinheim, Germany: Ernst & Sohn, pp. 157-202.
[4] Taffe, Alexander (2015): **Non-destructive testing methods in construction**. In: Martin Mertens (ed.): Handbook of structural testing. Condition testing of existing structures: stability, traffic safety, durability. Cologne: Rudolf Müller, pp. 271-274.
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Other/ Notes/ Remarks/ Comment

If prestressing steels at risk of stress corrosion cracking cannot be ruled out, then [7] must be observed. Prestressing steels classified as particularly at risk according to the guideline "Recommendation for the inspection and assessment of bridge structures built with quenched and tempered prestressing steel St 145/160 Neptun N40 up to 1965" issued by the BMV in 1993 and further supplements in 2012:

- Tempered prestressing steel St 145/160 Neptun N40 up to 1965
- Sigma oval prestressing steels produced until 1978
- tempered prestressing steels from the Hennigsdorf plant.

Physical basis	Electromagnetic measuring principle
Procedure **Radar** RAdio Detection And Ranging	Test task - Moisture distribution - Back panel, - Reinforcement - Tendons

Brief description

Non-destructive testing by transit time measurement after generation of electromagnetic pulses in the test head and their propagation according to the laws of elastic waves in the component.
[One-sided measurement on the component with transmitter and receiver = reflection arrangement]

Standard area of application (practical testing tasks)

- Fast and reliable detection of near-surface reinforcement up to the second reinforcement layer [1]
- Detection of metal cladding pipes, even behind reinforcement [1]
- Determination of the structure of several layers [1]
- Detection of objects and defects (differentiation between metallic reflectors, air or water-filled plastic pipes and larger air pockets) [1]
- Qualitative determination of the moisture distribution via calibration [1]

Application limits (technical, physical, economic)

- high concrete moisture (in young concrete) results in lower penetration depths
- No visibility behind steel/ densely reinforced components with bar spacing < 7 cm (due to total reflection on steel)
- Stop steel plate for better back panel information
- No information on grouting status in cladding pipes
- No clear detection of air layers that are only a few cm thick
- Detection range of radar waves in reinforced and unreinforced concrete: 1 to 4 m [1]

Special applications (additional testing tasks)

- Locating objects through targeted shadowing or direct reflection (shifting or absence of signals provide indications of objects)
- Tendons behind the second reinforcement layer that do not run parallel to the reinforcement near the surface at greater depths can be detected
- Adjustment of the polarization direction of the antennas to suppress near-surface reinforcement [4]
- Alternative to concrete cover measurement > 7 cm, but with lower accuracy [5]

Radar in transmission arrangement with transmitter and receiver on opposite sides of the object to be tested is used for special measurements such as the determination of material-related wave velocities.
- *Differentiation between corroded and non-corroded near-surface reinforcement (published in USA)*

On-site requirements

- Component surface must be dry
- There must be no metallic fabrics in the seal
- Material and corresponding propagation speed must be known
- Calibration of the running time on a component of known thickness

Procedure description

Long description

The RADAR method generates and transmits electromagnetic pulses.
"Wave propagation in the component depends on the distribution of dielectric properties. On its path, the wave is scattered and reflected at interfaces of materials with different dielectric properties." [1]
The wave is completely reflected on metallic objects, a total reflection takes place. Reflections also occur at the boundary surfaces between air (defect or rear wall) and concrete. The difference between the concrete/air and concrete/metal boundary layers becomes visible through different wave deflections/phase jumps of the singal.
RADAR is primarily used in the reflection arrangement, i.e. both the transmitter and receiver are located in one measuring unit. The measurements are triggered automatically by a measuring wheel at a close distance of a few millimeters or time-controlled. At each measuring point, the amplitude of the received reflections is plotted over time (A-scan), the measurement of many points one after the other along a line is called a radargram (B-scan), the two-dimensional measurement is called a time slice (C-scan).
Data processing of the results with a SAFT reconstruction by migration achieves a better imaging representation of the results.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Better distinguishability of neighboring rebars compared to magnetic inductive methods
- No information behind densely laid reinforcement compared to ultrasound
+/- with ultrasound, the material and corresponding propagation speed must be known, whereas with magnetic induction methods, the reinforcement diameter must be known

Measuring method

Measurement setup

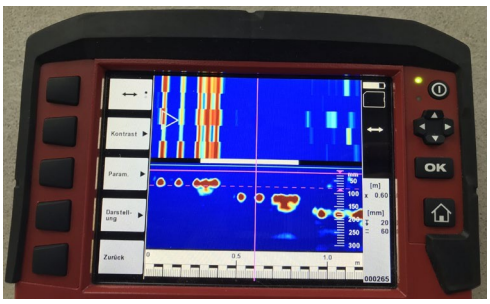
Radar on concrete test specimen

J. Wiese, HTW Berlin

Measurement results

Radar on concrete test specimens: evaluation

J. Wiese, HTW Berlin



Measuring devices

Radar measuring device with antenna frequency:

- f_{Radar} > 1 to 2.5 GHz from 7.5 to 30 cm detection depth for good resolution (higher frequency = lower penetration depth, higher resolution)
- f_{Radar} < 1 GHz up to 50 cm detection depth with lower resolution (low frequency = higher penetration depth, lower resolution)
- If necessary, auxiliary construction for guiding the radar unit
- If necessary, software for digital data processing and evaluation

Measured variable and target variable

- Measured variable: Running time in [ns]
- Target size: component thickness in [cm]
- d= v x t/2, v= Λ x f, R= (v2-v1)/ (v2+v1)
- v_{Luft} = 30 cm/ns, vconcrete, dry= 11-17 cm/ns, vconcrete, wet= 8 to 11 cm/ns
- Reflection coefficients: R= + 0.5 boundary layer concrete/air, R= -0.5 boundary layer concrete/water, R= -1 boundary layer concrete/steel (total reflection)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. **Information on the test task**
   - Definition of the test task and objective of the test
   - Inspection of test specifications/recommendations (standards, data sheets)
   - Information on the test object (ambient conditions, application limits, on-site requirements)
   - Procurement of information, if necessary by reviewing old and existing documents
2. **Test planning**
   - Definition of the test areas and a test system
   - Determination of the frequency with regard to penetration depth and resolution
   - Determination of the measuring direction with regard to the objects to be detected
3. **Performance of the test (taking into account 2.): Radar**
   - Measurement by scanning the surface with the radar tester
   - Plausibility check on site
4. **Documentation**
   - Logging of the implementation
   - Evaluation of the measurement results: Data reconstruction (migration/ SAFT)
   - Evaluation of the results in a test report
5. **Further information**
   - If necessary, further combinations of procedures with ultrasound, thermography, etc. [1]

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	1/5	3/5	3/5

Further information

Device manufacturer, software

Hilti: PS 1000 X-Scan system [Link: https://www.hilti.de/c/CLS_MEA_TOOL_INSERT_7127/CLS_CONCRETE_SCANNERS_7127/r6436760?itemCode=2154110]

Related methods/ measurement variants

Radar in transmission arrangement with transmitter and receiver on opposite sides of the object to be tested is used for special measurements such as the determination of material-related wave velocities.

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[1] German Society for Non-Destructive Testing e.V. (2008): **Leaflet on the radar method for non-destructive testing in construction. Leaflet B 10**. February 2008, revised version. Berlin: DGZfP, Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (DGZfP German Society for Non-Destructive Testing - Leaflets, B 10).

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[4] Diersch, Norman; Kind, Thomas; Taffe, Alexander; Kurz, Jochen (2014): **Investigation of prestressed bridge slabs under traffic with non-destructive testing methods**. In: Concrete and reinforced concrete construction 109 (7), pp. 444-452. DOI: 10.1002/best.201400010.

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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

- **International standards:**
  - ASTM D6087 - 97e1, 2008: Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar.
  - ASTM D4748 - 98, 2010: Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar.
  - ASTM D6429, 1999: Guide for Selecting Surface Geophysical Methods.
  - ASTM D6432 - 11, 2011: Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation.

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Other/ Notes/ Remarks/ Comment

- **International events on the radar process:**
- International Conference on Ground Penetrating Radar (GPR) since 1986 (2018: 17th International Conference on Ground Penetrating Radar)

- Note on verifying the minimum concrete cover: DBV Code of Practice: **Concrete cover and reinforcement. Ensuring the concrete cover when designing, producing and installing reinforcement and concrete in accordance with Eurocode 2** (2015). Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets).

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Physical basis	Electromagnetic measuring principle
Procedure **Active/instantaneous Thermography** Active/ Transient Thermography	Test task - Inhomogeneities - Moisture distribution - Delaminations

Brief description

Non-destructive testing through imaging detection of inhomogeneities in the near-surface area of a component through a deliberately variable heat flow and local temperature differences in the component. - Surface process

Standard area of application (practical testing tasks)

- Locating and determining the position of irregularities and concealed building structures such as cavities, defects, cracks, inclusions and layer detachments near the surface (up to 10 cm deep)
- Locating compaction defects (on reinforced concrete beams)

Application limits (technical, physical, economic)

- Detection criterion: Ratio of defect size to defect depth > 1 [10]
- Testing under ambient conditions such as rain, high humidity and strong winds as well as surface properties such as roughness, moisture and contamination can falsify the test result
- Complex geometries with strong inhomogeneity make testing more difficult

Special applications (additional testing tasks)

- Grouting defects in cladding tubes [10]
- Detection of cracks in tendons with electrical resistance heating [1]
- Selective heating of reinforcing bars with induction excitation (induction thermography)
- Large-scale application on industrial floors [11]

On-site requirements

- Accessibility of the component surface for the heating process
- dry and windless environment

Procedure description

Long description

In thermography, a distinction is made between active and passive thermography.
Passive thermography is used in building physics and uses the building's own heat for thermographic measurements to locate cold or thermal bridges.
In active thermography, on the other hand, the object is specifically heated using appropriate thermal excitation techniques. This creates an artificially generated, temporally and/or spatially variable heat flow (transient heat transfer due to heating or cooling processes), which generates a temperature gradient to the surface and/or environment. The temperature gradient is caused by the fact that "in the case of external heating, the heat accumulates in front of defects in the component if the defects have a lower heat penetration coefficient b [also: effusivity] than the surrounding material". [10] These targeted heating or subsequent cooling processes are analyzed thermographically.
Active thermography is differentiated according to the temporal excitation in: [10]
- Lock-in thermography (LT): Excitation by continuous sinusoidal signals of a defined frequency (periodic thermal oscillations) and evaluation by measuring the time delay (phase) and the amplitude of the response signal for the corresponding frequency (not practical for the construction industry because the recording time lasts around 24 hours)
- Impulse thermography (IT): Excitation by a thermal impulse with a large number of different frequencies and evaluation in the time domain via the temperature difference
- Pulse phase thermography (PPT): a further development of pulse thermography, excitation as in IT by a thermal pulse, evaluation by thermogram series in order to record the phase delay of the local heat propagation in the image by means of a Fourier transformation

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ completely non-destructive and contact-free
+ Introduction of transient and active methods in building thermography makes the old restriction to the heating season and simultaneously cool climate zones superfluous
+ Thermograms obtained by PPT provide a very good signal-to-noise ratio and thus a higher detection sensitivity of the defect geometry and better depth resolution than IT
- the deeper the objects are located, the longer the warm-up and observation times (up to 1 hour), resulting in thermal stress on the object being examined

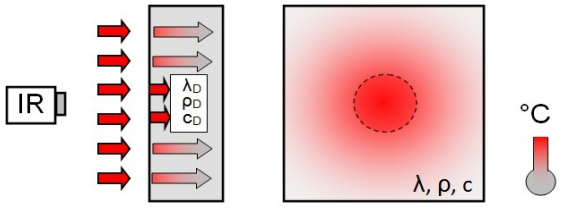
Measuring method

Measurement setup

Active thermography on concrete test specimens
J. Wiese, HTW Berlin

Measurement results

Active thermography: Scheme
A. Taffe, HTW Berlin [7]



- Infrared camera (IR camera) with accessories such as memory card and tripod
- Computer for digital recording
- Temperature and humidity meter
- Power connection and cable drum if necessary
- Thermal excitation source:
  - Heat radiation (solar radiation, infrared radiators, halogen lamps, flash lamps)
  - Convection (fan heater, heat gun, building dryer, blower door)
  - Heat conduction (heating mats, cooling pads)
  - Electromagnetic induction/ electric current

Measured variable and target variable

- Temperature-time curve: Course of the temperature T in [°C] over the time t in [s]
- Temperature contrasts in the recorded thermograms as a qualitative evaluation
- Evaluation of temperature-time curves/transients as quantitative information

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Selection of the test system: Determination of the thermal excitation source and a suitable IR camera
- Definition of the test areas, the test system and the positioning of the test system
- Definition of the required accuracy of the results (the more complex PPT for very subtle signals or high result quality; the less complex IT for normal cases)
- Determination of the type of temporal excitation (pulse duration) and spatial excitation

3. Performance of the test (taking into account 2.): Thermographic test
- Recording the thermograms

4. Evaluation and documentation
- Logging of the implementation and description of the environmental conditions
- Acquisition of a sequence of thermograms
- Evaluation of complete thermal sequences, individual thermograms or transients
- Evaluation of the results in a test report

5. Further information

Process effort (from 1: low effort to 5: high effort)

Technology	Time	Costs	Specialist knowledge
3/5	2/5	4/5	5/5

Further information

Device manufacturer, software

- InfraTec GmbH [https://www.infratec.de/thermografie/anwendungsgebiete/aktive-thermografie/]
- edevis GmbH [https://www.edevis.com/content/de/active_thermography.php]

Related methods/ measurement variants

- Induction thermography: Heating the rebars to locate the rebars

Bibliography I (technical literature)

[1] German Society for Non-Destructive Testing (2013): **Leaflet on the active thermography method for non-destructive testing in the construction industry**. Leaflet B 05. April 2013 edition. Berlin: DGZfP.
[2] **Infrared thermography**. Electrical and electromagnetic methods (2014). In: **DBV leaflet**: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Merkblätter), pp. 21-23.
[3] German Society for Non-Destructive Testing e.V. (2014): **Leaflet on non-destructive concrete cover measurement and reinforcement location on reinforced and prestressed concrete components**. revised edition April 2014. Berlin: DGZfP, Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (DGZfP German Society for Non-Destructive Testing - Leaflets, B 02).
[4] Dittiè, Georg (23. and 2006): Lecture 10 - **Thermography in tunnel structures**. In: Symposium Building Diagnosis - Practical Applications of Non-Destructive Testing. Berlin: DGZfP, Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V (DGZfP German Society for Non-Destructive Testing - Report Volumes, 100).
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[6] Dittiè, Georg (2016): Lecture 17 - **New applications of active building thermography**. In: Symposium Building Diagnosis - Practical Applications of Non-Destructive Testing and Future Tasks. Berlin: DGZfP, German Society for Non-Destructive Testing (DGZfP Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V - Berichtsbände, 157-Stick).
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[10] Arndt, Ralf; Hillemeier, Bernd; Maierhofer, Christiane; Rieck, Carsten; Röllig, Mathias; Scheel, Horst; Walther, Andrei (2004): **Non-destructive localization of defects and inhomogeneities in building components with impulse thermography**. In: Bautechnik 81 (10), pp. 786-793. DOI: 10.1002/bate.200490185.
[11] Hillemeier, B.; Walther, Andrei: **Poster 49 - Impulse thermography for the localization of voids in screeds**. In: DGZfP Annual Conference 2007, pp. 1-2. Available online at https://www.ndt.net/article/dgzfp07/Inhalt/p49.pdf.
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- ASTM D4788, 2013: **Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography**.

Bibliography II (regulations: standards, guidelines, information sheets)

Terminology (ICS 01.040.19)

- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Personnel management, vocational training (03.100.30)

- Infrared thermography testing is one of the classic NDT methods and is marked with the abbreviation "TT".

According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel***, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out infrared thermography testing.

Non-destructive testing (ICS 19.100)
- DIN EN 16714-1, 2016-11: Non-destructive testing - Thermographic testing - Part 1: General principles.
- DIN EN 16714-2, 2016-11: Non-destructive testing - Thermographic testing - Part 2: Equipment.
- DIN EN 16714-3, 2016-11: Non-destructive testing - Thermographic testing - Part 3: Definitions
- DIN EN 17119, 2018-10: Non-destructive testing - Thermographic testing - Active thermography.
- DIN 54183, 2018-02: Non-destructive testing - Thermographic testing - Inductively excited thermography.
- DIN 54184, 2017-10: Non-destructive testing - Pulse thermography with optical excitation.
- DIN 54185, 2018-10: Non-destructive testing - Thermographic testing - Lock-in thermography with optical Suggestion [draft]

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- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Physical basis	Electromagnetic measuring principle
Procedure **Radiographic testing / radiography** Radiographic Testing/ Radiography	Test task - Inhomogeneities - Reinforcement (reinforced concrete) - Tendons

Brief description

Non-destructive testing to determine the internal structure of the component to be tested by different attenuation (absorption) of ionizing primary radiation due to differences in density, thickness and material in the component. - Volume method

Standard area of application (practical testing tasks)

- Locating the position of the reinforcement, the course of tendons and the grouting condition of ducts [6]
- Determination of reinforcement diameter and detection of reinforcement with cross-section losses [6]
- Detection of defects and compaction deficiencies in concrete [6]
- Use on components with high stability relevance that require a detailed representation of the investigation area [4]

Application limits (technical, physical, economic)

- X-ray tube up to component thickness d < 30 cm (exposure time approx. 30 min.) [6]
- Gamma emitters with radionuclides iridium up to d < 40 cm or cobalt up to d < 60 cm (exposure time approx. 5 min.) [6]
- Betatron or linear accelerator up to component thickness d < 100 cm (exposure time < 1 min.) [6]
- Grouting condition of cladding pipes up to approx. 20 cm concrete thickness [6]
- Removal of the floor structure when verifying support reinforcement with large component thickness [6]

Special applications (additional testing tasks)

- Determination of the depth of reinforcement (by at least 2 exposures with different irradiation directions) [1]
- Measurement of the internal structure (by taking images from several angles using multi-angle technology or laminography) [1]
- Verification of grouting errors with a thickness < 60 cm [1]
- *Detection of corrosion on small samples (more as a scientific application)*

On-site requirements

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Accessibility on both sides of the component to be examined
- Dangerous goods regulations required for transportation of radionuclides
- Closing off the test area

Procedure description

Long description

In radiographic testing, a radiation source, X-ray tube or radioactive radiation source in the gamma range, is set up on one side of the component to be tested in accordance with the component thickness to be tested. The outgoing ionizing radiation is attenuated differently due to differences in density, thickness and material. The inner structure of the component is shown in an imaging image in various shades of gray. Concrete is generally shown in black due to its lower density, while the reinforcement is shown in shades of gray due to its higher density and greater absorption.
On the opposite side of the component, this attenuated primary radiation is detected and recorded using X-ray films, imaging plates, fluoroscopes, image intensifiers or flat panel detectors. [2]

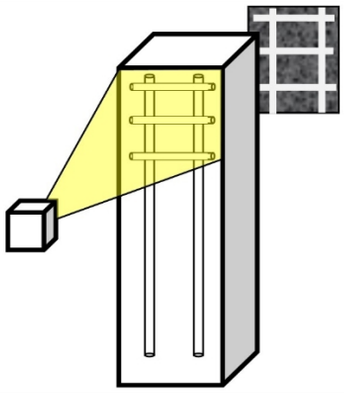
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ non-contact and completely non-destructive
+ most accurate results even with close-meshed and multi-layer reinforcement arrangement [6]
+ Detection of improperly installed reinforcement [6]
- Traffic restriction during the test due to radiation protection
- Transportation of dangerous goods

Measuring method

Measurement setup

Radiography: Principle sketch
A. Taffe, HTW Berlin
[3]



Measuring devices

- Radiation source (as a function of component thickness): [2,6]
  - X-ray tube
  - Gamma emitters with the radionuclides iridium or cobalt
  - Betatron or linear accelerator
- Image acquisition system: X-ray film, imaging plate, fluoroscope, image intensifier, flat panel detector [2]
- Control unit for regulating the voltage and current for the radiation intensity and energy [6]
- Power connection

Measured variable and target variable

- Reconstruction and visualization of the different radiation intensities in imaging form
- Specified feature(s): e.g. cracks, internal defects
  - qualitative: detected or not detected
  - Quantitative: e.g. dimensions and location of a damaged area, etc.

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning [1, DGZfP B02]
- Choice of radiation energy and radiation source as well as imaging technology (e.g. X-ray film, digital imaging plates)
- Determination of the test areas and a test system: Recording arrangement
- Determining the exposure time
- Determination of the area to be cordoned off on the basis of the Radiation Protection Ordinance

3. Performance of the test (taking into account 2.): Radiographic testing
- Analog film technology: film processing (developing, intermediate rinsing, fixing, final rinsing, wetting agent balance, drying)
- Attaching the image quality test

4. Evaluation and documentation
- Logging of the implementation
- If necessary, image processing of the scanned radiographic films with the aid of special image processing systems improves the informative value
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	3/5	5/5	5/5

Further information

Device manufacturer, software

- Yxlon International GmbH: Evo series [https://www.yxlon-portables.com/products]
- X-RAY WorX GmbH [https://www.x-ray-worx.com/x-ray-worx/index.php]
- Graetz Strahlungsmeßtechnik GmbH: Measuring devices for personal radiation protection, e.g. ED150 [http://www.graetz.com/produkte.html]

Related methods/ measurement variants

- alternative procedures:
  - magnetic inductive processes (alternating magnetic field) or
  - Radar (electromagnetic method)
- Coplanar translational laminography [2]
- Neutron computed tomography [7]

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[1] **Radiographic testing (RT)** (2018). In: German Society for Non-Destructive Testing e.V. (ed.): BC 3 M1 Basic Course Level 3. Module 1. Basic knowledge. Documents for teaching.
[2] **Radiography (radiographic testing)**. Electrical and electromagnetic methods (2014). In: **DBV leaflet**: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV)(DBV Deutscher Beton- und Bautechnik-Verein E. V. - Merkblätter), pp. 23-24.
[3] Taffe, Alexander (2015): **Non-destructive testing methods in construction**. In: Martin Mertens (ed.): Handbook of structural testing. Condition testing of existing structures: stability, traffic safety, durability. Cologne: Rudolf Müller, pp. 255-280.
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[6] Kapphahn, G. (2005): **Comparison of different NDT methods for reinforcement location**. In: 3rd Symposium "Experimental investigations of building structures". Dresden, pp. 1-11.
[7] Bergmeister, Konrad; Santa, Ulrich (2004): **Bridge inspection and monitoring. Non-destructive testing methods for structural elements**. In: Konrad Bergmeister and Johann Dietrich Wörner (eds.): Beton-Kalender. Bridges - Parking garages. Volume 1. 1 of 2. Berlin, Munich, Düsseldorf: Ernst & Sohn (93), pp. 428-433.

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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN 1330-3, 1997-10: Non-destructive testing - Terminology - Part 3: Terms used in industrial radiographic testing.

Personnel management, vocational training (03.100.30)

- Radiographic testing is one of the classic NDT methods and is marked with the abbreviation "RT". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out radiographic testing.

Non-destructive testing (ICS 19.100)

- DIN EN 14784-1, 2005-11: Non-destructive testing - Industrial computed radiography with phosphor imaging plates - Part 1: Classification of systems. [Part 2: Withdrawn]
- DIN EN 16016-01, 2011-12: Non-destructive testing - Radiographic methods - Computed tomography - Part 1: Terminology
- DIN EN 16016-2, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 2: Principles, equipment and specimens
- DIN EN 16016-03, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 3: Execution and evaluation
- DIN EN 16016-04, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 4: Qualification
- DIN EN 13068-1, 2000-02: Non-destructive testing - Radioscopic testing - Part 1: Quantitative measurement of imaging properties

- DIN EN 1306 8-2,2000-02: Non-destructive testing - Radioscopic testing - Part 2: Long-term stability testing of imaging systems

- EN 13068-3, 2001-12: Non-destructive testing - Radioscopic testing - Part 3: General principles for radioscopic testing of metallic materials using X-rays and gamma rays
- DIN EN 25580, Non-destructive testing - Viewing devices for industrial radiography - Minimum requirements
- DIN EN ISO 15708-1, Non-destructive testing - Radiographic methods - Computed tomography - Part 1: Terminology [draft]
- DIN EN ISO 15708-2, Non-destructive testing - Radiographic methods - Computed tomography - Part 2: Principles, equipment and specimens
- DIN EN ISO 15708-3, Non-destructive testing - Radiographic methods - Computed tomography - Part 3: Execution and evaluation
- DIN EN ISO 15708-4, Non-destructive testing - Radiographic methods - Computed tomography - Part 4: Qualification
- DIN EN ISO 10675-1, 2017-04: Non-destructive testing of welded joints - Acceptance limits for radiographic testing - Part 1: Steel, nickel, titanium and their alloys. [Part 2: Aluminum]
- DIN EN ISO 19232-1, Non-destructive testing - Image quality of radiographic images - Part 1: Image quality test pieces (wire web) - Determination of the image quality index
- DIN EN ISO 19232-2, Non-destructive testing - Image quality of radiographic images - Part 2: Image quality test pieces (step/hole type) - Determination of the image quality index
- DIN EN ISO 19232-4, Non-destructive testing - Image quality of radiographic images - Part 4: Experimental determination of image quality indices and image quality tables
- DIN EN ISO 20769-1, 2018-12: Non-destructive testing - Radiographic testing for corrosion and deposits in pipes using X-rays and gamma rays - Part 1: Tangential radiographic testing.
- DIN EN ISO 20769-2, 2018-12: Non-destructive testing - Radiographic testing for corrosion and deposits in pipes using X-rays and gamma rays - Part 2: Double-wall radiographic testing.

X-ray films (37.040.25)
- DIN EN ISO 11699-1, Non-destructive testing - Industrial films for radiographic testing - Part 1: Classification of film systems for industrial radiographic testing [Replacement for DIN EN 584-1:1994-10]
- DIN EN ISO 11699-2, Non-destructive testing - Industrial films for radiographic testing - Part 2: Control of film processing using reference values
- DIN EN 14096-1, 2003-08: Non-destructive testing - Qualification of X-ray film digitizing systems Part 1: Definitions; quantitative measurement of image quality parameters; standard reference film and quality assurance
- DIN EN 14096-2,2003-08: Non-destructive testing - Qualification of X-ray film digitizing systems - Part 2: Minimum requirements

DGZfP leaflets
- DGZfP - B02, 2014: Code of practice for non-destructive concrete cover measurement and reinforcement location on reinforced and prestressed concrete components.

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Protection of and in buildings in general (ICS 91.120.01)
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Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Guidelines for the implementation of federal construction tasks p. 1 13

Other/ Notes/ Remarks/ Comment

Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)

2.19 X-Ray Diffraction - XDF / X-ray diffraction

As of 18.12.2019

Physical basis	Electromagnetic measuring principle
Procedure **X-ray diffraction** X-Ray Diffraction XRD	Test task - Composition of building materials: Chemical element analysis

Brief description

Non-destructive testing for the fine structure examination of crystals in mineral building materials using the diffraction of X-rays.

Standard area of application (practical testing tasks)

- Standard laboratory analysis for the identification and localization of mineral crystalline phases (such as ettringite and thaumasite, which lead to floating phenomena in the concrete matrix) [1].

Application limits (technical, physical, economic)

- Ettringite and thaumasite form solid solutions, which makes sufficient identification by X-ray diffraction alone difficult (due to the unmanageable combination of compounds and superimposed X-ray reflections) and requires an optimally adjusted measuring system [1]

Special applications (additional testing tasks)

On-site requirements

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Material sample of the component to be tested is necessary

Procedure description

Long description

In X-ray diffractometry, a material sample is examined using monochromatic X-rays. "The radiation is scattered by the three-dimensionally regularly arranged atoms of a crystalline solid, so that the elementary waves emanating from each atom are superimposed in defined directions to form constructive interference. The resulting diffracted waves can be interpreted in simplified terms as reflections at 'net planes' within the crystal. [...] This "network plane distance d" is decisive for the path difference [...] of the interfering X-rays. Only if the path difference is a multiple of the wavelength of the X-rays used will there be constitutive interference and thus diffracted radiation. [...] The diffraction angles of an X-ray diagram can then be used to identify the crystalline phases present." [1]

Procedure advantages and disadvantages (compared to procedures for the same test task)

- only partially non-destructive through sampling
- Laboratory method

2.19 X-Ray Diffraction - XDF / X-ray diffraction

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- X-ray diffractometer consisting of:
  - X-ray tube
  - Goniometer
  - Detector
  - Automatic sample changer if necessary
- Power connection for X-ray diffractometer

Measured variable and target variable

- Representation of the mineral phases in an X-ray diffractogram [2]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Compliance with radiation protection regulations
- Determination of a representative sampling point

3. Performance of the audit (taking into account 2.)
- Sampling by drilling (drilling dust) or directly from visible efflorescence [2]
- Sample preparation: producing the geometry required for the measuring device
- Preparation of the test: Aligning and focusing the X-ray beam on the sample
- Carrying out the analysis: Irradiation of the sample

4. Documentation
- Logging of the implementation
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	5/5	4/5	4/5

166

Further information

Device manufacturer, software

- Malvern Panalytical GmbH: Aeris Cement Edition
[https://www.malvernpanalytical.com/de/products/product- range/aeris-range/aeris-cement-edition/]

Related methods/ measurement variants

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[2] Platts, Thomas (2012): **Moisture diagnostics in buildings**. In: Nabil A. Fouad (ed.): Bauphysik-Kalender 2012. Weinheim, Germany: Ernst & Sohn, pp. 401-418.

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Other/ Notes/ Remarks/ Comment

The "X-ray diffractometry" method is not listed as a method in the literature sources known for NDT construction, such as the DBV or DGZfP leaflets. The method is also not mentioned in other standard works such as the Handbook of Structural Testing.

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)

Physical basis	Electromagnetic measuring principle
Procedure **Neutron backscatter method with Neutron probe/ Isotope probe/ Troxler probe** Nuclear Gauge/ Troxler Gauge	Test task - Moisture distribution: Moisture content

Brief description

Non-destructive testing for moisture determination for the qualitative assessment of the moisture content of a component by emitting fast neutrons, which are slowed down by hydrogen nuclei, and measuring the slow neutrons, which represent a measure of the water content of the medium [Indirect moisture measurement method: Radiometric method]

Standard area of application (practical testing tasks)

- Moisture content in the building material [3]
- Standard application in foundation engineering for determining the moisture content in soils [3]

Application limits (technical, physical, economic)

-penetration depth is approx. 20 - 30 cm [1,2]
- embedded salts, reinforcement bars or other conductive materials do not influence the measurement [1,2]

Special applications (additional testing tasks)

- Use of gamma rays for density measurements (also for locating cavities and compaction defects)
- Calibration of the measurement procedure using the Darr method is possible, taking into account the properties of the neutron probe[2].

On-site requirements

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Dangerous goods regulations required for transportation of the neutron probe
- Creation of calibration curves [2]

Procedure description

Long description

"In the neutron backscatter method for determining the moisture content of building materials [or components], fast neutrons, i.e. neutrons with high kinetic energy, are irradiated into the building material. These neutrons interact with the atoms of the building material. This results in scattering, diffusion and, above all, deceleration of the fast neutrons, with hydrogen nuclei decelerating the fast neutrons most effectively. [...] This means that the energy loss experienced by a neutron in a collision with a hydrogen atom is also the greatest. [...]
So if a moist material is irradiated with fast neutrons, the intensity of the resulting slow neutron reflection allows conclusions to be drawn about the quantity of hydrogen atoms present and therefore the moisture content of the component. [...] The hydrogen content of the components in the measurement volume is measured. As a result, the neutron backscatter method also measures the chemically bound water in addition to the free and physically bound water. When calibrating the measuring device, the basic level resulting from the hydrogen content of the dry building material must therefore be taken into account. [...]
The decay of radioactive substances, which is necessary for the generation of the radiation used, does not take place continuously. Multiple measurements and averaging are therefore required for neutron moisture measurement." [2]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ large penetration depth / large measuring volume for actual moisture statements about the component [2]
- large measuring volume as an integral value over the pore volume, therefore no spatial resolution [2]
+ Possibility of long-term monitoring of drying or humidification processes [2]
+ independent of the electrical conductivity of the building material [2]
- Procedure is associated with great effort (radiation protection determination) -> use only in special cases [2]

2.20 Neutron probe

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- Neutron probe/isotope probe/ Troxler probe with radiation source (neutron or gamma emitter) and integrated counter tube

Measured variable and target variable

- Measured variable: number of slow neutrons generated per time
- Target value: Volume moisture u_V , the hydrogen content of the components in the measured volume (is evaluated fully automatically in the device)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Compliance with radiation protection regulations
- Organization of a hazardous goods transporter if necessary

3. Performance of the audit (taking into account 2.)
- Systematic scanning with the probe

4. Documentation
- Logging of the implementation
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	5/5	5/5	3/5

Further information

Device manufacturer, software

- Troxler Electronic Laboratories, Inc.: RoadReader 3450 Thin-layer & Full Depth Density

Related methods/ measurement variants

- Nuclear magnetic resonance/ NMR method: NMR-MOUSE® - Nuclear Magnetic Resonance Mobile Universal Surface Explorer (developed at the Institute of Technical and Macromolecular Chemistry at RWTH Aachen University) [5,6]

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[7] ASTM D6938 - 17a **Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)**

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- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Moisture measurement methods are divided into direct and indirect methods:

The direct methods provide a quantitative value of the moisture content; they do not require any further calibration measurements, but are carried out in a way that destroys the building material. The indirect methods only provide qualitative values of the moisture content or the moisture distribution without further calibration measurements; however, they can be carried out non-destructively. According to [1], the direct and indirect methods can be further subdivided:

170

2.20 Neutron probe

Direct procedures	Indirect procedures
- Darr weighing method - Calcium carbide method CM	1 Electrical process - Resistance method/ geoelectrics - Capacitive processes: - Pulse radar - Microwave process - Microwave drilling process - Time Domain Reflectometry TDR) 2 Radiometric methods - **Neutron backscattering** - Nuclear magnetic resonance NMR 3 Thermal methods - Infrared thermography 4 Hygrometric methods - Equalizing humidity probe

2.21 Potential field measurement

Physical basis	Electrochemical measuring principle
Procedure **Potential field measurement/ potential measurement** Potential Mapping	Test task - Corrosive areas

Brief description

Non-destructive testing by spatially resolved (voltage) measurement of the potential difference between a reference electrode placed on the concrete surface (with a defined reference potential) and the reinforcement cage of the concrete via an exposed connection point (damage-free reinforcement) and subsequent evaluation of the Voltage gradients between neighboring measuring points.

Standard area of application (practical testing tasks)

- Localization of areas with an increased probability of corrosion (corrosion-active areas) in the case of **chloride-induced** reinforcement corrosion (pitting corrosion) **as a snapshot of the corrosion activity** at the time of measurement

Application limits (technical, physical, economic)

- No conclusions on corrosion rate and corrosion-related cross-section loss
- Not suitable for prestressing wire fractures (maximum detection of areas of increased corrosion probability of the metallic cladding tube possible)
- No detection of damage without an ongoing corrosion process (e.g. dormant corrosion activity or corroded reinforcement)
- Do not use with electrolytically insulating coatings (e.g. bitumen or plastic) on the concrete surface or the reinforcement

Special applications (additional testing tasks)

- For measurements with a concrete cover > 10 cm and/or measurements on the component surface facing away from the reinforcement side, test measurements with subsequent verification of the results are necessary (maximum effect depth: approx. 20 cm, in individual cases possibly more)
- Indirect information about the humidity distribution, because humidity influences the potential values

On-site requirements

- Exposure of at least one contact point to the reinforcement/use of an existing earthing with secured penetrations.
- Removal of non-conductive coatings / seals
- If necessary, moisten the concrete surface to improve the electrolytic conductivity of the concrete (advantageous: through on-site water connection)

Procedure description

Long description

The potential field measurement is carried out between a reference electrode with a fixed, known potential as a variable reference point for the measurements and a direct connection to the electrically conductive reinforcement with an unknown potential at the reference point. An arbitrary grid of measurement points (potential field) is recorded by moving the reference electrode. The potential values recorded on the concrete surface with a high-impedance voltmeter allow conclusions to be drawn about the corrosion activity of the reinforcement. Strong local changes in the potential (gradients), so-called potential funnels, in a negative or positive direction over a measuring distance of 10 - 50 cm provide indications of active reinforcement corrosion. Further investigations such as the determination of chloride profiles, concrete cover measurements and the creation of exploratory openings are essential for evaluating the measurement results. The measurement is evaluated by a specialist with knowledge of the electrochemical processes involved in reinforcement corrosion in concrete.

Procedure advantages and disadvantages (compared to procedures for the same test task)

- Many influencing parameters (chloride content, concrete cover, moisture content, cement type, cracks, coatings and concrete temperature) affect the measurement
- to evaluate the measurement results, additional tests such as drill dust analysis, concrete cover and probing of the reinforcement are required

2.21 Potential field measurement

172

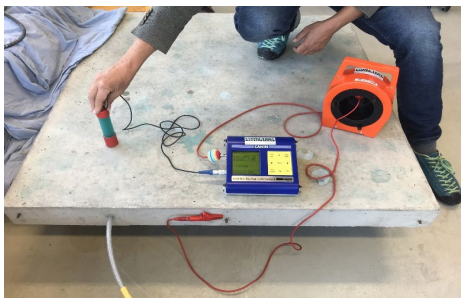
2.21 Potential field measurement

As of 18.12.2019

Measuring method

Measurement setup

Potential field measurement on concrete test specimens
J. Wiese, HTW Berlin



Measurement results

Potential field measurement on concrete test specimens: evaluation
S. Vonk/ J. Wiese, HTW Berlin

Measuring devices

- Reference electrodes made of metal/metal ion electrodes (usually: copper/copper sulphate electrode, possibly also mercury/mercury chloride electrode, silver/silver chloride electrode) as
  - Point and rod electrodes for individual measurements or
  - (Multi-) wheel electrode systems for area or linear measurements
- High-resistance voltmeter or manufacturer-specific device as well as cable and pliers

Measured variable and target variable

- Negative potentials in [- mV] (usually between - 100 and - 600 mV) with correct potential connection (negative pole of the voltmeter on the reinforcement)
- Corrosion-active areas usually become visible through location-dependent potential gradients / potential funnels, in which the potential is 200 to 400mV more negative than in the surrounding areas

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning [1]
- Definition of the test areas and a test system
- Determination of measuring grid: 25 x 25 cm useful for flat components
- Measuring field division: Measuring field size up to several hundred square meters, simple geometric shape, clearly define measuring field origin and measuring direction on the building
- Preparing the concrete surface: cleaning and, if necessary, evenly moistening the concrete surface

3. Performance of the test (taking into account 2.) [1]
- Preparation of the measuring system and the reference electrode: Calibration of the reference electrodes and functional test of the entire measuring system
- Contacting the reinforcement: spot exposure of the reinforcement in at least two places and measurement of the electrical resistance to verify through-contacting of the reinforcement

4. Documentation [1]
- Logging of the implementation
- Influences and sources of error: Concrete cover, moisture content of concrete, layers with high electrical resistance (e.g. repair mortar), exposed reinforcement and installation parts as well as deeper cracks can cause the potentials to shift into the positive/negative range
- Evaluation of the results in a test report

5. Further information
- Note: Liquid from the reference electrode sometimes leaks out and leaves stains on the concrete surface. For protection, a moistened cotton cloth can be used as an electrolyte bridge.

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	5/5

Further information

Device manufacturer, software

- Proceq: Profometer Corrosion (as a direct successor to Canin+) [2]

Related methods/ measurement variants

- Differential potential field measurement: Direct measurement of the voltage difference between several electrodes placed externally on the concrete surface or the measuring points [6]
- Galvanostatic pulse measurement/ polarization measurement: Measurement of the potential change after application of a brief anodic direct current pulse via a counter electrode at a measuring point; active corrosion can be inferred if the potential change is small; verification test for the classic Potential field measurement [7], [8]

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2.21 Potential field measurement

174

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Other/ Notes/ Remarks/ Comment

2.22 Indicator method: Phenolphthalein

As of 18.12.2019

Physical basis	Chemical measuring principle

Procedure	Test task
Indicator method: Phenolphthalein test Indicator Method: Phenolphthalein Test	- Carbonation: Depth of carbonation

Brief description

Non-destructive testing by point-by-point determination of the carbonation depth near the surface of the hardened concrete to assess the corrosion protection for reinforcement near the surface
(useful: in combination with the concrete cover measurement test task)

Standard area of application (practical testing tasks)

- Determination of the carbonation depth at the place of use, in the laboratory on test specimens or on drill core samples taken from the hardened concrete or fresh fragments (to assess whether the concrete in the area of the reinforcing steel has sufficient alkalinity to ensure the protective passive layer that forms on the reinforcing steel at a high pH value)

Application limits (technical, physical, economic)

- Testing only on freshly produced fracture surfaces
- Test not suitable for concretes made from alumina cement
- no differentiation between alkalinity loss due to carbonation and
loss due to other causes, such as exposure to acid or acidic gases [DIN EN 14630: 2006-10].

- Test not suitable for use on casing surface in borehole (non-carbonated cement is distributed in the borehole and may simulate an alkaline surface in the borehole) [1].

Special applications (additional testing tasks)

On-site requirements

- Produce freshly created fracture surfaces in flat surfaces by drilling two adjacent holes and then removing the web between them
- Observance of occupational health and safety

Procedure description

Long description

The phenolphthalein test is a simple method for determining the carbonation depth of hardened concrete and consists of detecting the change in pH value using a suitable indicator solution. This is an alcoholic phenolphthalein solution whose color changes from colorless to red-violet within 30 seconds of spraying in the pH > 9 range. The non-carbonated area turns red-violet, the non-carbonated area remains unchanged. Only concrete with a coloration therefore shows the basic, non-carbonated areas, which have sufficient alkalinity to ensure the passivity of the steel. The carbonation depth dk is determined as the distance between the colour change limit and the respective concrete surface. The carbonation depth is irregular, which is why both the mean value and the maximum value of the carbonation depth must be measured perpendicular to the concrete surface.
It should be noted that the aggregate must also remain neutral or uncolored. [DIN EN 14630: 2006-10]

Procedure advantages and disadvantages (compared to procedures for the same test task)

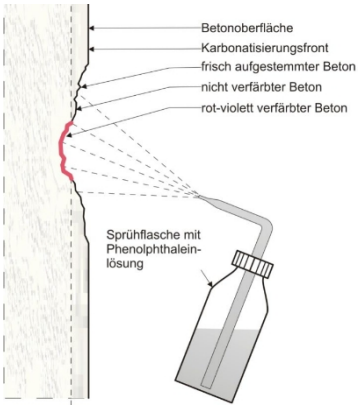
- Creation of fracture surfaces, therefore only limited damage resistance
- Harmful to health: phenolphthalein is carcinogenic, so special care must be taken when handling the chemical

176

Measuring method

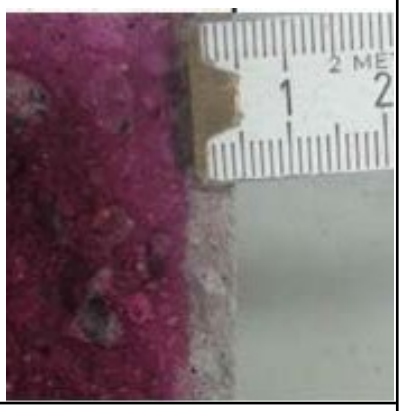
Measurement setup

Indicator method:
Phenolphthalein,
Schaurich, BAM



Measurement results

Carbonation depth
A. Taffe, HTW Berlin



Measuring equipment (measuring devices and test equipment)

Testing devices according to [DIN EN 14630: 2006-10]:
- Phenolphthalein indicator solution, usually 1 g phenolphthalein
- Ethyl alcohol, 70 ml (or other suitable alcohols, such as isopropyl alcohol)
- Distilled or deionized water, diluted to 30 ml
- labeled container with a nozzle for spraying the indicator solution (must not drip)
- Measuring device for determining the distance from the surface of the concrete to the carbonation limit, e.g. gauge or ruler with millimetre graduation

Measured variable and target variable

- Distance from the surface of the concrete to the carbonation limit in [mm]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system: Creation of a sampling plan

3. Performance of the test (taking into account 2.) [DIN EN 14630: 2006-10].
- Sampling:
  - Labeling of fragments/drill core samples
  - Dry storage until testing
- Determination of the carbonation depth:
  - Creating the test surface: breaking up the drill cores/ fragments along the longitudinal axis/ perpendicular to the concrete surface
  - Removal of dust and loose particles
  - Apply the indicator solution by wetting: Test immediately after breaking open the test pieces
- Measurement of the carbonation depth (recording of the result within 30 s)

4. documentation
- Logging of the implementation
- no colour change = carbonated area; colour change = non-carbonated area
- Assessment of the carbonation depth depending on: Concrete age, concrete composition, curing and storage climate
- Assessment of the carbonation limit, taking into account: dense and porous aggregates and pores
- Evaluation of the results in a test report

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	1/5	1/5	2/5

Further information

Device manufacturer, software

Related methods/ measurement variants

- Use of the alternative indicator: thymolphthalein (according to DAfStb booklet 422)
- LASER-induced plasma spectroscopy LIPS in special cases for the detection of increased carbon content in carbonated concrete

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Other/ Notes/ Remarks/ Comments

2.23 Salt analysis method

As of 18.12.2019

Physical basis	Chemical measuring principle

Procedure	Test task
Salt analysis method	- Composition of building materials: Element content - Salts harmful to buildings: Salt content

Brief description

Non-destructive testing to determine the presence and type of building-damaging salts using qualitative salt analysis and subsequent determination of the distribution and quantity of salts (salt concentration) using semi-quantitative or quantitative salt analysis.

Standard area of application (practical testing tasks)

- Detection of water-soluble salts such as chloride, nitrate, carbonate, sulphate (anions)

[Salts are composed of anions and cations; detection of cations (iron, lead, calcium, magnesium, potassium, copper) is generally irrelevant because they are harmless to building materials].

Application limits (technical, physical, economic)

Special applications (additional testing tasks)

On-site requirements

- Accessibility of the component surface for suitable extraction devices (core drill, drill dust extraction device)
- Taking a representative sample
- Qualified personnel for laboratory analyses: Work in the chemical laboratory requires great care and caution as well as specialist knowledge

Procedure description

Long description

Differentiation between qualitative salt analysis, semi-quantitative salt analysis and quantitative salt analysis.
Qualitative salt analysis only provides a statement as to whether salts are present; a distinction is made between dry-chemical and wet-chemical analysis methods. The dry chemical methods are suitable as a preliminary test for simple detection. The wet-chemical methods provide complete proof with their tests.
[Qualitative salt analysis] *"is based on the detection of chlorides by spraying silver nitrate and potassium chromate solution as indicators. In the spray test, a weak nitric acid silver nitrate solution pH = 5 is sprayed onto the fracture surface. After drying, the surface is sprayed with potassium chromate solution. If no chlorides are present, the concrete turns brown. On concrete containing chlorides, on the other hand, water-insoluble silver chloride is formed."* [1]
The **semi-quantitative salt analysis** can be carried out as a test in the laboratory or on site with a test strip on a sample piece and then serves as a basis for further tests such as sampling for the laboratory, decision on further samples, number of samples and locations of the samples; sampling on the surface of the object by scraping or brushing.
[To determine the chloride content, *"weakly concentrated nitric acid is poured over a fragment from the surface and sodium bicarbonate is added to the suspension. After filtering off the suspension, a test strip is immersed and a scale value is read. The chloride content results from the conversion of the scale value on the calibration table of the test strip pack."* [1]
Quantitative salt analysis is used to precisely determine the chloride content and the chloride penetration depth with depth-graded analyses of drill mud samples. Quantitative salt analysis can be carried out using gravimetry/weight analysis or volumetry (titration)/measurement analysis as well as photometry.
[In the photometric determination of the chloride content] *"the drilling dust is mixed with cold digestion solution and the solution is filtered. [...] The subsequent determination of the cement content is carried out in accordance with DIN 52170."* [1]

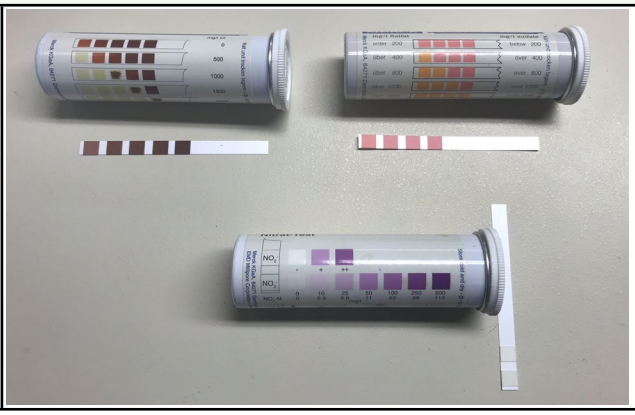
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ qualitative salt analysis: no destructive sampling
+/- semi-quantitative salt analysis: salt content in group classification, commercially available for purchase
- Quantitative salt analysis: destructive sampling, but exact salt content
- Determination of only one chemical element at a time in one analysis run on the same specimen (i.e. sample must be split)
- Quantitative methods are time-consuming due to the complex digestion of the sample and the use of equipment

Measuring method

Measurement setup

Test strips:
chloride test (top left),
sulphate test (top right),
nitrate test (bottom)
J. Wiese, HTW Berlin



Measuring equipment (measuring devices and test equipment)

- chemical solution or test strips
- Core drill, drill dust extractor for sampling

Measured variable and target variable

- Salt content as mass fraction of the sample in percent [M- %]
- Conversion to M-% related to cement, if necessary
- Chloride profile

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system: Creation of a sampling plan

3. Performance of the audit (taking into account 2.)
- Sampling on site - either taking drill dust (depth-graded) or taking drill core samples
- Carrying out the chemical analysis in the laboratory according to [4]

4. Documentation
- Logging of the implementation
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	4/5	4/5	4/5

Further information

Device manufacturer, software

Semi-quantitative salt analysis:
- Macherey-Nagel GmbH & Co. KG: QUANTOFIX test sticks [http://www.mn-net.com/tabid/4770/Default.aspx]
- Hach: QuanTab Test Strips [https://de.hach.com/quick.search-quick.search.jsa?keywords=quantab]

Related methods/ measurement variants

- alternative laboratory methods:
  - Energy Dispersive X-Ray Spectroscopy EDS/ Energy Dispersive X-Ray Spectroscopy EDX
  - X-ray diffraction/ X-ray diffraction XRD
- alternative laboratory and construction site method:
  - LASER-induced plasma spectroscopy LIPS/ LACER-Induced Breakdown Spectroscopy LIBS
  - X-ray fluorescence analysis XRF/ X-ray fluorescence spectroscopy XRF

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- DIN EN 14629:2007-06: Products and systems for the protection and repair of concrete structures - Test methods - Determination of chloride content in hardened concrete; German version EN 14629:2007

Cement. Gypsum. Lime. Mörel (ICS 91.100.10)
- DIN EN 196-2:2013-10: Test methods for cement - Part 2: Chemical analysis of cement; German version EN 196-2:2013 - Chapter 4: Wet chemical analysis

Mineral materials and products (ICS 91.100.15)
- DIN EN 1744-1:2013-03: Test methods for chemical properties of aggregates - Part 1: Chemical analysis; German version EN 1744 1:2009+A1:2012

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Other/ Notes/ Remarks/ Comments

2.24 Laser-induced plasma spectroscopy - LIPS

As of 18.12.2019

Physical basis	Chemical measuring principle

Procedure	Test task
LASER-induced plasma spectroscopy LIPS [LASER: Light Amplification by Stimulated Emission of Radiation] LASER-Induced Breakdown Spectroscopy LIBS	- Building material composition: Element content - Salts harmful to buildings: Salt content

Brief description

Non-destructive testing to determine the element distribution by exciting the component surface with a short, high-energy laser pulse, which leads to vaporization (laser ablation) and ionization (plasma generation) of the component surface.
surface; the emitted radiation is analyzed using optical spectroscopy. *(Atomic absorption spectroscopy method)*

Standard area of application (practical testing tasks)

- Detection of certain elements in concrete
- Determination of cement type (classification in the three-substance diagram: calcium, silicon and aluminum)
- Spot determination of chloride content or sulphate content and representation in a penetration profile
- Depth profiles of the element distribution for penetration behavior of salts harmful to the building: Drill core extraction and crevices in radial direction
- Determination of the carbonation depth

Application limits (technical, physical, economic)

- Determination of concrete composition: Strong scattering of the individual results due to heterogeneity of the concrete. Appropriate evaluation algorithms are therefore required to differentiate between concrete and aggregate.
- no statements about the bonding state of the elements, e.g. no differentiation between sulphates and sulphites [1]
- Use only in the near-surface area; core sampling is necessary for depth profiles
- Detection of the elements from hydrogen (Z=1) to uranium (Z=92) [1], [10]
- Detection limit of the main components and trace elements of the sample in the ppm range [1]
- Error in the range of 2-10 % [1]

Special applications (additional testing tasks)

- Detection of chlorides in crack tips [2]
- Proof of the application of hydrophobizing agents on the surface of components [1]
- Detection of contamination, e.g. by lead [1]
- Immediate determination of sufficient concrete removal during repair using portable LIBS [10]

On-site requirements

- either optically accessible examination surface with portable device in situ or sampling of the component to be examined for the laboratory [10]
- suitable set of reference samples with known element contents to calibrate the method for quantitative Measurement (indication of element contents in [M-%])

Procedure description

Long description

In laser-induced plasma spectroscopy or breakdown spectroscopy, the component surface to be examined is irradiated by a short (a few ns) and high-energy (a few mJ) laser pulse, which excites the atoms to be examined. The intensity of the exciting radiation is so high that the surface is heated, vaporized (laser ablation) and ionized (breaking up of molecular bonds = plasma generation = "breakdown"). The plasma emits characteristic fluorescence radiation (plasma emission), which is transmitted via fiber optic cables to a detection unit, e.g. grating spectrometer in Czerny-Turner configuration or Echelle spectrometer with CCD or ICCD lines or area sensors. The sample is analyzed by means of optical spectroscopy, the representation of the different spectral lines of the individual elements in a spectrum. The analysis only provides conclusions about the elements contained in the sample: The position of the spectral lines contains information about the detected element; the intensity of the line is a measure of the content of the element in the vaporized material. Quantitative information in [M.-%] is only possible using calibration curves of reference material. [6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ with portable device, only optical accessibility to the surface to be examined must be guaranteed
+ No sample change due to on-site application
+ in the laboratory: no further sample preparation is carried out when the sample is available
+ Results immediately available (measurement and evaluation within a few minutes) [10]
+ No danger to operators due to design and no environmentally hazardous chemicals
+ Chloride content: spot determination better than mean value of wet chemical analysis of drilling mud
- Drill core extraction and its splitting required when creating a depth profile

182

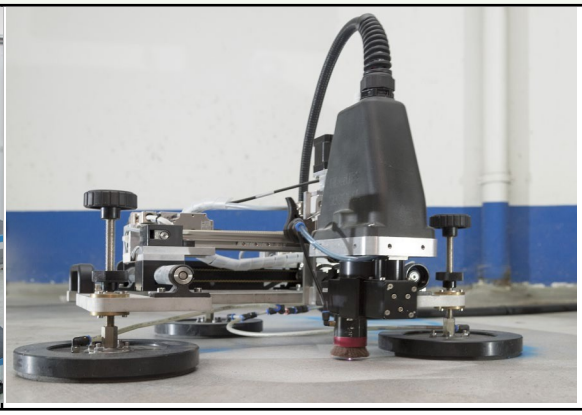
2.24 Laser-induced plasma spectroscopy - LIPS

As of 18.12.2019

Measuring method

Measurement setup

LIBS laboratory device (left),
Portable LIBS in use (right)
© T. Günther, BAM



Measuring equipment (measuring devices and test equipment)

- Laboratory: - Laser (usually ND:YAG laser) with optics for focusing the radiation (excitation in the spectrum range of infrared radiation) [1]
- Detection unit: usually echelle spectrometer with optics to detect the radiation and fiber optic cable with filter to transmit the radiation to the computer [1].
- Computer as control unit for measurement data acquisition and evaluation
- Specimen holder for testing in the laboratory and sliding device for moving the specimen
- Power connection for laboratory equipment

Measured variable and target variable

- Emission spectrum with wavelengths in [nm] in the ultraviolet radiation range and intensity in [w.e.].
- Representation of the overall spectrum with spectral lines of the various elements in a diagram: wavelength on x-axis; intensity on y-axis

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system: Creation of a sampling plan
- Suitable algorithm for distinguishing the measuring points in aggregate and cement paste (for data in [M.-%/cement])
- Suitable reference samples for calibrating the measurement with qualitative specification of the element proportions in [M.-%].

3. Performance of the audit (taking into account 2.)
- Sampling from the component to be tested
- Sample preparation: producing the geometry required for the measuring device
- Preparation of the test: Aligning and focusing the laser on the sample
- Measurement procedure: Laser bombardment and movement of the sample

4. Documentation
- Logging of the implementation
- Evaluation of the spectra
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	2/5	5/5	5/5

Further information

Device manufacturer, software

- SECOPTA analytics GmbH [https://www.secopta.de/]

Related methods/ measurement variants

LASER-induced plasma spectroscopy (= excitation with a laser beam, emission of characteristic fluorescence radiation from the detached plasma) works according to a similar physical principle to that of the laser:
- X-ray fluorescence analysis = excitation with X-rays, emission of characteristic X-rays
- X-ray analysis = excitation with electron beam, emission of characteristic X-rays

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184

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Other/ Notes/ Remarks/ Comments

Physical basis: Chemical measuring principle

Procedure

X-ray fluorescence analysis XRF/ X-ray fluorescence spectroscopy RFS

X-Ray Fluorescence Spectroscopy XRF

Test task

- Building material composition: Element content
- Salts harmful to buildings: Salt content

Brief description

Non-destructive testing to determine the elements by exciting a sample with primary X-rays from an X-ray tube, whereby the sample itself emits secondary, fluorescent X-rays, the spectrum of which is examined in an X-ray spectrometer. *(X-ray emission spectroscopy)*

Standard area of application (practical testing tasks)

-Identification of the chemical elements contained in a substance and for determining their quantity or for determining the thickness of layers" [DIN 51418-1:2008-08].
- Detection of certain elements in concrete
- Depth profiles of the element distribution: Drill core extraction and gaps in radial direction

Application limits (technical, physical, economic)

- Use only in the near-surface area; core sampling is necessary for depth profiles
- Detection of elements lighter than boron (atomic number Z=5) not possible [DIN 51418-2:2015-03] ; detection with reliable analysis values from fluorine (Z = 9) [DIN 51418-1:2008-08], good values from sodium (Z=11) , possible up to uranium (Z=92)

Special applications (additional testing tasks)

On-site requirements

- either optically accessible examination surface with portable device (handheld spectrometer) in situ or sampling of the component to be examined for the laboratory
- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Sample must have at least one flat surface from which the X-rays can be reflected (if necessary, press sample tablets)

Procedure description

Long description

X-ray fluorescence is based on the photoelectric effect. A material sample is excited by polychromatic X-rays. In the process, electrons close to the nucleus are lifted from the inner shells of the atom to those further out. This allows electrons from higher energy levels further away from the nucleus to fall back and fill the empty space near the nucleus in the atom. The energy released in this process is emitted in the form of element-specific, characteristic X-ray fluorescence radiation (fluorescence = spontaneous emission of light shortly after excitation of a material by electronic transitions). The spectrum of this fluorescence radiation can be analyzed by a radiation detector. The measured signal of this specific energy indicates the atomic number Z of the detected elements.
A distinction is made between two different types with regard to evaluation:
- Energy dispersive X-ray fluorescence analysis EDXRF/ Energy Dispersive XRF - EDXRF:
"Spectrometer in which the decomposition of the sample radiation according to its energy is carried out by the detector by electronic means" [DIN 51418-1:2008-08].
- Wavelength dispersive X-ray fluorescence analysis (WDXRF): "X-ray spectrometer in which the dispersion of the sample radiation is achieved by diffraction at a crystal" [DIN 51418-1:2008-08].

The energy dispersive measurement can be carried out with a handheld spectrometer, which enables in situ analysis. [DIN 51418-2:2015-03]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ with portable device, only optical accessibility to the surface to be examined must be guaranteed
+ No sample change due to on-site application
- Laboratory: Preparing the sample for the analyzer, such as creating the necessary geometry and a flat measuring surface [DIN 51418-2:2015-03]
+ Results immediately available (approx. 1 minute pure measuring time)
+ No danger to operators due to design and no environmentally hazardous chemicals
+ Low interference (occurrence and overlapping of fluorescence lines of different elements are rare, lines can b e clearly assigned)
+ Determination of several chemical elements in one analysis step on the same specimen (in contrast to wet chemical analysis)
- Detection of elements only from atomic number Z=5 (boron); in contrast, with LIBS detection from Z=1 (hydrogen)
- Drill core extraction and its splitting required when creating a depth profile

Measuring method

Measurement setup

XRF laboratory device
T. Schwarze, HTW Berlin/
KIWA Berlin

Measuring equipment (measuring devices and test equipment)

- Laboratory: **X-ray fluorescence spectrometer** consisting of:
  - Primary radiation source: X-ray tube (old. radioactive nuclides, synchrotron radiation source)
  - Detection unit
  - Sample to be analyzed (prepared if necessary)
  - Power connection for laboratory equipment
- In situ: **Handheld spectrometer** (handheld spectrometer)

Measured variable and target variable

- EDRFA: Energy in [keV] and intensity in [w.E.], measurement of all energies in energy-proportional voltage pulses
-WDRFA: Wavelength in [nm] and intensity in [w.e.], splitting the radiation into wavelengths
- Representation of the overall spectrum with spectral lines of the various elements in a diagram: energy or wavelength on x-axis; intensity on y-axis

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)

2. Test planning
- Determination of the test areas (or sampling point for laboratory tests)
- Compliance with radiation protection regulations

3. Performance of the audit (taking into account 2.)

- Insitu:
  - Attaching the handheld spectrometer and automatic measurement within seconds
- Laboratory:
  - Sampling from the component to be tested
  - Sample preparation: Creating the geometry required for the measuring device and creating a flat measuring surface
  - Preparation of the test: Aligning and focusing the X-ray beam on the sample
  - Carrying out the analysis: bombardment and sample procedure

4. Documentation and evaluation
- Evaluation of the spectra
- Output of the identified metals and their quantity
- Documentation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	4/5	5/5	5/5

Further information

Device manufacturer, software

- Helmut Fischer GmbH [Link: http://www.helmut-fischer.de/fileadmin/documents/broc/DE/BROC_X-RAY_Product_line_951-008_en.pdf]
- Spectro Analytical Instruments GmbH [https://www.spectro.de/produkte/rfa-spektrometer]

Related methods/ measurement variants

- X-ray fluorescence analysis (= excitation with X-rays, emission of characteristic X-rays) works according to a similar physical principle to that of the X-ray fluorescence:
  - X-ray analysis = excitation with electron beam, emission of characteristic X-rays
  - *LASER-induced plasma spectroscopy = excitation with a laser beam, emission of characteristic fluorescence radiation from the detached plasma*
- Special applications: Micro-XRF, total internal reflection XRF [11]

Overview of atomic spectrometric methods [2]

1. Atomic absorption spectrometry AAS
2. Atomic emission spectrometry AES differentiated according to the type of excitation in:
   - Flame Atomic Emission Spectrometry (F-AES)
   - Optical emission spectrometry with inductively coupled plasma (ICP-OES)
3. X-ray fluorescence spectrometry XRF/XRFS (X-ray fluorescence spectroscopy)

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Physicochemical analysis methods. Instrumental analysis (ICS 71.040.50)

- DIN 51418-1:2008-08 - X-ray spectral analysis - X-ray emission and X-ray fluorescence analysis (XRF) - Part 1: General concepts and principles
- DIN 51418-2:2015-03 - X-ray spectral analysis - X-ray emission and X-ray fluorescence analysis (XRF) - Part 2: Definitions and principles of measurement, calibration and evaluation
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Oxide (ICS 71.060.20)

- DIN 51001:2003-08 - Testing of oxidic raw materials and materials - General principles of X-ray fluorescence analysis (XRF)
- DIN 51001 Supplement 1:2010-05 - Testing of oxidic raw materials and materials - General working principles for X-ray fluorescence analysis (XRF) - Overview of material group-related digestion methods for the preparation of samples for XRF

Ceramic raw materials (ICS 81.060.10)

- DIN 51081:2002-12 - Testing of oxidic raw materials and materials - Determination of mass change during annealing

Cement. Gypsum. lime. Mortar. (ICS 91.100.10)
- DIN EN 196-2:2013-10: Test methods for cement - Part 2: Chemical analysis of cement; German version EN 196-2:2013
- Chapter 5: Chemical X-ray fluorescence analysis
- ISO 29581-2:2010-03 - Cement - Test methods - Part 2: Chemical analysis by the X-ray fluorescence method

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Other/ Notes/ Remarks/ Comments

2.26 Energy dispersive X-ray analysis - EDA

As of 18.12.2019

Physical basis	Chemical measuring principle

Procedure	Test task
Energy dispersive X-ray spectroscopy EDS/ Energy dispersive X-ray analysis EDA Energy Dispersive X-Ray Spectroscopy EDX	- Building material composition: Element content - Salts harmful to buildings: Salt content

Brief description

Non-destructive testing to determine the elements by exciting a sample with an electron beam, whereby the sample itself emits characteristic X-rays, the spectrum of which is examined in a scanning electron microscope. *(X-ray emission spectroscopy, atomic absorption spectroscopy method)*

Standard area of application (practical testing tasks)

- Qualitative and quantitative analysis of the elements from boron with determination of element distributions by spectral mappings and linescans [3]
- Semi-quantitative chemical analysis of concretes and cements, which allows conclusions to be on the phase composition and on the chemical reaction of phase formation, phase transformation and phase destruction [2]
- Detection of sulphate-containing mineral phases (ettringite type) next to CSH phases [2]
- Detection of building-damaging salts

Application limits (technical, physical, economic)

- Detection of elements from boron (atomic number Z=5) [3]
- Information depth up to several µm [3]

Special applications (additional testing tasks)

- Microstructural analysis of hydrating cements from the first minute of reaction [2]

On-site requirements

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- Material sample of the component to be tested is necessary
- Sample must be homogeneous and smooth [3]
- Sample must be suitable for vacuum [1]

Procedure description

Long description

In energy-dispersive X-ray spectroscopy, a material sample is excited by bombarding it with an electron beam of a certain energy. In the process, electrons close to the nucleus are lifted from the inner shells of the atom to those further out. This allows electrons from higher energy levels further away from the nucleus to fall back and fill the empty space near the nucleus in the atom. The energy released in this process is emitted as characteristic X-rays. Element distribution images are taken with a scanning electron microscope SEM for element analysis. [1]

An alternative evaluation method is wavelength dispersive X-ray spectroscopy (WDS); the sample radiation is dispersed by diffraction at a crystal.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+/- primarily applicable for scientific questions

+/- process is the subject of research for further applications [4,5,6]

- Conditionally non-destructive through sampling
- Laboratory method

190

Measuring method

Measurement setup

Laboratory device X-ray analysis
T. Schwarze, HTW Berlin/
KIWA Berlin

Measuring devices

- Scanning electron microscope with primary electron beam: hot cathode
- Detection unit: Si(Li) detector or silicon drift detector (SDD)
- Sample to be analyzed (prepared if necessary)
- Power connection

Measured variable and target variable

- EDS: Energy in [keV] and intensity in [w.E.], measurement of all energies in energy-proportional voltage pulses
(-WDS: wavelength in [nm] and intensity in [w.e.], splitting the radiation into wavelengths)
- Representation of the overall spectrum with spectral lines of the various elements in a diagram: energy or wavelength on x-axis; intensity on y-axis

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)

2. Test planning
- Determination of the test areas (or sampling point for laboratory tests)
- Compliance with radiation protection regulations

3. Performance of the audit (taking into account 2.)
- Sampling from the component to be tested
- Sample preparation: producing the geometry required for the measuring device
- Preparing the test: Aligning and focusing the electron beam on the sample
- Carrying out the analysis: bombardment of the sample

4. Documentation and evaluation
- Evaluation of the spectra
- Documentation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	5/5	4/5	4/5

Further information

Device manufacturer, software

EDAX Inc [https://www.edax.com/products/eds]

Related methods/ measurement variants

X-ray analysis (= excitation with an electron beam, emission of characteristic X-rays) works according to a similar physical principle to that used in the field of X-ray analysis:
- X-ray fluorescence analysis (= excitation with X-rays, emission of characteristic X-rays)
- *LASER-induced plasma spectroscopy = excitation with a laser beam, emission of characteristic fluorescence radiation from the detached plasma*

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[6] Mendonça Filho, F. F.; Pacheco, José; Çopuroğlu, Oğuzhan (2015): **Semi- and full quantitative EDS microanalysis of chlorine in reinforced mortars subjected to chloride ingress and carbonation**. In: 15th Euroseminar on Microscopy Applied to Building Materials

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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Concrete and precast concrete parts (ICS 91.100.30)
- ASTM C1723 - 16: Standard Guide for Examination of Hardened Concrete Using Scanning Electron Microscopy

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- VDI 6200, 2010-02: Stability of buildings - Regular inspection.

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- DIN 1076, 1999-11: Engineering structures in the course of roads and paths - monitoring and testing.

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Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

The "energy dispersive X-ray spectroscopy" method is not listed as a method in the literature sources known for NDT construction, such as the DBV or DGZfP leaflets. The method is also not mentioned in other standard works such as the Building Inspection Manual and the Building Physics Calendar series.

Part 3 - Test method Masonry

3.1 Visual inspection

Physical basis	Optical measuring principle
Procedure **Visual inspection** Visual Testing	Test task - State of preservation - Surface inhomogeneities: Surface cracks - Moisture distribution

Brief description

Non-destructive testing for the detection of damage, defects and faults and for assessing the condition of the Test surface by visual inspection of a test surface with or without aids. - Surface method

Standard area of application (practical testing tasks)

- Locating and evaluating superficial quality characteristics by perceiving, comparing, estimating, counting and Measure [DGZfP B6, 1]
- Visual inspection as a basic test for further investigations
- Checking the bricks of the masonry itself and checking the execution of the masonry:
  - Bricks of the masonry: dimensional accuracy, firing errors, lime inclusions
  - Execution of the masonry: bond of the masonry and complete mortaring
- Weathering damage (deformation, sanding, crumbling, chipping, crust formation)

Application limits (technical, physical, economic)

- Accessibility
- Lighting conditions
- Recognizability on the surface
- Viewing distance or visual inspection grid
- Size and shape of the object to be located

Special applications (additional testing tasks)

- Visual inspection is physically possible to assess the moisture distribution if residues of salts are visible on the concrete surface
- Recognizing plaster damage and especially cracks that may indicate damage and defects in the masonry

On-site requirements

- Accessible test surface (if necessary by erecting scaffolding and platforms; distances to the test object less than 600 mm and at an angle of not less than 30° to the test surface for the local visual inspection, distances greater than 600 mm for the overview inspection in accordance with DIN EN 13018)
- Sufficient lighting conditions (if necessary, add lighting sources with at least 160 lx for the overview inspection and at least 500 lx for the local visual inspection in accordance with DIN EN 13018)
- Preparing the surface: if necessary, clean the surface for a low degree of surface soiling

Procedure description

Long description

Differentiation between direct and indirect visual inspection according to [DIN EN 13018, 2016-06]:
- Direct visual inspection: "Visual inspection with an uninterrupted beam path between the eye of the inspector and the test surface. This test is carried out with or without aids, e.g. with a mirror, lens, endoscope or fiber optic device"
- Indirect visual inspection: "Visual inspection with an interrupted beam path between the inspector's eye and the inspection surface. Indirect visual inspection includes the use of photo and video technology, automated systems and robots"

The following damage, defects and faults can be detected with the visual inspection: [2]
- Cracks due to changes in the shape of the component in question
- Efflorescence due to salinization
- Crust formation (gypsum crusts and lime crusts)
- Crumbling due to the effects of frost
- Peeling: disc-shaped detachment on the surface
- Sanding and grinding due to frost, wind or salination
- Blasting (rust blasting, root blasting)
- Destruction of the masonry structure - starting from cracks - by root blasting of grasses, ferns, shrubs and trees
- Discoloration of natural stone
- Peeling and flaking of natural stone

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Visual inspection without tools is quick, depending on accessibility,
- Visual inspection without aids may not detect the features that can be detected with aids

3.1 Visual inspection

Measuring method

Measurement setup

Visual inspection of the masonry
Dr. Gabriele Patitz

Measuring devices

- If necessary, aids such as mirrors, lenses, endoscopes or photo and video technology or flashlights

Measured variable

Specified feature(s): e.g. surface cracks
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Ensure sufficient accessibility to the test area, using aids such as mirrors, magnifying glasses and endoscopes if necessary
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Performance of the test *(taking into account 2.):* Direct visual inspection [DIN EN 13018: 2016-06]
- Distance to the test surface < 600 mm
- Viewing angle of ≥ 30° to the test surface
- for overview inspections: Distance of > 600 mm permissible
- Additional lighting if necessary: at least 500 lx for local visual inspection and at least 160 lx for general inspection

4. Documentation
- Marking (e.g. with chalk) of the defined characteristic (inhomogeneity) on the structure to assess the damaged area (crack growth); indication of the test date for traceability
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary
- Proof of the tester's visual acuity (near vision and color vision)

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	1/5	1/5	3/5

Further information

Device manufacturer, software

-

Related methods/ measurement variants

Endoscopic procedures:

- Borescopes (rigid endoscopes)
- Fiberscopes (flexible endoscopes)
- Videoscopes (flexible video endoscopes)

Bibliography I (technical literature)

[1] Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (ed.): **BC 3 M1 Basic Course Level 3. Lessons. Visual inspection (VT) - V1 Basics of visual inspection**.

[2] Kastner, Richard H. (2004): **Altbauten - Beurteilen, Bewerten**. Stuttgart: Fraunhofer-IRB-Verl., Proceedings 5: Appearance, p.7-15

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[4] Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. (ed.): **BC 3 M1 Basic Course Level 3. Teaching Visual inspection (VT)**

Bibliography II (regulations: standards, guidelines, information sheets)

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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.
- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

- Visual inspection is one of the classic NDT procedures and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out the visual inspection.

Non-destructive testing (ICS 19.100)

- DIN EN 13018, 2016-06: Non-destructive testing - Visual inspection - General principles.
- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

DGZfP leaflets

- DGZfP - B6, 1996: Leaflet on visual inspection and endoscopy as optical methods for non-destructive testing in the building industry
- DGZfP - OV 01, 2013-11: Code of Practice on Optical Procedures - Part 1: Selection and initial testing of optical Visual inspection equipment; Part 2: Inspection of visual inspection equipment by the user.

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Civil engineering in general (ICS 93.010)

- DIN 1076, 1999-11: Engineering structures in the course of roads and paths - monitoring and testing.

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Other/ Notes/ Remarks/ Comment

Further information about the DGZfP (German Society for Non-Destructive Testing):

- 2nd specialist seminar on optical testing and measuring methods 2011
- 3rd specialist seminar on optical testing and measurement methods 2013
- 4th specialist seminar on optical testing and measuring methods 2015
- 5th specialist seminar on optical testing and measurement methods 2017

Physical basis	Optical measuring principle
Procedure **Endoscopy: Borescopes (rigid endoscopes)** Endoscopy: Borescope Inspection	Test task - Surface inhomogeneities: Surface cracks - Moisture distribution

Brief description

Non-destructive testing of an inaccessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of optical image transmission through a special lens system and an optical fiber for illumination. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)

Application limits (technical, physical, economic)

- Rough estimates of sizes and dimensions (for simple devices)
- No digital storage of images (for simple devices)
- Distortion effects of the optics can make it difficult to interpret the images

Special applications (additional testing tasks)

- Insertion of instruments through shaft
- Use of prismatic attachments and swivel mirrors for different viewing directions
- PCE Instruments offers borescopes with memory function as well as photo and video function [6]
- Endoscopy is physically possible to assess the moisture distribution if intensive moisture penetration through cracks is visible due to the appropriate drilling depth

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity (if necessary, use a drill with automatic switch-off)

Procedure description

Long description

The classic, lens-optical borescope consists of an eyepiece at one end, a tube with an image transmission system and an objective at the other end. The image transmission system consists of a special lens system that is rigidly arranged. Illumination is provided by light guides or a tiny light bulb integrated into the head. Depending on the version, the viewing direction changes: forwards, sideways, diagonally forwards or backwards. The interpretation of the circular images is complicated by the distortion effects of the optics and the unusual perspective and requires experience in interpreting the images.

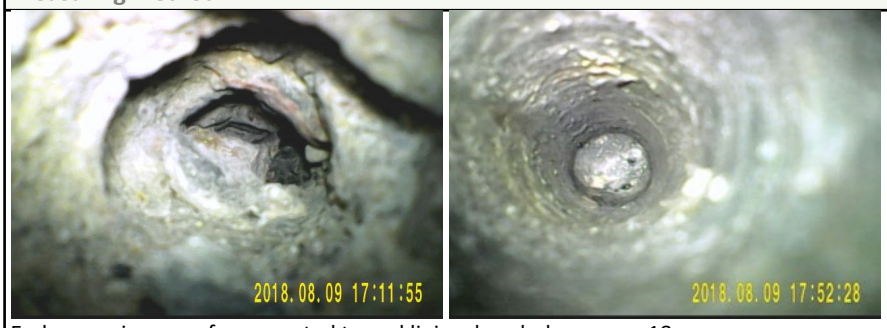
There are now also more advanced borescopes with fiber optic bundles for image transmission.

In addition to rigid borescopes, there are also flexible fiberscopes and flexible videoscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ better optical quality than flexible endoscopes
+ Higher resolution due to larger camera design compared to other endoscopes
- not bendable

Measuring method



Endoscopy images of a concreted tunnel lining, borehole approx. 18 mm
Left: Cavities and washouts; right: compact gallery concrete without damage
Dr. Gabriele Patitz

Measuring devices

- Borescope (consisting of an eyepiece, a long tube with an image transmission system and an objective) with diameters from 1.6 to 8 mm and lengths from 50 to 650 mm [3]
- Drill, if necessary
- Power connection for drill, if necessary

Measured variable

Specified feature(s): Cracks
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning
- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Performance of the examination (taking into account 2.): **Endoscopic examination with a borescope**

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec
- PCE Instruments

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
    (Special form: articulated arm endoscopes, rigid endoscopes with articulated arms in which deflecting prisms are installed)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

Bibliography (technical literature, data sheets, regulations, standards, codes of practice, references)

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[4] Hanel, A.: Chapter of Photogrammetry (PAK) 2013 SS - Techniques of Endoscopy

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Other/ Notes/ Remarks/ Comment

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- 3rd specialist seminar on optical testing and measuring methods - Lecture 01_2013-03
- 3rd specialist seminar on optical testing and measuring methods - Lecture 07_2013-03
- 4th specialist seminar on optical testing and measuring methods - Lecture 04_2015-03
- 5th specialist seminar on optical testing and measurement methods - Lecture 13_2017-03

Physical basis	Optical measuring principle
Procedure **Endoscopy: Fiberscopes (flexible endoscopes)** Endoscopy: Fiberscope Inspection	Test task - Surface inhomogeneities: Surface cracks - Moisture distribution

Brief description

Non-destructive testing of an inaccessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of image transmission via a bundle of optical fibers. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)

Application limits (technical, physical, economic)

- Rough estimates of sizes and dimensions (for simple devices)
- Lower resolution with smaller diameters due to lower number of pixels

Special applications (additional testing tasks)

- Endoscopy is physically possible to assess the moisture distribution if intensive moisture penetration through cracks is visible due to the corresponding drilling depth
- Use of special equipment for targeted examinations:
  - Connection of CCD cameras and photo cameras for documentation
  - Equipped with gripping tools for sampling
  - Connection of optical devices such as magnifying glasses or microscopes

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity (if necessary, use a drill with automatic switch-off)

Procedure description

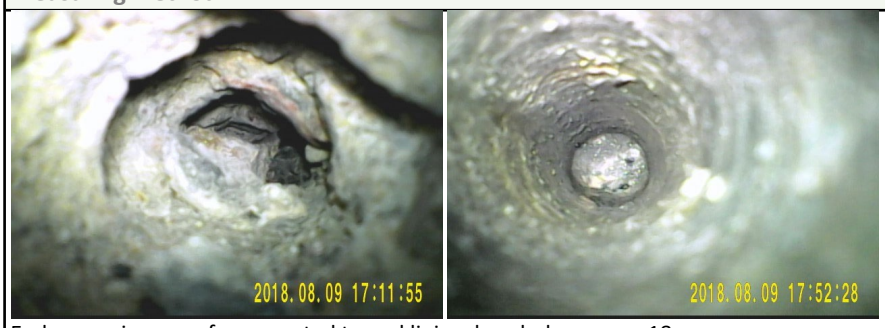
Long description

The fiberscope, also known as a fiber optic endoscope, consists of an image guidance system made of ordered glass fibers and a light guidance system. The image is transmitted from the objective to the eyepiece via the flexible glass fibers. The more glass fibers there are, the better the image resolution. The glass fiber bundle is also called an image guide bundle. Illumination takes place via an optical fiber bundle.
The interpretation of the circular images is made more difficult by the distortion effects of the optics, the unusual perspective and the limited image resolution (number of pixels) and requires experience in interpreting the images. In addition to flexible fiberscopes, there are also rigid borescopes and flexible videoscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,3,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ More flexible control than rigid endoscopes
+ Smaller device diameter than with videoscopes

Measuring method



Endoscopy images of a concreted tunnel lining, borehole approx. 18 mm
Left: Cavities and washouts; right: compact gallery concrete without damage
Dr. Gabriele Patitz

Measuring devices

- Fiberscope with a diameter of 2.5 to 4.2 mm and a length of up to 1200 mm [3]
- Miniature fiberscope with a diameter of 0.35 to 2.0 mm if necessary [3].
- Drill, if necessary
- Power connection for drill, if necessary

Measured variable

Specified feature(s): Cracks
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning
- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Carrying out the examination *(taking into account 2.)* : **Endoscopic examination with a fiberscope**
- Fiber optic tubing must not be kinked, otherwise the image transmission fibers will break

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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[2] **Endoscopy** (2014). In: DBV leaflet: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets), p. 31-33

[3] Karl Storz NDTec: **Flexible endoscopes**
https://www.karlstorzndtec.com/fileadmin/user_upload/produkte/Produktdatenblaetter/KSNDTec-Produktbrosch_PB3_06-D-2018-web.pdf

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Other/ Notes/ Remarks/ Comment

Further information about the DGZfP (German Society for Non-Destructive Testing):

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- 3rd specialist seminar on optical testing and measuring methods - Lecture 01_2013-03
- 3rd specialist seminar on optical testing and measuring methods - Lecture 07_2013-03
- 4th specialist seminar on optical testing and measuring methods - Lecture 04_2015-03
- 5th specialist seminar on optical testing and measurement methods - Lecture 13_2017-03

Physical basis	Optical measuring principle
Procedure **Endoscopy: Videoscopes (flexible video endoscopes)** Endoscopy: Videoscope Inspection	Test task - Surface inhomogeneities: Surface cracks - Moisture distribution

Brief description

Non-destructive testing of an inaccessible surface or cavity via an opening to explore the internal structure of the component to be tested by means of image transmission via an electrical cable with a CCD image converter chip for video recording and an optical fiber for illumination. [Indirect visual inspection]

Standard area of application (practical testing tasks)

- Visual inspection/exploration of component surfaces that are not directly accessible, such as bridge bearings
- Local insight into regular cavities and crevices
- Investigation of the continuation of cracks visible from the outside inside the structure (usually via borehole)

Application limits (technical, physical, economic)

Special applications (additional testing tasks)

- "Freezing" images
- Measurement of defects [4]
- Endoscopy is physically possible to assess the moisture distribution if intensive moisture penetration through cracks is visible due to the appropriate drilling depth

On-site requirements

- Presence of openings and cavities or
- Drill a hole with a diameter of approx. 10 to 25 mm to access the cavity, if necessary use a drill (with automatic switch-off)

Procedure description

Long description

The videoscope consists of a flexible endoscope and a measuring probe with an integrated video chip (CCD). The data is generated and transmitted digitally, enabling subsequent digital image processing.
Due to the unusual perspective, interpreting the circular images requires a certain amount of experience.
In addition to flexible videoscopes, there are also rigid borescopes and flexible fiberscopes. The choice of a suitable endoscope depends primarily on accessibility (straight, curved) and the expected image quality. [1,2,DGZfP B6]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Higher image resolution compared to rigid and flexible endoscopes
+ High resistance to breakage compared to fiberscopes with sensitive optical fibers
+ Storage of images and videos using digital technology

Measuring method

Measurement setup
Videoscope,
A. Taffe, HTW Berlin

Video copy
on masonry,
A. Taffe, HTW Berlin

Measuring devices

- Videoscope with diameter 4 to 6mm and up to 8000mm working length [3]
- Drill, if necessary
- Power connection for drill, if necessary

Measured variable

Specified feature(s): Cracks
- qualitative: detected or not detected
- Quantitative: e.g. dimensions of a damaged area, crack width etc. using aids such as integrated measuring scales or magnifying glasses

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents
- Selection and inspection of a visual inspection device according to DGZfP - OV 01

2. Test planning
- Definition of the test areas and a test system
- Establishing sufficient accessibility to the test area: use of an existing opening or creation of a borehole opening
- Creating sufficient lighting conditions, if necessary with the addition of additional lighting sources

3. Carrying out the examination *(taking into account 2.)* : **Endoscopic examination with a videoscope**

4. Documentation
- Logging of the implementation
- Logging of the defined characteristics (damage)
- Evaluation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
2/5	2/5	2/5	3/5

Further information

Device manufacturer, software

- Olympus
- Karl Storz NDTec

Related methods/ measurement variants

- Visual inspection VT
- **Endoscopic procedures:**
  - Borescopes (rigid endoscopes)
  - Fiberscopes (flexible endoscopes)
  - Videoscopes (flexible video endoscopes)

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[2] **Endoscopy** (2014). In: DBV leaflet: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Leaflets), p. 31-33

[3] Karl Storz NDTec: **VTec C compact system** https://www.karlstorzndtec.com/fileadmin/user_upload/produkte/Produktdatenblaetter/96191074_KSNDTec-SE-3-D.pdf

[4] Hanel, A.: Chapter of Photogrammetry (PAK) 2013 SS - Techniques of Endoscopy

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- DIN EN 1330-10, 2003-05: Non-destructive testing - Terminology - Part 10: Terms for visual inspection.

Personnel management, vocational training (ICS 03.100.30)

- Visual inspection is one of the classic NDT procedures and is identified by the abbreviation "VT". According to DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out the visual inspection.

Non-destructive testing (ICS 19.100)

- DIN EN 13018, 2016-06: Non-destructive testing - Visual inspection - General principles.
- DIN EN 13927, 2003-05: Non-destructive testing - Visual inspection - Equipment.

DGZfP leaflets

- DGZfP - B6, 1996: Leaflet on visual inspection and endoscopy as optical methods for non-destructive testing in the building industry
- DGZfP - OV 01, 2013-11: Code of Practice on Optical Procedures - Part 1: Selection and initial testing of optical Visual inspection equipment; Part 2: Inspection of visual inspection equipment by the user.

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Guidelines for the implementation of federal construction projects

- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Further information about the DGZfP (German Society for Non-Destructive Testing):

- 2nd specialist seminar on optical testing and measuring methods - Lecture 02_2011-12
- 3rd specialist seminar on optical testing and measuring methods - Lecture 01_2013-03
- 3rd specialist seminar on optical testing and measuring methods - Lecture 07_2013-03
- 4th specialist seminar on optical testing and measuring methods - Lecture 04_2015-03
- 5th specialist seminar on optical testing and measurement methods - Lecture 13_2017-03

Physical basis Mechanically excited measuring principle

Procedure

Tapping test/ tapping with a hammer

Tap Testing/ Hammer Tapping test

Test tasks

- (Change in) building material properties
- Surface inhomogeneities

Brief description

Non-destructive testing to assess the condition of the area near the surface of a test surface by tapping with fingers, knuckles, fist or hammer by generating a sound.

Standard area of application (practical testing tasks)

- Locating cavities near the surface of concrete components
- Determining the change in building material properties
- Tapping test as a basic test for further examinations

Application limits (technical, physical, economic)

- Experience and assessment skills of the examiners
- only examination of areas close to the surface (maximum 1st stone layer)
- Dependence of the sound:
  - the stress state, elasticity and vibration capacity of the material (robustness of the test surface)
  - from the component geometry, in particular component thickness

Special applications (additional testing tasks)

On-site requirements

- Avoidance of disturbing influences from noise sources in the test environment
- Accessibility
- Sufficient robustness of the test surface

Procedure description

Long description

In the tapping test, the condition of an area near the surface of a test surface is assessed. Tapping is usually carried out with the aid of a hammer.

The intensity of the tapping determines whether the layers close to the surface or the deeper component layers are made to vibrate. With weak tapping, the shock waves penetrate less deeply; with strong tapping, the shock waves penetrate deeper. When assessing the sound, it is important to differentiate between bright and muffled or high and low frequency sounds: a bright sound and a clearly noticeable rebound of the hammer indicate good concrete. To better differentiate the sound, it is advisable to tap different areas several times.

The sound depends on the air content inside the component, caused by the porosity of the material or by cavities, as well as on the state of tension, elasticity and vibration capacity of the material.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ quick first impression of possible cavities (suspected locations)

- subjective evaluation of the results depending on the experience of the tester
- The following investigations are necessary for clarification

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

- Carpenter's hammer

Measured variable

- Frequency content of the audibly reflected sound

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system

3. Performance of the test (taking into account 2.): Tapping test
- Tapping in a regular grid
- Marking of suspicious areas if necessary

4. Evaluation
- Subjective evaluation of the reflected sound

5. Documentation
- Logging of the implementation
- Logging of suspected locations in a register
- Evaluation of the results in a test report

5. further information
- Further examinations, e.g. with ultrasound

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
1/5	1/5	1/5	3/5

Further information

Device manufacturer, software

Related methods/ measurement variants

- Impact echo

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[1] Kastner, Richard H. (2004): Altbauten - Beurteilen, Bewerten. Stuttgart: Fraunhofer-IRB-Verl., p.18
[2] Ivanyi, György (2002): **Testing of concrete bridges. 2.2 Methods. 2.2.3 Tapping the surface. Technique of structural testing according to DIN 1076**. In: Fritz Vollrath and Heinz Tathoff (eds.): Handbuch der Brückeninstandhaltung. 2nd ed. Düsseldorf: Verlag Bau und Technik, pp. 59-72.
[3] Mertens, Martin; Gunkel, Oliver (2014): Structural testing according to DIN 1076: **Archaic tapping or modern technology?** Lecture 4. in: Symposium Building Diagnosis 2014: DGZfP, German Society for Non-Destructive Testing e.V (symposium on building diagnosis).

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Other/ Notes/ Remarks/ Comment

Physical basis	Mechanically excited measuring principle
Procedure **Impact echo** Impact Echo	Test task - Surface inhomogeneities - Delaminations - Back wall

Brief description

Non-destructive testing by means of excitation of elastic waves by a short mechanical impulse (impact with impactor), the impact, and measurement of the resonance frequency.
[One-sided measurement on the component with impactor and sensor]

Standard area of application (practical testing tasks)

- Determination of component thickness and layer thickness [4]
- Detection of localized or laminar bond defects or delamination [4]
- Locating cavities and cracks [4]
- Examination of the uniformity of the component by calibration via ultrasonic velocity [4]

Application limits (technical, physical, economic)

- not used for [3]
  - a large number of cracks in the masonry
  - Masonry with bricks of different strengths
  - heavily weathered and irregular surfaces
  - loose layers on the surface

Special applications (additional testing tasks)

On-site requirements

- for thickness measurement, the propagation velocity must be known (determination of the speed of sound at a point of known thickness in the same component) [3]
- Uniform masonry with a smooth surface [3]

Procedure description

Long description

In the impact echo method, the elastic waves are excited with a short manual impact on the component surface using an impactor, usually a sphere. The diameter of the impactor determines the contact time and the frequency content introduced. The wave generated is a Lamb wave. The measurement is carried out in a grid along defined lines or a surface. To measure the generated waves and the resonance frequencies, a sensor is pressed onto the component surface near the excitation point. No couplant is required for this. The distance of the reflector or the layer boundary from the concrete surface can be determined from the read frequencies if the propagation speed is known.
Total reflection occurs at the interface with air in the case of an impact echo. This means that no information can be obtained behind a layer of air.

Procedure advantages and disadvantages (compared to procedures for the same test task)

- Lower resolution and therefore less accurate than ultrasonic echo
- No precisely uniform energy input due to manual excitation
- Due to the application limits, impact echo can hardly be used on real walls

3.6 Impact echo

As of 18.12.2019

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

-Spherical impactor with small diameter (high frequency components) : small thicknesses and small objects at close range
- Impactor with large diameter (for low frequency ranges) : larger thicknesses
- Suitable selection of impactors (3 to 30 mm ball diameter) for a large depth spectrum

Measured variable and target variable

Knowledge: Speed of sound v in [m/s]
Measured variable: Frequency f in [Hz] in the upper audible and lower ultrasonic range between 2 and 40 kHz Target variable: Component thickness d in [m],
Calculation of the target value: d = v/(2*f)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning [1]
- Definition of the test areas and a test system
- Selection of a suitable impactor
- Determination of the propagation velocity preferably at a location with known thickness

3. Performance of the test (taking into account 2.): Impact echo

4. Evaluation [1]
- Shift of the resonance frequency for adjacent materials with high impedances such as steel
- even with good quality of the actual measurement signal, interfering reflections can occur on boundary surfaces or internal objects (side walls, joints, reinforcement bundles, pipes)

5. Documentation
- Logging of the implementation
- Logging of suspected locations in a register
- Evaluation of the results in a test report

5. further information
- Further examinations, e.g. with ultrasound

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	4/5

Further information

Device manufacturer, software

Related methods/ measurement variants

Bibliography I (technical literature)

[1] German Society for Non-Destructive Testing (2011): **Leaflet on the application of the impact echo method for non-destructive testing of concrete components**. Berlin: DGZfP, German Society for Non-Destructive Testing (DGZfP **Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. - Merkblätter**, B 11).
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Other/ Notes/ Remarks/ Comment

Physical basis: Mechanically excited measuring principle

Procedure

Ultrasonic transmission/ Transmission method

Ultrasonic transmission

Test task
- Surface inhomogeneities: Surface cracks
- State of preservation: Compressive strength

Brief description

Non-destructive testing for the detection of inhomogeneities by generating mechanically excited pulses in the test probe and their propagation and influence (e.g. reflection at the crack) according to the laws of elastic waves in the component to be tested [active emission of signals].
[Two-sided measurement on the component with transmitter and receiver on opposite or offset surfaces of the component.
test specimen = sound transmission]

Standard area of application (practical testing tasks)

- Detection of cavities in the order of 20 to 100 mm [7]
- Localization of inclusions and inhomogeneities (within stones) [3]
- Weathering condition and strength of natural stones [3] (limited possible according to [7])
- Course and depth of cracks as well as hidden shell detachments parallel to the surface [3] (possible to a limited extent according to [7])
- as a supplement to the radar method for detailed examinations of smaller components

Application limits (technical, physical, economic)

- up to approx. 50 - 70 cm component thickness [3]
- No information behind cavities (air) [3]
- Porosity, composition and microstructure of the masonry influence the test result [3]
-The examination of large surfaces is associated with high measurement and time expenditure, as the ultrasonic device must be moved manually for each measurement on the test surface [3]

Special applications (additional testing tasks)

- Determination of component thicknesses and layer thicknesses with ultrasound in reflection arrangement [7]

On-site requirements

- Accessibility to the test object from both sides [3] with measuring arrangement in transmission
- Calibrate rock strength measurements on extracted drill cores [2]

Procedure description

Long description

The ultrasonic method is primarily used on masonry in a transmission arrangement; ultrasonic pulses are generated in the frequency range between 20 kHz and 1 MHz. The testing device consists of an ultrasonic transmitter and - depending on the measuring arrangement - one or more receivers. The pulses generated are transverse waves. For the measurement, the test device must be pressed onto the concrete surface and moved in a grid. The grid is determined by the size of the objects to be detected. The elastic waves propagate in the medium; if the elastic waves hit a cavity, they cannot propagate and take a detour. This results in a change in the transit time, which then allows conclusions to be drawn about undamaged or damaged areas. Ultrasound is almost totally reflected at the interface with air. [3]
Reconstruction of the raw data using appropriate software provides an improved imaging representation of the Results. [7]

Procedure advantages and disadvantages (compared to procedures for the same test task)

- Non-destructive, non-contact
+ largely independent of humidity and salt in contrast to radar [3]
- due to high frequencies, thus short wavelengths and therefore higher absorption, the range is limited compared to microseismics, but the resolution is higher [3]
- No exploration of areas behind cavities in contrast to radar
- blind in the near-surface area

Measuring method

Measurement setup

Ultrasonic measurements for estimating structural loosening
Dr. Gabriele Patitz

Ultrasonic sensors for material assessment
Dr. Gabriele Patitz

Measuring devices

- Ultrasonic testing device with excitation frequency range between 20 kHz and 1 MHz [3]
  - High frequency: lower penetration depth, higher resolution
  - Low frequency: higher penetration depth, lower resolution

Measured variable and target variable

Knowledge or calculation: Speed of sound v in [m/s] Measured variable: Transit time t in [µs]
Target value: component thickness d in [m]
Calculation of the target value: d= v * t/2 (if necessary: v= Λ * f)

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Determination of the propagation velocity

3. Performance of the test (taking into account 2.): Ultrasonic testing
- Measurement by moving the ultrasonic test sensor in a specific grid

4. Evaluation and documentation
- Measurement data acquisition and visualization: e.g. reconstruction of raw data with SAFT evaluation
- Recording of the implementation and the measurement result
- Presentation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

Further information

Device manufacturer, software

- Proceq (product range: Pundit)

Related methods/ measurement variants

Ultrasound variants:

- Ultrasonic reflection/ transceiver method/ pulse-echo technology:
one-sided measurement with a single, combined transmitter and receiver probe
- Ultrasonic transmission/transmission technology according to DIN EN ISO 16823:
Two-sided transit time measurement on the component = sonication of the component with transmitter and receiver probe on opposite or offset surfaces of the test specimen

- same process principle as microseismics

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[4] Wendrich, Astrid (2009): **Non-destructive detection of anomalies in historic masonry with radar and ultrasound. Possibilities and limits**. Berlin: Federal Institute for Materials Research and Testing BAM (BAM dissertation series, Volume 47).
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[6] Binda, Luigia; Zanzi, Luigi; Rodriguez Santiago, Jesus; Knupfer, Beatriz; Johansson, Bernth; Modena, Claudio et al. (2006): **Onsiteformasonry project. On-site investigation techniques for the structural evaluation of historic masonry buildings** : EUR 21696 EN. Edited by Christiane Maierhofer and Christian Köpp. Brussels: European Commission, Directorate- General for Research, Directorate "Environment". Available online at https://publications.europa.eu/en/publication- detail/-/publication/f5ad6b4d-a0b5-4d79-888d-2fb1fe962da4/language-en.
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Personnel management, vocational training (03.100.30)

- Ultrasonic testing is one of the classic NDT methods and is identified by the abbreviation "UT". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out ultrasonic testing.

Non-destructive testing (ICS 19.100)

- DIN EN 12668, 2010-05: Non-destructive testing - Characterization and verification of ultrasonic testing equipment__ Part 1: Testing equipment
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- DIN EN ISO 16809, 2018-12: Non-destructive testing - Thickness measurement by ultrasonic. [Draft]
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Guidelines for the implementation of federal construction projects

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Other/ Notes/ Remarks/ Comment

Physical basis	Mechanically excited measuring principle
Procedure **Microseismics** Microseismic	Test task - State of preservation: Compressive strength - Surface inhomogeneities: Surface cracks

Brief description

Non-destructive testing using time-of-flight measurement by generating mechanically excited pulses in the test head and their propagation and influence (e.g. reflection at the crack) according to the laws of elastic waves in the component to be tested

Standard area of application (practical testing tasks)

- Investigation of larger components and pillars [3]
- Weathering condition and strength of natural stones [3]
- Course and depth of cracks and hidden shell detachments [3]
- Locating defects, cavities and inhomogeneities [3]

Application limits (technical, physical, economic)

- from approx. 50 - 70 cm component thickness [3]
- No information behind cavities (air) [3]
- Porosity, composition and microstructure of the masonry influence the test result [3]
-The examination of large surfaces is associated with high measuring and time expenditure, as the impulse hammer must be repositioned for each measurement on the test surface [3]

Special applications (additional testing tasks)

- Determination of component thicknesses with microseismics in reflection arrangement

On-site requirements

- Accessibility to the test object from both sides [3] with measuring arrangement in transmission
- Calibrate rock strength measurements on extracted drill cores [2]

Procedure description

Long description

The microseismic method is primarily used on masonry in a transmission arrangement; pulses in the frequency range between 1 kHz and 10 kHz are generated using a pulse hammer. The elastic waves are reflected at layer boundaries or at the interface of inhomogeneities or backscattered by reflectors such as metallic fasteners. In microseismics, there is almost total reflection at the interface with air. This means that no information can be obtained behind a layer of air. The travel time of the reflected pulses can then be used to determine the distance and extent of the detected objects from and to the probe. The reflected pulses are recorded with a geophone or accelerometer.
Reconstruction of the raw data with appropriate software provides an improved imaging representation of the results. [3,6]
Microseismics can be divided into transmission seismics, reflection seismics and refraction seismics, depending on the test task and measurement arrangement. [7]

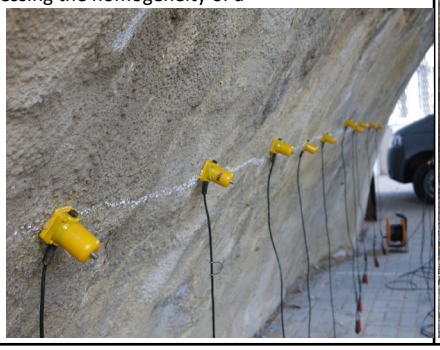
Procedure advantages and disadvantages (compared to procedures for the same test task)

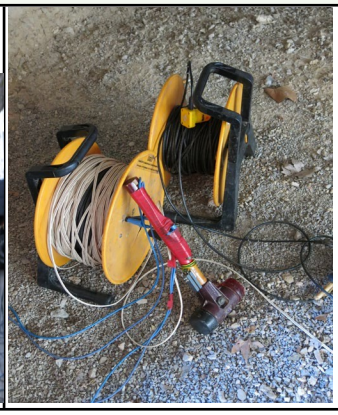
- Non-destructive, non-contact, suitable for construction sites
+ largely independent of humidity and salt in contrast to radar [3]
+ Due to lower frequencies, and therefore longer wavelengths and thus lower absorption, the range is greater compared to ultrasound, but the resolution is lower
- No exploration of areas behind cavities in contrast to radar

Measuring method

Measurement setup

Geophone display for assessing the homogeneity of a bridge pier
Dr. Gabriele Patitz





Seismics: Signal excitation by means of hammer blow
Dr. Gabriele Patitz

Measuring devices

- Signal excitation with impulse hammer with frequency range between 1 kHz and 10 kHz [3]
- Signal acquisition with geophone/accelerometer
- Determination of the transit time of the compression pulse with digital seismic equipment

Measured variable

Knowledge or calculation: Speed of sound v in [m/s] Measured variable: Transit time t in [µs]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system
- Determination of the propagation velocity

3. Performance of the test (taking into account 2.): Microseismics
- Measurement using signal excitation with impulse hammer and corresponding signal receiver

4. Evaluation and documentation
- Measurement data acquisition and visualization
- Recording of the implementation and the measurement result
- Presentation of the results in a test report

5. Further information
- Further examinations if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	4/5	3/5	4/5

Further information

Device manufacturer, software

Related methods/ measurement variants

- Same process principle as ultrasound
- Concrete: Parallel seismics on bored piles, sheet pile walls and diaphragm walls for length determination

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Other/ Notes/ Remarks/ Comment

The difference between microseismics and seismics lies in the excitation frequency range. In seismics, the range is less than 1 kHz, whereas in microseismics this range is between 1 and 20 kHz. In principle, microseismics is the application of seismics to a smaller range. But still with a wider range than the Ultrasound procedure.

Physical basis	Electrical measuring principle
Procedure **Geoelectrics/ Resistance method** Geoelectric	Test task - Inhomogeneities - Moisture distribution

Brief description

Non-destructive testing by measuring the potential difference between electrodes placed on the masonry surface that supply current to the masonry and subsequent evaluation of the specific resistance [Indirect moisture measurement: Electrical method].

Standard area of application (practical testing tasks) [2]

- Determination of moisture and salt distribution
- Locating cavities

Application limits (technical, physical, economic)

Special applications (additional testing tasks)

On-site requirements

- Ensure good electrical contact between the masonry and the measuring equipment, if necessary drill holes to insert the measuring equipment [1].

Procedure description

Long description

In geoelectrics, at least two electrodes with a connected current source and two probes for measuring the potentials are required to measure the resistance. Larger areas are measured using geoelectric tomography. For this purpose, a large number of mini-electrode probes, usually 24 to 48, are arranged along a measuring line and connected with a special cable. This measuring arrangement is called a multi-electrode array. Different probe-electrode combinations can be controlled with a switching device. The different measuring combinations result in a dense measuring grid and a large number of depth levels. The different conductivities in the test specimen can be visualized and evaluated using software. [2,4]

Procedure advantages and disadvantages (compared to procedures for the same test task)

- limited non-destructive by establishing good electrical contact between the Mauerwrek and the measuring apparatus by means of drill holes [3]

Measuring method

Measurement setup	Measurement results
-	-

Measuring devices

Geoelectric apparatus consisting of [1,4]:
- Electrode-probe combination for coupling to the test object (with high electrical resistance: ~ 10 MΩ)
- Power source as signal transmitter
- Voltmeter and ammeter for signal measurement
- If necessary, software for digital data processing and evaluation
- Drill, if necessary

Measured variable

- Measured variable: Potentials
- Target value: Areas with different specific resistances that indicate cavities or different moisture distributions

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Determination of the test areas and a test system: Determination of the measurement grid
- Determination of the propagation velocity
- If necessary, drill holes for measuring equipment

3. Performance of the test (taking into account 2.): Geoelectrics
- Resistance measurement

4. Evaluation and documentation
- Measurement data acquisition and visualization: data reconstruction
- Recording of the implementation and the measurement result
- Presentation of the results in a test report

5. Further information
- If necessary, further investigations/ further combinations of procedures

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	4/5	3/5	4/5

Further information

Device manufacturer, software

Related methods/ measurement variants

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Other/ Notes/ Remarks/ Comment

Moisture measurement methods are divided into direct and indirect methods:
The direct methods provide a quantitative value of the moisture content; they do not require any further calibration measurements, but are carried out in a way that destroys the building material. The indirect methods only provide qualitative values of the moisture content or the moisture distribution without further calibration measurements; however, they can be carried out non-destructively. According to [4], the direct and indirect methods can be further subdivided:

Direct procedures
- Darr weighing method
- Calcium carbide method CM

Indirect procedures
1 Electrical process
- **Resistance method/ geoelectrics**
- Capacitive processes:
  - Pulse radar
  - Microwave process
  - Microwave drilling process
  - Time Domain Reflectometry

TDR) 2 Radiometric methods
- Neutron backscattering
- Nuclear magnetic resonance NMR 3

Thermal methods
- Infrared thermography 4

Hygrometric methods
- Equalizing humidity probe

Physical basis	Electromagnetic measuring principle
Procedure **Radar** RAdio Detection And Ranging	Test task - Moisture distribution - Back panel, - Reinforcement

Brief description

Non-destructive testing by transit time measurement after generation of electromagnetic pulses in the test head and their propagation according to the laws of elastic waves in the component.
[One-sided measurement on the component with transmitter and receiver = reflection arrangement]

Standard area of application (practical testing tasks)

- Radar as an area survey for structural exploration
- Determination of component thickness, wall layer structure, stone embedment depths and internal condition
- Locating cavities
- Locating structural elements (steel girders, reinforcement in masonry, ring anchors, stone clamps)
- Qualitative determination of moisture and salt distribution (quantitative via calibrations)
- Differentiation of different structural states (compact - cavity-rich, moist - dry) as a basis for calibrating openings

Application limits (technical, physical, economic)

- Highly structured (ornamented) surfaces allow only a few or short data profiles
- with plastered MW, the determination of the stone embedment depth requires a very narrow measuring grid
- Penetration depth is influenced by conductivity: Damp masonry and dissolved salts have high conductivity, which causes high absorption and results in a low penetration depth [3]
- If the material contrast between the MW and the in-situ soil/rock is too low, it is not possible to determine the wall thickness
- Stopping a steel plate can possibly lead to better back wall information
- No clear detection of air layers that are only a few cm thick

Special applications (additional testing tasks)

- Locating objects through targeted shadowing (stopping a steel plate) or direct reflection (moving or not moving).
of signals)

On-site requirements

- Component surface must be dry
- there must be no metallic mesh in the plaster layer
- Material and corresponding propagation speed must be known
- Calibration of the running time on a component of known thickness

Procedure description

Long description

The radar method generates and transmits electromagnetic pulses.
"Wave propagation in the component depends on the distribution of dielectric properties. On its path, the wave is scattered and reflected at interfaces of materials with different dielectric properties." [1]
Brick outer shells and cavity-rich layered/filled inner fillings have different dielectric constant values, which is why shell boundaries can be distinguished. Reflections also occur at the interfaces between air (void/ cavity or rear wall) and masonry. The depth of the reflector in the component can be used to locate a cavity or determine the wall thickness.
RADAR is primarily used in the reflection arrangement, i.e. both the transmitter and receiver are located in one measuring unit. The measurements are triggered automatically at a close distance of a few millimeters or time-controlled. At each measuring point, the amplitude of the received reflections is plotted over time (A-scan), the measurement of many points one after the other along a line is called a radargram (B-scan), the flat measurement is called a time slice (C-scan). A radargram is a "cut" into the component along the measurement line. Time slices are the representation of reflection strengths at depths parallel to the component surface selected according to the exploration target.
Data processing of the results with a SAFT reconstruction by migration achieves a better imaging representation of the results.

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ completely non-destructive and (apart from impellers) contactless [3]
+ Results can be recorded and evaluated on site [3]
+ Exploration of areas behind cavities in contrast to ultrasound and microseismics [3]
+ Depth resolution (structures lying one behind the other can be imaged)
+ Fast and comprehensive: exploration of large areas in a comparatively short time (depending on accessibility)
- no statements on material strength in contrast to ultrasound [3]

Measuring method

Measurement setup

(1) Falkenbach viaduct, cavity search and exploration of stone embedment depths with a 1.5 GHz sensor, (2) Eisenstein viaduct, checking the success of grouting with a 900 MHz sensor, (3) 400 MHz sensor for exploring the condition of the masonry on a natural stone arch bridge, (4) 200 MHz sensor for exploring the thickness of retaining walls, © Dr. Gabriele Patitz

Measuring devices

Radar measuring device with antenna frequency: [4]

- f_{Radar} > 400 MHz to 2 GHz several centimeters to decimeters detection depth for good resolution near the surface (higher frequency = lower penetration depth, higher resolution)
- f_{Radar} < 200 Mhz up to several meters detection depth with lower resolution <200 MHz rather irrelevant, 900 MHz and 400 MHz are typical sensors suitable for masonry (low frequency = higher penetration depth, lower resolution)
- If necessary, auxiliary construction for guiding the sensors - Software for digital data processing and evaluation

Measured variable

- Measured variable: transit time in [ns], reflection strengths, absorption strengths
- Target value: component thickness in [cm], depth of built-in parts, homogeneity of internal wall fillings, moisture-salt distribution
- d= v x t/2, v= Λ x f, R= (v2-v1)/ (v2+v1)
- v_{Luft} = 30 cm/ns

Measurement implementation, measurement strategy (what, when, where, how often?)

1. **Information on the test task**
   - Definition of the test task and objective of the test (coordination of accuracy requirements)
   - Inspection of test specifications/recommendations (standards, data sheets)
   - Information on the test object (ambient conditions, application limits, on-site requirements)
   - Procurement of information, if necessary by reviewing old and existing documents
2. **Test planning**
   - Definition of the test areas and a test system
   - Determination of the frequency with regard to penetration depth and resolution
   - Definition of the measuring direction and measuring density (profile distances) in relation to the objects to be detected
3. **Performance of the test (taking into account 2.): Radar**
   - Checking the previously defined inspection plan and adjusting it on site if necessary
   - Measurement by scanning the surface with the radar tester
   - Plausibility check on site
4. **Documentation**
   - Logging of the implementation
   - Evaluation of the measurement results: Data reconstruction (migration/ SAFT)
   - Evaluation, addressing and interpretation of the results in a test report (presentation as a results plan)
5. **Further information**
   - If necessary, further combinations of procedures with ultrasound, thermography, etc. [1]
   - If necessary, specification of openings for specific calibrations
   - Combination with destructive methods if necessary

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	1/5	3/5	4/5

Further information

Device manufacturer, software

Related methods/ measurement variants

Radar in transmission arrangement with transmitter and receiver on opposite sides of the object to be tested is used for special measurements such as the determination of material-related wave velocities.

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230

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Other/ Notes/ Remarks/ Comment

International events on the radar process:

- International Conference on Ground Penetrating Radar (GPR) since 1986 (2018: 17th International Conference on Ground Penetrating Radar)

Physical basis	Electromagnetic measuring principle
Procedure **Microwaves** Measurement of the Moisture Content: Microwave Method	Test task - Moisture distribution: Moisture content

Brief description

Non-destructive testing to determine the relative moisture content by measuring the difference between the dielectric constant of water and the dielectric constant of the building material [Indirect moisture measurement: Dielectric method].

Standard area of application (practical testing tasks)

- Determination of surface moisture [1] as a large-area grid measurement [4]
- Determination of moisture distribution in the volume (e.g. in solid bricks, clinker bricks, hollow bricks, Poroton, sandstone) [1]

Application limits (technical, physical, economic)

- Penetration depths of 2-6 cm with resonator applicators (for surface moisture), up to 50 cm penetration depth with patch applicators (for volume moisture) [2]
- For the volume-related moisture, a largely material-independent calibration is possible; for the mass-related moisture, a specification of the bulk density of the building material is required for calibration [1]
- Microwaves are scattered by inhomogeneities in the test specimen, which can lead to a distortion of the received signal [1]

Special applications (additional testing tasks)

On-site requirements

- Calibration of the sensors in accordance with WTA data sheet [6]
- Outdoor temperature from 5°C [6]
- Accessibility to the test specimen from one side [3]
- Smooth and even test surface [3]

Procedure description

Long description

The microwave moisture measurement method is based on the dielectric effect and "on the outstanding dielectric properties of water. Water is a polar molecule, i.e. the centers of charge do not coincide locally within the molecule. This is why the water molecule aligns itself in a preferred direction in an externally applied field; it is polarizable. If a microwave field is applied, the molecules begin to rotate at the frequency of the field (orientation polarization).
This effect is characterized macroscopically by the physical quantity dielectric constant (abbreviation DK, formula symbol ε). The dielectric effect is so pronounced in water that the relative DK of water is around 80. The relative DK of most solids, including building materials, is considerably lower, in the range 2
...10 and preferably between 3 and 6. The measuring effect is therefore caused by the difference between the DK of water and the DK of the building materials. Due to the large difference between these values, even small amounts of water can be detected well.
For the measurement, a sensor (touch-on measuring head) is placed on the wall surface]. Both the electromagnetic wave entering the material and the wave reflected by the material are measured." [3]

Procedure advantages and disadvantages (compared to procedures for the same test task)

+ no influence of salts on moisture measurement in the microwave range due to high frequencies [2]
+ accurate recording of many measured values in a short time [3]

Measuring method	
Measurement setup -	Measurement results -

Measuring devices

Portable hand-held measuring device consisting of [6]:
- Microwave probe for volume measurement of the material moisture in the measured material or
- Microwave probe for surface measurement of material moisture (exciting frequency range of ~ 2.45 GHz)
- Control unit
- Software for evaluation

Measured variable

- Grid moisture graph with moisture distribution and depth layers

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system: Creation of a measurement concept
- Definition of measuring grid (starting point and scanning direction)
- Determining the local resolution

3. Performance of the test (taking into account 2.): Microwaves
- Performing the measurement by scanning the test surface with a microwave scanner

4. Documentation
- Logging of the implementation
- Data processing and evaluation with software
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	3/5	3/5	3/5

Further information

Device manufacturer, software

- hf sensor GmbH: MOIST series, e.g. MOIST 350 B: Portable grid moisture measurement system for construction applications [Link: http://www.hf-sensor.de/deutsch/feuchtemessung.html]

Related methods/ measurement variants

- Microwave borehole method [2,7]: developed at the Federal Institute for Materials Research BAM; was tested as part of [7]; introduction of sensors into the borehole for moisture profile measurements

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[5] Göller, A.: **MOIST SCAN 200 - Moisture scans on building components and walls**. Poster 01. In: Fachtagung Bauwerksdiagnose 2012, p. 1-7. Available online at http://bauwerksdiagnose2012.dgzfp.de/Portals/bwd2012/Dokumente/bb/p01.pdf.
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3.11 Microwaves

Other/ Notes/ Remarks/ Comment

Moisture measurement methods are divided into direct and indirect methods:
The direct methods provide a quantitative value of the moisture content; they do not require any further calibration measurements, but are carried out in a way that destroys the building material. The indirect methods only provide qualitative values of the moisture content or the moisture distribution without further calibration measurements; however, they can be carried out non-destructively. According to [2], the direct and indirect methods can be further subdivided:

Direct procedures
- Darr weighing method
- Calcium carbide method CM

Indirect procedures
1 Electrical process
- Resistance method/ geoelectrics
- Capacitive processes:
  - Pulse radar
  - **Microwave process**
  - **Microwave drilling process**
  - Time Domain Reflectometry

TDR) 2 Radiometric methods
- Neutron backscattering
- Nuclear magnetic resonance NMR 3

Thermal methods
- Infrared thermography 4

Hygrometric methods

Physical basis	Electromagnetic measuring principle
Procedure **Active/instantaneous Thermography** Active/ Transient Thermography	Test task - Inhomogeneities - Moisture distribution

Brief description

Non-destructive testing through imaging detection of inhomogeneities in the near-surface area of a component due to a specifically variable heat flow and local temperature differences in the component. -
Surface treatment

Standard area of application (practical testing tasks)

- Detection of cavities and inhomogeneities in the near-surface area up to 10 cm [6]
- Detection of plaster flaking on masonry and of structures behind coatings [6]
- Representation of the masonry structure (brick and joint) behind plaster [6]
- Detection of truss girders behind plaster layer
- Localization of connections and fasteners in double-shell masonry
- Determination of the moisture distribution in the near-surface area [6,7]

Application limits (technical, physical, economic)

- Testing under ambient conditions such as rain, high humidity and strong winds as well as surface properties such as roughness, moisture and contamination can falsify the test result
inhomogeneous, thick-walled components with complicated geometry more difficult to test

Special applications (additional testing tasks)

On-site requirements

- Accessibility of the component surface for the heating process
- dry and windless environment

Procedure description

Long description

In thermography, a distinction is made between active and passive thermography.
Passive thermography is used in building physics and uses the building's own heat for thermographic measurements to locate cold or thermal bridges.
In active thermography, on the other hand, the object is specifically heated using appropriate thermal excitation techniques. This creates an artificially generated, temporally and/or spatially variable heat flow (transient heat transfer due to heating or cooling processes), which generates a temperature gradient to the surface and/or environment. The temperature gradient is caused by the fact that "in the event of external heating, heat accumulates in front of defects in the component if the defects have a lower heat penetration coefficient b than the surrounding material." [2]
The targeted heating or cooling of the areas close to the surface is recorded thermographically with a thermal imaging camera and then evaluated. Inhomogeneities become visible through temperature differences. The heat transfer is influenced by the thermal conductivity, density and heat capacity of the test specimen. [6]
Active thermography is differentiated according to the temporal excitation: [3]
- Lock-in thermography (LT): Excitation by continuous sinusoidal signals of a defined frequency and evaluation by measuring the time delay (phase) and the amplitude of the response signal for the corresponding frequency (not practical for the construction industry because the recording time lasts around 24 hours)
- **Impulse thermography** (IT): Excitation by a thermal impulse with a large number of different frequencies and evaluation in the time domain via the temperature difference
- **Pulse phase thermography** (PPT): a further development of pulse thermography, excitation as in IT by a thermal pulse, evaluation by thermogram series in order to record the phase delay of the local heat propagation in the image by means of a fast Fourier transformation (FFT).

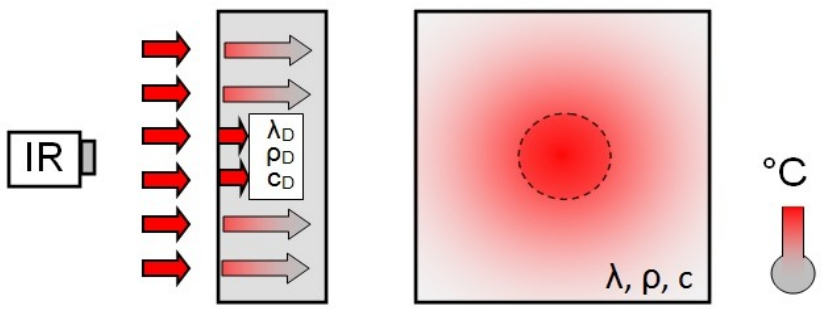
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ completely non-destructive and contact-free
+ Introduction of transient and active methods in building thermography makes the old restriction to the heating season and simultaneously cool climate zones superfluous
+ Thermograms obtained by PPT provide a very good signal-to-noise ratio and thus a higher detection sensitivity of the defect geometry and better depth resolution than IT
- Thermal load and dangers of the excitation source: the deeper the objects are located, the longer the warm-up and heating times. Observation times (up to 1 hour)

Measuring method

Measurement setup

Active thermography: Schematic
A. Taffe, HTW Berlin [7]



Measuring devices

- Infrared camera (IR camera) with accessories such as memory card and tripod
- Computer for digital recording
- Temperature and humidity meter
- Power supply (cable drums if necessary)
- Thermal excitation source: - thermal radiation (solar radiation, infrared radiators, halogen lamps, flash lamps)
  - Convection (fan heater, heat gun, building dryer, blower door)
  - Heat conduction (heating mats, cooling pads)
  - Electromagnetic induction/ electric current

Measured variable and target variable

- Temperature-time curve: Course of the temperature T in [C] over the time t in [s] [4]
- Temperature contrasts in the recorded thermograms (qualitative evaluation) [4]
- Evaluation of temperature-time curves/transients (quantitative information) [4]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Selection of the test system: Determination of the thermal excitation source and a suitable IR camera
- Definition of the test areas, the test system and the positioning of the test system
- Definition of the required accuracy of the results (the more complex PPT for very subtle signals or high result quality; the less complex IT for normal cases)
- Determination of the type of temporal excitation (pulse duration) and spatial excitation

3. Performance of the test (taking into account 2.): Thermographic test
- Recording the thermograms

4. Evaluation and documentation
- Logging of the implementation and description of the environmental conditions
- Acquisition of a sequence of thermograms
- Evaluation of complete thermal sequences, individual thermograms or transients
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	2/5	4/5	5/5

Further information

Device manufacturer, software

- InfraTec GmbH [https://www.infratec.de/thermografie/anwendungsgebiete/aktive-thermografie/]
- edevis GmbH [https://www.edevis.com/content/de/active_thermography.php]

Related methods/ measurement variants

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[2] **Infrared thermography. Electrical and electromagnetic methods** (2014). In: DBV leaflet: Application of non-destructive testing methods in construction. Berlin: Deutscher Beton- und Bautechnik-Verein e.V. (DBV) (DBV Deutscher Beton- und Bautechnik-Verein E. V. - Merkblätter), pp. 21-23.
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- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Personnel management, vocational training (03.100.30)

- Infrared thermography testing is one of the classic NDT methods and is marked with the abbreviation "TT".

According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel,*** a level 1, 2 or 3 personnel qualification must be obtained in order to carry out infrared thermography testing.

Non-destructive testing (ICS 19.100)
- DIN EN 16714-1, 2016-11: Non-destructive testing - Thermographic testing - Part 1: General principles.
- DIN EN 16714-2, 2016-11: Non-destructive testing - Thermographic testing - Part 2: Equipment.
- DIN EN 16714-3, 2016-11: Non-destructive testing - Thermographic testing - Part 3: Definitions
- DIN EN 17119, 2018-10: Non-destructive testing - Thermographic testing - Active thermography.
- DIN 54183, 2018-02: Non-destructive testing - Thermographic testing - Inductively excited thermography.
- DIN 54184, 2017-10: Non-destructive testing - Pulse thermography with optical excitation.
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- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comment

Physical basis	Electromagnetic measuring principle
Procedure **Radiographic testing / radiography** Radiographic Testing/ Radiography	Test task - Reinforced masonry

Brief description

Non-destructive testing to determine the internal structure of the component to be tested by different attenuation (absorption) of ionizing primary radiation due to differences in density, thickness and material in the component. - Volume method

Standard area of application (practical testing tasks)

- as a supplement to the radar method for targeted detailed investigations [2]
- Determination of the position and geometry of metallic fixtures such as steel beams, reinforcement and anchors [2]
- Determination of material differences [2]

Application limits (technical, physical, economic)

- difficult interpretation of the imaging image due to irregular component geometry (e.g. ornaments) [2]

Special applications (additional testing tasks)

On-site requirements

- Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)
- multi-sided accessibility of the component to be examined
- Dangerous goods regulations required for transportation of radionuclides

Procedure description

Long description

In radiographic testing, a radiation source, X-ray tube or radioactive radiation source in the gamma range, is set up on one side of the component to be tested in accordance with the component thickness to be tested. The outgoing ionizing radiation is attenuated differently due to differences in density, thickness and material. The internal structure of the component is displayed in an imaging image in various shades of gray. Masonry is generally shown in black due to its lower density, while the reinforcement is shown in shades of gray due to its higher density and greater absorption.
On the opposite side of the component, this attenuated primary radiation is detected and recorded using X-ray films, imaging plates, fluoroscopes, image intensifiers or flat panel detectors.
The exact geometry and position of built-in parts can be determined by means of reconstruction calculations using a large number of recording arrangements from different viewing angles (multi-angle technique). [1,2,4]

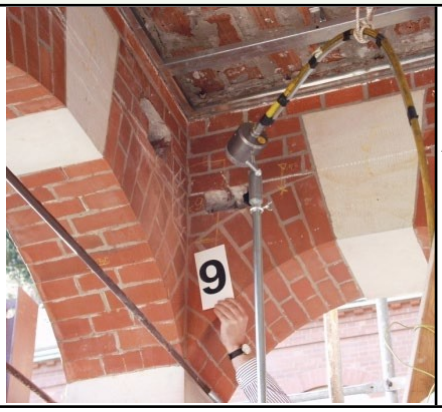
Procedure advantages and disadvantages (compared to procedures for the same test task)

+ Non-contact and completely non-destructive
- Traffic restriction during the test due to radiation protection
- Transportation of dangerous goods
- A large number of recordings and relocation of the test setup are time-consuming

Measuring method

Measurement setup

Radiography on masonry: radiation source, A. Taffe, HTW Berlin



Measurement results

Radiography on masonry: Image acquisition system, A. Taffe, HTW Berlin

Measuring devices

- Radiation source (as a function of component thickness): [1,4]
  - X-ray tube
  - Gamma emitters with the radionuclides iridium or cobalt
  - Betatron or linear accelerator
- Image acquisition system: X-ray film, imaging plate, fluoroscope, image intensifier, flat panel detector [1,4]
- Control unit for regulating the voltage and current for the radiation intensity and energy
- Power connection

Measured variable

- Reconstruction and visualization of the different radiation intensities in imaging form
- Specified feature(s): e.g. cracks, internal defects
  - qualitative: detected or not detected
  - Quantitative: e.g. dimensions and location of a damaged area, etc.

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, guidelines, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning [1, DGZfP B02]
- Choice of radiation energy and radiation source as well as imaging technology (e.g. X-ray film, digital imaging plates)
- Determination of the test areas and a test system: Recording arrangement
- Determining the exposure time
- Determination of the area to be cordoned off on the basis of the Radiation Protection Ordinance

3. Performance of the test (taking into account 2.): Radiographic testing
- Analog film technology: film processing (developing, intermediate rinsing, fixing, final rinsing, wetting agent balance, drying)
- Attaching the image quality test

4. Evaluation and documentation
- Logging of the implementation
- If necessary, image processing of the scanned radiographic films with the aid of special image processing systems improves the informative value
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
5/5	3/5	5/5	5/5

Further information

Device manufacturer, software

Related methods/ measurement variants

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- DIN EN 1330-3, 1997-10: Non-destructive testing - Terminology - Part 3: Terms used in industrial radiographic testing.

Personnel management, vocational training (03.100.30)
- Radiographic testing is one of the classic NDT methods and is marked with the abbreviation "RT". According to ***DIN EN ISO 9712:2012-12: Non-destructive testing - Qualification and certification of non-destructive testing personnel***, a level 1, 2 or 3 personnel qualification must be obtained in order to carry out radiographic testing.

Non-destructive testing (ICS 19.100)

- DIN EN 14784-1, 2005-11: Non-destructive testing - Industrial computed radiography with phosphor imaging plates - Part 1: Classification of systems. [Part 2: Withdrawn]
- DIN EN 16016-01, 2011-12: Non-destructive testing - Radiographic methods - Computed tomography - Part 1: Terminology
- DIN EN 16016-2, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 2: Principles, equipment and specimens
- DIN EN 16016-03, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 3: Execution and evaluation
- DIN EN 16016-04, 2012-01: Non-destructive testing - Radiographic methods - Computed tomography - Part 4: Qualification
- DIN EN 13068-1, 2000-02: Non-destructive testing - Radioscopic testing - Part 1: Quantitative measurement of imaging properties
- DIN EN 13068-2,2000-02: Non-destructive testing - Radioscopic testing - Part 2: Testing of long-term stability of imaging systems
- EN 13068-3, 2001-12: Non-destructive testing - Radioscopic testing - Part 3: General principles for radioscopic testing of metallic materials using X-rays and gamma rays
- DIN EN 25580, Non-destructive testing - Viewing devices for industrial radiography - Minimum requirements
- DIN EN ISO 15708-1, Non-destructive testing - Radiographic methods - Computed tomography - Part 1: Terminology [draft]
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- DIN EN ISO 15708-4, Non-destructive testing - Radiographic methods - Computed tomography - Part 4: Qualification
- DIN EN ISO 10675-1, 2017-04: Non-destructive testing of welded joints - Acceptance limits for radiographic testing - Part 1: Steel, nickel, titanium and their alloys. [Part 2: Aluminum]
- DIN EN ISO 19232-1, Non-destructive testing - Image quality of radiographic images - Part 1: Image quality test pieces (wire web)

Determining the image quality index

- DIN EN ISO 19232-2, Non-destructive testing - Image quality of radiographic images - Part 2: Image quality test pieces (step/hole type) - Determination of the image quality index
- DIN EN ISO 19232-4, Non-destructive testing - Image quality of radiographic images - Part 4: Experimental determination of image quality indices and image quality tables
- DIN EN ISO 20769-1, 2018-12: Non-destructive testing - Radiographic testing for corrosion and deposits in pipes using X-rays and gamma rays - Part 1: Tangential radiographic testing.
- DIN EN ISO 20769-2, 2018-12: Non-destructive testing - Radiographic testing for corrosion and deposits in pipes using X-rays and gamma rays - Part 2: Double-wall radiographic testing.

X-ray films (37.040.25)
- DIN EN ISO 11699-1, Non-destructive testing - Industrial films for radiographic testing - Part 1: Classification of film systems for industrial radiographic testing [Replacement for DIN EN 584-1:1994-10]
- DIN EN ISO 11699-2, Non-destructive testing - Industrial films for radiographic testing - Part 2: Control of film processing using reference values
- DIN EN 14096-1, 2003-08: Non-destructive testing - Qualification of X-ray film digitizing systems Part 1: Definitions; quantitative measurement of image quality parameters; standard reference film and quality assurance
- DIN EN 14096-2,2003-08: Non-destructive testing - Qualification of X-ray film digitizing systems - Part 2: Minimum requirements

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Other/ Notes/ Remarks/ Comment

Observance of and compliance with radiation protection regulations (StrlSchV Radiation Protection Ordinance)

3.14 Salt analysis method

As of 18.12.2019

Physical basis	Chemical measuring principle

Procedure	Test task
Salt analysis method	- Composition of building materials: Element content - Salts harmful to buildings: Salt content

Brief description

Non-destructive testing to determine the presence and type of building-damaging salts using qualitative salt analysis and subsequent determination of the distribution and quantity of salts (salt concentration) using semi-quantitative or quantitative salt analysis.

Standard area of application (practical testing tasks)

- Detection of water-soluble salts such as chloride, nitrate, carbonate, sulphate (anions)

[Salts are composed of anions and cations; detection of cations (iron, lead, calcium, magnesium, potassium, copper) is generally irrelevant because they are harmless to building materials].

Application limits (technical, physical, economic)

Special applications (additional testing tasks)

On-site requirements

- Accessibility of the component surface for suitable extraction equipment (core drill)
- Taking a representative sample
- Qualified personnel for laboratory analyses: Work in the chemical laboratory requires great care and caution as well as specialist knowledge

Procedure description

Long description

Differentiation between qualitative salt analysis, semi-quantitative salt analysis and quantitative salt analysis.
Qualitative salt analysis only provides a statement as to whether salts are present; a distinction is made between dry-chemical and wet-chemical analysis methods. The dry chemical methods are suitable as a preliminary test for simple detection. The wet-chemical methods provide complete proof with their tests.
The **semi-quantitative salt analysis** can be carried out as a test in the laboratory or on site with a test strip on a sample piece and then serves as a basis for further tests such as sampling for the laboratory, decision on further samples, number of samples and locations of the samples; sampling on the surface of the object by scraping off efflorescence.
Quantitative salt analysis is used to precisely determine the salt content and salt penetration depth with depth-graded analyses of samples. Quantitative salt analysis can be carried out using gravimetry/weight analysis or volumetry (titration)/measurement analysis as well as photometry. [1]

Procedure advantages and disadvantages (compared to procedures for the same test task)

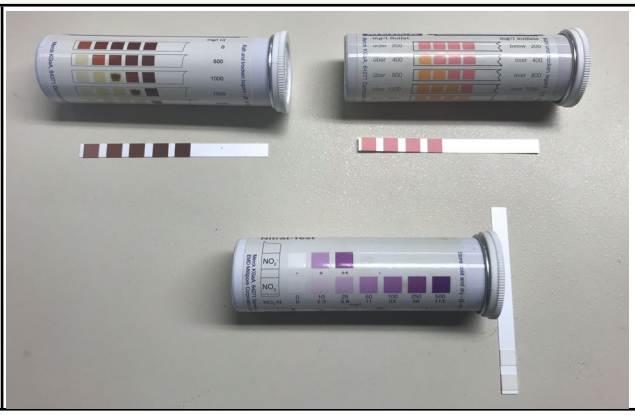
+ qualitative salt analysis: no destructive sampling
+/- semi-quantitative salt analysis: salt content in group classification, commercially available for purchase
- Quantitative salt analysis: destructive sampling, but exact salt content
- Determination of only one chemical element at a time in one analysis run on the same specimen (i.e. sample must be split)
- Quantitative methods are time-consuming due to the complex digestion of the sample and the use of equipment

244

Measuring method

Measurement setup

Test strips:
chloride test (top left),
sulphate test (top right),
nitrate test (bottom)
J. Wiese, HTW Berlin



Measuring equipment (measuring devices and test equipment)

- chemical solution or test strips
- Core drill for sampling

Measured variable and target variable

- Salt content as mass fraction of the sample in percent [M- %]

Measurement implementation, measurement strategy (what, when, where, how often?)

1. Information on the test task
- Definition of the test task and objective of the test
- Inspection of test specifications/recommendations (standards, data sheets)
- Information on the test object (ambient conditions, application limits, on-site requirements)
- Procurement of information, if necessary by reviewing old and existing documents

2. Test planning
- Definition of the test areas and a test system: Creation of a sampling plan

3. Performance of the audit (taking into account 2.)
- Sampling on site - either taking drill dust (depth-graded) or taking drill core samples
- Carrying out the chemical analysis in the laboratory

4. Documentation
- Logging of the implementation
- Evaluation of the results in a test report

5. Further information

Process effort (from **1: low effort** to **5: high effort**)

Technology	Time	Costs	Specialist knowledge
3/5	4/5	4/5	4/5

Further information

Device manufacturer, software

Semi-quantitative salt analysis:
- Macherey-Nagel GmbH & Co. KG: QUANTOFIX test sticks [http://www.mn-net.com/tabid/4770/Default.aspx]
- Hach: QuanTab Test Strips [https://de.hach.com/quick.search-quick.search.jsa?keywords=quantab]

Related methods/ measurement variants

Bibliography I (technical literature)

[1] Moschig, Guido F. (2014): Building refurbishment. Basics - planning - implementation. 4th edition. Wiesbaden: Springer Fachmedien Wiesbaden

Bibliography II (regulations: standards, guidelines, information sheets)

Terminology (ICS 01.040.19)
- DIN EN 1330-1, 2015-05: Non-destructive testing - Terminology - Part 1: General terms.
- DIN EN 1330-02, 1998-12: Non-destructive testing - Terminology - Part 2: Terms used by all non-destructive testing methods.

Bibliography III (General regulations)

Protection of and in buildings in general (ICS 91.120.01)
- VDI 6200, 2010-02: Stability of buildings - Regular inspection.

Civil engineering in general (ICS 93.010)
- DIN 1076, 1999-11: Engineering structures in the course of roads and paths - monitoring and testing.

Additional technical contract conditions and guidelines for civil engineering structures
- ZTV-ING - Part 3 - Solid construction. In: Federal Highway Research Institute (ed.): Zusätzliche Technische Vertragsbedingungen und Richtlinien für Ingenieurbauten.

Guidelines for the implementation of federal construction projects
- RÜV. Guideline for monitoring the traffic safety of federal construction facilities. In: Federal Ministry of Transport, Building and Urban Development (ed.): Richtlinien für die Durchführung von Bauaufgaben des Bundes, pp. 1-13.

Other/ Notes/ Remarks/ Comments