# INTERNATIONAL STANDARD

# ISO 24497-1

Second edition
2020-03

## Non-destructive testing — Metal magnetic memory —

## Part 1: Vocabulary and general requirements

*Essais non destructifs — Mémoire magnétique des métaux —*

*Partie 1: Vocabulaire et exigences générales*



Reference number
ISO 24497-1:2020(E)

# Contents

Page

# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.



This document was prepared by IIW, *International Institute for Welding*, Commission V, *NDT and Quality Assurance of Welded Products*.

This second edition cancels and replaces the first edition (ISO 24497-1:2007) and ISO 24497-2:2007, which have been technically revised and merged.

The main changes compared to the previous edition are as follows:

— the scope has revised and extended;

— new normative references have been added;

— Clause 3 has been revised;

— details on the test procedure have been added;

— details of the required test report have been added;

— a test example has been added in Annex A.

A list of all parts in the ISO 24497 series can be found on the ISO website.

Any feedback, question or request for official interpretation related to any aspect of this document should be directed to IIW via your national standards body. A complete listing of these bodies can be found at www.iso.org/members .html.

 

# Non-destructive testing — Metal magnetic memory —

# Part 1: Vocabulary and general requirements

## 1 Scope

This document specifies terms and definitions for non-destructive testing (NDT) by the technique of metal magnetic memory (MMM) as well as general requirements for application of this technique of the magnetic testing method.

The terms specified in this document are mandatory for application in all types of documentation and literature of non-destructive testing, using the metal magnetic memory technique.

This NDT technique has the following objectives:

— determination of the heterogeneity of the magneto-mechanical state of ferromagnetic objects, detection of defect concentration and boundaries of metal microstructure heterogeneity;

— determination of locations with magnetic stray field aberrations for further microstructural analysis and/or non-destructive testing and evaluation;



— early diagnostics of fatigue damage of the inspected object and evaluation of its structural life time;

— quick sorting of new and used inspection objects by their magnetic heterogeneity for further testing;



— efficiency improvement of non-destructive testing by combining metal magnetic memory testing with other NDT methods or techniques (ultrasonic testing, x-ray, etc.) by fast detection of the most probable defect locations;

— quality control of welded joints of various types and their embodiment (including contact and spot welding). See ISO 24497-2 for details of this application.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO/TS 18173, *Non-destructive testing — General terms and definitions*

ISO 24497-2, *Non-destructive testing°— Metal magnetic memory — Part 2: Testing of welded joints*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 18173 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

 

**3.1**
**metal magnetic memory**
**MMM**
magnetic state of a ferromagnetic object, depending on how the field has changed in the past and a consequence of the magneto-mechanical hysteresis of the material

Note 1 to entry: For a given magnetic field (e.g. the magnetic field of the earth), a ferromagnetic object formed in the course of its fabrication or in operation changes its residual magnetization due to diverse environmental factors which influence the magnetic domain distribution[35] (e.g. temperature, mechanical loads[6][10][17] or microstructural changes of the material).

**3.2**
**magnetic stray field**
**SF**
magnetic field that leaves or enters the surface of a part without intentional magnetization of that part

Note 1 to entry: A ferromagnetic material produces magnetic fields both within its own volume and in the space around it. The field generated by the magnetization distribution of the material itself is known as the stray field outside the body or as the demagnetizing field within it. Demagnetizing fields and stray fields are geometry dependent and arise whenever the magnetization is non-uniform or has a component normal to external or internal surfaces[46]. High local changes of the stray field – similar to magnetic flux leakage – can indicate heterogeneity of material properties.

Note 2 to entry: Other terms that have been used in literature are, for example, self-magnetic leakage field, residual magnetic field, surface magnetic field, magnetic leakage field, magnetic field density or surface field. Stray field is the recommended term for passive magnetic field measurements when used for non-destructive testing purposes, whereas magnetic flux leakage defines a magnetic flux intentionally amplified due to external sources before or during testing.



**3.3**
**metal magnetic memory testing**
**MMM testing**
technique of the magnetic testing method in NDT based on the measurement and analysis of the *magnetic stray field* (3.2) distribution on the surface of inspected objects (IOs) without intentional (active) magnetization

Note 1 to entry: Magnetic field sensitive probes are used to measure the stray field distribution

**3.4**
**stray field vector**
$\boldsymbol{H}_{\mathbf{SF,i}}$
magnitude in direction *i* (*i*= *x*, *y*, *z*) of the magnetic field of the inspected object surface determined by passive magnetic field sensing

**3.5**
**stray field indication**
**SFI**
any deviation from SF (stray field) uniformity caused by high mechanical stress/strain gradients as sources of local stray fields[6][10][17][47]

Note 1 to entry: An SFI is also formed at positions with local magnetic permeability changes, which can be caused by defect concentrations (e.g. cracks, pitting corrosion), boundaries of strong heterogeneities in the metal microstructure, impurities, abrupt geometry changes[24][25][57][60], internal and external surfaces[46], separation of the inspection objects body, irreversible deformations (with high dislocation densities) and changes of the chemical compositions (e.g. depositing or leaching).

Note 2 to entry: An SFI is not necessary a defect indication and requires interpretation to determine its relevance; see also Annex A. SFI replaces the term stress concentration zone (SCZ) as used before this revision. It is recommended to use SCZ only for locations where mechanical stress is concentrated (e.g. sharp corners, crack tips).

 

**3.6**
**stray field gradient**
***$K_{SF}$***
change in stray field magnitude with respect to change of sensor position and/or change of time, *t*, for the same sensor position

Note 1 to entry: The stray field gradient, $K^j_{SF,i}$, is calculated according to Formulae (2) and/or (3).

**3.7**
**median stray field gradient**
***$K_{med}$***
median slope of SF along and/or between measuring line(s) calculated according to Formula (4)

Note 1 to entry: It is related to the shape anisotropy of the IO and its magnetic polarization. If the magnetization state of initial operating state of the IO is unknown, the median gradient provides an estimation of the proper state of the IO. In particular, the normal SF component shows frequently a characteristic curve between positive and negative values.

Note 2 to entry: Changes of the median gradient between periodic ($\Delta t$, time-dependent) measurements and/or changes between working conditions of the IO, e.g. the in-service state and without operation loads can be related to magneto-mechanical effects.

**3.8**
**magnetic index**
***$m_i^j$***
ration of the local SFI gradient to the median SFI gradient for evaluation of the SFI, according to Formula (6)



**3.9**
**distance between neighbouring scanning lines**
***$\Delta y$***
distance between the centre points of the sensors in the head and/or distance between two adjacent measurement lines

Note 1 to entry: This distance affects the *stray field gradient* (3.6), $K^j_{SF,i}$.

**3.10**
**discrete sampling distance in the scanning line**
***$\Delta x$***
distance between two adjacent measuring points of the magnitude or components of the stray field

Note 1 to entry: This sampling distance affects the *stray field gradient* (3.6), $K^j_{SF,i}$.

**3.11**
**magnetic stray field diagram**
graph displaying the stray field distribution and/or *stray field gradient* (3.6) and/or *median stray field gradient* (3.7) versus the scanning path

**3.12**
**lift-off**
distance between surface of IO and centre of the magnetic probe's sensing area/volume

Note 1 to entry: A small lift-off is essential for the reliability of SFI evaluation.

## 4 General requirements

**4.1** The MMM technique is based on measurement and analysis of the SF distribution of ferromagnetic objects. The magnetization can reflect the microstructural and technological past and load history of ferromagnetic metallic components, including welded joints. SFs generated by the residual magnetization formed in magnetic fields during the process of the fabrication and the service life time of the IO shall be used during testing.

**4.2** The MMM technique enables the detection of SFIs and gives recommendations for additional non-destructive testing of vessels, pipelines, equipment (e.g. steam generators, turbines, heat exchangers, rails), and construction welded joints. ISO 24497-2 shall be applied for testing of welded joints.

NOTE SFIs of IOs are conditioned by the fabrication technology (fusion, forging, rolling, turning, press forming, thermal treatment, etc.).

**4.3** Under certain conditions the MMM technique can be used on non-magnetic IOs, particularly if a ferromagnetic phase is present (e.g. metastable austenitic steels, mill scale, coatings).

NOTE Metastable austenitic steels can be inspected if their microstructure is sensitive to $\gamma$ - $\alpha$ phase transformation[18]. The evaluation of SFs is restricted to the ferromagnetic phase.

**4.4** The temperature range during MMM testing shall be within the normal and safe working range for the operator (NDT inspector).

## 5 Requirements for the inspected object

**5.1** Equipment and structures (IOs) should be inspected by MMM in in-service state (under load) as well as in the maintenance state (after removal of operating loads). If possible, the initial magnetic service state of the IO should be determined.



**5.2** Surface dressing and preparation are not required. It is recommended to remove insulation to reduce sensor to surface lift-off to gain reliability and avoid SFI from the insulation. In particular cases, non-magnetic insulation can be allowed during inspection. Any permissible insulation layer shall be verified experimentally. The results shall be attached to the test report.



**5.3** Limiting factors for the application of MMM testing are the following:

— de-magnetization and intentional magnetization of the IO;

— foreign external (electro-)magnetic fields near to the inspected object, near the inspected region of interest;

— temperature changes can influence the test results (e.g. at Curie temperature);

— Sensor to IO surface distance (lift-off) and its changes during the measurement.

**5.4** Strong temperature changes in the IO cause changes of the thermoremanent magnetization and should be taken into account during processing of the inspection results.

**5.5** Sources of SFI along the IO are the following:

— shape and geometry of the IO (geometry changes and the edges of the IO) are sources of SF and have to be considered, because surface geometry are sources of strong local stray and demagnetizing fields[24][25][46][60];

— high mechanical stress gradients;

— boundaries of heterogeneous plastic deformation;

— changes in the microstructure;

— external magnetic fields, e.g. (welding) electric current flow at the inspected object, strong and heterogeneous magnetic fields close to the tested area;

 

— foreign ferromagnetic material on the inspected object and near the region of interest;

— local "artificial" magnetization, induced due to former magnetic fields;

— second phase particles with different magnetic properties;

— temperature changes.

All the above sources can influence the evaluation of an SFI and should be taken into account for SFI assessment.

## 6 Requirements for the test equipment

**6.1** The operation principle shall be based on sensitive magnetic sensors detecting the SF of the near-surface area of the IO. Magnetic-sensitive probes (e.g. fluxgate transducers) in magnetometer or gradiometer configuration can be used.

**6.2** MMM instruments shall have a display of the testing parameters, a microprocessor based digital data acquisition and storage and a position encoded movement of the sensors. An external computer interface shall enable external data storage, retrieving and display of results. External evaluation software should be provided together with the instrument.

**6.3** The sensor type and sensing size is determined by the specific inspection tasks. The equipment should have at least two measurement channels, one for the SF measurement at the IO and the other for compensation of influences of external magnetic fields, $H_e$. The sensor type and setup (e.g. gradiometer/magnetometer) shall be documented in the test report.



**6.4** The sensor shall be manipulated by a scanner and a position encoder shall determine the actual sensor position during the scanning path. On an IO, where it is difficult to use a scanner, it is allowed to acquire real-time data.



**6.5** The following factors influence the SF measurements:

— sensor lift-off from the IO surface;

— sensor sampling rate along the IO surface;

— sensor sensitivity;

— sensor size;

— alignment of the sensor sensitive direction in relation to IO;

— rotation of the sensors in relation to external field sources (e.g. magnetic field of the earth).

**6.6** MMM instruments shall fulfil at least the following minimum requirements:

— the relative error of the measured magnitude of the magnetic SF for each sensor shall be less than ±5 %;

— the range of sensor sensitivity should be in the order of 1 nT/√(Hz) to 100 μT/√(Hz);

— the relative error of the length measurement shall be less than ±5 %;

— the measurement range of the sensors shall not be less than ±1 000 A/m at a resolution of at least 1 A/m;

— the sampling distance (distance between the two adjacent measurement points) shall be in the order of the sensor size and according to the test procedure;

 

NOTE The sampling size affects SF gradients and SFI detection and evaluation (see 7.2).

— the overall electronic noise level generated by sensors and system shall be less than ±5 A/m;

— inspection tools shall be operable at temperatures from -20 °C to +60 °C.

# 7 Preparation for testing

**7.1** The preparation procedure shall contain the following basic stages:

— analysis of the technical documentation of the IO and preparation of the IO chart (inspection plan, preparation of IO logfile);

— selection of sensors and equipment;

— preparation of a written procedure for this testing;

— setting and calibration of instruments and sensors according to the written instruction;

— segmentation of the IO into individual inspection areas and inspection units and their indication in the IO logfile.

**7.2** The analysis of technical documentation of the inspected object includes the following:

— information about the steel grades and the dimensions and positions of the selected inspection areas;



— analysis of the IO operation modes and reasons of possible failures (damages);



— surface condition of the IO (e.g. mill scale, polished, corrosion, paint);



— geometry of the IO, design and locations of welded joints.



# 8 Test procedure

**8.1** The magnetization of the inspection object is generally unknown. The three Cartesian components of the SF shall be measured along the IO surface by continuous or discrete scanning with the instrument sensors. If possible, the sensor alignment shall coincide Cartesian with the scanning direction. Otherwise, this shall be documented in the test report.

The IO position in relation to external magnetic field shall not be changed during the measurement. The surface of the test object shall be covered with a dense network of measurement lines. The positions with extreme $H_{SF,i}$ changes on the IO surface shall be determined and registered by the measurement system.

The modulus of the resulting field, $||H_{SF}||$ in A/m, is calculated in accordance with Formula (1):

$$\|H_{SF}\| = \sqrt{H_{SF,x}^2 + H_{SF,y}^2 + H_{SF,z}^2} \quad (1)$$

where

$H_{SF,x}$ and $H_{SF,y}$ are two mutually perpendicular tangential components; and

$H_{SF,z}$ is the normal component of the SF in relation to the IO surface.

If one of the tangential components of the SF is hardly different from the external field (e.g. the magnetic field of the earth) or is close to zero for the whole measurement line, 2-dimensional discontinuities (e.g. cracks) orthogonal to this direction can hardly be detected.

NOTE The rotation of the IO in the Earth's magnetic field can provide a remedy for zero tangential SF values.

 

If the dominant SF direction of the IO is not parallel to the measurement line, the measurement shall be repeated along this direction. Otherwise, the subsequent evaluation steps shall be calculated between the measuring lines and along the principal direction of the (internal) field after the change of basis. The rotation of the SF direction between periodic measurements can indicate magneto-mechanical effects.

If the IO in operation is part of a magnetic circuit (in contact with other ferromagnetic objects) and is removed for inspection, additional demagnetization fields in the IO are enabled. If the IO is removed from its operation position, the magnetic fields in operation position as well as in inspection position shall be determined and documented in the test report.

**8.2** For qualitative assessment of a SFIs, the gradient, $K^j_{\mathrm{SF,i}}$ in A/m$^2$, indicating the changes of magnitude of the magnetic stray field $H_{\mathrm{SF}}$[7][16][19][22][24][46] in the direction $j$ ($j$ = $x,y,z$) shall be determined in accordance with Formula (2):

$$K^{j}_{SF} = \frac{\left|\Delta \left\| H_{SF} \right\| \right|}{\Delta d} \tag{2}$$

or separately for each magnetic field component, $i$ ($i$ = $x,y,z$), in accordance with Formula (3)

$$K^{\mathrm{j}}_{\mathrm{SF,i}} = \frac{\left|\Delta H_{\mathrm{SF,i}}\right|}{\Delta d} \tag{3}$$

where



$\Delta H_{\mathrm{SF,I}}$ is the difference of the $H_{\mathrm{SF,i}}$ field between two adjacent scanning points;

$\Delta d$ is the distance between these adjacent points [in the scanning line ($\Delta d = \Delta x$) or between neighbouring lines ($\Delta d = \Delta y$)];



$i$ is the magnetic field component, $H_{\mathrm{SF,i}}$, ($i$ = $x,y,z$), for which the gradient is calculated;

$j$ is the spatial direction, ($j$ = $x,y,z$), for which the gradient is calculated.

The gradient shall be calculated in both in-plane ($x,y$) directions of the IO for all measured magnetic field components ($x,y,z$).

$K(t+\Delta t)_{\mathrm{SF,i}}$ values shall be compared to previous (time, $t$) measurement results $K(t)_{\mathrm{SF,i}}$ if possible.

**8.3** High $K^j_{\mathrm{SF,i}}$ values of the normal and/or tangential components are SFIs. The median value, $K^j_{\mathrm{med,SF,i}}$, of all normal and tangential components of the field shall be calculated for all SFIs revealed on the inspected object. Evaluation of edge effects and geometry changes should be avoided, for both $K^j_{\mathrm{SF,i}}$ and $K^j_{\mathrm{med,i}}$, in A/m$^2$ [see Formula (4)]

$$K^{\mathrm{j}}_{\mathrm{med,i}} = \mathrm{median}\left(K^{\mathrm{j}}_{\mathrm{SF,i}}\right) \tag{4}$$

**8.4** Intersections of the normal SF component with the median slope of the measurement lines are SFIs, if the point of intersection is additionally related to a higher magnitude of at least one of the tangential SF components.

**8.5** SFIs are as in accordance Formula (5):

$$K^{\mathrm{j}}_{\mathrm{SF,i}} > K^{\mathrm{j}}_{\mathrm{med,i}} \tag{5}$$