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Non-destructive testing — Metal magnetic memory —

Part 2: Inspection of welded joints

Essais non destructifs — Mémoire magnétique des métaux —

Partie 2: Examen des assemblages soudés

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Foreword

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

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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 ISO 24497-3:2007, which has been technically revised.

The main changes are as follows:

— Clauses 2 and 3 have been updated;

— the scope has been modified, MMM is a technique of the MT method;

— Clause 4 has been modified;

— Clauses 5, 6 and 7 have been replaced by references to ISO 24497-1;

— figures and annexes have been modified for more exact descriptions.

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 2:
Inspection of welded joints

1 Scope

This document specifies general requirements for the application of the non-destructive (NDT) metal magnetic memory (MMM) testing technique of the magnetic testing method for quality assurance of welded joints.

This document can be applied to welded joints in any type of ferromagnetic products: pipelines, vessels, equipment, and metal constructions, as agreed with the purchaser.

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 17635, *Non-destructive testing of welds — General rules for metallic materials*

ISO 24497-1:2020, *Non-destructive testing — Metal magnetic memory — Part 1: Vocabulary and general requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 24497-1 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/

4 Basic principles

4.1 MMM testing is based on measurement and analysis of the distribution of stray fields (SF) on the material of welded joints reflecting their technological past. Residual magnetization, induced during the welding process, for example, is the main driving force for the SF inspection.

4.2 MMM testing permits the detection of stray field indications (SFI) and gives recommendations for additional non-destructive testing in critical zones of vessels, pipelines, equipment, and construction welded joints.

4.3 MMM testing allows the inspection of welded joints of any size and configuration (butt, tee, fillet, lap, edge, intermittent, etc.) on all types of ferromagnetic and metastable austenitic steels and alloys, as well as on cast irons.

NOTE The evaluation of SFI of metastable austenitic steels is restricted to ferromagnetic phases.

4.4 MMM testing can be carried out on the weld after construction, during operation, or after repair.

4.5 The following indications can be found during MMM testing:

— zones of probable location of all types of micro- and macro-defects (pores, slag inclusions, discontinuities, cracks, ruptures);

— SFIs caused by the welding process and SFIs along the welded joints.

4.6 MMM testing can be used for inspection of the weld properties:

— the degree of quality degradation of welds by defects, and the presence of developing defects;

— the quality of welded joints for selection, acceptance and optimization of welding technology.

4.7 The MMM testing temperature range shall be from −20 °C to +60 °C, limited only by the conditions of the operators and sensors operational range.

4.8 Following MMM testing, conventional non-destructive testing methods shall be applied in zones of SFIs and probable locations containing micro- and macro-defects. ISO 17635 shall be used for selection of suitable NDT methods.

4.9 Weld seams are sources of local SF due their geometry, welding process and changes of the magnetic properties in the heat affected zone (HAZ), weld metal (WM) and parent metal (PM). For more information, see Bibliographic references [1], [2], [3] as well as the bibliography of ISO 24497-1.

5 Requirements for the inspected object

The requirements for the inspected object (IO) are defined in ISO 24497-1.

6 Testing equipment requirements

The requirements for the test equipment are defined in ISO 24497-1.

7 Preparation for testing

Preparation for testing is described in ISO 24497-1.

8 Test procedure

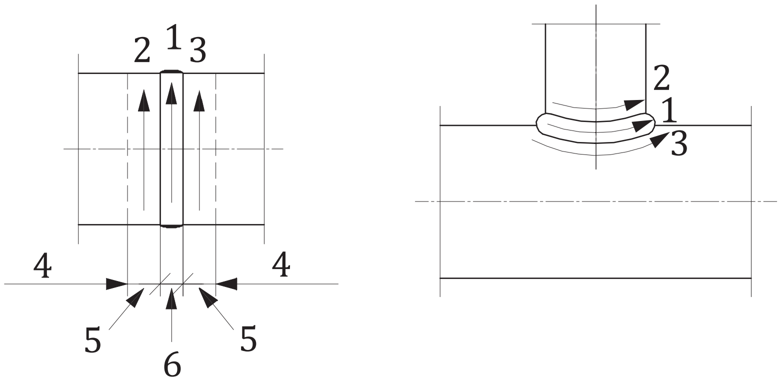
8.1 General

The mathematical basics of the MMM technique are described in ISO 24497-1.

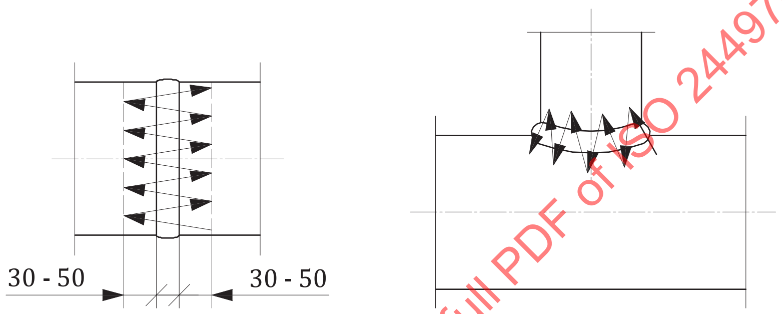
8.2 Manual inspection of welded joints

Sequences of manual scanning with the sensor of the instrument for evaluation of several types of welded joints are shown in Figure 1.

Dimensions in millimetres



a) Scanning sequence parallel to the welded joint



b) Scanning sequence perpendicular to the welded joint

Key

1, 2, 3	inspection zones
4	parent metal
5	heat affected zone of welded joint
6	weld material
30-50	width (in mm) of HAZ to be inspected

Figure 1 — Manual scanning sequences of the sensor for evaluation of several types of welded joints

The magnetic sensor (e.g. flux-gate transducer) is placed perpendicular to the inspection surface. It is then moved by the operator manually and sequentially:

— first along the entire perimeter of a weld (separately along a weld material and along the heat-affected zones on both sides of the weld);

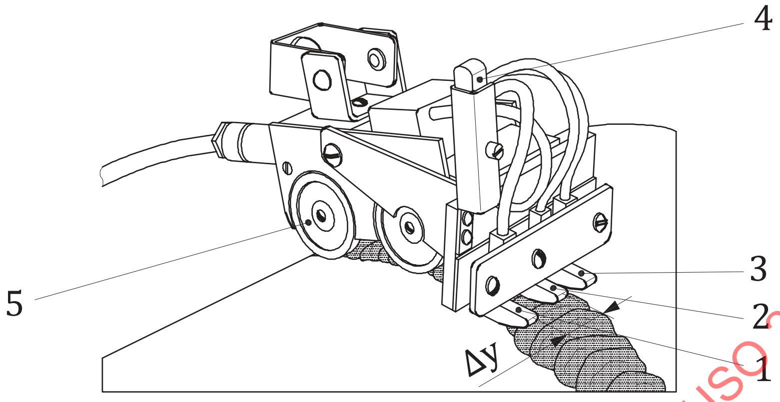
— then perpendicular to the weld, with a distance from the edge of the weld of 30 mm to 50 mm on both sides of the parent material of a pipe, see Figure 1.

The operator records the inspection data in a logbook: magnetic stray field indications with positive or negative amplitudes of SF ($H_{SF,i}$ in A/m). The discontinuous change of the sign and value of the $H_{SF,i}$ field indicates strong changes in the SF along the $H_{SF,i}$ = 0 line for a specific segment of the welded joint. These segments shall be marked (e.g. by chalk or paint).

8.3 Inspection of welded joints using a scanning system

An example for a scanning sensor for a butt-welded joint is shown in Figure 2. The inspection is carried out using a scanning head consisting of four flux-gate sensors 1, 2, 3, 4 (or others with sufficient sensitivity) and a position encoder, built into the case of a trolley to measure the length of an inspection segment simultaneously with the measurement of the magnitude of magnetic SF components, $H_{SF,i}$. As shown in Figure 2, during inspection, sensors 1 and 3 are sampling the heat-affected zones from both sides of a weld, and sensor 2 is centred between them. Sensor 4 is optional for compensation of external magnetic fields, H_e (gradiometer setup).

Prior to the start of an inspection the sampling distance of the measurement of the $H_{\mathrm{SF,i}}$ shall be set according to Clause 5. This sampling distances along the measurement line shall not exceed the wall thickness of the weld or the order of the sensor size.



Key

1, 2, 3 magnetic field sensors of the scanner for H_{SF} field recording on a weld surface
4 magnetic field sensor (optional) for compensation of an external magnetic field, H_e
5 wheel of a position encoder
Δy distance between adjacent transducers 1, 2, and 3

Figure 2 — Example of a 4-channel sensor in gradiometric configuration for inspection of butt-welded joints

The distance Δy between adjacent sensors 1, 2, and 3 shall be set in accordance with the dimensions of the welded joint and shall be recorded. If the optional gradiometer setup is used for measurement (as shown in Figure 2) the base line distance (distance between sensors 4 and 1) shall be specified in the test report.

NOTE Weld seams can show high SF gradients inherently. Small variations of both, the distance Δy between adjacent sensors and/or the sensor position in y-direction for the scanning sequence parallel to the welded joint can result in high variations of K_{SF} gradients.

9 Processing of test results

9.1 Using the results of MMM inspection, the following parameters are determined:

a) the magnetic field gradient for each measurement channel, see Formula (1):

$$K_{\mathrm{SF,i}}^{\mathrm{x}} = \frac{\left|\Delta H_{\mathrm{SF,i}}\right|}{\Delta x} \tag{1}$$

where Δx is the distance between adjacent points of the measurement lines (sampling distance) [see ISO 24497-1:2020, Formula (3) for the general case];

b) the magnetic field gradient between measurement lines, see Formula (2):

$$K_{SF,i}^{y} = \frac{\left|\Delta H_{SF,i}\right|}{\Delta y} \tag{2}$$

where Δy is the base distance between measurement lines;

c) calculation of median $K^j_{med,i}$ values according to ISO 24497-1:2020, Formula (4), values for each measurement channel and the basic distance between measurement channels;

d) the magnetic parameters, m^j_i [according to ISO 24497-1:2020, Formula (6)], describing the degree of non-uniformity of the SF distribution, depending on the welded joint quality:

$$m_i^j = \frac{K_{SF,i}^j}{K_{med,i}^j} \tag{3}$$

NOTE Subscript i denotes the Cartesian components ($i = x, y, z$) of the magnetic field relative to the IO, where z is the surface normal and the index j denotes the direction of the gradient calculation ($j = x, y, z$) in the same Cartesian space.

9.2 Areas with the magnetic parameter, m_i, above a threshold value, m_{lim}, are SFIs (see also ISO 24497-1). At SFIs, weld defects are probable.

NOTE The threshold value m_{lim} of m_i can be determined for objects with the same geometry and material produced with the same manufacturing process, when the defect or operation limit is specified on the basis of other destructive or non-destructive testing methods. Otherwise, $m_{lim} = 1$ and $K_{SFI,i} > K_{med,i}$.

9.3 From the results of the MMM testing, the segments are identified for additional inspection by other non-destructive or destructive testing methods.

9.4 The results of the measurements are recorded and summarized. The testing logfile shall be enclosed. An example of a test report is given in Annex A.

9.5 An example of $H_{SF,i}$ test results using a manual device is shown in Annex B.

9.6 An example of test results for a scanning device is shown in Annex C. The parameters $K^j_{med,\,i}$, $K_{SF,i}$, and m_i are calculated according to ISO 24497-1:2020, Clause 8.

Annex A
(informative)

Test report

Name of company ______________________________

Name of equipment, type, serial number ______________________________

Number of logbook, figure, scheme ______________________________

Test log No. ______________________________

Name of the inspection object and inspection volume ______________________________

Name of the technique or written procedure ______________________________

Inspection data

No.	Location of SFI (figure, scheme) in welded joint	Extrema (min/max) of $H_{SF,i}$	Values of inspection parameters					Results of inspection by other methods (destructive or non-destructive)	Notes
			$K^j_{SF,i}$ of SFI	$K^j_{max,i}$	$K^j_{med,i}$	m^j_i	Sensor lift-off		

Detected segments of SFI:

Conclusions:

for additional testing and repair ______________________________

The testing was carried out by ______________________________

(position, name and signature)

Certificate No. and qualification of operator ______________________________

Date of testing: ______________________________

Annex B
(informative)

Example of manual stray field measurements

This example describes manual testing of a butt-welded joint. MMM testing was performed along the heat–affected zone (HAZ), [line a in Figure B.1 a)], according to the scheme of testing shown in Figure 1 a). For example, the distribution of the magnetic field $H_{SF,z}$ along the circumference of a butt-welded joint in the HAZ and in a zone with a stray field indication, [SF line (b), with $H_{SF,z} = 0$ crossings] is shown in Figure B.1 b). In Figure B.1 b), the points 1-6 were marked. Multiple changes of the field $H_{SF,z}$ polarity ($H_{SF,z}$=0) were detected in these points 1-6. This section of the diagram is the area of an SFI. Multiple changes of the field $H_{SF,z}$ polarity, ($H_{SF,z}$=0 crossings), in the points 1-6 were caused by intersections of the SF line (c) with the $H_{SF,z} = 0$ line (a) in Figure B.1 c) during scanning along the HAZ of the weld.

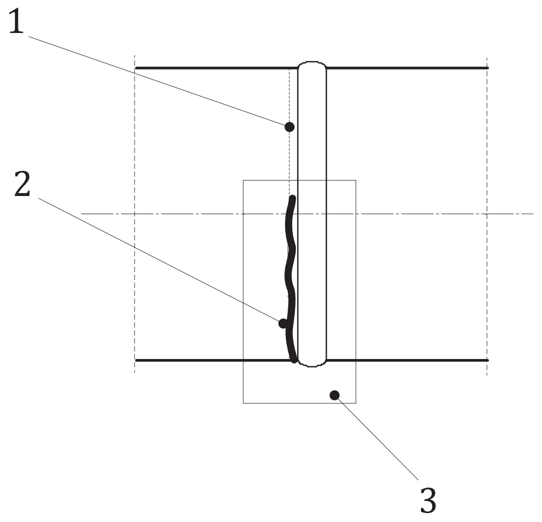
To define the stray field indication near to the SF line, ($H_{SF,z} = 0$ line), on an equal length Δy from both sides of the line [Figure B.1 d)] the value $H_{SF,z}$ is measured, and the gradient of the value of $H_{SF,z}$ along the length Δy is determined. This gradient, $\left|\Delta H_{SF,z}\right|/2\Delta y$, according to ISO 24497-1:2020, Formula (3), characterizes the magnetic field gradient, $K^{y}_{SF,z}$.

For example, for segments of a welded joint, see Figure B.1 c), the $K^{y}_{SF,z}$ values for points 1 and 2 [see Figure B.1 d)] are as follows:

— For point 1: $K^{y}_{SF,z} = \dfrac{|15-(-10)|}{2" y}$ A/m/mm $= \dfrac{25\ A/m}{20\ \text{mm}} = 1{,}25\ \dfrac{A/m}{\text{mm}} = 1\ 250\ \text{A/m}^2$

— For point 2: $K^{y}_{SF,z} = \dfrac{|15-(-30)|}{2" y}$ A/m/mm $= \dfrac{45\ A/m}{20\ \text{mm}} = 2{,}25\ \dfrac{A/m}{\text{mm}} = 2\ 250\ \text{A/m}^2$

Consequently, the maximum value of $K^{y}_{SF,z}$ is in point 2.



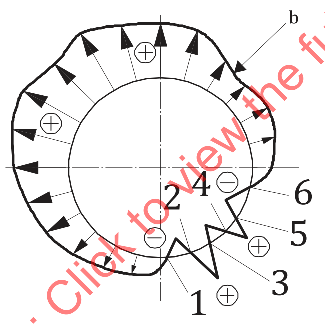
a) Scheme of testing and location of the detected SF line ($H_{SF,z}$=0 line)

Key

1 scanning line along HAZ of the weld

2 $H_{SF,z}$=0 line

3 detailed view of SFI in Figure B.1 c)

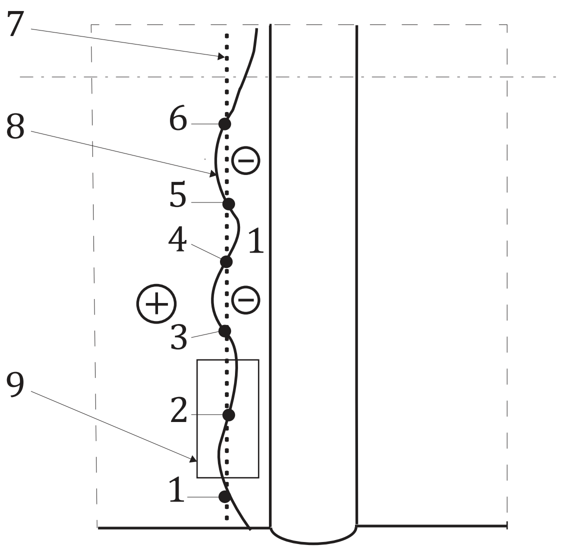


b) Cross-sectional presentation of the magnetic field $H_{SF,z}$ along the circumference of a butt-welded joint in HAZ

Key

b circumferential distribution of the magnetic field $H_{SF,z}$

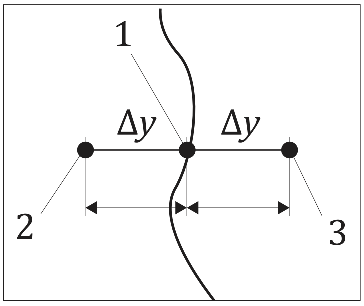
1 - 6 intersection points of $H_{SF,z}$=0 line during scanning along the HAZ of the weld



c) Detailed view of SFI of Figure B.1a) - locations of intersection points 1-6 of the SF line ($H_{SF,z}$ = 0 line) during scanning along the HAZ of the weld

Key

1 - 6 intersection points of $H_{SF,z}$=0 line during scanning along the HAZ of the weld
7 scanning line along HAZ of the weld
8 $H_{SF,z}$=0 line
9 detailed view in Figure B.1 d)



d) Detailed view of region 9 in Figure B.1 c) - scheme of field $H_{SF,z}$ measurements for gradient $K^{y}_{SF,z}$ calculation

Key

1 intersection point 2 of $H_{SF,z}$=0 line of Figures B.1 b) and B.1 c)
2 point of the field measurement $H_{SF,z}$=30 A/m
3 point of the field measurement $H_{SF,z}$=15 A/m
Δy distance between points of the field $H_{SF,z}$ measurements and $H_{SF,z}$=0 line (Δy = 10 mm)

Figure B.1 — Example of the magnetic field $H_{SF,z}$ distribution along the circumference of a butt-welded joint in a zone with stray field indications

Annex C
(informative)

Example of stray field measurements using a scanning system

This example describes the inspection of a circumferential welded joint in a thick-walled boiler drum (1 800 mm outer diameter and 87 mm wall thickness of a low alloy, high temperature steel) of a power plant block.

The inspection results of MMM testing using a device according to Figure 2 are shown in Figure C.1.

The circumferential (x-) distribution of the field $H_{SF,z}$ (stray field normal to the IO surface) along heat affected zones (HAZ) on both sides of the weld is shown in the upper part of Figure C.1 a). The SFIs are marked by (3), in which the stray fields $H_{SF,z}$ have a changing polarity with maximum amplitude. The calculated distributions of the modulus $K^x_{SF,z}=|dH_{SF,z}/dx|$ along both HAZ are shown on the foot of the Figure C.1 b). The maximum values of $K^x_{SF,z}$ in both graphs are given as:

$$\max\left(K^x_{1,SF,z}\right)=3\,500\,A/m^2;$$

$$\max\left(K^x_{2,SF,z}\right)=6\,200\,A/m^2$$

$$\max\left(K^y_{b,SF,z}\right)=3\,500\,A/m^2$$

The $\max\left(K^y_{b,SF,z}\right)=3\,500\,A/m^2$ is a SFI found after gradient calculation ($dH_{SF,z}/dy$) between measurement line 1 and 2 (not indicated in Figure C.1). The median stray field gradients $K^x_{1,med,z}$, $K^x_{2,med,z}$ and $K^y_{b,med,z}$ are:

$$K^x_{1,med,z}=\text{median}\left(K^x_{1,SF,z}\right)=\text{median}\left(\frac{\left|\Delta H_{1,SF,z}\right|}{\Delta x}\right)=2\,350\,A/m^2$$

$$K^x_{2,med,z}=\text{median}\left(K^x_{2,SF,z}\right)=\text{median}\left(\frac{\left|\Delta H_{2,SF,z}\right|}{\Delta x}\right)=3\,400\,A/m^2$$

$$K^y_{b,med,z}=\text{median}\left(K^y_{b,SF,z}\right)=\text{median}\left(\frac{\left|\Delta H_{b,SF,z}\right|}{\Delta y}\right)=1\,700\,A/m^2$$

$K_{1,\,med}$, $K_{2,\,med}$ are marked with threshold lines (8) and (9) in Figure C.1 b). Thus, the magnetic indices $m^j_{k,z}$ (k = 1,2,b) for the three maximum SFIs are:

$$m^x_{1,z}=\frac{\max\left(K^x_{1,SF,z}\right)}{K^x_{1,med,z}}=\frac{3\,500}{2\,350}\cong 1,5$$

$$m^x_{2,z}=\frac{\max\left(K^x_{2,SF,z}\right)}{K^x_{2,med,z}}=\frac{6\,200}{3\,400}\cong 1,85$$

$$m^y_{b,z}=\frac{\max\left(K^y_{b,SF,z}\right)}{K^y_{b,med,z}}=\frac{3\,500}{1\,700}\cong 2,1$$