INTERNATIONAL STANDARD

ISO 20890-5

First edition
2020-06

Guidelines for in-service inspections for primary coolant circuit components of light water reactors —

Part 5: Eddy current testing of steam generator heating tubes

Lignes directrices pour les contrôles périodiques des composants du circuit primaire des réacteurs à eau légère —

Partie 5: Essai de tuyaux de chauffage pour générateurs de vapeur par courant de Foucault

Reference number
ISO 20890-5:2020(E)

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Foreword

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This document was prepared by ISO/TC 85, *Nuclear energy, nuclear technologies, and radiological protection*, Subcommittee SC 6, *Reactor technology*.

A list of all parts in the ISO 20890 series can be found on the ISO website.

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Guidelines for in-service inspections for primary coolant circuit components of light water reactors —

Part 5:
Eddy current testing of steam generator heating tubes

1 Scope

This document gives guidelines for pre-service inspection (PSI) and in-service inspections (ISI) by eddy current tests on non-ferromagnetic steam generator heating tubes of light water reactors, whereby the test is carried out using mechanised test equipment outwards from the tube inner side.

An in-service eddy current test of steam generator heating tube plugs as a component of the primary circuit is not an object of this document. Owing to the different embodiments of steam generator heating tube plugs, the use of specially adapted test systems to be qualified is necessary.

Test systems for the localisation of inhomogeneities (surface) and requirements for test personnel, test devices, the preparation of test and device systems, the implementation of the testing as well as the recording are defined.

NOTE Data concerning the test section, test extent, inspection period, inspection interval and evaluation of indications is defined in the nuclear safety standards.

It is recommended that the technical specifications are based on experience on U-tube bends with even bend radius (similar to the S/KWU design). To test other kind of tube bends (e.g. U-tube bends with two 90° bends) further qualifications will be provided.

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 8596, *Ophthalmic optics — Visual acuity testing — Standard and clinical optotypes and their presentation*

ISO 9712:2012, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 12718, *Non-destructive testing — Eddy current testing — Vocabulary*

ISO 15548-1, *Non-destructive testing — Equipment for eddy current examination — Part 1: Instrument characteristics and verification*

ISO 15548-2, *Non-destructive testing — Equipment for eddy current examination — Part 2: Probe characteristics and verification*

ISO 15548-3, *Non-destructive testing — Equipment for eddy current examination — Part 3: System characteristics and verification*

ISO 15549, *Non-destructive testing — Eddy current testing — General principles*

ISO 18490, *Non-destructive testing — Evaluation of vision acuity of NDT personnel*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12718 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
analysis system
<eddy current testing> test system that is used with scanning sensors or segment sensors at steam generator heating tubes for more precise characterisation of *indications* (3.2)

3.2
indication
representation or signal from a discontinuity in the format allowed by the NDT method used

[SOURCE: ISO/TS 18173:2005, 2.14]

Note 1 to entry: Signal that is initiated by operationally induced damage mechanisms, geometrical as well as material or design induced influences.

3.3
evaluation
assessment (3.5) of *indications* (3.2) revealed by NDT against a predefined level

Note 1 to entry: Inspection of the recorded signals in respect to completeness and analysis capacity, localisation and registration of indications according to defined criteria, representation of the test results.

[SOURCE: EN 1330-2:1998, 2.10]

3.4
basic frequency
test frequency that is used primarily for the localisation and analysis of indications in the standard technique

3.5
assessment
comparison of the analysed measuring data with specified criteria

3.6
form indication
signal that is caused by geometrically induced influences

3.7
calibration
<eddy current testing> determination of the interrelation between the output measured data of the eddy current test device and the associated *indications* (3.2), resulting from definite reference defects at reference specimens

3.8
calibration block
<eddy current testing> piece of material of specified composition, surface finish, heat treatment and geometric form, by means of which *eddy current test equipment* (3.15) can be assessed and calibrated

[SOURCE: ISO 5577:2017, 5.4.1]

3.9
test supervisor
responsible for application of the test method and for the individual details of the test implementation including monitoring of the activities for preparation and implementation of the test as well as analysis of the test results

3.10
test sensitivity
change to the initial variable of the *eddy current test system* (3.15) (amplitude/phase), in relation to the change in the underlying input variable (e.g. wall thickness attenuation)

3.11
probe
body containing exciter elements (e.g. coils) and measuring elements

3.12
standard technique
<eddy current testing> test system that is carried out with internal coaxial *probes* (3.11) with coaxial coils at steam generator heating tubes

3.13
interference signals
signals that impede the detection and analysis of indications

3.14
reference block
<eddy current testing> block of material representative of the material to be tested with similar electromagnetic properties containing well-defined artificial discontinuities, used to adjust the sensitivity and/or time base of the *eddy current test equipment* (3.15) in order to compare detected discontinuity *indications* (3.2) with those arising from the known artificial discontinuities

Note 1 to entry: Specified metallurgical, geometrical and dimensional characteristics means for example material, weld seam implementation, form, wall thickness with reference characteristics (e.g. notches, drill holes) that are adapted to the test assignment.

[SOURCE: ISO 5577:2017, 5.4.2]

3.15
eddy current test equipment
eddy current test system, test robot and its measured data logging as well as the analysis unit including software

4 Inspection technique

4.1 Preliminary remark

The suitability of the inspection technique and the test device system shall be validated corresponding to the requirements of the applicable regulations of the nuclear safety standard.

NOTE The procedure for the qualification is described in ENIQ report nr. 31[4].

A general test procedure shall be prepared. Annex A contains the items of the general test procedure.

A calibration procedure can be agreed between the contract partner and shall be documented.

4.2 General

During the eddy current testing of steam generator heating tubes, it is the task of the evaluation to differentiate the recorded signals according to

— operational indications (location, expansion and possibly their type, e.g. cracks, abrasions, dents),

— geometric indications (e.g. of structural parts such as spacers, tube bottom, rolled-in slugs), and

— other indications (e.g. of local fluctuations in the electrical conductivity and permeability, electrical interference, wobble effect of the probes, impurities on the inside or outside of the tube, production indications as well as any external parts present).

To attain a sufficiently accurate reproduction of the signal sequence, the spatial resolution shall be set so that the required spatial resolution is ensured by the selected sampling rate and the probe speed.

The probe speed shall be dependent on the base frequency and sample rate and shall be no faster than the speed required to obtain a clear signal from the reference standard through-wall hole, within the calibration limitations described in 6.3.3.2.

The following inspection technique can be used for the eddy current testing of steam generator heating tubes as part of the standard technique:

— Multiple frequency technique with internal bobbin probe (differential arrangement, see 4.3.1; absolute arrangement, see 4.3.3);

— Linking of the signals of multiple frequencies with internal bobbin probe in differential arrangement (see 4.3.2).

If the standard technique is inadequate for evaluation of the eddy current signals, eddy current techniques for more extensive evaluation (see 4.4 for additional techniques, e.g. rotating scanning probes, matrix probes with T/R technique) or other non-destructive testing methods (e.g. ultrasonic testing, visual inspection) shall be applied.

Supplementary to the standard technique, eddy current techniques for more extensive analyses can also be used as localisation systems in case of specific requirements (e.g. testing in the area of tube bottom/roll-in slugs).

4.3 Standard technique

4.3.1 Multiple frequency technique with internal bobbin probe in differential arrangement

4.3.1.1 Basic frequency

The total tube circumference is recorded integrally when testing with an internal coaxial probe. The extension of indication can therefore only be determined in the axial direction. In the undisturbed area, evaluation of the signals of a frequency for determining location, depth and axial extension of an operational change is sufficient.

If indications overlap (e.g. operational indications and form indications), a statement is generally only possible with restrictions. The multifrequency technique shall then be used in the mix (linking of multiple frequencies) (see 4.3.2).

When testing operationally indications, the test frequencies used are generally in the range from 10 kHz to 1 MHz. The basic frequency shall be selected so that the phase offset angle between a 20 % flat-bottom hole applied on the outside of a reference specimen and a through-wall drilled hole is in the range from 90° to 120°.

4.3.1.2 Comparison between the signals of several individual frequencies with internal bobbin probe

If indications occur, further frequencies can be used for the differentiation of interference signals and operationally indications in addition to the basic frequency. The individual frequencies shall be selected so that a significant phase offset angle is reached between indications and interference signals.

4.3.2 Linking the signals of multiple frequencies with internal bobbin probe in differential arrangement (mixed technique)

4.3.2.1 General

Two to four frequencies are used generally for this inspection technique.

Linking the signals of multiple frequencies (mix) allows a quantitative analysis of operationally indications even when indications with interference signals overlap. However, the test sensitivity (fault detectability) generally declines for areas in which the evaluation is conducted in the mix.

The following two mixes shall be used as a minimum:

— 2-frequency mix for the area of the spacers and the area of the tube bottom;

— 3-frequency mix for the area of tube bottom with tube expansion (roll-in).

4.3.2.2 Two-frequency mix

The frequencies shall be selected so that the interference signals of all structural parts (e.g. spacers, corrugated iron, and oscillation limiters) are suppressed. The phase offset angle between a wall thickness weakening of 20 % applied on the outside of a reference specimen and a wall penetrating reference fault shall be in the range from 80° to 100°.

4.3.2.3 Three-frequency mix

The frequencies shall be selected so that the interference signals of rolling and tube bend upper edges or support plates and “pilger effects” are suppressed simultaneously. In addition, the mix phase offset angle for wall thickness weakening applied to the outside of a reference specimen of 60 % and 20 % shall exhibit a difference of minimum 40°.

4.3.3 Multifrequency system with internal bobbin probe in absolute arrangement

In contrast to the multiple frequency technique in differential arrangement, the absolute arrangement serves for localising and evaluating flat incident indications with large extension in the axial direction (e.g. large area abrasion in the area of tube bends) or for determining the sedimentation level in the area above the tube bottom.

4.4 Inspection techniques for more extensive analyses

To supplement the standard inspection technique, probes are specifically used for the analysis of already localised operational indications. These probes serve for characterisation of the indications in respect to

— circumferential expansion,

— longitudinal expansion,

— determining the number of indications both in the longitudinal and circumferential direction,

— indication orientation, and

— indication type.

Here a detailed determination of the indication position in relation to structural parts can be made. Owing to the smaller coil length of coverage, the smaller zone of interaction or the width of coverage, the test sensitivity is increased in the longitudinal direction and in the circumferential direction (i.e. in the entire range of the tube circumference). The multiple frequency technique is usually used here in the same way as the standard inspection technique. The following are typically used as analysis probes:

— Rotating scanning probes;

— Segmentcoils;

— Matrix probes (array probes).

The following clauses in this document define the requirements for the standard inspection techniques and shall be applied correspondingly to the analysis techniques used. Special requirements for the analysis techniques require separate definition.

5 Requirements

5.1 Test personnel

5.1.1 Task of NDT personnel

NDT personnel[4] have a great responsibility, not only with respect to their employers or contractors but also under the rules of good workmanship. The NDT personnel may be independent and free from economic influences with regard to his test results, otherwise the results are compromised. The NDT personnel shall be aware of the importance of his signature and the consequences of incorrect test results for safety, health and environment. Under legal aspects, the falsification of certificates is an offence and judged according to the national legal regulations. A tester may find himself in a conflicting situation about his findings with his employer, the responsible authorities or legal requirements.

Finally, the NDT personnel is responsible for all interpretations of test results carrying his signature. NDT personnel should never sign test reports beyond their certification (see Table 1).

NOTE For reasons of readability, the male form is used with personal names, however the female form is also always intended.

5.1.2 Personnel requirements

The test personnel comprise operating personnel for test robots, operating personnel for eddy current test devices and analysts as well as the test supervisor.

Those personnel, using qualified non-destructive testing (NDT) procedures and equipment, should be qualified through one or any combination of the following:

— certification through a national NDT personnel certification scheme;

— theoretical and/or open trials;

— blind trials.

Any personnel certification requirements invoking relevant national NDT personnel certification schemes (e.g. ISO 9712) should be validated according to Table 1. Any additional personnel training requirements should also be specified in the qualification dossier.

If no relevant scheme exists or if extra personnel qualification is needed, the qualification body should determine the additional practical and theoretical examinations needed beyond those in the national certification scheme, include these in the qualification procedure and ensure that the NDT procedure also includes the necessary requirements. The qualification procedure should describe the proposed system.