IEC 63078

Edition 1.0 2019-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Installations for electroheating and electromagnetic processing – Test methods for induction through-heating installations

Installations pour traitement électrothermique et électromagnétique – Méthodes d'essai pour les installations de chauffage par induction

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INTERNATIONAL
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INSTALLATIONS FOR ELECTROHEATING AND ELECTROMAGNETIC PROCESSING – TEST METHODS FOR INDUCTION THROUGH-HEATING INSTALLATIONS

FOREWORD

International Standard IEC 63078 has been prepared by IEC technical committee 27: Industrial electroheating and electromagnetic processing.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
27/1118/FDIS	27/1119/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

This International Standard is to be used in conjunction with IEC 60398:2015.

The clauses of this document supplement, modify or replace clauses of IEC 60398. When this document states “addition”, "modification" or “replacement”, the relevant text in IEC 60398 is to be adapted accordingly.

Subclauses which are additional to those in IEC 60398 are numbered starting from 101. Additional annexes are numbered AA, BB, etc.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Induction through-heating and induction melting are very important applications of induction heating. However, an induction through-heating installation is more complex than an induction melting furnace, as it includes more heating manners, varieties and sizes. In addition, some performance tests which are very useful to users, for example the determination of temperature homogeneity of billets and energy efficiency of the installation, are not easy to carry out.

Induction through-heating installations are widely used in many industries for example machine building and metallurgy, for heating billets or workpieces of alloy steel, copper, aluminum, etc. before their subsequent hot forming (e.g. forging, extruding and rolling), with clean and fast heating, easy temperature control and automation as well as a high degree of energy-saving.

This document was prepared on the basis of IEC 60398:2015, with some references made to IEC 62076:2006 and "Induction Heating – Industrial Applications" published by UIE in 1992.

INSTALLATIONS FOR ELECTROHEATING AND ELECTROMAGNETIC PROCESSING – TEST METHODS FOR INDUCTION THROUGH-HEATING INSTALLATIONS

1 Scope

This clause of IEC 60398:2015 is replaced by the following.

This document specifies the test procedures, conditions and methods for determining the main performance parameters and operational characteristics of induction through-heating installations.

Measurements and tests that are solely used for the verification of safety requirements of the installations are outside the scope of this document and are covered by IEC 60519-1 and IEC 60519-3.

This document is applicable to the induction heating installations which through-heat the whole or part of metal billet or workpiece for its subsequent hot forming (e.g. forging, extruding and rolling), using low, mains or medium frequencies. It is possible to use it as a reference for other induction heating installations for heat-treatment and other purposes as well as superconducting DC induction through-heating installations.

This document includes the concept and material on energy efficiency dealing with the electrical and processing parts of the installations, as well as the overall performance.

2 Normative references

This clause of IEC 60398:2015 is applicable except as follows.

Replacement:

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

Modification:

Delete footnotes

Additions:

IEC 60398:2015, *Installations for electroheating and electromagnetic processing – General performance test methods*

IEC 60519-1:—[1], *Safety in installations for electroheating and electromagnetic processing – Part 1: General requirements*

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1 Sixth edition under preparation. Stage at the time of publication: IEC PRVC 60519-1:2019.

IEC 60519-3:2005, *Safety in electroheat installations – Part 3: Particular requirements for induction and conduction heating and induction melting installations*

3 Terms and definitions

This clause of IEC 60398:2015 is applicable except as follows.

Replacement:

For the purposes of this document, the terms and definitions given in IEC 60398:2015 and the following apply.

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

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

Additions:

NOTE 101 For the following definitions of terms related to some parts and electrical parameters of power circuit of induction through-heating equipment, see also the explanatory diagrams in Annex AA. The symbols are also listed in Annex BB.

3.101
induction through-heating installation
installation comprising induction through-heating equipment and the electrical and mechanical auxiliaries necessary for the operation and utilization of the equipment

Note 1 to entry: The electrical auxiliaries comprise all electrical components in the power circuit of induction through-heating equipment, power supply for mechanical auxiliaries and control system; and the mechanical auxiliaries comprise billet handling mechanism and its mechanical power as well as water cooling system, etc.

3.102
induction through-heating equipment
equipment consisting of one or more heating inductors, supporting frames (cabinets) and the connections for cooling water and electricity, etc., for induction heating and holding of billet

3.103
batch heating
repetitive static heating manner, which involves placing an individual billet into a heating inductor for heating and holding, and then extracting it

[SOURCE: IEC 62076:2006, 3.39， modified – The differences between induction through-heating and induction melting in workload name and technological process have been considered.]

3.104
stage heating
heating manner having two or more heating inductors, in which, for a two heating inductor equipment for example, the billet is firstly placed into a heating inductor for heating, secondly moved to another heating inductor for holding and then extracted

3.105
continuous heating
heating manner, in which the billets progress continuously or rhythmically through one or more heating inductors for heating and holding

[SOURCE: IEC 62076:2006, 3.40， modified – The differences between induction through-heating and induction melting in workload name and technological process have been considered.]

3.106
lining
<heating inductor> part of inductor, which is placed between the induction coil and heated billet as a thermal insulation, and usually consists of a refractory layer and a temperature holding layer or is directly formed by ramming or pouring refractory materials

3.107
power circuit of induction through-heating equipment
circuit consisting of the power source(s) and compensated circuit(s) of the induction through-heating equipment, including the conductors connecting both

3.108
power source
equipment for the supply of power to the compensated circuit of induction through-heating equipment, being mains frequency single phase or three phases power supply or semiconductor frequency converter and having the following main specified characteristics:

- frequency f_2 or frequency band $f_{21}....f_{22}$
- voltage U_2 (RMS value)
- current I_2 (RMS value)
- active power P_2

[SOURCE: IEC 62076:2006, 3.13， modified – The types of power source used have been specified and supplemented, see Annex AA.]

3.109
compensated circuit of induction through-heating equipment
electric circuit comprising one or more inductors, a compensating capacitor bank and a load-matching transformer (if applicable)

Note 1 to entry: See Annex AA.

3.110
mass of test billets
G_{test}
out of the through-heated billets, total mass of those qualified used for the determination of specific energy consumption and productivity

3.111
dimensions of billet
maximum dimensions of the overall billets with any transport or protection means, which the induction through-heating equipment is designed for and is marked on the rating plate, expressed in diameter × length or width × thickness × length

3.112
billet temperature
θ_b
temperature of the billet at a given time of the through-heating cycle

3.113
starting temperature of billet
θ_{bs}
temperature of the billet at the beginning of the through-heating cycle

3.114
final temperature of billet
θ_{bf}
temperature of the billet attained at the end of the holding period of the through-heating cycle

3.115
rated temperature of billet
θ_{br}
temperature to be requested by through-heating technology for the billet of a given material, which the induction through-heating equipment is designed for and which is marked on the rating plate

3.116
temperature homogeneity of billet
$\Delta\theta_{b}$
homogeneous degree of billet temperature when it is extracted after heating and holding, which is expressed as the maximum and minimum deviations of the temperatures measured at the temperature measuring points with the rated temperature of the billet (they may be positive or negative), or expressed as the transverse (radial) temperature difference and the longitudinal temperature difference of the billet for the long billets with a circular or rectangular, etc. uniform cross section

Note 1 to entry: Requirements and measuring conditions for the determination of billet temperature homogeneity are specified in Annex CC.

3.117
transverse temperature difference of billet
radial temperature difference of billet
$\Delta\theta_{bt(r)}$
maximum and minimum temperature differences which may be positive or negative, between periphery and centre on the cross section of a long billet with a uniform cross section when it is extracted after its heating and holding

Note 1 to entry: Usually, the temperature at the centre of a billet cross section is lower.

Note 2 to entry: The radial temperature difference $\Delta\theta_{br}$ applies for a billet with a circular cross section.

3.118
longitudinal temperature difference of billet
$\Delta\theta_{bl}$
difference between the maximum temperature and the minimum temperature along the longitudinal direction of a long billet with a uniform cross section when it is extracted after its heating and holding

Note 1 to entry: Usually, the temperature at two ends of a billet is lower.

3.119
inlet temperature of cooling water
θ_{wi}
temperature of the cooling water when entering the cooling water circuit of the heating inductor

[SOURCE: IEC 62076:2006, 3.33， modified – The term and its symbol have been changed, the words “coolant” and “inductor assembly” have been replaced by “cooling water” and “heating inductor”.]

3.120
outlet temperature of cooling water
θ_{wo}
temperature of the cooling water when leaving the cooling water circuit of the heating inductor, with the induction through-heating equipment operating at rated conditions

[SOURCE: IEC 62076:2006, 3.34， modified – The term and its symbol have been changed, the words “coolant”, “inductor assembly” and “furnace” have been replaced respectively by “cooling water”, “heating inductor” and “induction through-heating equipment”.]

3.121
equipment duty at rated conditions
rated equipment duty
induction through-heating equipment operation with specified dimensions of lining and billet, specified billet quantity, rated power and rated frequency range without exceeding the maximum voltage and current defined by the supplier

3.122
thermal steady state
<equipment> thermal state in which the whole energy input into the induction through-heating equipment is used for the compensation of its thermal losses

Note 1 to entry: In thermal steady state, the temperatures of all constructional components of induction through-heating equipment and all the outlet temperatures of the cooling water are relatively stable and do not rise.

[SOURCE: IEC 62076:2006, 3.36, modified – The “furnace” has been replaced by “induction through-heating equipment” and the note added.]

3.123
hot state
<equipment> thermal steady state of the induction through-heating equipment when the billet is at its final temperature

[SOURCE: IEC 60683:2011, 3.13， modified – The definition suitable for induction through-heating equipment has been given with the ambiguous term “thermal condition” replaced by “thermal steady state” and “furnace” by “induction through-heating equipment”.]

3.124
cold state
<equipment> thermal state in which the induction through-heating equipment is not energized and the temperature of the whole equipment is at ambient temperature

[SOURCE: IEC 60683:2011, 3.4， modified – The definition suitable for induction through-heating equipment has been given.]

3.125
holding power
P_{h}
<equipment> active power supplied to the power circuit of induction through-heating equipment, in order to maintain the specified billet at a specified temperature for its temperature homogeneity

[SOURCE: IEC 60398:2015, 3.3.2， modified – The original definition including its two notes, has been simplified according to induction through-heating equipment.]

3.126
electrical energy consumption of the equipment
electrical energy supplied to the power circuit of induction through-heating equipment during the defined time period

Note 1 to entry: E_{ae}.is the active electrical energy consumption.

Note 2 to entry: E_{re} is the reactive electrical energy consumption.

[SOURCE: IEC 62076:2006, 3.42， modified – The words “energy consumption” and “furnace” have been changed to “electrical energy consumption” and “induction through-heating equipment”, and "during the defined time period" and the notes have been added.]

3.127
electrical energy consumption of the installation
active electrical energy consumption
E_{ai}
electrical energy supplied to the induction through-heating installation during the defined time period, including the active electrical energy consumption of the equipment E_{ae} and the active electrical energy consumption of electrical and mechanical auxiliaries of the equipment E_{aa}

3.128
specific electrical energy consumption of the equipment/installation
e_e/e_i
ratio of the electrical energy consumption of the equipment/installation E_{ae}/E_{ai} for heating specified billets from their starting temperature θ_{bs} to rated temperature θ_{br} and then holding them for temperature homogeneity, to the total mass of qualified billets of those through-heated billets, during a complete cycle of the batch heating type installation or a longer defined time period of the continuous heating type and stage heating type installations

Note 1 to entry: For a partial through-heating application, only the total mass of the through-heated parts of qualified billets is considered.

[SOURCE: IEC 60398:2015, 3.2.3， modified – The words “energy consumption” and “energy” have been changed to “electrical energy consumption”, the definition suitable for three types of induction through-heating equipment/installation has been given with a note added.]

3.129
productivity
g
<installation> ratio of the total mass of qualified billets of those through-heated billets for heating specified billets from their starting temperature θ_{bs} to rated temperature θ_{br} and then holding them for temperature homogeneity, to the time of a complete cycle of the batch heating type installation or a longer defined time period of the continuous heating type and stage heating type installations, during the complete cycle or the defined time period

Note 1 to entry: For partial through-heating application, only the total mass of the through-heated parts of qualified billets is considered.

[SOURCE: IEC 60050-841:2004, 841-22-71, modified – The definition suitable for three types of induction through-heating installation has been given with a note added.]

3.130
heating efficiency of the equipment/installation
η_e/η_i
ratio of the usable enthalpy increase in the qualified billets of those through-heated billets to the active electrical energy consumption of the equipment E_{ae} or to the active electrical energy consumption of the installation E_{ai} during a complete cycle of the batch heating type installation or a longer defined time period of the continuous heating type and stage heating type installations

[SOURCE: IEC 60398:2015, 3.2.4， modified – The definition suitable for three types of induction through-heating equipment/installation has been given.]

4 Basic provisions for testing and test conditions

This clause of IEC 60398:2015 is applicable except as follows.

4.3 Boundaries of the energy using system for testing

Additional subclause:

4.3.101 Boundaries of induction through-heating installation for testing

The energy consumption of an induction through-heating installation shall also include:

a) energy consumption of the power circuit of the induction through-heating equipment for heating and holding billets;

b) energy consumption of the control system of the installation.

The corresponding energy consumption supplied by some public service, for example hydraulic and/or pneumatic pumping station(s) to the installation, may be estimated according to the practical use or ignored when it is very small compared with the whole energy consumption of the installation.

4.4 General requirements for testing

This subclause of IEC 60398:2015 is applicable except for the following replacement and additions.

Replacement (of the first paragraph of this subclause of IEC 60398:2015):

The relevant safety requirements in IEC 60519-1:—, IEC 60519-3:2005 and the manufacturer's instructions shall be observed and necessary protective measures taken during all tests, to ensure safety.

Additions:

The tests of an induction through-heating installation are divided into cold state tests and hot state tests. Unless otherwise specified, the hot state tests shall be undertaken after the cold state tests are qualified.

The cold state tests shall be undertaken after manufacture or repair as well as during installation and regulation in the cold state. Installation and test preparation shall be carried out according to the manufacturer's instructions. Before the test, the electrical connections, switches, control system and some dimensions, etc. of the installation shall be inspected.

The hot state tests shall be undertaken with a new lining of specified dimensions and materials as agreed between the manufacturer and the user. The requirements for test billets shall be in accordance with 6.7.101. The technological process for heating and holding shall be agreed between the manufacturer and the user. The technological process also includes the loading, temperature measurement and unloading of billet. Where a test is to be performed in the hot state (see 3.123), the induction through-heating equipment shall have been in operation for at least 8 h (depending on the dimensions of billet or agreed between the manufacturer and the user) prior to the test. In the case where it starts with a new lining, it shall have been in operation for at least 24 h prior to the test.

The electrical data at the input of the supply line to be established by the tests of items b), c) and e) of 8.3 are related to the rated voltage U_n and the rated frequency f_n. Admissible deviations from the rated voltage and frequency shall be agreed between the manufacturer and the user. If during the test these deviations are exceeded, this shall be taken into account in the evaluation.

In the case where a mains transformer is used solely for the induction through-heating equipment, the electrical values at the input of the supply line may be determined from the corresponding values on the secondary side of the transformer taking into account its characteristic.

All measurements are to be taken using appropriate devices and following accurately the instructions for their use. The accuracy tolerances of all measuring instrument or devices (for values of electrical data, temperature and mass) shall be established and agreed between the manufacturer and the user.

In addition, all equipment composing the induction through-heating installation shall comply with their relevant specifications.

Attention should be drawn to the different parameters to be considered as regards the rated values of an induction through-heating equipment and to the tests intended for their verification; irrespective of the size of the equipment, its performance depends on:

– the heating type of the equipment;
– the design of the equipment and its heating inductor themselves;
– the material, shape and dimensions of the billet;
– the type and automation degree of the handling mechanisms of the billet;
– the type and frequency of the power supply unit used to feed the equipment;
– the type of control and regulating system of the power supply unit for the equipment;
– the ability of the power supply unit of the equipment to react to rapid variations of reactive power.

4.6 Environmental conditions during tests

Addition:

The inlet and outlet temperatures of cooling water of cooling circuits, especially for heating inductors, shall observe the manufacturer’s instructions. Excessive or less cooling will influence the measurement of energy efficiency.

5 Comparing equipment or installations

This clause of IEC 60398:2015 is applicable.

6 Measurements and workloads

This clause of IEC 60398:2015 is applicable except as follows.

6.3 Frequency measurement

Addition:

The accuracy of frequency measurement shall be of class 1.5 or better for mains frequency and medium frequency.

6.4 Measurement of electric data

6.4.1 Supply voltage

Addition:

NOTE Information on the influences of actual supply voltage or its variation on the performance of the installation can be found in 8.10 of IEC 60398:2015.

6.4.2 Voltage, current, electrical power and resistance

Addition:

The accuracy of equipment for voltage, current, power and electric energy measurements in the medium frequency shall be of class 2.5 or better.

When the waveforms of voltage and current show distortion, for example in the input and output terminals of the semiconductor frequency converter, special care should be taken and the measuring equipment used shall be able to show true RMS independent from the waveform.

6.4.3 Measurement positions

Addition:

For measurement positions of all electrical parameters of the power circuit of the induction through-heating equipment, see Figures AA.1 to AA.3; they are at the output terminals of the supply disconnecting device for the electrical energy consumption measurement of the power circuit, and at the output terminals of the power distribution cabinet in shop for other electrical and mechanical auxiliaries (see 4.3 of IEC 60398:2015 and b) of 4.3.101).

6.7 Workload

Additional subclause:

6.7.101 Test billet of induction through-heating installation

Actual billets shall be used as test billets and their material, shape and dimensions shall be in accordance with the design specifications of the installation. Test billets are provided by the user and their surfaces shall be clean and dry as well as have no scale and obvious burr, especially for the determination of temperature homogeneity of the billet in order to accurately measure the surface temperature.

7 Numerical modelling

This clause of IEC 60398:2015 is applicable with the following addition.

NOTE 101 For the numerical modelling method determining temperature homogeneity of billet, see Annex CC.

8 List of tests

8.1 General requirements

The test items related to safety and mechanical aspects also are important parts of a complete set of tests of the installation. Main safety test items include the measurements of insulation resistance, electric or magnetic fields and touch current as well as the protection test by automatic disconnection of supply, voltage test, dielectric test and accessibility test of live parts, etc. and the test methods shall follow 18.6.1 to 18.6.3 and 18.7.1 to 18.7.4 of IEC 60519-1:—. Mechanical test items include various tests of billet handling mechanisms, the test methods are intended to follow relevant ISO standards.

The tests of the induction through-heating installation may be selected from the tests listed in IEC 60398:2015, with necessary supplements made, according to the installation’s features and user’s needs. For the test items listed below, this document provides test methods which modify or supplement the related test methods in IEC 60398:2015 and IEC 60519-1:—, according to the installation’s features.

8.2 Cold state tests

The following cold state tests are related to safety (see Annex DD):

a) electrical withstand test of heating inductors (see Clause DD.1);
b) tightness test of cooling water circuits (see Clause DD.2);
c) flow test of cooling water circuits (see Clause DD.3).

8.3 Hot state tests

The following hot state tests are optional and may be selected as required for the characterization and evaluation of an induction through-heating installation:

a) measurement of temperature rise of cooling water (see 9.101);
b) determination of power and power factor of power circuit of induction through-heating equipment (see 9.102);
c) determination of holding power (see 9.103);
d) determination of temperature homogeneity of billet (see 9.104);
e) determination of specific electrical energy consumption and productivity (see 9.105);
f) determination of heating efficiency of the equipment/installation (see 9.106);
g) measurement of temperatures of structural components subject to heat (see 9.107).

9 Technical tests and efficiency of the installation

NOTE This clause corresponds to Clauses 8 and 9 of IEC 60398:2015.

The relevant parts of Clauses 8 and 9 of IEC 60398:2015 are applicable except as follows.

Additional subclauses:

9.101 Measurement of temperature rise of cooling water

This test shall be carried out in the hot state (see 3.123 and 4.4) of the induction through-heating equipment operating at its rated equipment duty (see 3.121), with the flow rate specified by the manufacturer, at the end of the test given in 9.6. The temperature of the cooling water shall be measured by thermometers or monitored by sensors at the inlet and outlet of the cooling water circuits of the equipment. The difference between the outlet and inlet temperatures is the value of temperature rise of the cooling water. During the test, the outlet temperature and the temperature rise shall be within the manufacturer's specifications.

It is recommended that several readings be taken, for example, every 5 min towards the end of the test period given in 9.6, to ascertain that the equipment has attained a stable hot state condition.

9.102 Determination of input power P and power factor λ of power circuit of induction through-heating equipment

The active power P is to be measured and the apparent power S can be determined by the measurements of the current I and voltage U at rated equipment duty (see 3.121) and in the hot state (see 3.123 and 4.4) of the induction through-heating equipment, see Figure AA.1. The power factor λ can be calculated as the ratio of the active power and the apparent power.

A low content of voltage and/or current harmonics does not significantly affect the test result; in these conditions, the power factor λ becomes practically equal to the cos φ measured by means of a cos φ-meter. In the case of a three-phase supply, it should be ensured that, during these measurements, currents in the three phases show no significant unbalance. It should be considered as a guideline that this requirement is met when the deviation of the current values from their mean value does not exceed ±10 %. Where the out-of-balance of the three-phase line currents exceeds ±10 %, an appropriate and more accurate method should be employed.

Active and reactive power remaining relatively constant during this test, active power may also be determined by the active energy (measured by an energy-meter) consumed during a given time period divided by the time of the time period. Similarly, power factor λ may be determined by measuring the active and reactive energy consumed in the same time period by means of adequate energy-meters.

9.103 Determination of holding power P_h

The test shall be carried out after the induction through-heating equipment containing the specified billet has been in normal operation for a sufficient time to ensure that it is in the hot state (see 3.123 and 4.4). The measurement shall be undertaken during a certain time period at the latter stage of the billet holding operation. The temperature of the billet shall be monitored so that the final temperature of the billet is maintained as constant as practicable throughout the time period.

For the batch heating type equipment and continuous heating type equipment only having one heating inductor, the holding-electrical consumption is measured directly at the input to its power circuit (see Figure AA.1).

For the continuous heating type equipment and stage heating type equipment having several heating inductors and one of them specially for holding the billet:

– the holding-electrical consumption is measured at the input of the power circuit which supplies electrical energy only to the heating inductor for holding;
– or in the case where the heating inductors for heating and holding are supplied by the same rectifier transformer (see Figure AA.2), the holding-electrical consumption is the electrical energy consumption E_{sfch} measured at the input of the frequency converter which supplies electrical energy only to the compensated circuit containing the heating inductor for holding, divided by the efficiency of the rectifier transformer η_{rt};
– or in the case where the heating inductors for heating and holding are supplied by the same rectifier (see Figure AA.3), measure the DC input power P_{sih} of the series type inverter which supplies electrical energy only to the compensated circuit containing the heating inductor for holding, at some time of the above-mentioned time period when the power is more stable.

The holding power is calculated by dividing the holding-electrical consumption measured during the above-mentioned time period by the time of the time period; or by dividing the above-mentioned P_{sih} by the rectifier transformer efficiency η_{rt} and the rectifier efficiency η_r.

For other power sources with different structure, the determination of holding power may be carried out with reference to the above-mentioned test methods.

9.104 Determination of billet temperature homogeneity $\Delta\theta_b$

See Annex CC.

9.105 Determination of specific electrical energy consumption e_e/e_i and productivity g

Unless otherwise arranged, determination of the specific electrical energy consumption e_e/e_i and productivity g is carried out at the site of the user.

The measurement shall be carried out after the induction through-heating equipment has been in normal operation for a sufficient time, to ensure that it is in the hot state (see 3.123 and 4.4). For the boundaries of induction through-heating installation for testing, see 4.3.101. For the measuring positions of the electrical energy consumptions of the power circuit of induction through-heating equipment as well as its electrical and mechanical auxiliaries, see 6.4.3. In addition, the starting temperature of the billet shall be measured and the billet temperature before its extracting shall be monitored.

The supplementary specifications for different heating types of installations are as follows:

a) Batch heating type installation

Not less than three successive operation cycles shall be undertaken. The active electrical energy consumption of the equipment E_{ae} and the active electrical energy consumption of electrical and mechanical auxiliaries of the equipment E_{aa} as well as the mass of the test billet G_{test} are measured during each operation cycle (including the loading, heating, holding and unloading of the billet).

The specific electrical energy consumption of the installation e_i is calculated by dividing E_{ae} and E_{aa} by G_{test}. The specific electrical energy consumption of the equipment e_e is calculated by dividing E_{ae} by G_{test}. The productivity g is calculated by dividing G_{test} by the time of the operation cycle. Take the average of the values measured in the above-stated several operation cycles as the determination result.

b) Continuous heating type and stage heating type installations

E_{ae}, E_{aa} and G_{test} are measured during a longer defined time period of the equipment's continuous operation. The time of the defined time period shall not be less than 4 h to approximately 8 h, depending on the dimensions of the billet or is agreed between the manufacturer and the user.

The calculations of the specific electrical energy consumption of the equipment/installation e_e/e_i are the same as in item a) above. The productivity g is calculated by dividing G_{test} by the time of the defined time period.

For a partial through-heating application, the total mass of the through-heated parts of qualified billets shall be considered in the above-mentioned calculations.

9.106 Determination of heating efficiency of the equipment/installation η_e/η_i

The heating efficiency of the induction through-heating equipment/installation may be calculated by use of e_e and e_i measured in 9.105 as follows:

$$\eta_e = e_{min} / e_e \quad (1)$$

$$\eta_i = e_{min} / e_i \quad (2)$$

$$e_{min} = 0{,}278\ c_p(T) \times \Delta T \quad (3)$$

where

η_e is the heating efficiency of the induction through-heating equipment, in %;

η_i is the heating efficiency of the induction through-heating installation, in %;;

e_{min} is the theoretical minimum specific electrical energy consumption of the billet, in kW·h/t;

e_e is the specific electrical energy consumption of the induction through-heating equipment, in kW·h/t;

e_i is the specific electrical energy consumption of the induction through-heating installation, in kW·h/t;

$c_p(T)$ is the specific heat of the billet, in kJ/kg °C, its possible nonlinear characteristic with temperature and step change at some point shall be considered;

ΔT is the temperature change of the billet from its starting temperature to its final temperature, in °C.

The heating efficiency including unqualified billets may also be calculated when requested.

9.107 Measurement of temperatures of structural components subject to heat

This test shall be carried out in the hot state (see 3.123 and 4.4) of the induction through-heating equipment operating at rated conditions, for example, immediately after the test described in 9.105.

The measuring points of the surface temperature are specified as follows:

a) the arbitrary points on surfaces of the end plates fixing the induction coil and the supporting frame or cabinet of heating inductor;

b) the arbitrary points on surfaces of the connection terminals of induction coil as well as heavy current busbars and their connection terminals.

For the end plates fixing the induction coil, their surface adjacent to the port of induction coil is not within the measuring range.

The surface temperature shall be measured by means of a contact thermocouple, thermometer or equivalent sensor with accuracy of class 2.5 or better.

Annex A
(informative)

Energy efficiency assessment

Annex A of IEC 60398:2015 is applicable.

Annex B
(informative)

Visual display of energy efficiency related information

Annex B of IEC 60398:2015 is applicable.

Annex C
(informative)

Estimating energy use

Annex C of IEC 60398:2015 is applicable.

Annex D
(informative)

Energy recoverability

Annex D of IEC 60398:2015 is applicable.

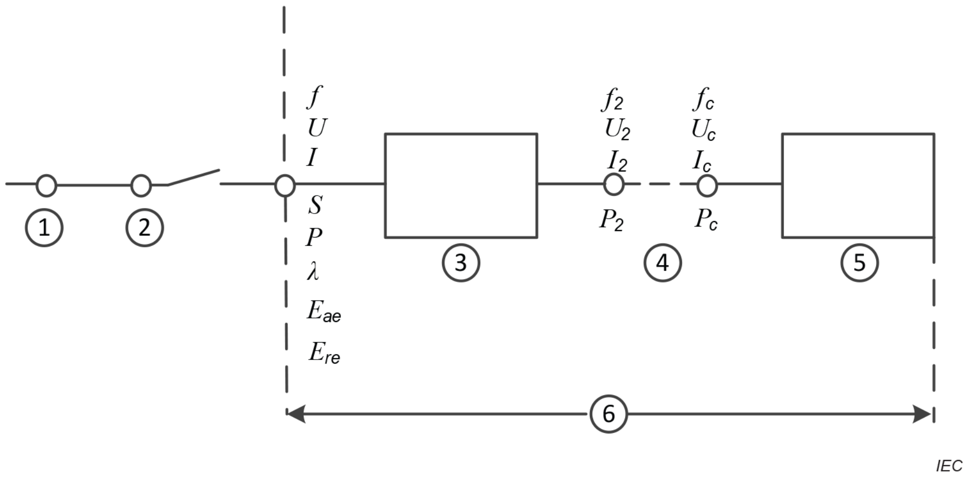
Annex AA
(normative)

Explanatory diagrams for symbols and definitions relating to the power circuit of induction through-heating equipment

AA.1 Power circuit of induction through-heating equipment

See Figures AA.1 to AA.3.

NOTE For the list of symbols, see Annex BB.



Key

1 supply line

2 supply disconnecting device

3 power source

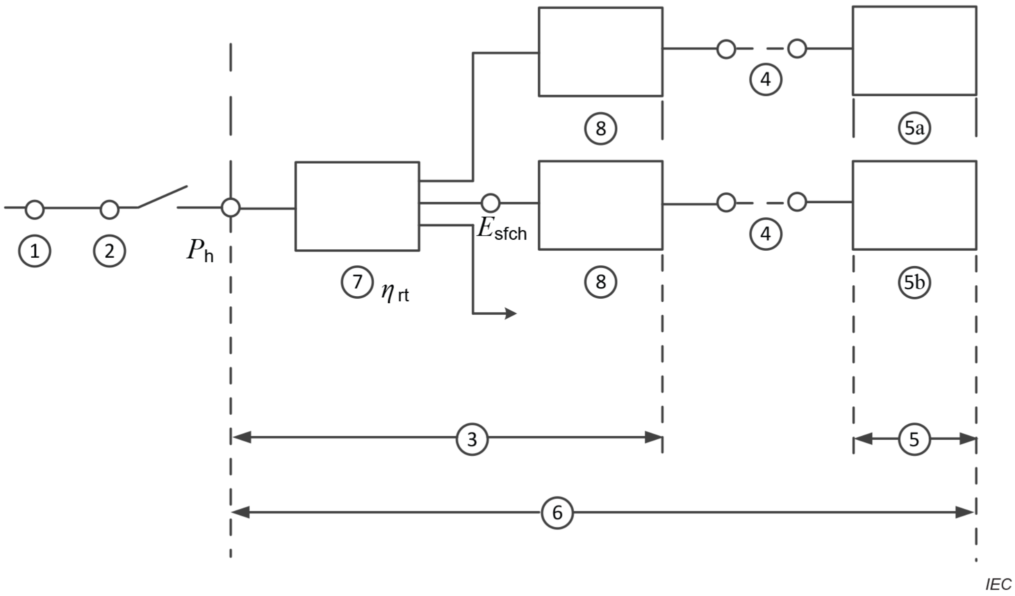
4 connection, for example, busbars, flexible cables (active and/or reactive impedances)

5 compensated circuit/load

6 power circuit of induction through-heating equipment

After the supply disconnecting device, several power circuits may be connected in parallel, which are composed of ③,④ and ⑤ and may have the same or different operation parameters. Sometimes one power source may supply several compensated circuits/loads, which may have the same or different structure and operation parameters, see Figure AA.2 and Figure AA.3.

Figure AA.1 – Basic power circuit of the induction through-heating equipment



Key

1 to 6 see Figure AA.1

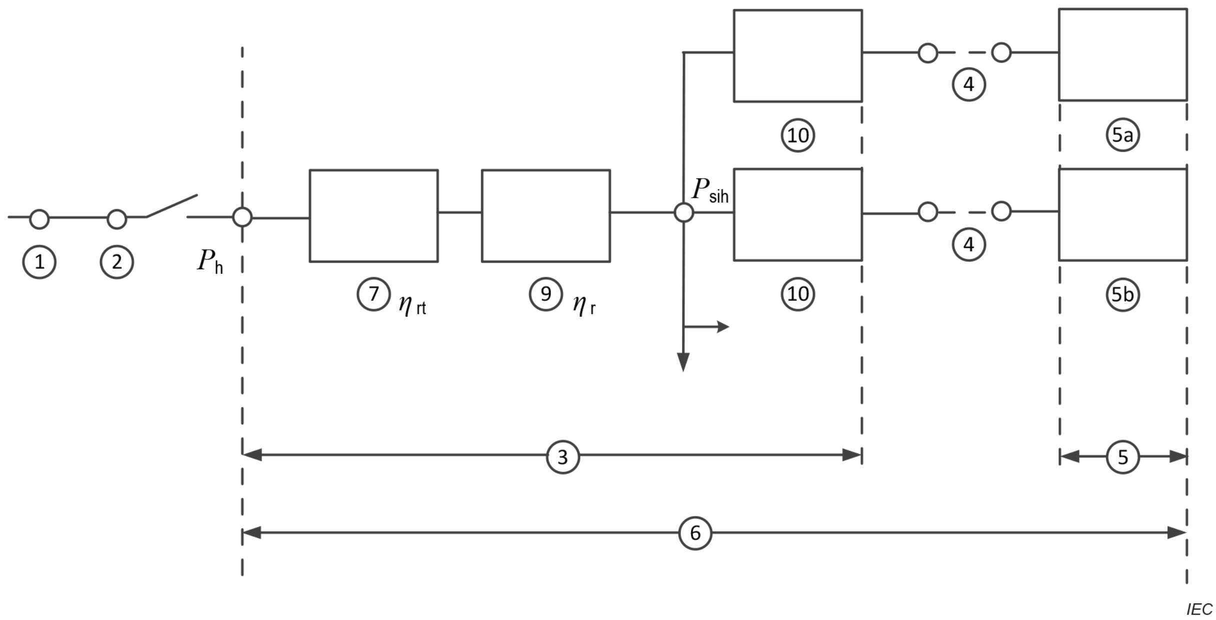
7 rectifier transformer (for large power);

8 semiconductor frequency converter (usually having different parameters)

5a compensated circuit/load having heating inductor for heating

5b compensated circuit/load having heating inductor for holding

Figure AA.2 – Power circuit of the induction through-heating equipment having one rectifier transformer as well as several semiconductor frequency converters and compensated circuits/loads



Key

1 to 7, 5a and 5b	see Figure AA.2
9	rectifier
10	series type inverter (usually having different parameters)

NOTE 9 and 10 compose a series type semiconductor frequency converter.

Figure AA.3 – Power circuit of the induction through-heating equipment having one rectifier transformer, one rectifier as well as several series type inverters and compensated circuits/loads

AA.2 Examples of power sources

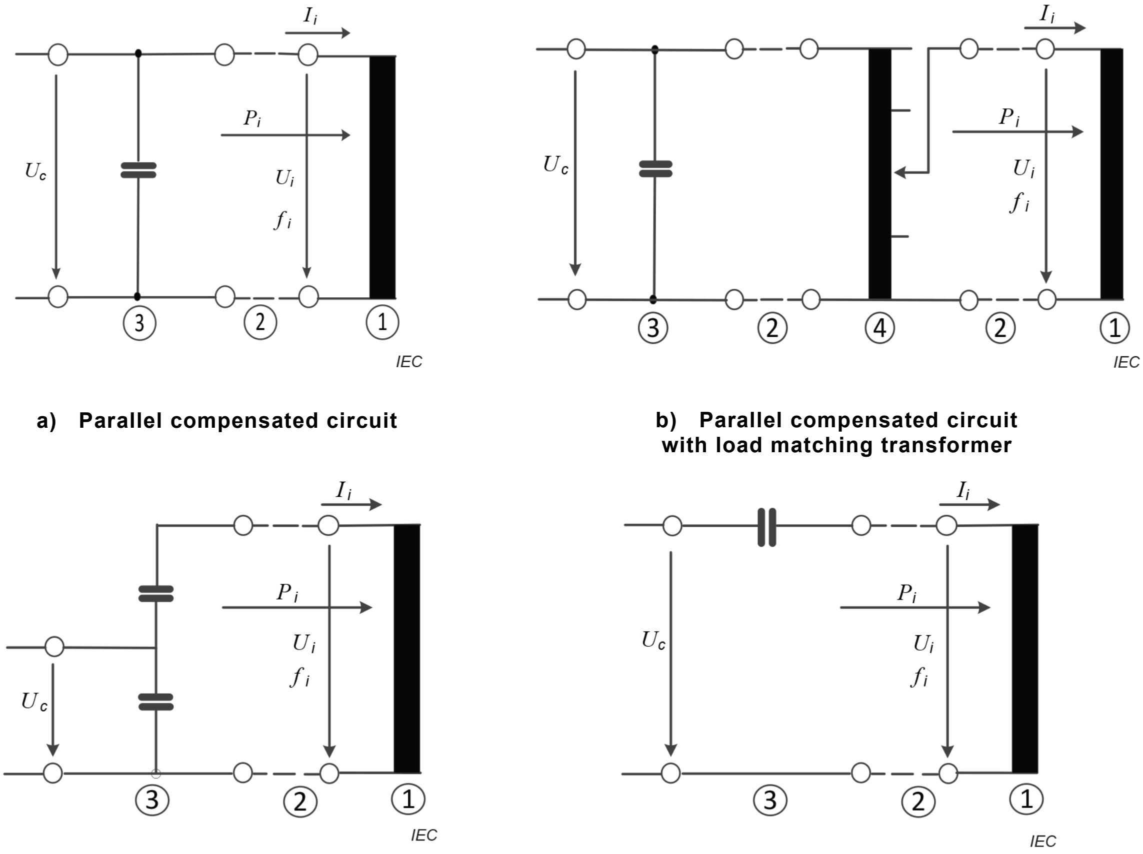
Power sources can be:

- Single-phase supply. Tap-changing transformer or other voltage-regulating device + load-switching contactors for mains-frequency single-phase induction through-heating equipment.
- Three-phase supply. Tap-changing transformer or other voltage-regulating device, load-switching contactors + phase-balancing equipment for mains-frequency single-phase induction through-heating equipment.
- Three-phase supply. Semiconductor frequency converter, including switching devices and rectifier transformer (for large power converter), for single-phase induction through-heating equipment operating at other than mains-frequency, see Figure AA.2 and Figure AA.3.
- Three-phase supply. Tap-changing transformer or other voltage-regulating device, load-switching contactors + phase-balancing equipment for the induction through-heating equipment with several heating inductors. The phase-balancing equipment may be omitted, if three identical heating inductors/loads are connected respectively to each phase.

AA.3 Examples of compensated circuit of induction through-heating equipment

See Figure AA.4.

NOTE For the list of symbols, see Annex BB.



a) **Parallel compensated circuit**

b) **Parallel compensated circuit with load matching transformer**

c) **Parallel compensated circuit with capacitive voltage transformation**

d) **Series compensated circuit**

Key

1 heating inductor, which may consist of one coil or several coils in series or in parallel (predominantly inductive load with active component)

2 connection (for example, busbars, flexible cables) representing active and/or reactive impedances

3 compensating capacitors

4 load matching transformer

Figure AA.4 – Examples of compensated circuits

Annex BB
(informative)

List of symbols used in this document

Symbol	Terms
$\cos \varphi$	power factor of the power circuit of induction through-heating equipment under sinusoidal conditions
$c_p(T)$	specific heat of the billet
e_e	specific electrical energy consumption of induction through-heating equipment
e_i	specific electrical energy consumption of induction through-heating installation
e_{min}	theoretical minimum specific electrical energy consumption of billet
E_{aa}	active electrical energy consumptions of electrical and mechanical auxiliaries of the induction through-heating equipment
E_{ae}	active electrical energy consumption of the power circuit of induction through-heating equipment
E_{ai}	active electrical energy consumption of the induction through-heating installation
E_{re}	reactive electrical energy consumption of the power circuit of induction through-heating equipment
E_{sfch}	electrical energy consumption of the semiconductor frequency converter supplying to the compensated circuit/load for holding
f	frequency at the supply line to the power circuit of induction through-heating equipment
f_2	frequency at the output of the power source
f_c	frequency at the input of the compensated circuit (= f_2)
f_i	frequency across the terminals of the heating inductor
g	productivity
G_{test}	mass of test billet
I	current at the supply line to the power circuit of induction through-heating equipment
I_2	current at the output of the power source
I_c	current at the input of the compensated circuit (= I_2)
I_i	current absorbed by the heating inductor of induction through-heating equipment
P	active power at the supply line to the power circuit of induction through-heating equipment
P_2	active power at the output of the power source
P_c	active power at the input of the compensated circuit
P_h	holding power of the induction through-heating equipment
P_I	power absorbed by the heating inductor of induction through-heating equipment
P_{sih}	DC input power of the series type inverter supplying to the compensated circuit/load for holding
S	apparent power at the supply line to the power circuit of induction through-heating equipment
U	voltage at the supply line to the power circuit of induction through-heating equipment
U_2	voltage at the output of the power source
U_c	voltage at the input of the compensated circuit
U_i	voltage across the terminals of the heating inductor of induction through-heating equipment
θ_b	billet temperature
θ_{bf}	final temperature of billet
θ_{br}	rated temperature of billet
θ_{bs}	starting temperature of billet
θ_{wi}	inlet temperature of the cooling water
θ_{wo}	outlet temperature of the cooling water

Symbol	Terms
$\Delta\theta_{b}$	temperature homogeneity of billet
$\Delta\theta_{bl}$	longitudinal temperature difference of billet
$\Delta\theta_{br}$	radial temperature difference of billet
$\Delta\theta_{bt}$	transverse temperature difference of billet
λ	power factor of the power circuit of induction through-heating equipment
η_{e}	heating efficiency of induction through-heating equipment
η_{i}	heating efficiency of induction through-heating installation
η_{r}	efficiency of rectifier
η_{rt}	efficiency of rectifier transformer

Annex CC
(normative)

Determination of billet temperature homogeneity $\Delta\theta_b$

CC.1 General requirements and measuring conditions

The temperature field inside the billet depends on the Joule heat distribution produced by the eddy currents which are induced within the billet due to the electromagnetic induction effect, and the temperature balance within the billet formed by thermal conduction and the heat losses of the billet surfaces, etc. Determination of temperature homogeneity of the billet shall comply with the specifications in 8.12.3 of IEC 60398:2015 and the following additions.

a) The determination of the temperature homogeneity of billets is carried out on the billet which has fulfilled the heating and holding process agreed between the manufacturer and the user, after the induction through-heating equipment has been in normal operation for a sufficient time, to ensure that it is in the hot state (see 3.123 and 4.4).

b) The temperature measurement shall be in accordance with 6.5 of IEC 60398:2015 and the additional specifications of this annex. All the instruments and sensors for temperature measurement used during the test, shall be appropriate and calibrated within the scope of the measured temperature, with the correction given. The temperatures at all measuring points of the billet shall be measured by use of the same instrument and sensor or instruments/sensors of the same type and specifications, and the temperature measurements shall be fulfilled at the same time or during a period as short as possible.

c) The test billets shall comply with the specifications in 6.7.101.

d) It should be pointed out that the position of the temperature control point for heating and holding the billet has an important influence on the determination result of the temperature homogeneity of the billet. It should be at the position where the highest temperature of the billet is always reached during heating.

CC.2 Three measuring methods

There are three methods for measuring the temperature homogeneity of the billet as follows.

a) Surface measuring method

   This is a measuring method by which the temperatures on the surfaces of the billet to be extracted or just extracted or at the specified points on the surfaces (see Clause CC.3), are measured by use of infrared camera, pyrometer, thermo-paint or contact thermocouple to determine the temperature homogeneity of the billet. The method is simple and convenient, and is applicable to various heating types of induction through-heating equipment, normal test and actual production, and can summarily reflect the temperature homogeneity of the billet.

   When measuring, the influences of the following factors on the measured temperature shall be considered and eliminated:

   – surface conditions of the billet, for example surface roughness and scale or other deposits on the surface; it is recommended to clear any potential scale on the measuring point before temperature measurement;

   – medium absorption on measuring path and the interference of outside light, etc., when using an infrared camera and a pyrometer.

   When using thermo-paint, it shall be pre-spread on all the specified temperature measuring points of the test billet's surfaces, the spot shall be big enough to show the temperature of each point or ensure that the whole surface of the billet is covered as requested, to show the temperature distribution.

   When using an infrared camera and a pyrometer, their probes shall be nearly at the vertical direction of the measured surface.

If applicable, it is recommended to use an infrared camera to measure the 2D temperature distribution of the billet surface, for example, for the determination of the transverse or radial temperature difference of the billet end surface; or to use a remote point infrared temperature measuring equipment to measure the temperature on the longitudinal axis which passes the side surface's centre of the moving billet, for the determination of the longitudinal temperature difference of the billet side surface. The infrared equipment's response time shall be set according to the billet moving speed.

b) Thermocouple-embedded measuring method

This is a measuring method by which thermocouples are embedded into the pre-drilled holes and localized at the surface layer and interior of the test billet according to the requirements for temperature measuring points (see Clause CC.3), to determine the temperature homogeneity of the billet. The diameter of the hole can be such that a thermocouple can be inserted more tightly into it. Measures should be taken to ensure the thermocouple junction is at the specified position and in tight contact with the billet. This method may be used to measure the 3D temperature distribution of the billet, monitor reliably and continuously the temperature change of each measuring point during the whole through-heating process and accurately determine the temperature homogeneity and final temperature of the billet. However, it has some shortages, such as more complication, drilling damage to billet, more and longer thermocouple lead, etc. It is only applicable to the stationary billet when heated and mainly used for the verification of inductor design to obtain optimal temperature homogeneity of the billet. The data obtained by this method may be used to verify the surface measuring method and the numerical modelling method mentioned below. This method does not apply to a higher frequency.

The temperatures of the thermocouples which are fixed at the temperature measuring points of the billet shall be, simultaneously and continuously, measured and recorded by use of DC digital voltmeters or thermocouple A/D modules of PLC, having an accuracy of class 0.1 or 0.2 and a resolution of at least 0,001 mV.

It is recommended to pre-measure temperatures of all points before starting the formal test, to verify that the temperature measuring system is in working condition.

c) Numerical modelling method

The numerical modelling based on Maxwell's equation for electromagnetic field and Fourier's equation for thermal field can be used to solve and analyse the 3D temperature distribution of the inductively through-heated billet, with the finite element method adopted to tackle the non-linear behaviour caused by the temperature variation of the billet and the coupled electromagnetic and thermal process. The temperature homogeneity of the billet can then be obtained.

This method has successfully been used in the optimized design of induction through-heating equipment to obtain the billet temperature distribution required by hot forming process, and can considerably reduce test expense and errors. The general requirements for the method shall be in accordance with Clause 7, its feasibility and calculating accuracy shall be verified by the thermocouple-embedded measuring method, and corresponding or better accuracy reached.

CC.3 Arrangement of temperature measuring points

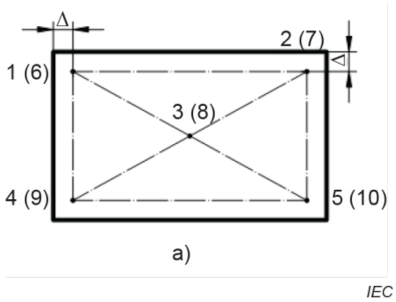
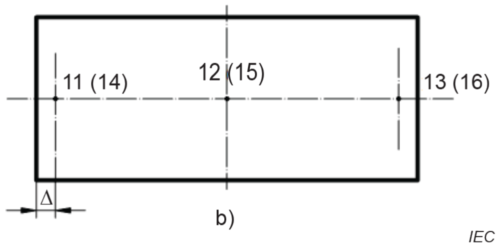
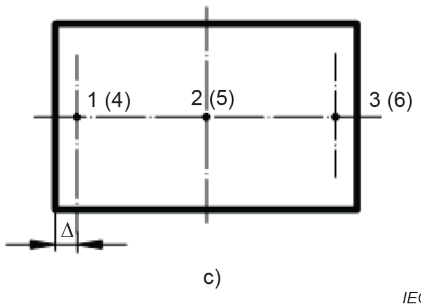
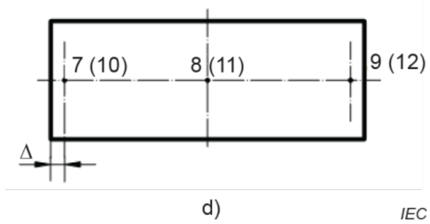
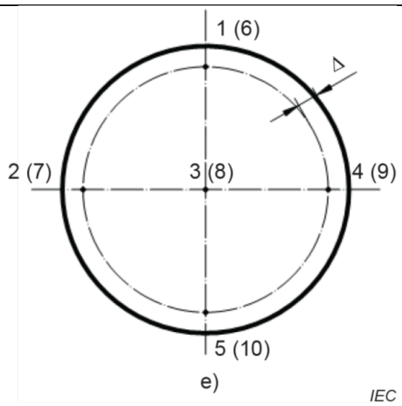
Considering convenience and feasibility of actual temperature measurement, the temperature measuring points should be set on the end and side surfaces of the billet and not at its top, bottom and deeper interior, unless otherwise specified by the user.

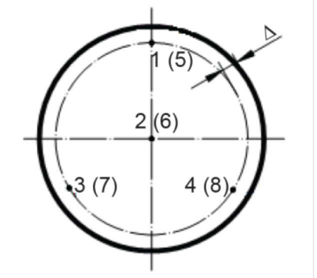
On the surfaces of the billet, the distance of a measuring point from the periphery of surface is Δ, Δ is about 5 mm to 10 mm, dependent on the dimensions of the billet. For the thermocouple-embedded measuring method, the depth of the holes on the surfaces is also Δ.

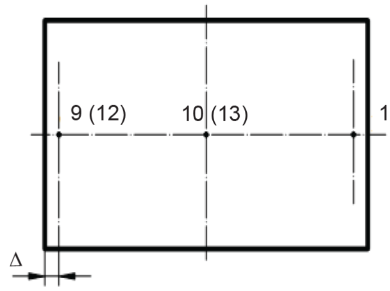
The arrangement of the least measuring points for the surfaces of the billets having rectangular or circular cross sections is shown in Table CC.1. The four measuring points 7, 10 and 9, 12 in Table CC.1, item d) may be replaced with the measuring points 3, 1 and 6, 4 in item c) respectively. Thus the number of measuring points may be correspondingly reduced, which is preferable, especially for the thermocouple-embedded measuring method. The same applies to Table CC.1, item f) and item e). For the thermocouple-embedded measuring method, another measuring point shall be set at the centre of the billet.

For a longer billet, measuring points may be appropriately added at equal distance, on the longitudinal axes of two side surfaces and on the longitudinal axis through the centre of the billet (the latter is applicable to the thermocouple-embedded measuring method), as agreed between the manufacturer and the user. For billets having other shapes of cross section and non-identical cross section, the arrangement of measuring points may be agreed between the manufacturer and the user, referring to the above-mentioned requirements.

Table CC.1 – Arrangement of temperature measuring points of the billets

<table>
<tr><th>Shape of cross section</th><th>Dimensions of end surface</th><th>Two end surfaces</th><th>Two side surfaces</th></tr>
<tr><td rowspan="2">rectangle</td><td>larger</td><td>
</td><td>
</td></tr>
<tr><td>smaller or flatter</td><td>
</td><td>
</td></tr>
<tr><td>circle</td><td>larger diameter</td><td>
</td><td>
</td></tr>
</table>

<table>
<tr><th>Shape of cross section</th><th>Dimensions of end surface</th><th>Two end surfaces</th><th>Two side surfaces</th></tr>
<tr><td></td><td>smaller diameter</td><td>

g)
IEC</td><td>

h)
IEC</td></tr>
<tr><td colspan="4">NOTE The Arabic numerals in items a) to h) are the labels of measuring points, the numerals in brackets are the ones for opposite end surface or side surface.</td></tr>
</table>

CC.4 Determination method

CC.4.1 Batch heating type induction through-heating installation

a) Surface measuring method

When using an infrared camera and a pyrometer, the test shall be continuously carried out according to the requirements in Clause CC.1 and Clause CC.2 a), on the even billets which comprise no less than four pieces (dependent on the dimensions of the billet) and are just extracted from the heating inductor for holding. For each just-extracted billet, the test shall be done at once to successively measure the temperature distribution on two end surfaces and two side surfaces. The measuring sequence of all measured surfaces is just the opposite for two adjacent billets to eliminate the influence of the measuring sequence on the temperature measurement. Due to a quick cooling and oxidizing of the billet surface (especially the end surface) after its extraction, the circulating measuring time for each billet shall be as short as possible and should not exceed 10 s to 20 s, depending on the dimensions of the billet and the rated temperature.

Having finished all the measurements and calculated the average value of each point's temperature readings, the temperature homogeneities of the tested billets, i.e. temperature homogeneity of billet, transverse temperature difference of billet, radial temperature difference of billet and longitudinal temperature difference of billet, are respectively determined according to the definitions of 3.116 to 3.118 as follows:

$$\Delta\theta_{bmax} = \theta_{bmax} - \theta_{br} \quad (CC.1)$$

$$\Delta\theta_{bmin} = \theta_{bmin} - \theta_{br} \quad (CC.2)$$

$$\Delta\theta_{bt(r)max} = \theta_{bt(r)max} - \theta_{bt(r)o} \quad (CC.3)$$

$$\Delta\theta_{bt(r)\,min} = \theta_{bt(r)\,min} - \theta_{bt(r)o} \quad (CC.4)$$

$$\Delta\theta_{bl} = \theta_{bl\,max} - \theta_{bl\,min} \quad (CC.5)$$

where

$\Delta\theta_{bmax}$, $\Delta\theta_{bmin}$ are the maximum and minimum temperature deviations of the tested billets, in °C;

θ_{bmax}, θ_{bmin} are the maximum and the minimum among the corrected average values of the temperatures measured at the measuring points of the tested billets, in °C;

θ_{br} is the rated temperature of billet, in °C;

$\Delta\theta_{bt(r)max}$, $\Delta\theta_{bt(r)\,min}$	are the maximum and minimum transverse (radial) temperature differences of the tested billets, in °C;
$\theta_{bt(r)\,max}$, $\theta_{bt(r)\,min}$	are the maximum and minimum among the corrected average value of the temperatures measured at the measuring points on the periphery of an end surface of the tested billets, in °C;
$\theta_{bt(r)o}$	is the corrected average value of the temperatures measured at the centre of an end surface of the tested billets, in °C;
$\Delta\theta_{bl}$	is the longitudinal temperature difference of the billet, in °C;
$\theta_{bl\,max}$, $\theta_{bl\,min}$	are the maximum and minimum among the corrected average values of the temperatures measured at the measuring points on the longitudinal axis of a side surface of the tested billets, in °C.

Respectively take the average of the values of the various temperature homogeneity of the billet measured on the two end surfaces or the two side surfaces as their respective determination results.

When using an infrared camera, a pyrometer and a thermo-paint, the measuring points for calculating the temperature homogeneity of the billet may be in accordance with the specifications set out in Clause CC.3 or be extended to the whole or partial surface containing these measuring points. Find the maximum and the minimum among the temperatures at these points or on the surface and carry out calculations according to Formulas (CC.1) to (CC.5).

When the temperature measurement is carried out by use of the contact thermocouples which are fixed on the temperature measuring points of the surface according to the methods mentioned in 6.5.2 of IEC 60398:2015, the temperatures of all points shall be continuously measured and recorded during the test, following the applicable requirements of Clause CC.2 b).

b) Thermocouple-embedded measuring method

For the temperature data of all measuring points measured according to the requirements in Clause CC.1 and Clause CC.2 b), only the latter ones during the holding stage are taken, and then the same calculations and treatment as in a) of this subclause are made according to Formulas (CC.1) to (CC.5), to obtain the temperature homogeneities of the tested billets.

c) Numerical modelling method

When calculating the temperature homogeneities of the billet based on the data of billet temperature distribution obtained by use of the numerical modelling method described in Clause CC.2 c), temperature measuring points shall at least include the points specified in Clause CC.3 or should be extended to the whole billet. Then make calculations according to Formulas (CC.1) to (CC.5).

CC.4.2 Continuous heating type and stage heating type induction through-heating installations

Generally, only the surface measuring method and the numerical modelling method can be adopted, the determination method shall be respectively in accordance with CC.4.1 a) and c).

For a continuous heating type installation, the temperatures of all points on the side surface's longitudinal axes of the tested billets which are extracted at a specified speed, may be continuously measured and recorded by use of an infrared temperature measuring equipment fixed at the place adjacent to the exit port, and then its longitudinal temperature difference $\Delta\theta_{bl}$ is calculated according to the maximum and the minimum of the measured temperature curve or data. Take the average of $\Delta\theta_{bl}$ values of the tested billets which are continuously extracted and comprise no less than four pieces as a determination result. This method may avoid some error sources generally encountered with an infrared camera. When billets are conveyed one against the other and are not differentiated, the temperature is continuously measured for a period (at least, more than four pieces), to determine the maximum and the minimum values during the period and obtain $\Delta\theta_{bl}$.

Annex DD
(informative)

Methods for safety tests

DD.1 Electrical withstand test of heating inductor

This test shall be performed at mains frequency with a substantially sine-wave voltage of ($2U_n$ + 1 000) V (with a minimum of 2 000 V) where U_n is the rated voltage of the heating inductor coil. The voltage shall be applied between components which are live when the induction through-heating equipment is in normal operation and all other metal parts of the heating inductor (including track, fastenings and supporting frame or cabinet etc.) which are to be connected together and earthed for this test. The voltage shall be raised progressively within 10 s to its test value, which then should be maintained for 1 min.

The electrical withstand test for heating inductor is performed after its lining is rammed or fitted. In the case of water-cooled coils, the cooling water hoses are disconnected so that the components which are normally live during the service of the equipment are not connected electrically to the supporting frame or cabinet of the heating inductor via the water.

No breakdown or flashover of the insulation shall occur during these tests.

DD.2 Tightness test of cooling water circuits

The test is to verify the tightness of the cooling water circuits. After closing the outlet of water circuits, the water pressure is raised by a pump to 150 % of the pressure specified by the manufacturer of the induction through-heating equipment. This pressure is to be maintained in the closed water circuits for at least 5 min. Neither water leakage nor pressure decrease shall occur during this test.

Pressure surges are to be avoided during the test.

DD.3 Flow test of cooling water circuits

The test is to verify that the cooling water circuits will carry the specified flow without exceeding a specified pressure drop.

The water flow of the circuit shall be measured by use of a flowmeter or determined by the volume of flowing-out water during a certain time period divided by the time.

Bibliography

The Bibliography of IEC 60398:2015 is applicable with the following additions.

Additions:

IEC 62076:2006, *Industrial electroheating installations – Test methods for induction channel and induction crucible furnaces*

IEC 60683:2011*, Industrial electroheating equipment – Test methods for submerged-arc furnaces*

UIE, *Induction Heating – Industrial Applications*, 1992

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