Railway applications – Traction transformers and inductors on board rolling stock

Applications ferroviaires – Transformateurs de traction et bobines d'inductance à bord du matériel roulant
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Applications ferroviaires – Transformateurs de traction et bobines d'inductance à bord du matériel roulant
CONTENTS

FOREWORD ......................................................................................................................... 6
1 Scope .............................................................................................................................. 8
2 Normative references ................................................................................................. 8
3 Terms and definitions ................................................................................................. 9
   3.1 General definitions ............................................................................................... 10
   3.2 Definitions for transformers ............................................................................... 11
   3.3 Definitions for inductors ..................................................................................... 11
4 Classification .................................................................................................................. 12
   4.1 Classification of transformers ............................................................................. 12
   4.2 Classification of inductors ................................................................................... 12
5 Service conditions ........................................................................................................ 12
6 Rated current and load profile ..................................................................................... 13
   6.1 Load profile .......................................................................................................... 13
   6.2 Rated current ......................................................................................................... 13
7 Rated voltage and power of transformer windings ......................................................... 13
   7.1 Rated line-side voltage ....................................................................................... 13
   7.2 Rated secondary voltage ..................................................................................... 13
   7.3 Rated power of transformer ................................................................................. 14
8 Transformer tappings .................................................................................................... 14
9 Cooling ......................................................................................................................... 14
   9.1 Identification of transformers and inductors according to cooling method .......... 14
   9.2 Arrangement of symbols ..................................................................................... 15
      9.2.1 Enclosed transformers and inductors ............................................................... 15
      9.2.2 Non-enclosed transformers and inductors ....................................................... 15
      9.2.3 Air cooling .................................................................................................... 15
10 Temperature limits ...................................................................................................... 15
   10.1 Classification of insulating materials ................................................................. 15
   10.2 Temperature limits of solid insulation ............................................................... 16
   10.3 Temperature limits for liquid ............................................................................ 16
   10.4 Temperature limits for other parts ..................................................................... 17
11 Mechanical design ...................................................................................................... 17
12 Rating plates ............................................................................................................... 17
13 Tests ............................................................................................................................. 18
   13.1 Categories of tests ............................................................................................. 18
      13.1.1 General ......................................................................................................... 18
      13.1.2 Type tests ..................................................................................................... 18
      13.1.3 Routine tests ............................................................................................... 18
      13.1.4 Investigation tests ....................................................................................... 18
   13.2 Tests on transformers ......................................................................................... 18
      13.2.1 General – List of tests .................................................................................. 18
      13.2.2 Tolerances ................................................................................................... 20
      13.2.3 Visual checks (type, routine test) and functional tests (optional type and routine test) .......................................................................................................................... 20
      13.2.4 Mass (type and optional routine test) ............................................................ 20
      13.2.5 Measurement of winding resistance (type and routine tests) ....................... 21
### Annex A (informative) List of items for which an agreement between purchaser and manufacturer is needed or for which further information or specifications shall be given by the purchaser or by the manufacturer

#### A.1 Items subject to agreement between purchaser and manufacturer

<table>
<thead>
<tr>
<th>A.1.1</th>
<th>Transformer and inductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1.2</td>
<td>Transformers</td>
</tr>
<tr>
<td>A.1.3</td>
<td>Inductors</td>
</tr>
</tbody>
</table>

#### A.2 Information to be given by purchaser to manufacturer

<table>
<thead>
<tr>
<th>A.2.1</th>
<th>Transformers and inductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.2.2</td>
<td>Transformers</td>
</tr>
<tr>
<td>A.2.3</td>
<td>Inductors</td>
</tr>
</tbody>
</table>

#### A.3 Information to be given by manufacturer to purchaser

| A.3.1 | Transformers and inductors |

---

### 13.2 Tests on inductors

<table>
<thead>
<tr>
<th>13.2.1</th>
<th>List of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.2.2</td>
<td>Tolerances</td>
</tr>
<tr>
<td>13.2.3</td>
<td>Visual checks (type and routine test)</td>
</tr>
<tr>
<td>13.2.4</td>
<td>Mass (type and optional routine test)</td>
</tr>
<tr>
<td>13.2.5</td>
<td>Measurement of winding resistance (type and routine test)</td>
</tr>
<tr>
<td>13.2.6</td>
<td>Determination of losses (type test)</td>
</tr>
<tr>
<td>13.2.7</td>
<td>Measurement of inductance (type and routine tests)</td>
</tr>
<tr>
<td>13.2.8</td>
<td>Temperature-rise test (type tests)</td>
</tr>
<tr>
<td>13.2.9</td>
<td>Insulation resistance test (optional type and routine test)</td>
</tr>
<tr>
<td>13.2.10</td>
<td>Dielectric tests (type and routine tests)</td>
</tr>
<tr>
<td>13.2.11</td>
<td>Partial discharge test (type or optional routine test for dry-type, investigation test for immersed type)</td>
</tr>
<tr>
<td>13.2.12</td>
<td>Short-circuit withstand test (optional type test)</td>
</tr>
<tr>
<td>13.2.13</td>
<td>Shock and vibration test (optional type test)</td>
</tr>
<tr>
<td>13.2.14</td>
<td>Voltage transmission ratio – VTR (optional type test)</td>
</tr>
<tr>
<td>13.2.15</td>
<td>Noise measurement (type test)</td>
</tr>
<tr>
<td>13.2.16</td>
<td>Leakage magnetic flux density measurement (optional type test)</td>
</tr>
<tr>
<td>13.2.17</td>
<td>Electrical Frequency Response Analysis FRA (investigation test)</td>
</tr>
<tr>
<td>13.2.18</td>
<td>Inrush current measurement (optional type test)</td>
</tr>
</tbody>
</table>

---

### 13.3 Tests on transformers and inductors

| 13.3.1 | Measurement of voltage ratio, polarities and vector groups (type and routine tests) |
| 13.3.2 | Measurement of no-load primary current and losses (type and routine tests) |
| 13.3.3 | Measurement of impedance voltages or short-circuit impedances (type and routine tests) |
| 13.3.4 | Measurement of fundamental load losses (type and routine tests) |
| 13.3.5 | Determination of total losses (type test) |
| 13.3.6 | Temperature-rise test (type test) |
| 13.3.7 | Insulation resistance test (optional type and routine test) |
| 13.3.8 | Temperature-rise test (type tests) |
| 13.3.9 | Dielectric tests (type and routine tests) |
| 13.3.10| Partial discharge test (type or optional routine test for the dry-type) |
| 13.3.11| Short-circuit withstand test (optional type test) |
| 13.3.12| Shock and vibration test (optional type test) |
| 13.3.13| Measurement of inductance (type and routine tests) |
| 13.3.14| Measurement of winding resistance (type and routine test) |
| 13.3.15| Determination of losses (type test) |
| 13.3.16| Measurement of impedance voltages or short-circuit impedances (type test) |
| 13.3.17| Measurement of inductance (type and routine tests) |
| 13.3.18| Determination of total losses (type test) |
| 13.3.19| Temperature-rise test (type test) |
| 13.3.20| Measurement of fundamental load losses (type and routine tests) |
| 13.3.21| Measurement of winding resistance (type and routine test) |
| 13.3.22| Determination of losses (type test) |
| 13.3.23| Measurement of inductance (type and routine tests) |
| 13.3.24| Measurement of winding resistance (type and routine test) |
| 13.3.25| Determination of losses (type test) |
| 13.3.26| Measurement of inductance (type and routine tests) |
| 13.3.27| Measurement of winding resistance (type and routine test) |
| 13.3.28| Determination of losses (type test) |
| 13.3.29| Measurement of inductance (type and routine tests) |
| 13.3.30| Measurement of winding resistance (type and routine test) |
| 13.3.31| Determination of losses (type test) |
| 13.3.32| Measurement of inductance (type and routine tests) |
| 13.3.33| Measurement of winding resistance (type and routine test) |
| 13.3.34| Determination of losses (type test) |
| 13.3.35| Measurement of inductance (type and routine tests) |
| 13.3.36| Measurement of winding resistance (type and routine test) |
| 13.3.37| Determination of losses (type test) |
| 13.3.38| Measurement of inductance (type and routine tests) |
| 13.3.39| Measurement of winding resistance (type and routine test) |
| 13.3.40| Determination of losses (type test) |
| 13.3.41| Measurement of inductance (type and routine tests) |
| 13.3.42| Measurement of winding resistance (type and routine test) |
| 13.3.43| Determination of losses (type test) |
| 13.3.44| Measurement of inductance (type and routine tests) |
| 13.3.45| Measurement of winding resistance (type and routine test) |
| 13.3.46| Determination of losses (type test) |
Table 4 – Temperature limits for liquid ................................................................. 16
Table 5 – List of checks and tests to be made on traction transformers ............ 19
Table 6 – Tolerances ............................................................................................. 20
Table 7 – Reference temperatures ....................................................................... 21
Table 8 – Dielectric test voltage .......................................................................... 30
Table 9 – Partial discharge measurements ............................................................ 35
Table 10 – List of checks and tests to be made on inductors ................................. 43
Table 11 – Tolerances .......................................................................................... 44
Table 12 – Test method of voltage between terminals withstand test ................... 49
Table C.1 – Temperature limits and expected lifetime for a dry-type transformer or
inductor (examples) ................................................................................................. 61
Table C.2 – Load cycle histogram ......................................................................... 62
Table C.3 – Temperature histogram ..................................................................... 62
Table C.4 – Temperature rise test results .............................................................. 63
Table C.5 – Thermal endurance calculation ........................................................... 63
Table C.6 – Equivalent current and temperatures .................................................. 64
INTERNATIONAL ELECTROTECHNICAL COMMISSION

RAILWAY APPLICATIONS – TRACTION TRANSFORMERS AND INDUCTORS ON BOARD ROLLING STOCK

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International Standard IEC 60310 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways.

This fourth edition cancels and replaces the third edition issued in 2004 and constitutes a technical revision.

This edition takes into account the new generic railway standards, more specifically general service conditions referring to IEC 62498-1 and shock and vibration considerations referring to IEC 61373. It also includes the following significant technical changes with regard to the previous edition:

- temperature limits;
- temperature-rise test;
- dielectric tests;
- partial discharge test;
– inductance measurement methods;
– voltage between terminals withstand test;
– thermal ageing and insulation lifetime (informative);
– examples of thermal endurance calculation (informative);
– wet dielectric tests (informative);
– load profiles (informative).

The text of this standard is based on the following documents:

<table>
<thead>
<tr>
<th>FDIS</th>
<th>Report on voting</th>
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<tbody>
<tr>
<td>9/2080/FDIS</td>
<td>9/2117/RVD</td>
</tr>
</tbody>
</table>

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

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

The committee has decided that the contents of this publication 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 publication. At this date, the publication will be

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• withdrawn,
• replaced by a revised edition, or
• amended.

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RAILWAY APPLICATIONS –
TRACTION TRANSFORMERS AND
INDUCTORS ON BOARD ROLLING STOCK

1 Scope

This International Standard applies to traction and auxiliary power transformers installed on
board rolling stock and to the various types of power inductors inserted in the traction and
auxiliary circuits of rolling stock, of dry or liquid-immersed design.

NOTE The requirements of IEC 60076 (all parts) are applicable to transformers and inductors where they do not
conflict with this standard, or with the specialized IEC publications dealing with traction applications.

This standard can also be applied, after agreement between purchaser and manufacturer, to
the traction transformers of three-phase a.c. line-side powered vehicles and to the
transformers inserted in the single-phase or poly-phase auxiliary circuits of vehicles, except
instrument transformers and transformers of a rated output below 1 kVA single-phase or
5 kVA poly-phase.

This standard does not cover accessories such as tap changers, resistors, heat exchangers,
fans, etc., intended for mounting on the transformers or inductors, which are tested separately
according to relevant rules.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and
are indispensable for its application. For dated references, only the edition cited applies. For
undated references, the latest edition of the referenced document (including any
amendments) applies.

IEC 60050-811, International Electrotechnical Vocabulary (IEV) – Chapter 811: Electric traction

IEC 60060-1, High-voltage test techniques – Part 1: General definitions and test requirements

IEC 60060-2, High-voltage test techniques – Part 2: Measuring systems

IEC 60076-1:2011, Power transformers – Part 1: General

IEC 60076-2, Power transformers – Part 2: Temperature rise for liquid-immersed transformers

IEC 60076-3: Power transformers – Part 3: Insulation levels, dielectric tests and external
clearances in air

IEC 60076-4, Power transformers – Part 4: Guide to the lightning impulse and switching
impulse testing – Power transformers and reactors

IEC 60076-5, Power transformers – Part 5: Ability to withstand short circuit


IEC 60076-7, Power transformers – Part 7: Loading guide for oil-immersed power transformers
3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60076-1 and IEC 60050-811 together with the following apply.
NOTE When the term "transformer" is used alone, it applies to both traction and auxiliary transformers.

The term "transformer(s)/inductor(s)" appears in clauses applicable to both transformers and inductors to avoid duplication of text.

The term "inductor" is used in this standard with the same meaning as the term "reactor" mentioned in IEC 60050-421, IEC 60050-811 and IEC 60076-6.

3.1 General definitions

3.1.1 load profile
current/power versus time under specified conditions including voltage

3.1.2 cooling medium
cooling medium used to extract the heat out of the transformer/inductor e.g. air, water, oil, heat sink, etc.

3.1.3 rated insulation voltage
$U_{Nm}$
r.m.s. withstand voltage value assigned by the manufacturer to the equipment or a part of it, characterising the specified permanent (over 5 min) withstand capability of its insulation

Note 1 to entry: $U_{Nm}$ is a voltage between a live part of equipment and earth or another live part. For rolling stock, earth refers to the car body.

Note 2 to entry: For circuits, systems and sub-systems in railway applications this definition is preferred to "highest voltage for equipment" which is widely used in international standards.

Note 3 to entry: $U_{Nm}$ is higher than or equal to the working voltage. As a consequence, for circuits directly connected to the contact line, $U_{Nm}$ is equal to or higher than $U_{max}$, as specified in IEC 60850. For circuits connected to electronic converter $U_{Nm}$ is higher than or equal to the d.c. link voltage.

Note 4 to entry: $U_{Nm}$ is not necessarily equal to the rated voltage which is primarily related to functional performance.

3.1.4 nominal voltage
$U_n$
suitable approximate voltage used to designate or identify a given supply system

3.1.5 rated voltage
$U_r$
value of voltage assigned for a specific operating condition

3.1.6 rated impulse voltage
$U_{NI}$
impulse voltage value, characterizing the specified withstand capability of its insulation against transient over-voltages
3.1.7

**test voltage**

$U_a$

r.m.s. value derived from $U_{Nm}$ used for separate source voltage, induced voltage, voltage between terminals withstand, depending on test carried out.

3.1.8

**recurring peak voltage**

$U_{mT}$, $U_{mG}$

maximum peak value of periodic excursions of the voltage waveform between terminals ($U_{mT}$) or between terminals and ground ($U_{mG}$).

3.2 Definitions for transformers

3.2.1

**voltage transmission ratio**

VTR

ratio between the secondary voltage and the primary voltage when a specified impulse or a.c. square voltage is applied on the primary.

The VTR is expressed as a percentage of this applied voltage.

3.2.2

**impedance voltage**

voltage applied to reach the rated current in short-circuit.

This is expressed as a percentage of this applied voltage to the rated voltage at reference temperature.

Note 1 to entry: When expressed as a percentage or per unit, this is equal to the short circuit impedance referred to in IEC 60076-1:2011, 5.7.

3.2.3

**tolerance**

permitted deviation between the declared value of a quantity and the measured value.


3.3 Definitions for inductors

Values of inductance for inductors are related to the different classes of utilisation and are defined as follows, with the understanding that they include an indication of the nature and value of the current used in their measurement.

3.3.1

**a.c. inductance**

inductance derived from the measurement of the alternating current carried by the inductor when it is supplied by a sinusoidal alternating voltage of specified value and frequency.

3.3.2

**differential inductance**

inductance defined from the derivative of the linked flux as a function of current (equal to the slope of the magnetic characteristic).

Note 1 to entry: It is derived from the transient record of instantaneous voltage and current in the inductor or from the measurement of the variation of magnetic flux.
3.3.3 Incremental inductance

Inductance seen by the a.c. current of a particular value and frequency superimposed on a direct current through the inductor.

Note 1 to entry: It should be mentioned that the ripple factor of a pulsating current, expressed as a percentage, is conventionally defined by the formula:

\[
\frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} \times 100
\]

where \( I_{\text{max}} \) and \( I_{\text{min}} \) respectively represent the maximum and minimum values of the current wave.

Note 2 to entry: It is derived from a record of the terminal voltage.

4 Classification

4.1 Classification of transformers

The transformers mentioned above may be:

- traction transformers to supply the propulsion circuits, and optionally also other equipment;
- auxiliary transformers to supply electrical equipment except propulsion circuits.

Windings mentioned in the standard may be:

- line side windings which are directly connected to the power supply line;
- traction windings which supply the propulsion circuits;
- auxiliary windings which are used for other purposes.

4.2 Classification of inductors

According to their use, inductors can be classified as follows:

- inductors for alternating current:
  - inductors that carry alternating current, such as transition inductors used for transition between tappings of tap changers, inductors for a.c. commutator motor braking circuits, interference suppression inductors, tuned filter inductors, etc.;
- inductors for direct current:
  - inductors that carry direct current with small or negligible a.c. components, such as d.c. line filter inductors, inductive shunts for traction motors, inductors for d.c. motor braking circuits, etc.;
- inductors for pulsating current:
  - inductors that carry direct or alternating current with a significant periodic ripple, such as smoothing inductors for traction motors, sinusoidal filter inductors in auxiliary converters, etc.

5 Service conditions

The normal service conditions for transformers and inductors shall be in accordance to IEC 62498-1. Special service conditions shall be agreed between the purchaser and manufacturer.
6 Rated current and load profile

6.1 Load profile

A transformer/inductor is designed to operate on the train in steady-state and transient (surge) conditions, both in normal and overload conditions.

The purchaser should specify the load profile according to Annex E (informative). The current frequency spectrum shall be specified by the responsible party.

6.2 Rated current

The rated current of a winding is the current this winding can sustain permanently at the reference temperature for continuous load.

The rated current shall be calculated according to either of following methods:

a) r.m.s. current derived from the load profiles;

b) considering thermal ageing of insulating materials according to Annex B (informative).

Special attention should be paid to varying cooling modes and to the averaging time window.

The reference temperature for continuous load is the cooling medium temperature at the external interface of the transformer/inductor. It shall:

c) either be directly specified by the purchaser;

   Specified values should be based on the air temperature external to vehicle as defined in IEC 62498-1.

d) or calculated by the manufacturer based on the temperature histogram provided by the purchaser and the method of Annex B (informative): see cooling medium reference temperature for lifetime calculation in B.4.2.

For a traction winding, the rated current shall correspond to the principal tapping. This definition of rated current applies when other windings, which are normally on load, deliver their rated loads.

7 Rated voltage and power of transformer windings

7.1 Rated line-side voltage

The rated line-side voltage is the r.m.s. voltage applicable in normal operating conditions to the line-side winding group. If this winding has tappings, the rated voltage shall be referred to the principal tapping.

Unless otherwise agreed between purchaser and manufacturer, the rated line-side voltage is specified as being equal to the nominal voltage of the traction system.

NOTE IEC 60850 gives the list of the nominal voltages of traction systems.

7.2 Rated secondary voltage

The rated voltage of a secondary winding of a transformer is the r.m.s. no-load voltage at the terminals of the winding when the principal tapping of the line-side winding of the transformer is fed at its rated voltage and frequency.
7.3 Rated power of transformer

The rated power of a transformer winding is defined as the product of the rated voltage of this winding and its rated current.

NOTE Transformers usually have several secondary windings (e.g. traction, auxiliaries, train heating). The rated power of the line-side winding of a transformer can be less than the sum of the rated powers of its various secondary windings.

8 Transformer tappings

In order to permit variation of the voltage ratio of the transformer, one or more of its windings may be equipped with intermediate tappings, which shall be indicated on the diagram and in the specification, with a statement of their maximum operating characteristics.

The principal tapping is that which enables the rated traction motor voltage to be obtained at the terminals of the motors when they are taking their rated current, the transformer line-side winding being supplied at rated voltage and frequency.

When both line-side windings and traction windings have intermediate tappings, the principal tappings shall be indicated.

For multi-system vehicles, the principal tappings may be different for each system.

The no-load voltage ratio shall be defined for the principal tapping and for other tappings.

9 Cooling

9.1 Identification of transformers and inductors according to cooling method

Transformers and inductors shall be identified according to the cooling method employed. Letter symbols for use in connection with each cooling method shall be as given in Table 1.

<table>
<thead>
<tr>
<th>Type of cooling medium</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral oil or other insulating liquid with fire-point ≤ 300 °C</td>
<td>O</td>
</tr>
<tr>
<td>Insulating liquid with fire-point &gt; 300 °C</td>
<td>K</td>
</tr>
<tr>
<td>Insulating liquid having a fire-point greater than its boiling-point</td>
<td>L</td>
</tr>
<tr>
<td>Gas</td>
<td>G</td>
</tr>
<tr>
<td>Water</td>
<td>W</td>
</tr>
<tr>
<td>Air</td>
<td>A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of circulation</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td>N</td>
</tr>
<tr>
<td>Forced non-directed</td>
<td>F</td>
</tr>
<tr>
<td>Forced-directed</td>
<td>D</td>
</tr>
</tbody>
</table>

In transformers and inductors with forced-directed circulation, a certain portion of the forced flow is channelled so as to pass through the windings. Some windings, however, may have a non-directed flow, for instance separate tapping windings, auxiliary windings and stabilizing windings.

The type of coolant shall be subject to approval by the purchaser.
9.2 Arrangement of symbols

9.2.1 Enclosed transformers and inductors

Transformers and inductors shall be identified by symbols of four letters for each cooling method for which a rating is specified by the manufacturer.

The order in which the symbols shall be used is given in Table 2. Oblique strokes shall be used to separate the group symbols for different cooling methods.

<table>
<thead>
<tr>
<th>1st letter</th>
<th>2nd letter</th>
<th>3rd letter</th>
<th>4th letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicating the cooling medium that is in contact with the winding</td>
<td>Indicating the cooling medium that is in contact with the external cooling system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of cooling medium</td>
<td>Type of circulation</td>
<td>Type of cooling medium</td>
<td>Type of circulation</td>
</tr>
</tbody>
</table>

Example: a liquid-immersed transformer with forced-directed liquid circulation and forced-air circulation would be designated by ODAF or KDAF.

For oil-immersed transformers in which the alternatives of natural or forced cooling with non-directed oil flow are possible, typical designations are: ONAN/ONAF, ONAN/OFAF.

For a dry-type transformer in a non-ventilated protective enclosure with natural air cooling inside and outside the enclosure, the designation is: ANAN.

9.2.2 Non-enclosed transformers and inductors

Dry-type transformers and inductors without protective enclosures are identified by two symbols only for the cooling medium that is in contact with the windings or the surface coating of windings with an overall coating (e.g. epoxy resin).

The cooling method of a dry-type transformer without a protective enclosure or with a ventilated enclosure and with natural air cooling is designated by: AN.

9.2.3 Air cooling

When transformers or inductors are cooled by the draught of air caused by the motion of the vehicle or by a forced-air cooling system which is not tested with the transformer or inductor, the air flow (or velocity) on which the rated power of the equipment is based shall be indicated by the purchaser.

10 Temperature limits

10.1 Classification of insulating materials

The different classes of solid materials (EIM – Electrical Insulating Material) and systems (EIS – Electrical Insulating System) used at present for the insulation of the windings of transformers and inductors to which this standard applies are defined in IEC 60085 and listed in Table 3.

For a given solid insulation material the thermal class may be different depending on the surrounding medium (air, mineral oil, ester fluids, etc.).

The thermal class of the solid materials used for the insulation of the windings shall be indicated by the manufacturer.
10.2 Temperature limits of solid insulation

The maximum temperature of the transformer and inductor components shall not exceed the limits given in Table 3.

Temperature limits apply to short time maximum temperature considering hot spot.

These absolute temperatures are related to the worst case specified operating conditions.

For the long time operation temperature limits refer to 13.2.11.6

### Table 3 – Temperature limits of solid insulation

<table>
<thead>
<tr>
<th>RTE (Relative Thermal Endurance) or ATE (Assessed Thermal Endurance)</th>
<th>Thermal class</th>
<th>Maximum temperature Immersed type °C</th>
<th>Maximum temperature Dry-type °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTE or ATE &lt; 90</td>
<td>70</td>
<td>No guidance</td>
<td>No guidance</td>
</tr>
<tr>
<td>90 ≤ RTE or ATE &lt; 105</td>
<td>90 (Y)</td>
<td>No guidance</td>
<td>No guidance</td>
</tr>
<tr>
<td>105 ≤ RTE or ATE &lt; 120</td>
<td>105 (A)</td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td>120 ≤ RTE or ATE &lt; 130</td>
<td>120 (E)</td>
<td>135</td>
<td>145</td>
</tr>
<tr>
<td>130 ≤ RTE or ATE &lt; 155</td>
<td>130 (B)</td>
<td>170</td>
<td>155</td>
</tr>
<tr>
<td>155 ≤ RTE or ATE &lt; 180</td>
<td>155 (F)</td>
<td>195</td>
<td>180</td>
</tr>
<tr>
<td>180 ≤ RTE or ATE &lt; 200</td>
<td>180 (H)</td>
<td>220</td>
<td>205</td>
</tr>
<tr>
<td>200 ≤ RTE or ATE &lt; 220</td>
<td>200 (N)</td>
<td>240</td>
<td>225</td>
</tr>
<tr>
<td>220 ≤ RTE or ATE &lt; 250</td>
<td>220 (R)</td>
<td>260</td>
<td>245</td>
</tr>
<tr>
<td>250 ≤ RTE or ATE</td>
<td>250</td>
<td>No guidance</td>
<td>No guidance</td>
</tr>
</tbody>
</table>

* For immersed type insulation systems, temperature limits are higher than for dry-type because of reduced oxidation of insulation materials. The exceptions are insulation systems based on cellulose (105 and 120 class), for which the temperature limits are based on IEC 60076-7.

* Dry-type limits are according to IEC 60076-12:2008, Table 2.

Other limits may be adopted by agreement between purchaser and manufacturer when certain combinations of insulating materials are used. It becomes especially important when materials of different thermal classes are combined within one insulation system. Then, thorough evaluation of the thermal capacity of such created system is necessary.

To estimate life time refer to Annex B (informative) and Annex C (informative).

10.3 Temperature limits for liquid

The temperature of the liquid shall not exceed the limits of Table 4.

### Table 4 – Temperature limits for liquid

<table>
<thead>
<tr>
<th>Fire point class (IEC 61039)</th>
<th>Mineral oil (IEC 60296)</th>
<th>Synthetic ester fluid (IEC 61099)</th>
<th>Silicon fluid (IEC 60836)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum temperature for long term load, bulk fluid breathing or sealed °C</td>
<td>105</td>
<td>130</td>
<td>155</td>
</tr>
</tbody>
</table>
The values of temperature are based on IEC 60076-14. The recommended temperature limits are valid for the specific environment for insulation systems. Sealed systems limit the impact of oxygen and moisture as typical aging factors. For the free breathing system, maintenance has to be adapted.

10.4 Temperature limits for other parts

Tank surface maximum temperature shall be agreed between purchaser and manufacturer.

The temperature of the cores and other parts of the transformer or inductor shall in no case reach a value which will cause damage to these parts or adjacent ones, or undue ageing of the insulating liquid.

11 Mechanical design

The mechanical behaviour can be proved by Finite Element Analysis (FEA) calculation (method, model calibration and fatigue limits) to be agreed between the purchaser and manufacturer, or by the shock and vibration test. If the FEA method is chosen it should at least include the static load cases, the modal analysis up to 60 Hz and a relevant fatigue analysis that is based on the spectral power density defined by the IEC 61373 test conditions as input signal. A relevant damage evaluation shall be made with a recognized standard method (e.g. Single moment, Rayleigh, etc.). The material data have to be taken in accordance with this standard. The calculation shall take the welds into account and safety coefficient applied in accordance with the relevant standard agreed with the purchaser shall be used. The liquid has to be taken into account and the way it has been simulated has to be demonstrated.

12 Rating plates

Each unit that can be handled independently shall be provided with its own rating plate showing at least the items indicated below, unless otherwise agreed between purchaser and manufacturer:

- manufacturer's name;
- manufacturer's type designation or number;
- manufacturer's serial number;
- date and place of manufacturing;
- connection diagram;
- tappings;
- rated power, voltage and frequency of each winding;
- rated current (r.m.s. value, or mean direct current);
- value of the inductance (at one or more specified reference current values);
- volume of cooling medium and type (only for the liquid filled);
- name of cooling fluid (only for the liquid filled);
- identification of cooling method;
- total mass.

The identification plate shall be placed in such a way that it will be easily inspected and cleaned in normal maintenance operations once the transformer is installed in the final application.