

# INTERNATIONAL STANDARD

## NORME INTERNATIONALE

**Laminations for transformers and inductors –  
Part 1: Mechanical and electrical characteristics**

**Tôles découpées pour transformateurs et inductances –  
Partie 1: Caractéristiques électriques et mécaniques**



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IEC 60740-1

Edition 1.0 2005-08

# INTERNATIONAL STANDARD

## NORME INTERNATIONALE

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**Laminations for transformers and inductors –  
Part 1: Mechanical and electrical characteristics**

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INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

COMMISSION  
ELECTROTECHNIQUE  
INTERNATIONALE

PRICE CODE  
CODE PRIX

**XA**

ICS 29.100.10

ISBN 978-2-88912-783-2

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# INTERNATIONAL ELECTROTECHNICAL COMMISSION

## LAMINATIONS FOR TRANSFORMERS AND INDUCTORS –

### Part 1: Mechanical and electrical characteristics

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International Standard IEC 60740-1 has been prepared by IEC technical committee 51: Magnetic components and ferrite materials.

IEC 60740-1 cancels and replaces IEC 60740 published in 1982 and its amendment 1 (1991). The main changes are listed below:

- a) ranges with lamination strips YS, YSUI 1, YSUI 2 and laminations YEE 2-...L added;
- b) range YEI 1 extended at the above end;
- c) ranges YED 2, YEF 2, YEL 2, YES 2, Type YM 1-5a and YM 1-7a cancelled;
- d) national designations cancelled;
- e) electrical characteristics for the laminations specified;
- f) mechanical characteristics for laminations added;
- g) holes added for lamination types YEI 1, YUI 1, YUI 2, YM 1;
- h) in Annex A, a conversion of the polarisation  $\hat{J}$  and the field strength  $\hat{H}$  in a specific total apparent power is defined. For the characteristics of the reactive power and the power loss, equations and constants are specified.

This bilingual version (2011-11) corresponds to the monolingual English version, published in 2005-08.

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

| FDIS        | Report on voting |
|-------------|------------------|
| 51/823/FDIS | 51/836/RVD       |

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

The French version of this standard has not been voted upon.

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

IEC 60740 consists of the following parts under the general title *Laminations for transformers and inductors*:

Part 1: Mechanical and electrical characteristics

Part 2: Specification for the minimum permeabilities of laminations made of soft magnetic metallic materials.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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

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

# LAMINATIONS FOR TRANSFORMERS AND INDUCTORS –

## Part 1: Mechanical and electrical characteristics

### 1 Scope

This part of IEC 60740 specifies the characteristics of laminations. Their preferred use is cores for transformers and inductors. The laminations are made of sheets and strips of magnetic materials, specified in IEC 60404-8-4 and IEC 60404-8-7.

### 2 Normative references

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

IEC 60050-221, *International Electrotechnical Vocabulary (IEV) – Chapter 221: Magnetic materials and components*

IEC 60404-1:2000, *Magnetic materials – Part 1: Classification*

IEC 60404-8-4:1998, *Magnetic materials – Part 8-4: Specifications for individual materials – Cold-rolled non-oriented electrical steel sheet and strip delivered in the fully-processed state*

IEC 60404-8-7:1998, *Magnetic materials – Part 8-7: Specifications for individual materials – Cold-rolled grain-oriented electrical steel sheet and strip delivered in the fully-processed state*

IEC 60404-11:1999, *Magnetic materials – Part 11: Method of test for the determination of surface insulation resistance of magnetic sheet and strip*

IEC 61021-1:1990, *Laminated core packages for transformers and inductors used in telecommunication and electronic equipment – Part 1: Dimensions*

IEC 61021-2:1995, *Laminated core packages for transformers and inductors used in telecommunication and electronic equipment – Part 2: Electrical characteristics for cores using YEE 2 laminations*

ISO 286-1:1988, *ISO system of limits and fits – Part 1: Bases of tolerances, deviations and fits*

### 3 Terms, definitions and symbols

For the purposes of this document, the definitions of IEC 60050-221 and the following apply.

#### 3.1

##### **lamination**

produced from a magnetic alloy sheet, usually consisting of one piece or several joined pieces, forming one complete layer of a laminated core

#### 3.2

##### **lamination strip**

produced from a magnetic alloy sheet, which can be composed to a layer of laminations or stacks for limbs or yokes

#### 3.3

##### **square stack**

results, if the height of the package  $h_p$  is equal to the limb width  $d$ .

#### 3.4

##### **specific power loss**

loss of the core in an alternating field with specified frequency and sinusoidal waveform, generating a specified flux density divided by the core mass:

$$p_{Fe} = \frac{P_{Fe}}{m_{Fe}} \quad (1)$$

where

$p_{Fe}$  is the specific power loss, in W/kg;

$P_{Fe}$  is the power loss, in W;

$m_{Fe}$  is the core mass, in kg.

NOTE 1 In the power loss both the hysteresis loss and eddy current loss are included.

NOTE 2 This is valid for cores with and without an air gap in the magnetic path.

#### 3.5

##### **specific reactive power**

reactive power of the core in an alternating field by specified frequency and sinusoidal, specified flux density divided by the core mass:

$$p_{BFe} = \frac{P_{BFe}}{m_{Fe}} \quad (2)$$

where

$p_{BFe}$  is the specific reactive power, in VA/kg;

$P_{BFe}$  is the reactive power, in VA;

$m_{Fe}$  is the core mass, in kg.

### 3.6

#### specific reactive power of the air gap

in an alternating field and sinusoidal, specified flux density is the r.m.s. reactive power in the air gap, divided by the core mass:

$$p_{BL} = 0,25 \cdot \frac{l_L \cdot f \cdot \hat{B}^2}{l_{Fe} \cdot \rho} \quad (3)$$

where

$p_{BL}$  is the specific reactive power of the air gap, in VA/kg;

$\hat{B}$  is the peak flux density, in T;

$f$  is the frequency, in Hz;

$\rho$  is the density of the core, in kg/dm<sup>3</sup>;

$l_L$  is the length of the air gap, in µm;

$l_{Fe}$  is the path length, in cm.

### 3.7

#### specific total apparent power of cores without air gap

in the mean flux path, the specific total apparent power consists of the specific reactive power and the specific power loss of the core and is the product of sinusoidal voltage and r.m.s. current divided by the core mass:

$$p_S = \sqrt{p_{BFe}^2 + p_{Fe}^2} \quad (4)$$

$$p_S = \frac{U \cdot I}{m_{Fe}} = \frac{P_S}{m_{Fe}} \quad (5)$$

where

$P_S$  is the total apparent power, in VA;

$p_S$  is the specific total apparent power, in VA/kg;

$p_{BFe}$  is the specific reactive power, in VA/kg;

$p_{Fe}$  is the specific power loss, in W/kg;

$U$  is the voltage, in V;

$I$  is the r.m.s. current, in A;

$m_{Fe}$  is the core mass, in kg.

### 3.8

#### specific total apparent power of cores with air gap

in the mean flux path, the specific total apparent power consists of the specific reactive power of the core, the specific reactive power of the air gap and the specific power loss:

$$P_S = \sqrt{(p_{BFe} + p_{BL})^2 + p_{Fe}^2} \quad (6)$$

where

- $p_S$  is the specific total apparent power, in VA/kg;  
 $p_{BFe}$  is the specific reactive power of the core, in VA/kg;  
 $p_{BL}$  is the specific reactive power of the air gap, in VA/kg;  
 $p_{Fe}$  is the specific power loss, in W/kg.

### 3.9

#### magnetic path length

arithmetic mean of the longest and the shortest path length of the core neglecting radii.

NOTE For details of the calculation for each core, see 13.3 to 13.10.

### 3.10 Symbols

- $A_{Fe}$  core cross-section, in mm<sup>2</sup>;  
 $\hat{B}$  peak flux density, in T;  
 $\hat{B}_n$  nominal peak flux density, in T;  
 $\hat{B}_0$  peak flux density for the characteristic of the specific reactive power, in dT;  
 $C_1$  core constant 1, in mm<sup>-1</sup>;  
 $C_2$  core constant 2, in mm<sup>-3</sup>;  
 $c_1, c_2$  constants for the characteristic of the specific reactive power;  
 $c_3, c_4$  constants for the characteristic of the specific power loss;  
 $d$  limb width, in mm;  
 $f$  frequency, in Hz;  
 $\hat{H}$  peak field strength, in A/m;  
 $h_p$  stack height, in mm;  
 $I$  current, in A;  
 $I_1, I_2, I_3$  currents in the phases of three-phase cores, in A;  
 $\hat{J}$  peak polarisation, in T;  
 $l$  magnetic path length, in mm;  
 $l_{Fe}$  magnetic path length, in mm;  
 $l_{Fe1}, l_{Fe2}$  magnetic path lengths for three-phase cores, in mm;  
 $l_L$  path length of the air gap, in µm;  
 $l_q$  magnetic path length cross to the rolling direction, in mm;  
 $l_w$  magnetic path length in rolling direction, in mm;  
 $m_{Fe}$  core mass, in kg;  
 $N$  number of turns;  
 $N_1$  number of turns of winding  $N_1$ ;  
 $N_2$  number of turns of winding  $N_2$ ;  
 $P_1, P_2, P_3$  power loss in the phases of three-phase cores, in W;  
 $P_{BFe}$  reactive power of the core, in VA;  
 $P_{BL}$  reactive power of the air gap, in VA;  
 $P_{Fe}$  power loss, in W;

|                       |                                                                         |
|-----------------------|-------------------------------------------------------------------------|
| $P_m$                 | test value of the power loss, in W;                                     |
| $P_S$                 | total apparent power, in VA;                                            |
| $p_B$                 | specific reactive power, in VA/kg;                                      |
| $p_{BFe}$             | specific reactive power of the core, in VA/kg;                          |
| $p_{BL}$              | specific reactive power of the air gap, in VA/kg;                       |
| $p_{Fe}$              | specific power loss; in W/kg;                                           |
| $p_{Fe0}$             | cardinal value for the specific power loss, in W/kg;                    |
| $p_S$                 | specific total apparent power, in VA/kg;                                |
| $p_{S0}$              | cardinal value of the total apparent power, in VA/kg;                   |
| $p_{S, \sin}$         | specific total apparent power at sinusoidal current; in VA/kg;          |
| $R_1$                 | resistance of winding $N_1$ , in $\Omega$ ;                             |
| $R_2$                 | resistance of winding $N_2$ , in $\Omega$ ;                             |
| $R_n$                 | precision resistor, in $\Omega$ ;                                       |
| $R_V$                 | resistance of the voltmeter, in $\Omega$ ;                              |
| $R_W$                 | resistance of the voltage path of the wattmeter, in $\Omega$ ;          |
| $U$                   | voltage, in V;                                                          |
| $U_1$                 | voltage of the source, in V;                                            |
| $U_{2 \text{ r.m.s}}$ | voltage of the winding $N_2$ , in V;                                    |
| $U_{2 \text{ avg}}$   | voltage of the winding $N_2$ , in V;                                    |
| $\hat{U}_n$           | peak value of the voltage across $R_n$ , in V;                          |
| $V_{Fe}$              | core volume, in $\text{mm}^3$ ;                                         |
| $x$                   | tolerance factor;                                                       |
| $y$                   | auxiliary value for the characteristics of the specific reactive power; |
| $y_1, y_2$            | constants for the characteristics of the specific reactive power;       |
| $y_3$                 | constant for the characteristics of the specific power loss;            |
| $\eta$                | stacking factor;                                                        |
| $\mu_0$               | magnetic constant, in H/cm ( $4 \cdot \pi \cdot 10^{-9}$ H/cm);         |
| $\mu_a$               | amplitude permeability;                                                 |
| $\mu_i$               | initial permeability;                                                   |
| $\pi$                 | in this standard = 3,1416;                                              |
| $\rho$                | the density of the core alloy, in $\text{kg/dm}^3$ .                    |

## 4 Materials and lamination thicknesses

### 4.1 Materials

Laminations are made from one of the materials specified in Table 1.

**Table 1 – Preferred magnetic steel and alloys used for laminations**

| Material                     | Approximate composition in addition to iron          | Density<br>kg/dm <sup>3</sup> | Designation |                                           |
|------------------------------|------------------------------------------------------|-------------------------------|-------------|-------------------------------------------|
|                              |                                                      |                               | IEC 60404-1 | IEC 60404-8-4<br>IEC 60404-8-7            |
| Non-oriented silicon steel   | 1 % to 3 % silicon                                   | 7,65                          | C 21        | M 270-35A 5<br>M 330-35A 5<br>M 330-50A 5 |
|                              |                                                      | 7,7                           |             | M 400-50A 5<br>M 530-50A 5                |
|                              |                                                      | 7,8                           |             | M 800-50A 5                               |
| Grain-oriented silicon steel | 3,2 % silicon                                        | 7,65                          | C 22        | M 165-35S 5                               |
| Nickel-iron alloys           | 72 % to 83 % nickel                                  | 8,7                           | E 1         | _____                                     |
|                              | 45 % to 50 % nickel (both oriented and non-oriented) | 8,25                          | E 3         |                                           |
|                              | 35 % to 40 % nickel                                  | 8,15                          | E 4         |                                           |
| Cobalt-iron alloys           | 47 % to 50 % cobalt (isotropic)                      |                               | F 1         |                                           |

### 4.2 Nominal lamination thickness

Lamination thickness shall be selected from one of the values specified in Table 2, according to the material in use.

**Table 2 – Material and lamination thickness**

| Material designation                             | Thickness<br>mm |      |      |     |     |     |      |
|--------------------------------------------------|-----------------|------|------|-----|-----|-----|------|
|                                                  | 0,5             | 0,38 | 0,35 | 0,3 | 0,2 | 0,1 | 0,05 |
| C 21                                             | o               | -    | o    | -   | -   | -   | -    |
| C 22                                             | -               | -    | o    | -   | -   | -   | -    |
| E 1                                              | -               | x    | x    | o   | o   | o   | x    |
| E 3 non-oriented                                 | -               | x    | x    | o   | o   | o   | x    |
| E 3 grain-oriented                               | -               | -    | -    | -   | -   | o   | x    |
| E 4                                              | -               | x    | x    | o   | o   | o   | x    |
| F 1                                              | -               | -    | x    | o   | o   | o   | x    |
| NOTE o: preferred value, x: usual, -: not usual. |                 |      |      |     |     |     |      |

The allowed tolerance of the thickness of the laminations in Table 3 is corresponding to the appropriate value taken from IEC 60404-8-4 and IEC 60404-8-7.

**Table 3 – Tolerance of the thickness of laminations**

| Material designation | Tolerances<br>mm |                   |
|----------------------|------------------|-------------------|
|                      | Thickness 0,5 mm | Thickness 0,35 mm |
| C 21                 | ± 0,04           | ± 0,028           |
| C 22                 | -                | ± 0,03            |

### 4.3 Minimum stacking factor

The minimum stacking factor  $\eta$  for usual materials and thickness shall be not lower than the values shown in Table 4. They are valid for uniform stacks with a minimum height of 10 mm subjected to a uniform pressure of 15 kN/m<sup>2</sup> perpendicular to the lamination.

**Table 4 – Lamination thickness and stacking factor**

| Lamination thickness<br>mm | Minimum stacking factor $\eta$     |                                      |                                            |
|----------------------------|------------------------------------|--------------------------------------|--------------------------------------------|
|                            | Non-oriented silicon steel<br>C 21 | Grain oriented silicon steel<br>C 22 | Nickel-iron and cobalt-iron alloys<br>E, F |
| 0,5                        | 0,95                               | –                                    | –                                          |
| 0,35                       | 0,94                               | 0,95                                 | 0,94                                       |
| 0,30                       | –                                  | –                                    | 0,92                                       |
| 0,20                       | -                                  | –                                    | 0,9                                        |
| 0,10                       | 0,9                                | 0,9                                  | 0,85                                       |
| 0,05                       | -                                  | 0,88                                 | 0,8                                        |

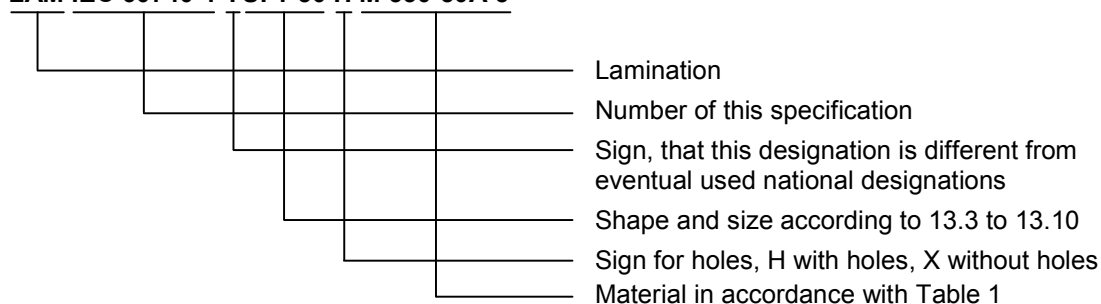
## 5 Designation of laminations and lamination strips

The designation contains all information needed to describe the laminations sufficiently and unmistakably.

### 5.1 Specified complete shapes

#### 5.1.1 Lamination outline shapes

**LAM IEC 60740-1 YUI 1-50 H M 530-50A 5**



IEC 1195/05

### 5.1.2 Specified shape with lamination strips

**LAM IEC 60740-1 YSUI 1-50 X M 165-35S 5**

| 13.4.1 | 13.4.2 | 13.4.3 | 13.4.4 | 13.4.5 | 13.4.6 | 13.4.7 | 13.4.8 | 13.4.9 | 13.4.10 | 13.4.11 | 13.4.12 | 13.4.13 | 13.4.14 | 13.4.15 | 13.4.16 | 13.4.17 | 13.4.18 | 13.4.19 | 13.4.20 | 13.4.21 | 13.4.22 | 13.4.23 | 13.4.24 | 13.4.25 | 13.4.26 | 13.4.27 | 13.4.28 | 13.4.29 | 13.4.30 | 13.4.31 | 13.4.32 | 13.4.33 | 13.4.34 | 13.4.35 | 13.4.36 | 13.4.37 | 13.4.38 | 13.4.39 | 13.4.40 | 13.4.41 | 13.4.42 | 13.4.43 | 13.4.44 | 13.4.45 | 13.4.46 | 13.4.47 | 13.4.48 | 13.4.49 | 13.4.50 | 13.4.51 | 13.4.52 | 13.4.53 | 13.4.54 | 13.4.55 | 13.4.56 | 13.4.57 | 13.4.58 | 13.4.59 | 13.4.60 | 13.4.61 | 13.4.62 | 13.4.63 | 13.4.64 | 13.4.65 | 13.4.66 | 13.4.67 | 13.4.68 | 13.4.69 | 13.4.70 | 13.4.71 | 13.4.72 | 13.4.73 | 13.4.74 | 13.4.75 | 13.4.76 | 13.4.77 | 13.4.78 | 13.4.79 | 13.4.80 | 13.4.81 | 13.4.82 | 13.4.83 | 13.4.84 | 13.4.85 | 13.4.86 | 13.4.87 | 13.4.88 | 13.4.89 | 13.4.90 | 13.4.91 | 13.4.92 | 13.4.93 | 13.4.94 | 13.4.95 | 13.4.96 | 13.4.97 | 13.4.98 | 13.4.99 | 13.4.100 | 13.4.101 | 13.4.102 | 13.4.103 | 13.4.104 | 13.4.105 | 13.4.106 | 13.4.107 | 13.4.108 | 13.4.109 | 13.4.110 | 13.4.111 | 13.4.112 | 13.4.113 | 13.4.114 | 13.4.115 | 13.4.116 | 13.4.117 | 13.4.118 | 13.4.119 | 13.4.120 | 13.4.121 | 13.4.122 | 13.4.123 | 13.4.124 | 13.4.125 | 13.4.126 | 13.4.127 | 13.4.128 | 13.4.129 | 13.4.130 | 13.4.131 | 13.4.132 | 13.4.133 | 13.4.134 | 13.4.135 | 13.4.136 | 13.4.137 | 13.4.138 | 13.4.139 | 13.4.140 | 13.4.141 | 13.4.142 | 13.4.143 | 13.4.144 | 13.4.145 | 13.4.146 | 13.4.147 | 13.4.148 | 13.4.149 | 13.4.150 | 13.4.151 | 13.4.152 | 13.4.153 | 13.4.154 | 13.4.155 | 13.4.156 | 13.4.157 | 13.4.158 | 13.4.159 | 13.4.160 | 13.4.161 | 13.4.162 | 13.4.163 | 13.4.164 | 13.4.165 | 13.4.166 | 13.4.167 | 13.4.168 | 13.4.169 | 13.4.170 | 13.4.171 | 13.4.172 | 13.4.173 | 13.4.174 | 13.4.175 | 13.4.176 | 13.4.177 | 13.4.178 | 13.4.179 | 13.4.180 | 13.4.181 | 13.4.182 | 13.4.183 | 13.4.184 | 13.4.185 | 13.4.186 | 13.4.187 | 13.4.188 | 13.4.189 | 13.4.190 | 13.4.191 | 13.4.192 | 13.4.193 | 13.4.194 | 13.4.195 | 13.4.196 | 13.4.197 | 13.4.198 | 13.4.199 | 13.4.200 | 13.4.201 | 13.4.202 | 13.4.203 | 13.4.204 | 13.4.205 | 13.4.206 | 13.4.207 | 13.4.208 | 13.4.209 | 13.4.210 | 13.4.211 | 13.4.212 | 13.4.213 | 13.4.214 | 13.4.215 | 13.4.216 | 13.4.217 | 13.4.218 | 13.4.219 | 13.4.220 | 13.4.221 | 13.4.222 | 13.4.223 | 13.4.224 | 13.4.225 | 13.4.226 | 13.4.227 | 13.4.228 | 13.4.229 | 13.4.230 | 13.4.231 | 13.4.232 | 13.4.233 | 13.4.234 | 13.4.235 | 13.4.236 | 13.4.237 | 13.4.238 | 13.4.239 | 13.4.240 | 13.4.241 | 13.4.242 | 13.4.243 | 13.4.244 | 13.4.245 | 13.4.246 | 13.4.247 | 13.4.248 | 13.4.249 | 13.4.250 | 13.4.251 | 13.4.252 | 13.4.253 | 13.4.254 | 13.4.255 | 13.4.256 | 13.4.257 | 13.4.258 | 13.4.259 | 13.4.260 | 13.4.261 | 13.4.262 | 13.4.263 | 13.4.264 | 13.4.265 | 13.4.266 | 13.4.267 | 13.4.268 | 13.4.269 | 13.4.270 | 13.4.271 | 13.4.272 | 13.4.273 | 13.4.274 | 13.4.275 | 13.4.276 | 13.4.277 | 13.4.278 | 13.4.279 | 13.4.280 | 13.4.281 | 13.4.282 | 13.4.283 | 13.4.284 | 13.4.285 | 13.4.286 | 13.4.287 | 13.4.288 | 13.4.289 | 13.4.290 | 13.4.291 | 13.4.292 | 13.4.293 | 13.4.294 | 13.4.295 | 13.4.296 | 13.4.297 | 13.4.298 | 13.4.299 | 13.4 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|------|
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IEC 1196/05

## 5.2 Lamination strips for specified shapes

### 5.2.1 Lamination strips for yokes

**LAM IEC 60740-1 YSUI 1-50 Y X M 165-35S 5**

|                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EXM 125 637 45 Y<br>TSSP 125 Y X M 125 635 9 | <div style="margin-bottom: 10px;">Lamination</div> <div style="margin-bottom: 10px;">Number of this standard</div> <div style="margin-bottom: 10px;">Sign, that this designation is different from eventual used national designations</div> <div style="margin-bottom: 10px;">Sign, that the shape is made of lamination strips</div> <div style="margin-bottom: 10px;">Shape and size according to 13.4.2 or 13.5.2</div> <div style="margin-bottom: 10px;">Sign for lamination strips for yokes</div> <div style="margin-bottom: 10px;">Sign for holes, H with holes, X without holes</div> <div>Material in accordance with Table 1</div> |
|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

IEC 1197/05

### 5.2.2 Lamination strips for limbs

**LAM IEC 60740-1 YSUI 1-50 L X M 165-35S 5**

| EX | 12 | 03 | 45 | 1 | 100 | 100 | 1 | 100 | 000 | 0 |                                                                                   |
|----|----|----|----|---|-----|-----|---|-----|-----|---|-----------------------------------------------------------------------------------|
|    |    |    |    |   |     |     |   |     |     |   | Lamination                                                                        |
|    |    |    |    |   |     |     |   |     |     |   | Number of this standard                                                           |
|    |    |    |    |   |     |     |   |     |     |   | Sign, that this designation is different from eventual used national designations |
|    |    |    |    |   |     |     |   |     |     |   | Sign, that the shape is made of lamination strips                                 |
|    |    |    |    |   |     |     |   |     |     |   | Shape and size according to 13.4.2 or 13.5.2                                      |
|    |    |    |    |   |     |     |   |     |     |   | Sign for lamination strips for limbs                                              |
|    |    |    |    |   |     |     |   |     |     |   | Sign for holes, H with holes, X without holes                                     |
|    |    |    |    |   |     |     |   |     |     |   | Material in accordance with Table 1                                               |

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**LAM IEC 60740-1 YS100 × 500 X M 165-35S 5**

IEC 1199/05

where

$C_1$  is the core constant 1, in  $\text{mm}^{-1}$ ;

$C_2$  is the core constant 2, in  $\text{mm}^{-3}$ ;

$l_{\text{Fe}}$  is the magnetic path length, in mm, calculated as in 7.3;

$A_{\text{Fe}}$  is the core cross-section, in  $\text{mm}^2$ , taking into account the stacking factor  $\eta$ , see 7.4.

Further, the core volume, in  $\text{mm}^3$ , and the core mass, in kg, are calculated as follows:

$$V_{\text{Fe}} = l_{\text{Fe}} \cdot A_{\text{Fe}} \quad (9)$$

$$m_{\text{Fe}} = V_{\text{Fe}} \cdot \rho \quad (10)$$

where  $\rho$  is the density of the alloy, in  $\text{kg/dm}^3$ .

The effective parameters of laminated cores with square cross-section and a stacking factor of 0,95 are shown in Tables 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27. For the laminations in 13.3, 13.4.1 and 13.5.1 the equations for the core constants are given subsequent to the associated tables.

### 7.3 Magnetic path length

The magnetic path length  $l_{\text{Fe}}$  is calculated as the arithmetic mean of the longest and the shortest path length of the core neglecting radii.

NOTE For details on the calculation for each core, see 13.3, 13.4.1 and 13.5.1.

### 7.4 Core cross-section

The core cross-section is calculated as the product of (centre) limb width, stack height and stacking factor:

$$A_{\text{Fe}} = d \cdot h_p \cdot \eta \quad (11)$$

where

$A_{\text{Fe}}$  is the core cross-section, in  $\text{mm}^2$ ;

$d$  is the limb width, in mm;

$h_p$  is the stack height, in mm;

$\eta$  is the stacking factor.

For cores with square stack ( $h_p = d$ ) shown in Tables 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27 and with  $\eta = 0,95$ , the core cross-section is:

$$A_{\text{Fe}} = 0,95 \cdot d^2 \quad (12)$$

For other stack heights and stacking factors differing from Table 4, the values for  $A_{\text{Fe}}$  and  $C_1$  shall be corrected by multiplying with the following factors:

The factor for  $A_{\text{Fe}}$  is:

$$\frac{h_p \cdot \eta}{d \cdot 0,95}$$

The factor for  $C_1$  is:

$$\frac{d \cdot 0,95}{h_p \cdot \eta}$$

NOTE Alternatively, for a given core stack, the core cross-section may be determined as follows:

For YEI, YEx, YUI and YM:

$$A_{Fe} = \frac{m_{Fe}}{l_{Fe} \cdot \rho} \quad (13)$$

## 8 General conditions for electrical measurements

### 8.1 Atmospheric conditions

Unless otherwise stated, all tests shall be carried out at room temperature.

### 8.2 Test coils

The electrical tests in Clauses 15 and 16 are valid for the square stack. The stack height of the test coil and of the core may be changed, if the values are not changed. However, the test coils shall be suitable to the stack of laminations to be tested. The voltage winding  $N_2$  shall be the inner winding and be as close as possible to the core, and its resistance  $R_2$  shall be small compared to the resistance of its load.

The resistance in the supply circuit, including the coil resistance  $R_1$  and the resistance of the current measuring device (current meter, current amplifier or precision resistor), shall be small, so that they do not result in any appreciable distortion of the voltage.

### 8.3 Test cores

The laminations shall physically be in accordance with the requirements of Clauses 4 and 13 and shall be selected at random from those which are fully processed for the end application. They shall be interleaved as a stack and shall consist of equal numbers of all necessary parts designing a complete layer of lamination.

NOTE Using grain-oriented and non-oriented silicon steel the laminations may be interleaved equilateral. Only in case of arbitration they shall be interleaved one by one throughout the stack.

Test cores made of lamination strips are a matter of agreement between customer and manufacturer.

### 8.4 Harmonic content of the voltage

In order to obtain comparable results, sinusoidal flux density shall be used for the measurements. During the test, the harmonic content shall not exceed 6 %. Where two voltmeters  $V_1$  and  $V_2$  in Figure 1a are connected in parallel to the winding  $N_2$ , the first one is measuring the r.m.s. value and the second one is measuring the average value. The form factor shall be calculated from the ratio of the r.m.s. value to the average value. If this form factor is between 1,10 and 1,12 and at the same time the wave-shape as observed on the oscilloscope does not show obvious distortion, the harmonic content of the secondary voltage across the winding  $N_2$  and hence of the flux density will be sufficiently small.

## 9 Measurements at high field strength

### 9.1 General

One of the circuits of Figure 1a, Figure 1b or Figure 2 shall be used. The test conditions shall be in accordance with the values specified in Table 5. Test certificates for lots of delivery are a matter of agreement between customer and manufacturer.

**Table 5 – Test conditions for the materials C 21, C 22 and F 1 for power loss and total apparent power**

| Material designation                 | Thickness<br>mm | Frequency<br>Hz | Peak flux density<br>T |
|--------------------------------------|-----------------|-----------------|------------------------|
| Non-oriented silicon steel<br>C 21   | 0,35 and 0,5    | 50 or 60        | 1,5                    |
|                                      | 0,1             | 400             | 1,0                    |
| Grain-oriented silicon steel<br>C 22 | 0,35            | 50 or 60        | 1,7                    |
|                                      | 0,1 and 0,15    | 400             | 1,0                    |
| Cobalt-iron alloys<br>F 1            | 0,2 and 0,35    | 50 or 60        | 2,0                    |
|                                      | 0,1             | 400             | 1,7                    |

For the following equations the following symbols are used:

|                 |                                                                          |
|-----------------|--------------------------------------------------------------------------|
| $U_2$           | is the voltage on winding $N_2$ , in V;                                  |
| $f$             | is the frequency, in Hz;                                                 |
| $\hat{B}$       | is the peak flux density, in T;                                          |
| $A_{Fe}$        | is the core cross-section, in mm <sup>2</sup> (see 7.4);                 |
| $I$             | is the current, in A;                                                    |
| $I_1, I_2, I_3$ | currents in the phases of three-phase cores, in A;                       |
| $m_{Fe}$        | is the core mass, in kg;                                                 |
| $N_1$           | is the number of turns of the winding $N_1$ ;                            |
| $N_2$           | is the number of turns of the winding $N_2$ ;                            |
| $P_{Fe}$        | is the power loss, in W;                                                 |
| $P_m$           | is the test value of power loss, in W;                                   |
| $P_S$           | is the total apparent power, in VA;                                      |
| $P_1, P_2, P_3$ | is the power loss in the phases of three-phase cores, in W;              |
| $R_2$           | is the resistance of the winding $N_2$ , in $\Omega$ ;                   |
| $R_V$           | is the resistance of the voltmeter $V_2$ , in $\Omega$ ;                 |
| $R_W$           | is the resistance of the voltage winding of the wattmeter, in $\Omega$ . |

## 9.2 Measurement of power loss

### 9.2.1 Power loss for single-phase cores

Where the circuit of Figure 1a is used, both switches are closed for the determination of the form factor (see 8.4). Switch  $S_1$  is then opened and the source voltage  $U_1$  is adjusted so that the reading of the secondary voltage  $U_2$  on the average sensing voltmeter  $V_2$  has the value calculated from the following equation:

$$U_2 = \frac{2 \cdot \pi \cdot f}{\sqrt{2}} \cdot A_{Fe} \cdot \hat{B} \cdot N_2 \cdot \frac{1}{1 + R_2 \cdot \left( \frac{1}{R_V} + \frac{1}{R_W} \right)} \quad (14)$$

With switch  $S_1$  open and switch  $S_2$  closed, the wattmeter is read. Neglecting the copper losses in winding  $N_1$  and in the ammeter, the power loss  $P_{Fe}$  are calculated with the following equation from the measured power loss  $P_m$ :

$$P_{Fe} = \left[ P_m \cdot \frac{N_1}{N_2} - U_2^2 \cdot \left( \frac{1}{R_V} + \frac{1}{R_W} \right) \right] \cdot \left[ 1 + R_2 \cdot \left( \frac{1}{R_V} + \frac{1}{R_W} \right) \right] \quad (15)$$

NOTE 1 The result of the measurement is often expressed in terms of specific power loss  $p_{Fe} = \frac{P_{Fe}}{m_{Fe}}$ , in W/kg.

Where instruments incorporating linear preamplifiers (see Figure 1b) or similar devices with very high input impedance are used for voltage measurements, and with direct reading of the actual values of voltage and power, these equations are reduced to the expressions:

$$U_2 = \frac{2 \cdot \pi \cdot f}{\sqrt{2}} \cdot A_{Fe} \cdot \hat{B} \cdot N_2 \quad (16)$$

$$P_{Fe} = P_m \cdot \frac{N_1}{N_2} \quad (17)$$

NOTE 2 Where these impedances are not extremely high, but still much higher than  $R_2$ , the following simplified equation may be used:

$$P_{Fe} = P_m \cdot \frac{N_1}{N_2} - U_2^2 \cdot \left( \frac{1}{R_V} + \frac{1}{R_W} \right) \quad (18)$$

Where no direct reading is possible, for example if external preamplifiers are used, the gains of these amplifiers shall be taken into account.

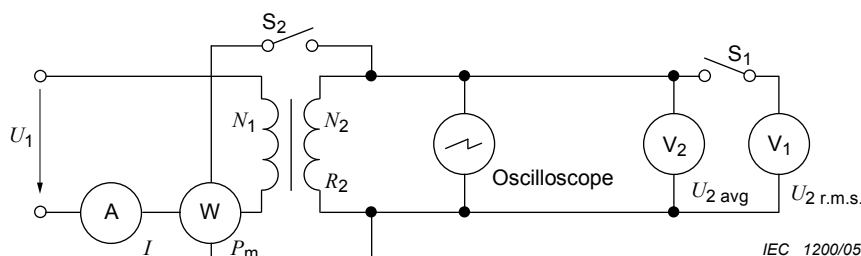


Figure 1a – Direct method

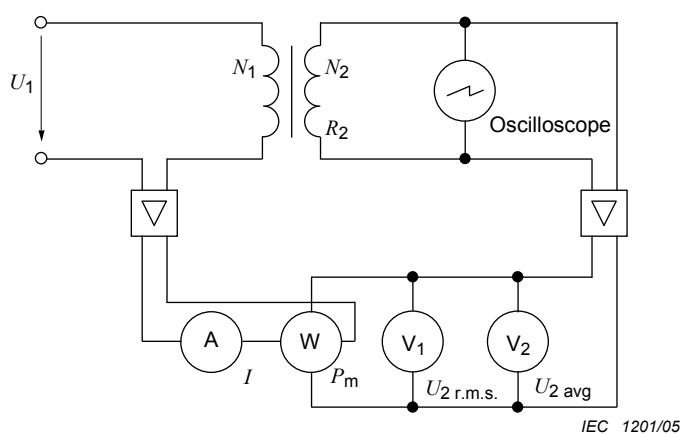


Figure 1b – Indirect method

Figure 1 – Measurements at high field strength, direct and indirect method, single-phase cores

### 9.2.2 Power loss for three-phase cores

The power loss in three-phase cores shall be measured with three watt meters using the circuit as shown in Figure 2. The induced secondary voltage shall be measured at the secondary winding of the middle limb. The total power loss are the sum of the three phases regarding the correct algebraic sign.

$$P_{Fe} = P_1 + P_2 + P_3 \quad (19)$$

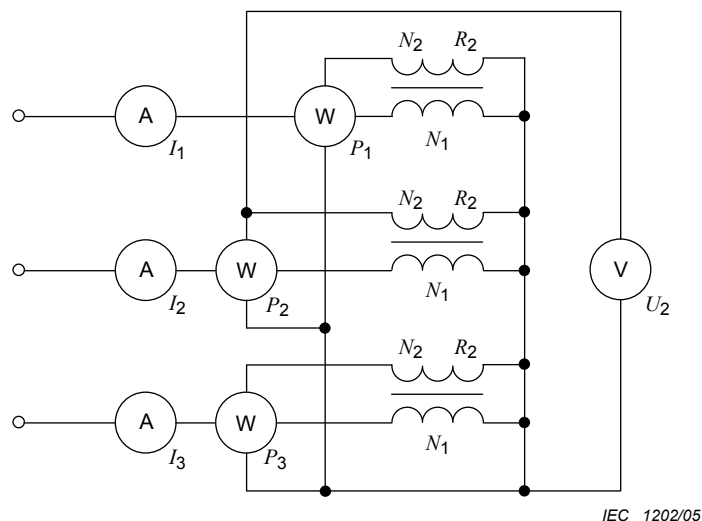


Figure 2 – Measurements at high field strength, direct method, three-phase cores

## 9.3 Measurement of total apparent power

### 9.3.1 Total apparent power for single-phase cores

Where the circuit of Figure 1a is used, both switches are closed in order to determine the form factor (see 8.4). Switch  $S_1$  is then opened and the primary voltage adjusted as described in 9.2.1. With both switches  $S_1$  and  $S_2$  open, the primary current  $I$  and the secondary voltage  $U_2$  are measured. The total apparent power is calculated using the following equation:

$$P_S = U_2 I \frac{N_1}{N_2} \cdot \frac{R_V + R_2}{R_V} \quad (20)$$

NOTE The result of the measurement is often expressed in terms of specific total apparent power  $p_S = P_S / m_{Fe}$ , in VA/kg (5).

Where instruments are used which incorporate linear preamplifiers (see Figure 1b) or similar devices with very high input impedance for voltage measurements, and with a direct reading of the actual values of voltage and power, this equation is reduced to the expression:

$$P_S = U_2 I \frac{N_1}{N_2} \quad (21)$$

Where no direct reading is possible, for example external preamplifiers are used, the gains of these amplifiers shall be taken into account.

### 9.3.2 Total apparent power for three-phase cores

The total apparent power for three-phase cores shall be measured as shown in Figure 2 and is calculated as the sum of the three currents multiplied with the voltage  $U_2$ :

$$P_S = U_2 (I_1 + I_2 + I_3) \quad (22)$$

## 10 Measurements at low and medium field strength

### 10.1 General

The circuit of Figure 3 shall be used. The measuring conditions shall be taken from the values specified in Table 6 and Table 7. Test certificates for lots of delivery are a matter of agreement between customer and manufacturer.

**Table 6 – Conditions for the measurement of amplitude permeability of cores using laminations of silicon steel**

| Thickness<br>mm | Frequency<br>Hz | Peak flux density<br>T |
|-----------------|-----------------|------------------------|
| 0,05 up to 0,5  | 50 or 60        | 0,1 or 1,0             |

For the following equations the following symbols are used:

- $A_{Fe}$  is the core cross-section, in  $mm^2$  (see 7.4);
- $\hat{B}$  is the peak flux density, in T;
- $C_1$  is the core constant 1, in  $cm^{-1}$  (see 7.2);
- $f$  is the frequency, in Hz;
- $\hat{H}$  is the peak field strength, in A/m;
- $\mu_0$  is the magnetic constant, in H/cm ( $4 \cdot \pi \cdot 10^{-9}$  H/cm);
- $\mu_a$  is the amplitude permeability;
- $N_1$  is the number of turns of the winding  $N_1$ ;
- $N_2$  is the number of turns of the winding  $N_2$ ;
- $R_2$  is the resistance of the winding  $N_2$ , in  $\Omega$ ;
- $R_n$  is the resistance of the precision resistor, in  $\Omega$ ;
- $R_V$  is the resistance of the voltmeter  $V_2$ , in  $\Omega$ ;
- $U_2$  is the voltage on winding  $N_2$ , in V;
- $\hat{U}_n$  is the peak value of the voltage across  $R_n$ , in V.

### 10.2 Measurement of amplitude permeability

The primary voltage is adjusted so that the reading of the r.m.s. voltage  $U_2$  on the voltmeter  $V_2$  meets the value calculated from the following equation:

$$U_2 = \frac{2 \cdot \pi \cdot f}{\sqrt{2}} \cdot A_{Fe} \cdot \hat{B} \cdot N_2 \cdot \frac{R_V}{R_V + R_2} \quad (23)$$

The peak value  $\hat{I}$  of the primary current is measured by means of a peak voltmeter connected across a known precision resistor  $R_n$  in the primary circuit or by means of a probe. The amplitude permeability  $\mu_a$  is calculated from the following equation:

$$\mu_a = \frac{1}{\mu_0} \cdot \frac{\hat{B}}{\hat{H}} = \frac{1}{\mu_0} \cdot \frac{\sqrt{2} \cdot U_2}{\hat{U}_n} \cdot \frac{C_1}{2 \cdot \pi \cdot f} \cdot \frac{1}{N_1 \cdot N_2} \cdot R_n \cdot \frac{R_V + R_2}{R_V} \quad (24)$$

NOTE 1 For very small currents  $\mu_a$  tends towards the initial permeability  $\mu_i$ .

NOTE 2 In some cases, it is convenient to use the complex permeability and its components.

NOTE 3 Specification for the minimum permeability of laminations made of soft magnetic metallic materials, see IEC 60740-2.

**Table 7 – Conditions for the measurement of amplitude permeability of cores using laminations of nickel-iron alloys**

| Material designation                           | Thickness<br>mm | Preferred frequency<br>Hz |            |      | Amplitude of field strength<br>A/m |
|------------------------------------------------|-----------------|---------------------------|------------|------|------------------------------------|
|                                                |                 | 50 or 60                  | 300 or 400 | 1000 |                                    |
| E 1                                            | 0,05            | x                         | x          | x    | 0,2 or 0,4                         |
|                                                | 0,1             | x                         | x          | -    |                                    |
|                                                | 0,2             | x                         | -          | -    |                                    |
|                                                | 0,35            | x                         | -          | -    |                                    |
| E 3<br>(both oriented<br>and non-<br>oriented) | 0,05            | x                         | x          | -    | 0,4                                |
|                                                | 0,1             | x                         | x          | -    |                                    |
|                                                | 0,2             | x                         | -          | -    |                                    |
|                                                | 0,35            | x                         | -          | -    |                                    |
| E 4                                            | 0,05            | x                         | x          | x    | 0,4 or 1,6                         |
|                                                | 0,1             | x                         | x          | -    |                                    |
|                                                | 0,2             | x                         | -          | -    |                                    |
|                                                | 0,35            | x                         | -          | -    |                                    |

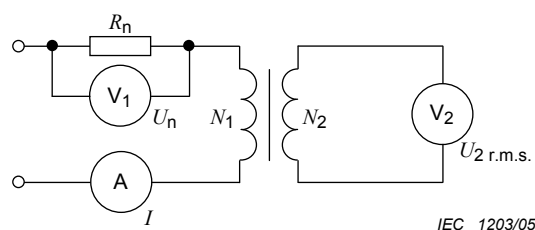


**Figure 3 – Measurements at low and medium field strength**

## 11 Preferred ranges of laminations

This clause describes the preferred shapes and ranges of limb width  $d$ . Table 8 shows a summary of these shapes and ranges with some general information.

**Table 8 – Summary of preferred shapes**

| Shape     | Clause | Limb width <i>d</i><br>mm | Description                                            |
|-----------|--------|---------------------------|--------------------------------------------------------|
| YS        | 13.2   | -                         | Lamination strips                                      |
| YEI 1     | 13.3   | 10 up to 80               | Range, allowing punching without scrap                 |
| YUI 1     | 13.4   | 10 up to 80               | Range, allowing punching without scrap                 |
| YUI 2     | 13.5   | 10 up to 80               | Range, allowing punching without scrap                 |
| YEx 2     | 13.6   | 2,4 up to 12              | Range with small dimensions                            |
| YEE 2-..L | 13.7   | 6 up to 12                | Range with small dimensions, using two long E parts    |
| YEx 3     | 13.8   | 10 up to 40               | Range with small dimensions and with large window area |
| YEx 4     | 13.9   | 2,4 up to 12              | Range with small dimensions and small mounting area    |
| YM 1      | 13.10  | 5 up to 34                | Range for laminations with low stray field             |

## 12 Dimensions and tolerances

### 12.1 Dimensions

The dimensions, or relation of dimensions, and tolerances of the preferred ranges of laminations are specified in the tables shown in 13.3 to 13.10. The tolerance on the lamination thickness is specified in Table 3.

### 12.2 Tolerances

The tolerances shall be in accordance with the requirements of ISO 286-1. The values corresponding to the reference designations at the head of each column of dimensions in the tables shown in 13.3 to 13.10 are taken from Table 9.

**Table 9 – Tolerance according to ISO 286-1**

| Size range<br>mm | ISO Tolerance code |             |             |             |             |
|------------------|--------------------|-------------|-------------|-------------|-------------|
|                  | IT 10<br>µm        | IT 11<br>µm | IT 12<br>µm | IT 13<br>µm | IT 14<br>µm |
| up to 3          | 40                 | 60          | 100         | 140         | 250         |
| > 3 up to 6      | 48                 | 75          | 120         | 180         | 300         |
| > 6 up to 10     | 58                 | 90          | 150         | 220         | 360         |
| > 10 up to 18    | 70                 | 110         | 180         | 270         | 430         |
| > 18 up to 30    | 84                 | 130         | 210         | 330         | 520         |
| > 30 up to 50    | 100                | 160         | 250         | 390         | 620         |
| > 50 up to 80    | 120                | 190         | 300         | 460         | 740         |
| > 80 up to 120   | 140                | 220         | 350         | 540         | 870         |
| > 120 up to 180  | 160                | 250         | 400         | 630         | 1000        |
| > 180 up to 250  | 185                | 290         | 460         | 720         | 1150        |
| > 250 up to 315  | 210                | 320         | 520         | 810         | 1300        |
| > 315 up to 400  | 230                | 360         | 570         | 890         | 1400        |
| > 400 up to 500  | 250                | 400         | 630         | 970         | 1550        |

NOTE The tolerance code indicates the value of the tolerance in relation to the nominal dimension.

For example, in Table 17, YEx 2-10:

size  $a = 32$  mm with the tolerance IT 12 js =  $a \pm 0,5 \times 250 \mu\text{m} = 32 \text{ mm} \pm 0,125 \text{ mm}$ ;

size  $e = 22,4$  mm with the tolerance + IT 11 =  $e + 130 \mu\text{m} = 22,4 \text{ mm} + 0,13 \text{ mm}$ .

### 12.3 Symmetry tolerances

The symmetry tolerances of dimensions  $a$  and  $e$  with respect to the centre line shall not exceed half the tolerance specified for the width of the (centre) limb (dimension  $d$ ).

## 13 Dimensions and effective parameters

### 13.1 General

In the following figures, the direction of rolling is indicated by a double arrow.

Subclauses 13.3 to 13.10 include the dimensions, the tolerances and the effective parameters, with their respective equations. The effective parameters are based on a stacking factor  $\eta = 0,95$  and a stack height  $h_p = d$ . For the calculation, in the case of different stacking factors and heights, see 7.4.

### 13.2 Lamination strips Type YS

Lamination strips are specified as single strips with the nominal width  $d$  and the length  $a$ . For square lamination strips, the direction of rolling is to be indicated. Holes are a matter of agreement between customer and manufacturer.

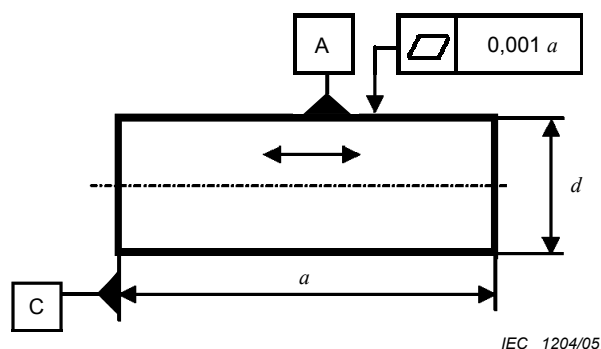


Figure 4 – Lamination strips Type YS, dimensions and tolerances

Table 10 – Tolerances for lamination strips

| Length $a$<br>mm | Tolerance<br>mm | Width $d$<br>mm  | Tolerance<br>mm |
|------------------|-----------------|------------------|-----------------|
| $\leq 200$       | +0,25           | $\leq 150$       | +0,2            |
| $> 200 \leq 400$ | +0,3            | $> 150 \leq 250$ | +0,4            |
| $> 400 \leq 800$ | +0,35           | $> 250$          | +0,5            |
| $> 800$          | +0,5            |                  |                 |

### 13.3 Laminations Type YEI 1

Laminations Type YEI 1, sizes from YEI 1-10 to YEI 1-80 are usual, where the numbers 10 to 80 are the nominal width of the centre limb.

Preferred dimensions  $d$ : 10, 13 (YEI 1-13 has a centre limb width 12,8 mm), 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 58, 64, 72 and 80 mm.

For the relation of the other dimensions of the lamination Type YEI 1 to the dimension  $d$ , see Table 11.

For the diameter for the holes  $h$  and for the tolerance factor  $x$  there is no fixed relation to dimension  $d$ , these dimensions are according to Table 12 in steps adjusted to dimension  $d$ . For representation of the dimensions, see Figure 5.

Laminations without holes are subject to an agreement between customer and manufacturer.

NOTE For laminations Type YEI 1, the coil formers IEC 61797-1, Type YEI 1, may be used.

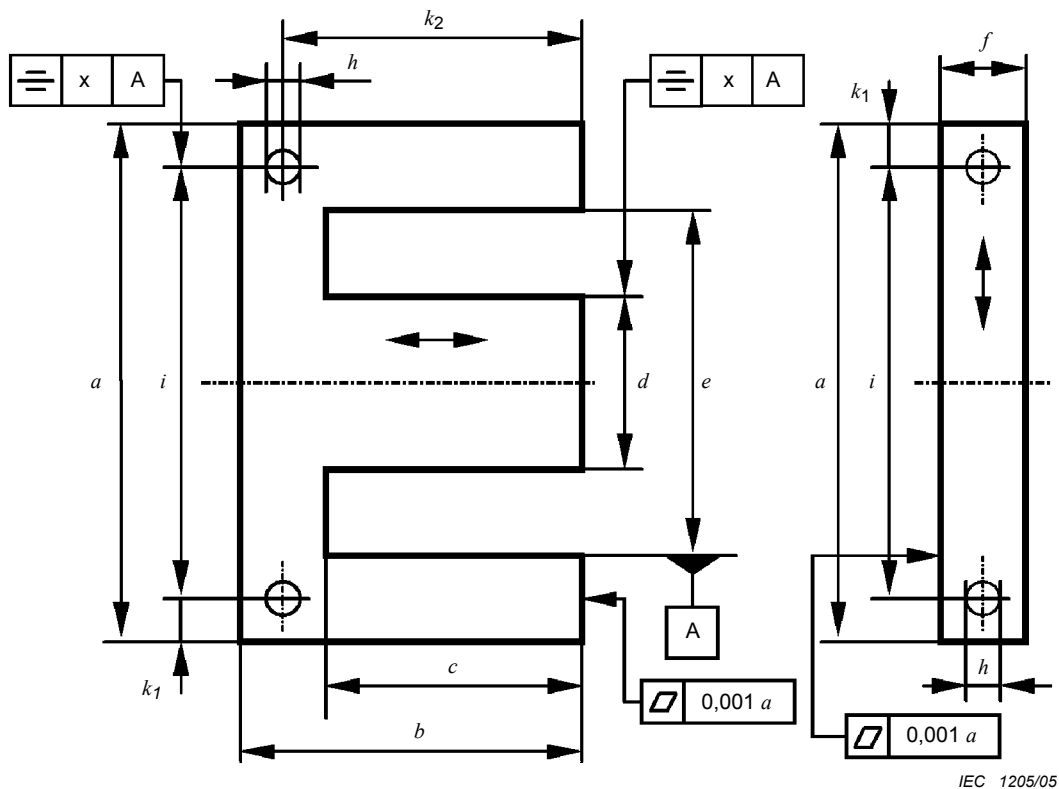


Figure 5 – Laminations Type YEI 1, dimensions

**Table 11 – Laminations Type YEI 1, relation factor of dimensions and tolerances**

| Dimension             | Relation factor | Tolerance code |
|-----------------------|-----------------|----------------|
| <i>a</i>              | 3 <i>d</i>      | IT 12 js       |
| <i>b</i>              | 2 <i>d</i>      | IT 12 js       |
| <i>c</i>              | 1,5 <i>d</i>    | IT 12 JS       |
| <i>d</i>              | 1 <i>d</i>      | IT 12 js       |
| <i>e</i>              | 2 <i>d</i>      | IT 12JS        |
| <i>f</i>              | 0,5 <i>d</i>    | IT 12 js       |
| <i>i</i>              | 2,5 <i>d</i>    | IT 12 JS       |
| <i>k</i> <sub>1</sub> | 0,25 <i>d</i>   | -              |
| <i>k</i> <sub>2</sub> | 1,75 <i>d</i>   | IT 12 JS       |

**Table 12 – Laminations Type YEI 1, diameter of the holes and tolerance factor *x***

| Dimension | Tolerance code | Lamination YEI 1-..., Dimension <i>d</i><br>mm |          |          |          |          |          |          |          |
|-----------|----------------|------------------------------------------------|----------|----------|----------|----------|----------|----------|----------|
|           |                | 10 to 13                                       | 14 to 16 | 17 to 20 | 21 to 28 | 29 to 36 | 37 to 45 | 46 to 59 | 60 to 80 |
| <i>h</i>  | JS 14          | -                                              | 3,5      | 3,5      | 4,5      | 5,5      | 6,6      | 8        | 10,5     |
| <i>x</i>  | -              | 0,1                                            | 0,1      | 0,2      | 0,2      | 0,2      | 0,4      | 0,4      | 0,5      |

The effective parameters are calculated as follows:

$$\text{Core cross-section} \quad A_{\text{Fe}} = d \cdot h_p \cdot \eta, \text{ in mm}^2 \quad (25)$$

$$\text{Magnetic path length} \quad l_{\text{Fe}} = b + c + f + (a + e - d)/2 = 6 \cdot d, \text{ in mm} \quad (26)$$

$$\text{Core volume} \quad V_{\text{Fe}} = A_{\text{Fe}} \cdot l_{\text{Fe}}, \text{ in mm}^3 \quad (27)$$

$$\text{Core constant} \quad C_1 = l_{\text{Fe}} / A_{\text{Fe}}, \text{ in mm}^{-1} \quad (28)$$

where

*d* is the limb width, in mm;

*h<sub>p</sub>* is the stack height, in mm;

*η* is the stacking factor.

### 13.4 Laminations Type YUI 1

#### 13.4.1 Lamination outline shapes Type YUI 1

Laminations Type YUI 1, sizes from YUI 1-10 to YUI 1-80 are usual, where the numbers 10 to 80 expresses the approximate width of the limb.

Preferred dimensions *d*: 10, 13, 16, 20, 25, 30, 34, 38, 44, 50, 56, 60, 70 and 80 mm.

For the relation of the other dimensions of the lamination Type YUI 1 to the dimension *d*, see Table 13.

For the diameter for the holes  $h$  and for the tolerance factor  $x$  there is no fixed relation to dimension  $d$ , these dimensions are according to Table 14 in steps adjusted to dimension  $d$ . Representation of the dimensions see Figure 6.

Laminations without holes are matter of agreement between customer and manufacturer.

NOTE For laminations Type YUI 1, the coil formers IEC 61797-1, Type YUI 1, may be used.

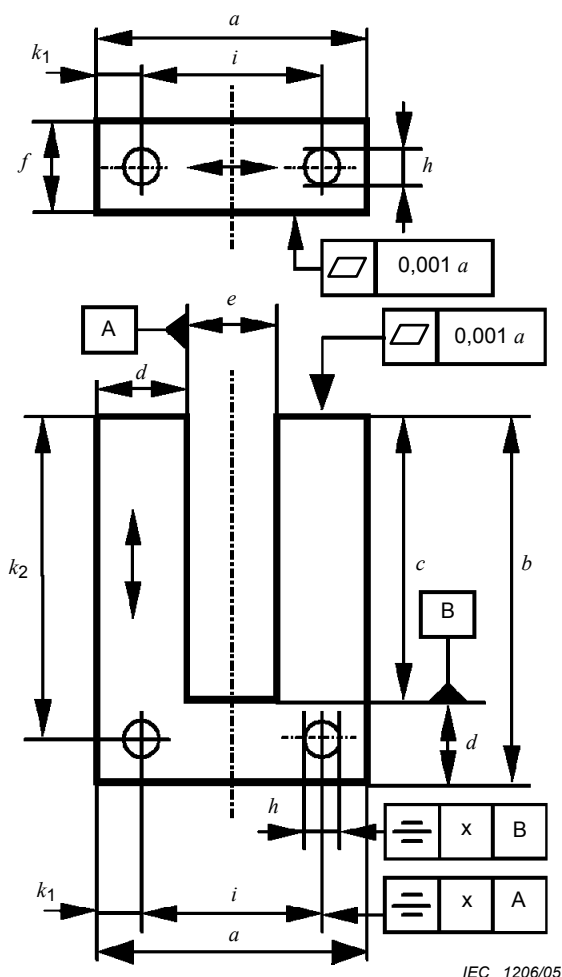


Figure 6 – Laminations Type YUI 1, dimensions

Table 13 – Laminations Type YUI 1, relation of dimensions and tolerances

| Dimension | Relation factor | Tolerance code |
|-----------|-----------------|----------------|
| $a$       | $3 d$           | IT 12 js       |
| $b$       | $4 d$           | IT 12 js       |
| $c$       | $3 d$           | IT 12 JS       |
| $d$       | $1 d$           | -              |
| $e$       | $1 d$           | IT 12 JS       |
| $f$       | $1 d$           | IT 12 js       |
| $i$       | $2 d$           | IT 12 JS       |
| $k_1$     | $0,5 d$         | -              |
| $k_2$     | $3,5 d$         | IT 12 JS       |

**Table 14 – Laminations Type YUI 1, diameter of the holes and tolerance factor  $x$** 

| Dimension | Tolerance code | Lamination YUI 1-... , dimension $d$<br>mm |          |          |          |          |          |          |          |
|-----------|----------------|--------------------------------------------|----------|----------|----------|----------|----------|----------|----------|
|           |                | 10 to 14                                   | 15 to 19 | 20 to 24 | 25 to 29 | 30 to 37 | 38 to 43 | 44 to 60 | 61 to 80 |
| $h$       | JS 14          | 3,5                                        | 4,5      | 4,5      | 5,5      | 7,8      | 11       | 11       | 15       |
| $x$       | -              | 0,1                                        | 0,1      | 0,2      | 0,2      | 0,2      | 0,2      | 0,4      | 0,4      |

The effective parameters are calculated as follows:

$$\text{Core cross-section} \quad A_{\text{Fe}} = d \cdot h_p \cdot \eta, \text{ in mm}^2 \quad (29)$$

$$\text{Magnetic path length} \quad l_{\text{Fe}} = 2 \cdot b + 2 \cdot (a - d) = 12 \cdot d, \text{ in mm} \quad (30)$$

$$\text{Core volume} \quad V_{\text{Fe}} = A_{\text{Fe}} \cdot l_{\text{Fe}}, \text{ in mm}^3 \quad (31)$$

$$\text{Core constant} \quad C_1 = l_{\text{Fe}} / A_{\text{Fe}}, \text{ in mm}^{-1} \quad (32)$$

where

$d$  is the width of the limb, in mm;

$h_p$  is the stack height, in mm;

$\eta$  is the stacking factor.

#### 13.4.2 Lamination strip shape Type YSUI 1

The lamination Type YUI 1 may also be constructed with lamination strips. For the layer plan of the separate strips, see Figure 7. The dimensions and tolerances of the strips are according to the dimensions and tolerances of the outline shapes. As a matter of agreement between customer and manufacturer the strip shapes may be provided with holes (sign H). The size and position of the holes shall be analogous in accordance with the holes in the outline shapes in Figure 6. Other holes are a matter for agreement between customer and manufacturer.

NOTE For lamination strip shapes Type YSUI 1, the coil formers IEC 61797-1, Type YUI 1, may be used.

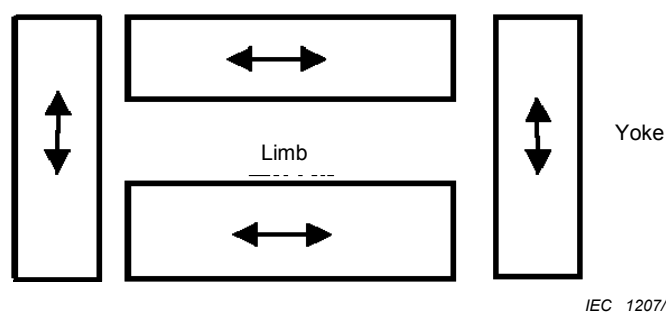


**Figure 7 – Layer plan for the lamination strip shapes Type YSUI 1**

## 13.5 Lamination Types YUI 2

### 13.5.1 Lamination outline shape Type YUI 2

Laminations Type YUI 2, sizes from YUI 2-10 to YUI 2-80 are usual, where the number 10 to 80 expresses the approximate width of the limb.

Preferred dimensions  $d$ : 10, 13, 16, 20, 25, 30, 34, 38, 44, 50, 56, 60, 70 and 80 mm.

For the relation of the other dimensions of the lamination Type YUI 2 to the dimension  $d$ , see Table 15.

For the diameter for the holes  $h$  and for the tolerance factor  $x$ , there is no fixed relation to dimension  $d$ , these dimensions according to Table 16 in steps are adjusted to dimension  $d$ . For representation of the dimensions, see Figure 8.

Laminations without holes are subject to an agreement between customer and manufacturer.

NOTE For laminations Type YUI 2 the coil formers IEC 61797-1, Type YUI 1, may be used.

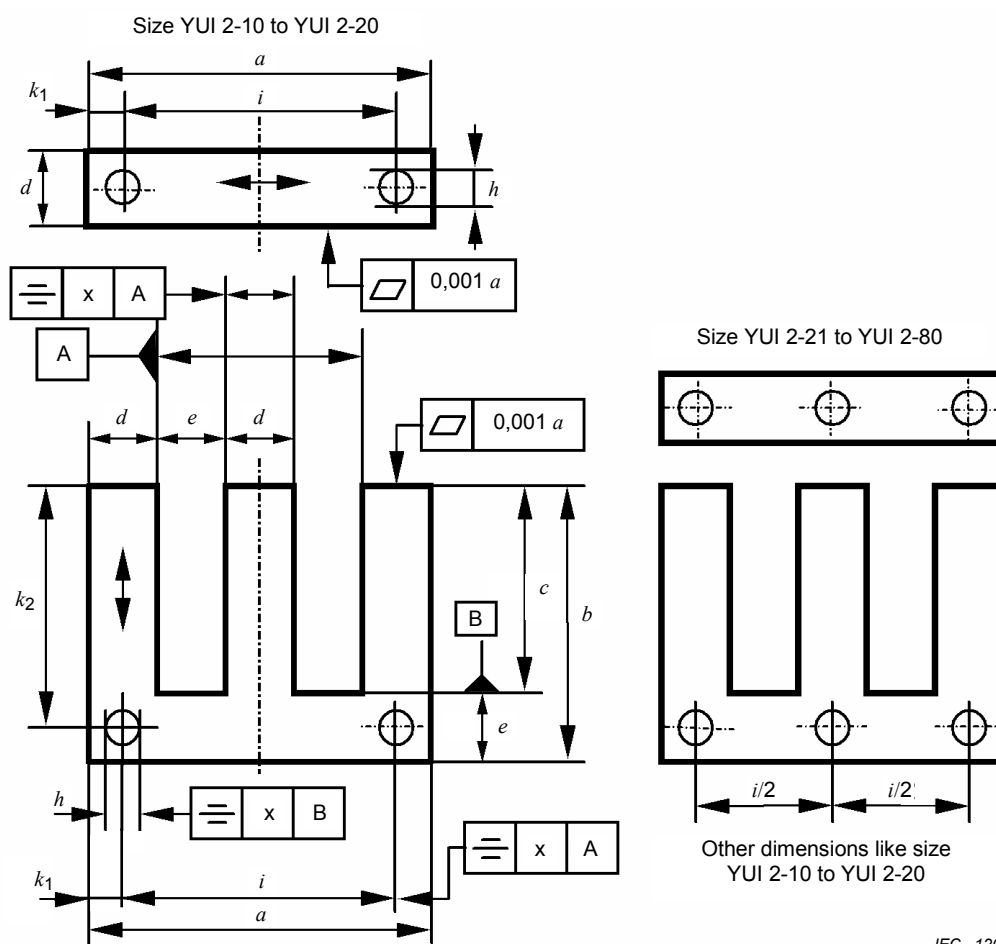


Figure 8 – Laminations Type YUI 2, dimensions

**Table 15 – Laminations Type YUI 2, relation of dimensions and tolerances**

| Dimension | Relation factor | Tolerance code |
|-----------|-----------------|----------------|
| $a$       | $5 \cdot d$     | IT 12 js       |
| $b$       | $4 \cdot d$     | IT 12 js       |
| $c$       | $3 \cdot d$     | IT 12 JS       |
| $d$       | $1 \cdot d$     | IT 12 js       |
| $e$       | $1 \cdot d$     | -              |
| $i$       | $4 \cdot d$     | IT 12 JS       |
| $k_1$     | $0,5 \cdot d$   | -              |
| $k_2$     | $3,5 \cdot d$   | IT 12 JS       |

**Table 16 – Laminations Type YUI 2, diameter of the holes and tolerance factor  $x$** 

| Dimen-<br>sion | Tolerance<br>code | Lamination YUI 2-... , dimension $d$ in mm |          |          |          |          |          |          |
|----------------|-------------------|--------------------------------------------|----------|----------|----------|----------|----------|----------|
|                |                   | 10 to 14                                   | 15 to 19 | 20 to 24 | 25 to 29 | 30 to 37 | 38 to 60 | 61 to 80 |
| $h$            | JS 14             | 3,5                                        | 4,5      | 4,5      | 5,5      | 7,8      | 11       | 15       |
| $x$            |                   | 0,1                                        | 0,1      | 0,2      | 0,2      | 0,2      | 0,4      | 0,4      |

The effective parameters are calculated as follows:

$$\text{Core cross-section} \quad A_{\text{Fe}} = d \cdot h_p \cdot \eta, \text{ in mm}^2; \quad (33)$$

$$\text{Magnetic path length} \quad l_{\text{Fe1}} = b + d, \text{ in mm}; \quad (34)$$

$$l_{\text{Fe2}} = b + 3 \cdot d, \text{ in mm}; \quad (35)$$

$$l_{\text{Fe}} = l_{\text{Fe1}} + 2 \cdot l_{\text{Fe2}} = 19 \cdot d; \quad (36)$$

$$\text{Core volume} \quad V_{\text{Fe}} = A_{\text{Fe}} \cdot l_{\text{Fe}}, \text{ in mm}^3; \quad (37)$$

$$\text{Core constant} \quad C_1 = l_{\text{Fe}} / A_{\text{Fe}}, \text{ in mm}^{-1}. \quad (38)$$

where

$d$  is the limb width, in mm;

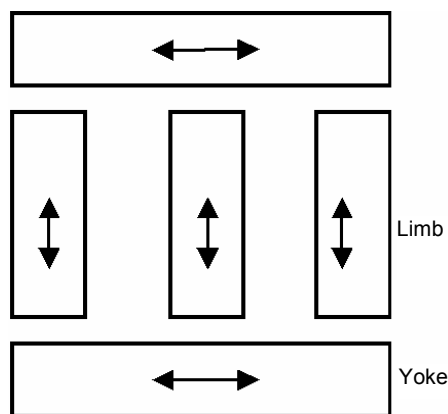
$h_p$  is the stack height, in mm;

$\eta$  is the stacking factor.

### 13.5.2 Lamination strip shape Type YSUI 2

The lamination Type YUI 2 also may be constructed with lamination strips. For the layer plan of the separate strips, see Figure 9. The dimensions and tolerances of the strips are according to the dimensions and tolerances of the outline shapes. As a matter of agreement between customer and manufacturer, the strip shapes may be provided with holes (sign H). The size and position of the holes shall be analogous in accordance with the holes in the outline shapes in Figure 8. Other holes are a matter for agreement between customer and manufacturer.

NOTE For lamination strip shapes Type YSUI 2, the coil formers IEC 61797-1, Type YUI 1, may be used.



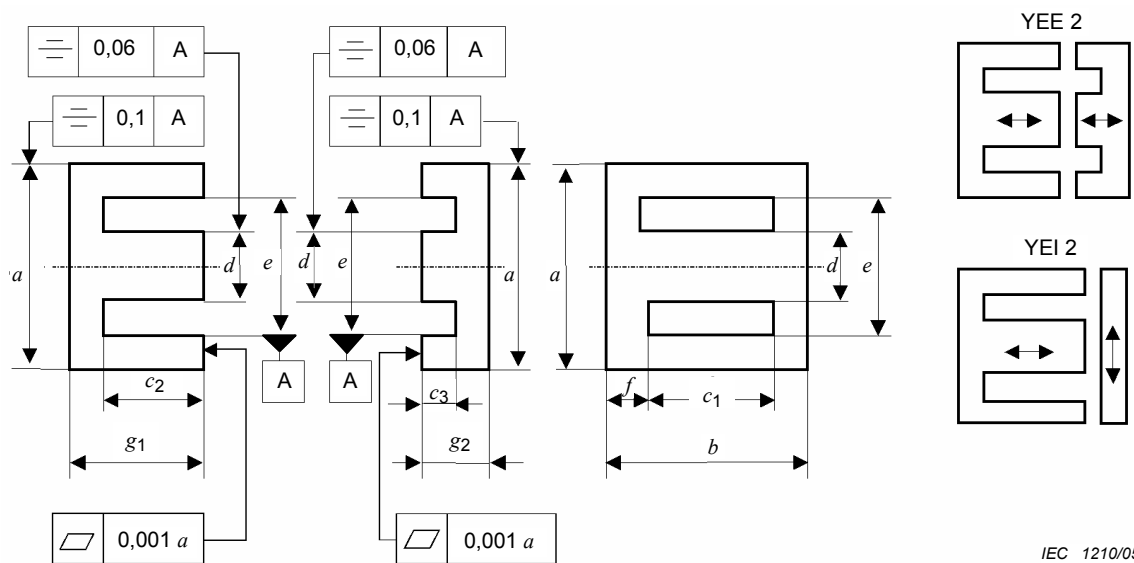
IEC 1209/05

Figure 9 – Layer plan for the lamination strip shapes Type YSUI 2

### 13.6 Lamination Types YEx 2, YEE 2 and YEI 2

YEx 2 designates YEE 2 or YEI 2. The corresponding type YEE 2-.. L is described in 13.7. For laminated core packages using YEE 2 laminations, see IEC 61021-1 and IEC 61021-2.

NOTE For laminations Type YEx 2, the coil formers IEC 61797-1, Type YEx 2, may be used.



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Figure 10 – Laminations Type YEx 2, dimensions

**Table 17 – Laminations Type YEx 2, dimensions and tolerances**

| Designation     | Reference letter and tolerance code (see Table 9) |                |                       |                       |                       |             |                |               |                       |                       |
|-----------------|---------------------------------------------------|----------------|-----------------------|-----------------------|-----------------------|-------------|----------------|---------------|-----------------------|-----------------------|
|                 | <i>a</i>                                          | <i>b</i>       | <i>c</i> <sub>1</sub> | <i>c</i> <sub>2</sub> | <i>c</i> <sub>3</sub> | <i>d</i>    | <i>e</i>       | <i>f</i>      | <i>g</i> <sub>1</sub> | <i>g</i> <sub>2</sub> |
|                 | IT 12 js                                          | IT 13 js       | + IT 13<br>0          | + IT 12<br>0          | + IT 12<br>0          | 0<br>–IT 11 | + IT 11<br>0   |               | IT 12 js              | IT 12 js              |
| YEx 2-2         | 8                                                 | 8              | 5,6                   | 4,3                   | 1,3                   | 2,4         | 5,6            | 1,2           | 5,5                   | 2,5                   |
| YEx 2-3         | 10                                                | 10             | 7                     | 5,5                   | 1,5                   | 3           | 7              | 1,5           | 7                     | 3                     |
| YEx 2-4         | 12,6                                              | 12,6           | 8,8                   | 6,7                   | 2,1                   | 3,8         | 8,8            | 1,9           | 8,6                   | 4                     |
| YEx 2-5         | 16                                                | 16             | 11,2                  | 8,6                   | 2,6                   | 4,8         | 11,2           | 2,4           | 11                    | 5                     |
| YEx 2-6         | 20                                                | 20             | 14                    | 11                    | 3                     | 6           | 14             | 3             | 14                    | 6                     |
| YEx 2-8         | 25                                                | 25             | 17,4                  | 13,2                  | 4,2                   | 7,6         | 17,4           | 3,8           | 17                    | 8                     |
| YEx 2-10        | 32                                                | 32             | 22,4                  | 17,2                  | 5,2                   | 9,6         | 22,4           | 4,8           | 22                    | 10                    |
| YEx 2-12        | 40                                                | 40             | 28                    | 22                    | 6                     | 12          | 28             | 6             | 28                    | 12                    |
| Relation factor | $3,33 \cdot d$                                    | $3,33 \cdot d$ | $2,33 \cdot d$        |                       |                       | $1 \cdot d$ | $2,33 \cdot d$ | $0,5 \cdot d$ |                       |                       |

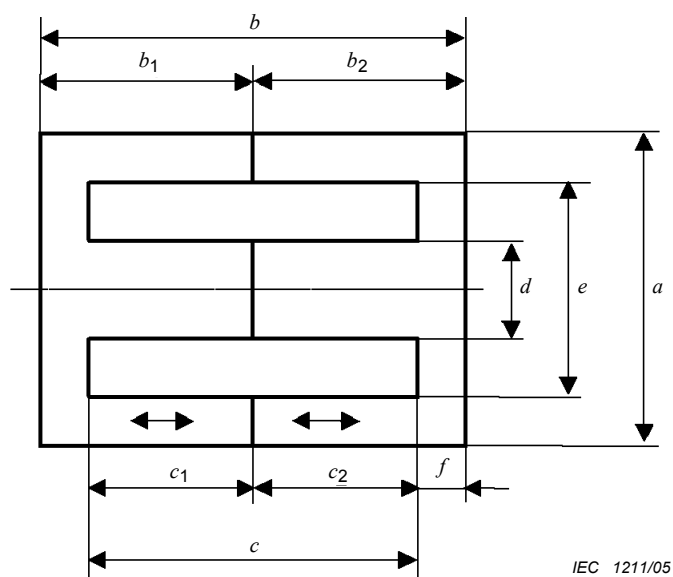
**Table 18 – Laminations Type YEx 2, effective parameters**

| Designation | Effective parameters for $h_p = d$ and $\eta = 0,95$ |                                        |                                            |                                            |
|-------------|------------------------------------------------------|----------------------------------------|--------------------------------------------|--------------------------------------------|
|             | Core cross-section<br>$A_{Fe}$<br>mm <sup>2</sup>    | Magnetic path length<br>$l_{Fe}$<br>mm | Core volume<br>$V_{Fe}$<br>cm <sup>3</sup> | Core constant<br>$C_1$<br>cm <sup>-1</sup> |
| YEx 2-2     | 5,47                                                 | 19,2                                   | 0,105                                      | 35,1                                       |
| YEx 2-3     | 8,55                                                 | 24,0                                   | 0,205                                      | 28,1                                       |
| YEx 2-4     | 13,7                                                 | 30,2                                   | 0,414                                      | 22,0                                       |
| YEx 2-5     | 21,9                                                 | 38,4                                   | 0,841                                      | 17,5                                       |
| YEx 2-6     | 34,2                                                 | 48,0                                   | 1,64                                       | 14,0                                       |
| YEx 2-8     | 54,9                                                 | 59,8                                   | 3,28                                       | 10,9                                       |
| YEx 2-10    | 87,6                                                 | 76,8                                   | 6,73                                       | 8,77                                       |
| YEx 2-12    | 136,8                                                | 96,0                                   | 13,1                                       | 7,02                                       |

Magnetic path length  $l_{Fe} = b + c_1 + (a + e - d) / 2$  (39)

### 13.7 Lamination Types YEE 2-..L

NOTE For laminations Type YEE 2-..L, the coil formers IEC 61797-1, Type YEE 2-..L, may be used.



$$b_1 = b_2 \quad c_1 = c_2$$

Figure 11 – Laminations Type YEE 2-...L, using two long E parts, dimensions

Table 19 – Laminations Type YEE 2-...L, using two long E parts, dimensions and tolerances

| Designation     | Reference letter and tolerance code (see Table 9) |               |                 |              |                 |                |
|-----------------|---------------------------------------------------|---------------|-----------------|--------------|-----------------|----------------|
|                 | <i>a</i>                                          | <i>b</i>      | <i>c</i>        | <i>d</i>     | <i>e</i>        | <i>f</i>       |
|                 | IT 13 js                                          | IT 14 js      | IT 14 JS        | 0<br>-IT 11  | +IT 11<br>0     |                |
| YEE 2-6 L       | 20                                                | 28            | 22              | 6            | 14              | 3              |
| YEE 2-8 L       | 25                                                | 34            | 26,4            | 7,6          | 17,4            | 3,8            |
| YEE 2-10 L      | 32                                                | 44            | 34,4            | 9,6          | 22,4            | 4,8            |
| YEE 2-12 L      | 40                                                | 56            | 44              | 12           | 28              | 6              |
| Relation factor | 3,33 <i>d</i>                                     | 4,67 <i>d</i> | 3,67 · <i>d</i> | 1 · <i>d</i> | 2,33 · <i>d</i> | 0,5 · <i>d</i> |

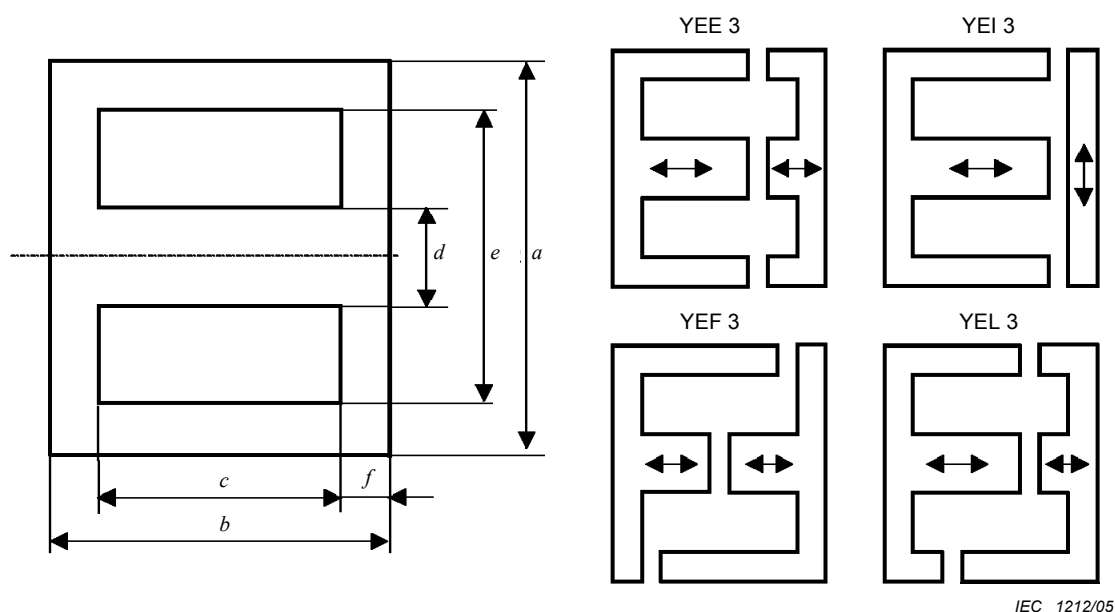
**Table 20 – Laminations Type YEE 2-..L,  
using two long E parts effective parameters**

| Designation | Effective parameters for $h_p = d$ and $\eta = 0,95$ |                      |                             |                           |
|-------------|------------------------------------------------------|----------------------|-----------------------------|---------------------------|
|             | Core cross-section                                   | Magnetic path length | Core volume                 | Core constant             |
|             | $A_{Fe}$<br>mm <sup>2</sup>                          | $l_{Fe}$<br>mm       | $V_{Fe}$<br>cm <sup>3</sup> | $C_1$<br>cm <sup>-1</sup> |
| YEE 2-6 L   | 34,2                                                 | 64                   | 2,19                        | 18,7                      |
| YEE 2-8 L   | 54,9                                                 | 77,8                 | 4,27                        | 14,2                      |
| YEE 2-10 L  | 87,6                                                 | 100,8                | 8,83                        | 11,5                      |
| YEE 2-12 L  | 136,8                                                | 128                  | 17,51                       | 9,36                      |

Magnetic path length  $l_{Fe} = b + c + (a + e - d) / 2$  (40)

### 13.8 Lamination Types YEx 3, YEE 3, YEF 3, YEI 3 and YEL 3

YEx 3 designates YEE 3, YEF 3, YEI 3 or YEL 3.



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**Figure 12 – Laminations Type YEx 3, dimensions**

**Table 21 – Laminations Type YEx 3, dimensions and tolerances**

| Designation     | Reference letter and tolerance code (see Table 9) |               |               |             |             |               |
|-----------------|---------------------------------------------------|---------------|---------------|-------------|-------------|---------------|
|                 | <i>a</i>                                          | <i>b</i>      | <i>c</i>      | <i>d</i>    | <i>e</i>    | <i>f</i>      |
|                 | ± IT 12                                           | ± IT 12       | +IT 12<br>0   | 0<br>-IT 12 | +IT 12<br>0 |               |
| YEx 3-10        | 40                                                | 35            | 25            | 10          | 30          | 5             |
| YEx 3-12        | 48                                                | 42            | 30            | 12          | 36          | 6             |
| YEx 3-16        | 64                                                | 56            | 40            | 16          | 48          | 8             |
| YEx 3-20        | 80                                                | 70            | 50            | 20          | 60          | 10            |
| YEx 3-25        | 100                                               | 87,5          | 62,5          | 25          | 75          | 12,5          |
| YEx 3-32        | 128                                               | 112           | 80            | 32          | 96          | 16            |
| YEx 3-40        | 160                                               | 140           | 100           | 40          | 120         | 20            |
| Relation factor | $4 \cdot d$                                       | $3,5 \cdot d$ | $2,5 \cdot d$ | $1 \cdot d$ | $3 \cdot d$ | $0,5 \cdot d$ |

**Table 22 – Laminations Type YEx 3, effective parameters**

| Designation | Effective parameters for $h_p = d$ and $\eta = 0,95$ |                                          |                                   |                                     |
|-------------|------------------------------------------------------|------------------------------------------|-----------------------------------|-------------------------------------|
|             | Core cross-section<br>$A_{Fe}$<br>$mm^2$             | Magnetic path length<br>$l_{Fe}$<br>$mm$ | Core volume<br>$V_{Fe}$<br>$cm^3$ | Core constant<br>$C_1$<br>$cm^{-1}$ |
| YEx 3-10    | 95                                                   | 90                                       | 8,55                              | 9,47                                |
| YEx 3-12    | 136,8                                                | 108                                      | 14,8                              | 7,89                                |
| YEx 3-16    | 243,2                                                | 144                                      | 35,0                              | 5,92                                |
| YEx 3-20    | 380                                                  | 180                                      | 68,4                              | 4,74                                |
| YEx 3-25    | 594                                                  | 225                                      | 134                               | 3,79                                |
| YEx 3-32    | 973                                                  | 288                                      | 280                               | 2,96                                |
| YEx 3-40    | 1 520                                                | 360                                      | 547                               | 2,37                                |

Magnetic path length  $l_{Fe} = b + c + (a + e - d) / 2 = 9 \cdot d$  (41)

### 13.9 Lamination Types YEx 4, YEE 4 and YEF 4

YEx 4 designates YEE 4 or YEF 4.

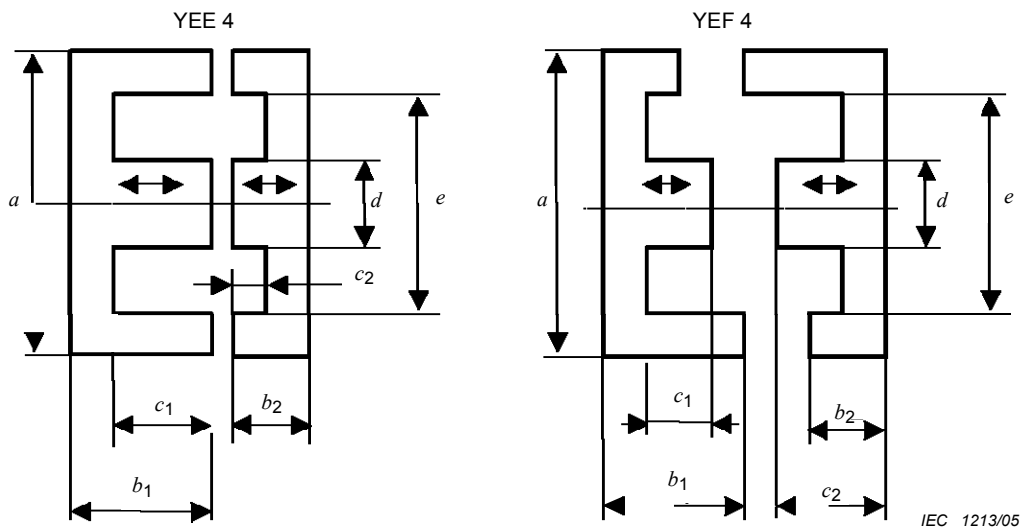


**Figure 13 – Laminations Type YEx 4, dimensions**