

Laminations for transformers and inductors —

Part 1: Mechanical and electrical characteristics

The European Standard EN 60740-1:2005 has the status of a
British Standard

ICS 29.100.10

National foreword

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Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 59 and a back cover.

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 23 December 2005

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ISBN 0 580 47102 0

Amendments issued since publication

Amd. No.	Date	Comments

EUROPEAN STANDARD

EN 60740-1

NORME EUROPÉENNE

EUROPÄISCHE NORM

October 2005

ICS 29.100.10

English version

Laminations for transformers and inductors
Part 1: Mechanical and electrical characteristics
(IEC 60740-1:2005)

Tôles découpées pour transformateurs
et inductances
Partie 1: Caractéristiques électriques
et mécaniques
(CEI 60740-1:2005)

Kernbleche für Transformatoren
und Drosseln
Teil 1: Mechanische und elektrische
Eigenschaften
(IEC 60740-1:2005)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

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Foreword

The text of document 51/823/FDIS, future edition 1 of IEC 60740-1, prepared by IEC TC 51, Magnetic components and ferrite materials, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60740-1 on 2005-08-01.

The following dates were fixed:

- | | | |
|--|-------|------------|
| – latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement | (dop) | 2006-05-01 |
| – latest date by which the national standards conflicting
with the EN have to be withdrawn | (dow) | 2008-08-01 |

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60740-1:2005 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

IEC 61797-1	NOTE	Harmonized as EN 61797-1:1996 (not modified).
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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;

ρ is the density of the core, in kg/dm³;

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 mm²;
 $\hat{B}$ 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⁻¹;
 C_2 core constant 2, in mm⁻³;
 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 Ω ;
R_2	resistance of winding N_2 , in Ω ;
R_n	precision resistor, in Ω ;
R_V	resistance of the voltmeter, in Ω ;
R_W	resistance of the voltage path of the wattmeter, in Ω ;
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 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;
η	stacking factor;
μ_0	magnetic constant, in H/cm ($4 \cdot \pi \cdot 10^{-9}$ H/cm);
μ_a	amplitude permeability;
μ_i	initial permeability;
π	in this standard = 3,1416;
ρ	the density of the core alloy, in 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 kg/dm ³	Designation	
			IEC 60404-1	IEC 60404-8-4 IEC 60404-8-7
Non-oriented silicon steel	1 % to 3 % silicon	7,65	C 21	M 270-35A 5 M 330-35A 5 M 330-50A 5
		7,7		M 400-50A 5 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 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 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 η 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/m² perpendicular to the lamination.

Table 4 – Lamination thickness and stacking factor

Lamination thickness mm	Minimum stacking factor η		
	Non-oriented silicon steel C 21	Grain oriented silicon steel C 22	Nickel-iron and cobalt-iron alloys 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

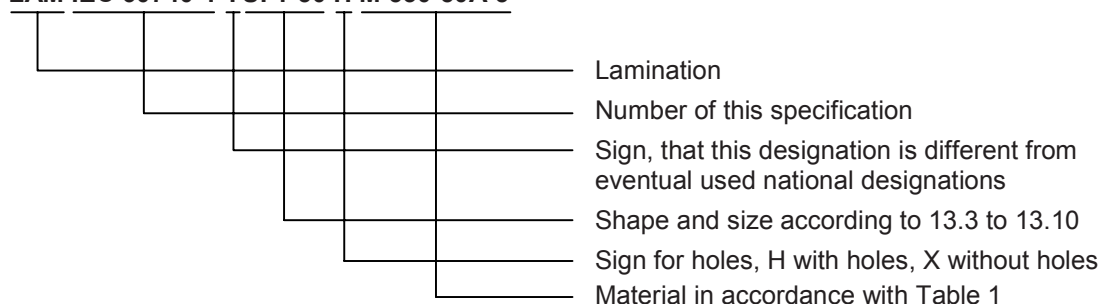
5 Designation of laminations and lamination strips

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

	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 yokes
	Sign for holes, H with holes, X without holes
	Material in accordance with Table 1

IEC 1197/05

5.2.2 Lamination strips for limbs

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

[illegible]

IEC 1198/05

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

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where

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

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

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

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

Further, the core volume, in 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 ρ is the density of the alloy, in 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_{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_{Fe} is the core cross-section, in mm^2 ;

d is the limb width, in mm;

h_p is the stack height, in mm;

η 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_{Fe} and C_1 shall be corrected by multiplying with the following factors:

The factor for A_{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.