BS EN 60205:2017

BSI Standards Publication

Calculation of the effective parameters of magnetic piece parts

bsi.

National foreword

This British Standard is the UK implementation of EN 60205:2017. It is identical to IEC 60205:2016. It supersedes BS EN 60205:2006+A1:2009 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/51, Transformers, inductors, magnetic components and ferrite materials.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2017

ISBN 978 0 580 91814 8
ICS 29.100.10

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2017.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 60205

March 2017

ICS 29.100.10

Supersedes EN 60205:2006

English Version

Calculation of the effective parameters of magnetic piece parts (IEC 60205:2016)

Calcul des paramètres effectifs des pièces ferromagnétiques (IEC 60205:2016)

Berechnung der effektiven Kernparameter magnetischer Formteile (IEC 60205:2016)

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

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 60205:2017 E

European foreword

The text of document 51/1149/FDIS, future edition 4 of IEC 60205, prepared by IEC/TC 51 "Magnetic components, ferrite and magnetic powder materials" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60205:2017.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-09-23
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2019-12-23

This document supersedes EN 60205:2006.

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

IEC 62317-13	NOTE	Harmonized as EN 62317-13.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

CALCULATION OF THE EFFECTIVE PARAMETERS OF MAGNETIC PIECE PARTS

FOREWORD

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International Standard IEC 60205 has been prepared by IEC technical committee 51: Magnetic components, ferrite and and magnetic powder materials.

This fourth edition cancels and replaces the third edition published in 2006 and Amendment 1:2009. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) addition, in 5.1, of the drawing of a core of rectangular cross-section with chamfer;
b) addition, in 5.1.3, of the equation of a core of rectangular cross-section with chamfer;
c) equations in 5.1.4, 5.6, 5.7, 5.8, 5.9, 5.11, 5.12, 5.14 are amended or replaced;
d) drawings RM6-S and RM6-R in 5.7 are amended;
e) addition of EC-cores, see 5.15.

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

FDIS	Report on voting
51/1149/FDIS	51/1156/RVD

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

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

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

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

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The purpose of this revision is to provide formulae by which everybody can reach the same effective parameter values. Firstly, it is necessary to have a sufficient number of significant figures when figures are rounded off in the process of calculation. Additionally, some of the calculation formulae have been changed to get closer to the actual shape.

In this revision, the basic idea of calculation has not been changed. Recently, analysis of the magnetic field in the core has been considerably improved, so that, based on these ideas, development of new approaches and formulae can be expected.

Furthermore, the new "EC-cores" have been added.

The parameters in the existing IEC standards will be revised with the outcome from the formulae of this document.

CALCULATION OF THE EFFECTIVE PARAMETERS OF MAGNETIC PIECE PARTS

1 Scope

This document specifies uniform rules for the calculation of the effective parameters of closed circuits of ferromagnetic material.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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

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

4 Basic rules applicable to this standard

4.1 All results shall be expressed in units based on millimetres, shall be accurate to three significant figures, but to derive l_e , A_e , and V_e the values of C_1 and C_2 shall be calculated to five significant figures. All angles are in radians.

NOTE The purpose of specifying this degree of accuracy is only to ensure that parameters calculated at different establishments are identical and it is not intended to imply that the parameters are capable of being determined to this accuracy.

4.2 A_{min} is the nominal value of the smallest cross-section. A_g is the geometrical cross-section of a ring core with rectangular shape. All the dimensions used to calculate A_{min} shall be the mean values between the tolerance limits quoted on the appropriate piece part drawing. All results shall be expressed in units based on millimetres, and shall be accurate to three significant figures.

The minimum physical cross-section area A_{min} is given as: $A_{min} = \min(A_i)$

NOTE A_g to be used for the measurement of the saturation flux density B_{max} on ring cores with rectangular cross-section.

4.3 Calculations are only applicable to the component parts of a closed magnetic circuit.

4.4 All dimensions used for the purpose of calculations shall be the mean value within the tolerance limits quoted on the appropriate piece part drawing.

4.5 All irregularities in the outline of the core, such as small cut-outs, notches, chamfers, etc. shall be ignored unless otherwise described.

4.6 When the calculation involves the sharp corner of a piece part, then the mean length of flux path for that corner shall be taken as the mean circular path joining the centres of area of the two adjacent uniform sections, and the cross-sectional area associated with that length shall be taken as the average area of the two adjacent uniform sections.

Calculation of effective parameters l_e , A_e and V_e.

The effective parameters can be defined as

$$l_e = C_1^2/C_2 \quad A_e = C_1/C_2 \quad V_e = l_e A_e = C_1^3/C_2^2$$

where

l_e is the effective magnetic length of the core (mm);

A_e is the effective cross-sectional area (mm^2);

V_e is the effective volume (mm^3);

C_1 is the core constant (mm^{-1});

C_2 is the core constant (mm^{-3}).

5 Formulae for the various types of cores

5.1 Ring cores

5.1.1 Ring cores in general

Drawings of ring cores are shown in Figure 1.

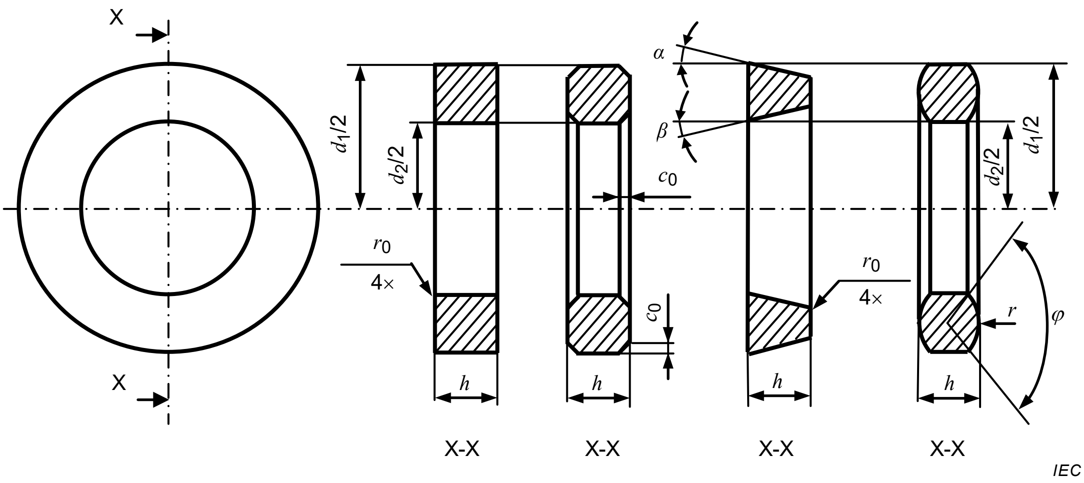


Figure 1 – Ring cores

$$C_1 = \frac{2\pi}{h_e \ln(d_1/d_2)}$$

$$C_2 = \frac{4\pi(1/d_2 - 1/d_1)}{h_e^2 \ln^3(d_1/d_2)}$$

5.1.2 For ring cores of rectangular cross-section with sharp corners

$$h_e = h$$

The geometrical cross-section of a ring core with rectangular shape A_g is given as:

$$A_g = h\frac{d_2 - d_1}{2}$$

5.1.3 For ring cores of rectangular cross-section with an appreciable average rounding radius r_0

$$h_e = h(1 - k_1) \quad k_1 = \frac{1{,}7168 r_0^2}{h(d_1 - d_2)}$$

5.1.4 For ring cores of rectangular cross-section with appreciable chamfer c_0

$$h_e = h(1 - k_3) \quad k_3 = \frac{4 c_0^2}{h(d_1 - d_2)}$$

The geometrical cross-section of a ring core with appreciable chamfer shape A_g is given as:

$$A_g = h\frac{d_2 - d_1}{2} - 2c_0^2$$

5.1.5 For ring cores of trapezoidal cross-section with sharp corners

$$h_e = h(1 - k_2) \quad k_2 = \frac{h(\tan\alpha + \tan\beta)}{d_1 - d_2}$$

5.1.6 For ring cores of trapezoidal cross-section with an appreciable average rounding radius r_0

$$h_e = h(1 - k_1 - k_2)$$

5.1.7 For ring cores of cross-section with circular arc frontal sides

$$h_e = h - \frac{d_1 - d_2}{4\sin^2(\varphi/2)}\left(2\sin\frac{\varphi}{2} - \frac{\sin\varphi}{2} - \frac{\varphi}{2}\right)$$

$$\varphi = 2\arcsin\frac{d_1 - d_2}{4r}.$$

When the winding is uniformly distributed over a ring core, it may be expected that, at all points inside the ring core, the flux lines will be parallel to its surface.

No leakage flux will therefore leave or enter the ring core. This justifies the use of a theoretically more correct derivation of the effective parameters, which does not make use of the assumption that the flux is uniformly distributed over the cross-section.

5.2 Pair of U-cores of rectangular section

Drawings of a pair of U-cores of the rectangular section are shown in Figure 2.

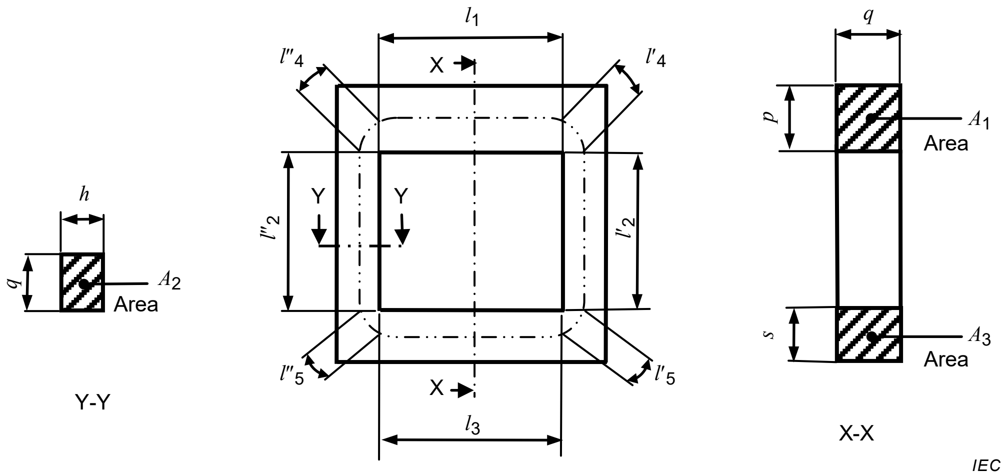


Figure 2 – Pair of U-cores of the rectangular section

Length of flux path associated with area A_2:

$$l_2 = l_2' + l_2''$$

Mean length of flux paths at corners:

$$l_4 = l_4' + l_4'' = \frac{\pi}{4}(p + h)$$

$$l_5 = l_5' + l_5'' = \frac{\pi}{4}(s + h)$$

Mean areas associated with l_4 and l_5:

$$A_4 = \frac{A_1 + A_2}{2}$$

$$A_5 = \frac{A_2 + A_3}{2}$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{A_i^2}$$

5.3 Pair of U-cores of rounded section

Drawings of a pair of U-cores of the rounded section are shown in Figure 3.

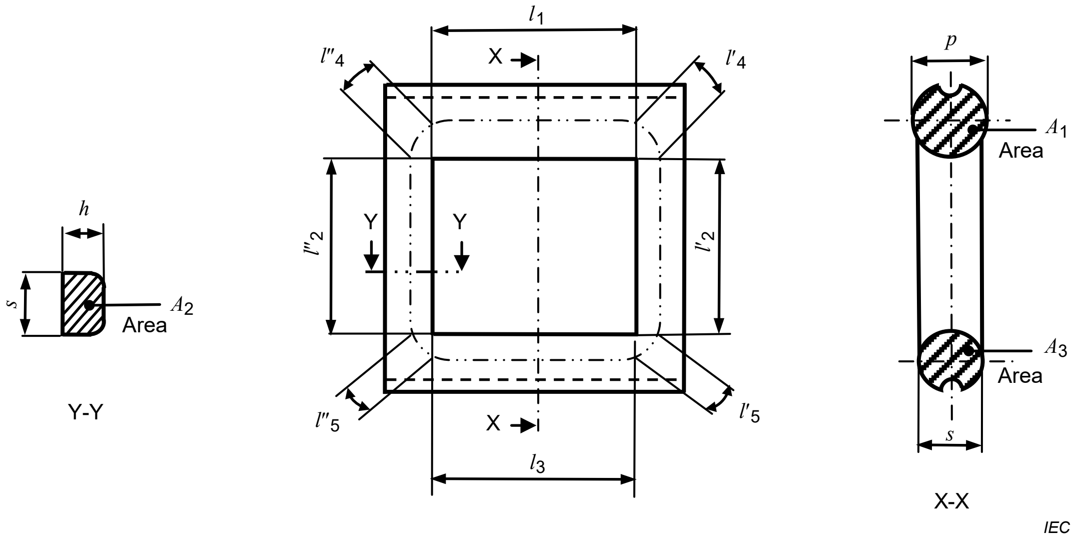


Figure 3 – Pair of U-cores of rounded section

In calculating A_2 ignore any ridges introduced for the purpose of facilitating manufacture.

Length of flux path associated with area A_2:

$$l_2 = l'_2 + l''_2$$

Mean length of flux path at corners:

$$l_4 = l'_4 + l''_4 = \frac{\pi}{4}(p + h)$$

$$l_5 = l'_5 + l''_5 = \frac{\pi}{4}(s + h)$$

Mean areas associated with l_4 and l_5:

$$A_4 = \frac{A_1 + A_2}{2}$$

$$A_5 = \frac{A_2 + A_3}{2}$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{A_i^2}$$

5.4 Pair of E-cores of rectangular section

Drawings of a pair of E-cores of the rectangular section are shown in Figure 4.

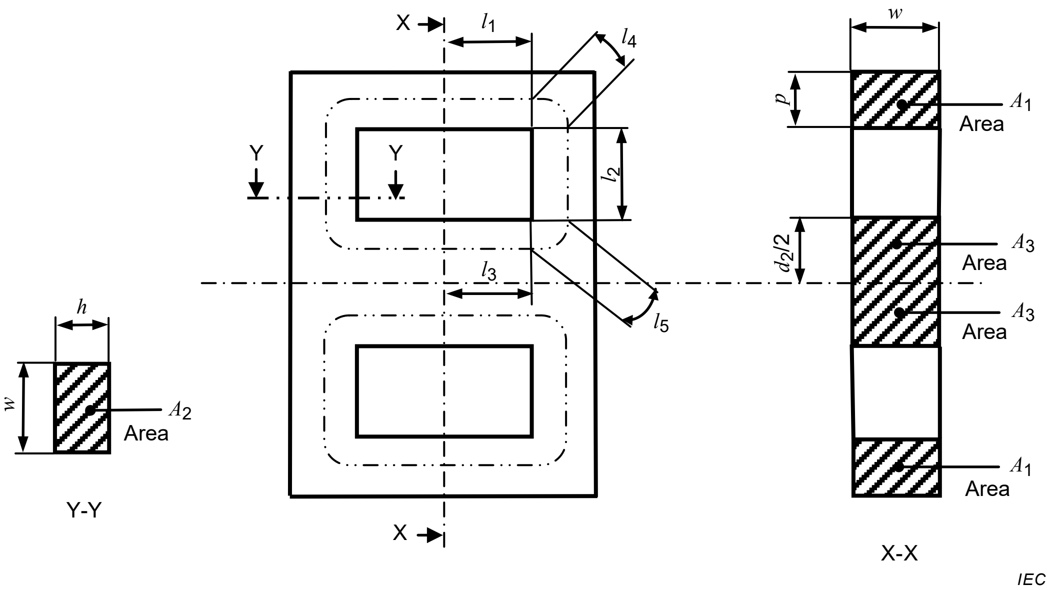


Figure 4 – Pair of E-cores of rectangular section

Area of half the centre limb: A_3

Mean length of flux paths at corners:

$$l_4 = \frac{\pi}{8}(p + h)$$

$$l_5 = \frac{\pi}{8}\left(\frac{d_2}{2} + h\right)$$

Mean areas associated with l_4 and l_5:

$$A_4 = \frac{A_1 + A_2}{2}$$

$$A_5 = \frac{A_2 + A_3}{2}$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{2A_i^2}$$

5.5 Pair of ETD/EER-cores

Drawings of a pair of ETD/EER-cores are shown in Figure 5.

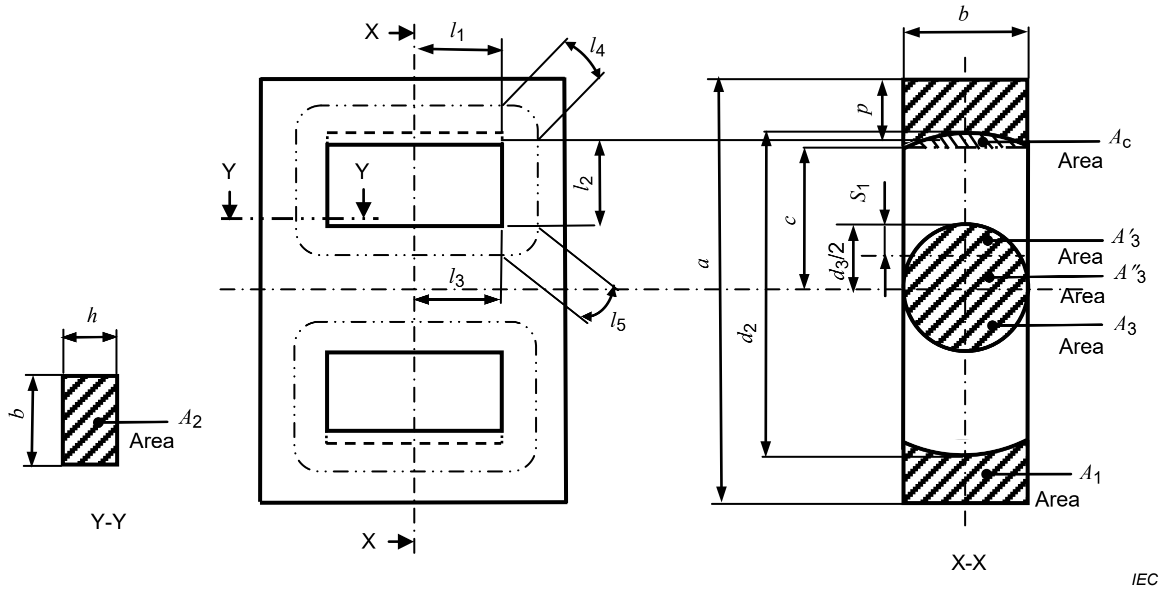


Figure 5 – Pair of ETD/EER-cores

A_1 is equal to the rectangle $b\left(\frac{1}{2}a-c\right)$ less the cap or segment A_c

$$A_c=\frac{1}{4}d_2{}^2\arcsin\left(\frac{b}{d_2}\right)-\frac{1}{4}b\sqrt{d_2{}^2-b^2}$$

$$A_1=\frac{1}{2}ab-\frac{1}{4}b\sqrt{d_2{}^2-b^2}-\frac{1}{4}d_2{}^2\arcsin\left(\frac{b}{d_2}\right)$$

Mean length of flux path at back walls:

$$l_2=\frac{1}{4}\left(d_2+\sqrt{d_2{}^2-b^2}\right)-\frac{d_3}{2}$$

NOTE l_2 is taken from the mean value of $\frac{1}{2}(d_2-d_3)$ and $(c-d_3/2)$.

Area of half the centre limb:

$$A_3=A'_3+A''_3$$

The condition to obtain $A'_3=A''_3$ is

$$S_1=0{,}2980d_3$$

Mean length of flux path at corners:

$$l_4=\frac{\pi}{8}(p+h)$$

where $p = \frac{a}{2} - l_2 - \frac{d_3}{2}$

$$l_5 = \frac{\pi}{8}(2S_1 + h)$$

Mean areas associated with l_4 and l_5:

$$A_4 = \frac{A_1 + A_2}{2}$$

$$A_5 = \frac{A_2 + A_3}{2}$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{2A_i^2}$$

5.6 Pair of pot-cores

Drawings of a pair of pot-cores are shown in Figure 6.

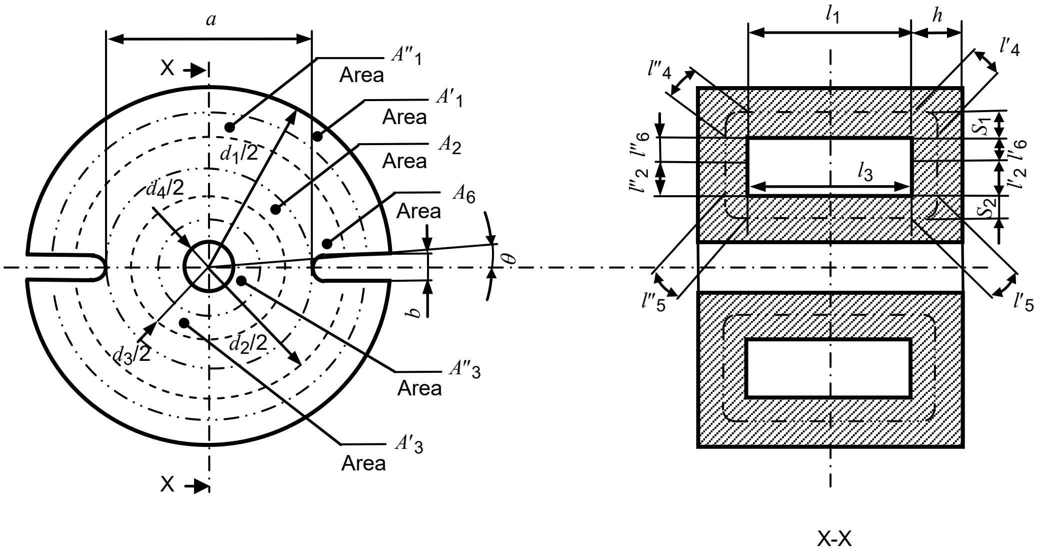


Figure 6 – Pair of pot-cores

Area of outer ring:

$$A_1 = A_1' + A_1''$$

The condition to obtain $A'_1 = A''_1$ is

$$S_1 = -\frac{d_2}{2} + \sqrt{\frac{1}{8}\left(d_1^2 + d_2^2\right)}$$

Area of centre limb:

$$A_3 = A'_3 + A''_3$$

The condition to obtain $A'_3 = A''_3$ is

$$S_2 = \frac{d_3}{2} - \sqrt{\frac{1}{8}\left(d_3{}^2 + d_4{}^2\right)}$$

Area of ring:

$$A_1 = \frac{1}{4}(\pi - n\theta)\left(d_1{}^2 - d_2{}^2\right)$$

$$\theta = \arcsin\frac{2b}{d_1 + d_2}$$

where

b is the slot width;

n is the number of slots.

Core factors associated with l_2:

$$\frac{l_2}{A_2} = \frac{1}{\pi h}\ln\frac{a}{d_3}$$

$$\frac{l_2}{A_2{}^2} = \frac{a - d_3}{\pi^2 a d_3 h^2}$$

Area of centre limb:

$$A_3 = \frac{\pi}{4}\left(d_3{}^2 - d_4{}^2\right)$$

Mean length of flux paths at corners:

$$l_4 = l'_4 + l''_4 = \frac{\pi}{4}\left(2S_1 + h\right)$$

$$l_5 = l'_5 + l''_5 = \frac{\pi}{4}\left(2S_2 + h\right)$$

Areas associated with l_4 and l_5:

A_4 for cores with back-wall slot:

$$A_4 = \frac{1}{8}(\pi - n\theta)(d_1^2 - d_2^2) + \frac{h}{2}(\pi d_2 - nb)$$

A_4 for cores without back-wall slot:

$$A_4 = \frac{1}{8}(\pi - n\theta)(d_1^2 - d_2^2) + \frac{\pi}{2} d_2 h$$

$$A_5 = \frac{\pi}{8}\left(d_3{}^2 - d_4{}^2 + 4 d_3 h\right)$$

Core factors associated with l_6:

$$\frac{l_6}{A_6} = \frac{1}{(\pi - n\theta)h} \ln \frac{d_2}{a}$$

$$\frac{l_6}{A_6{}^2} = \frac{d_2 - a}{a d_2 (\pi - n\theta)^2 h^2}$$

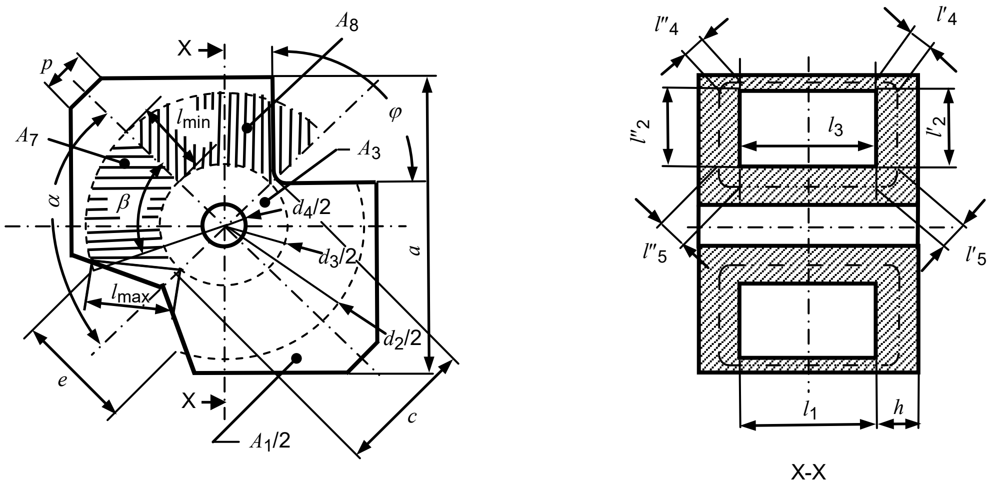
$$C_1 = \sum_{i=1}^{6} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{6} \frac{l_i}{A_i{}^2}$$

5.7 Pair of RM-cores

Drawings of a pair of RM-cores Type 1 through Type 4 are shown in Figure 7.

This calculation is also applicable to the core type without a hole.

Type 1 – RM6–S



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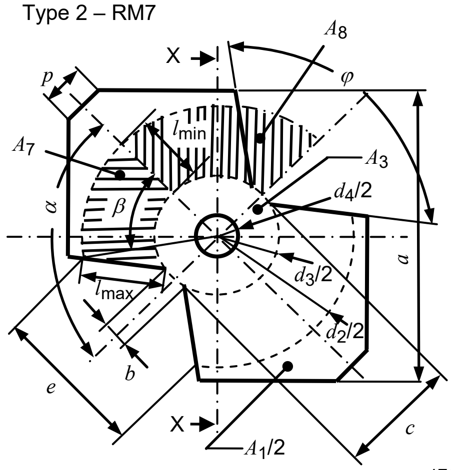
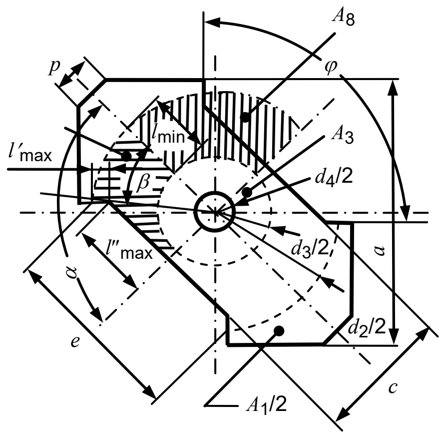
Type 2 – RM7



IEC

Type 3 – RM4, RM5, RM8, RM10, RM12, RM14



$l_{max} = l'_{max} + l''_{max}$

IEC

Type 4 – RM6–R

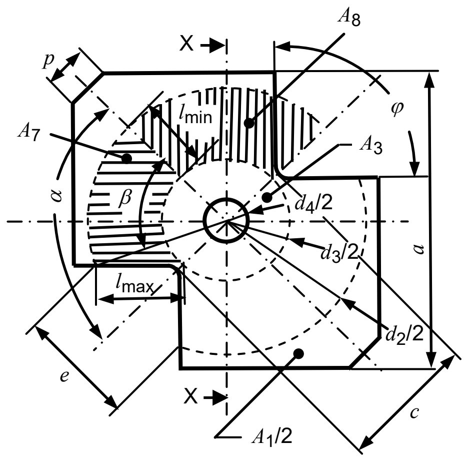


Figure 7 – Pair of RM-cores

Total area of the outer leg:

$$A_1 = \frac{1}{2}a^2\left\{1+\tan\left(\beta-\frac{\pi}{4}\right)\right\}-\frac{\beta}{2}d_2{}^2-\frac{1}{2}p^2$$

where $\beta = \alpha - \arcsin\frac{e}{d_2}$

Core factors associated with l_2:

$$\frac{l_2}{A_2} = \frac{\ln\frac{d_2}{d_3}f}{D\pi h}$$

where $f = \frac{l_{min}+l_{max}}{2l_{min}}$, $D = \frac{A_7}{A_8}$

$$l_2 = l_2' + l_2''$$

$$\frac{l_2}{A_2{}^2} = \frac{\left(1/d_3 - 1/d_2\right)f}{\left(D\pi h\right)^2}$$

Type 1, Type 4:

$$l_{max} = \sqrt{\frac{1}{4}\left(d_2{}^2+d_3{}^2\right)-\frac{1}{2}d_2 d_3\cos(\alpha-\beta)}$$

Type 2:

$$l_{max} = \sqrt{\frac{1}{4}\left(d_2^{\,2} + d_3^{\,2}\right) - \frac{1}{2} d_2 d_3 \cos(\alpha - \beta)} - \frac{b}{2\sin\frac{\varphi}{2}}$$

Type 3:

$$l_{max} = \frac{1}{2\tan\beta \cdot \sin\frac{\varphi}{2}}[e\tan\beta - c(1 - \sin\frac{\varphi}{2})]$$

Type 1:

$$A_7 = \frac{1}{4}\left\{\frac{\beta}{2} d_2^{\,2} + \frac{1}{2} e^2 \tan\beta - \frac{1}{2} e^2 \tan\left(\alpha - \frac{\varphi}{2}\right) - \frac{\pi}{4} d_3^{\,2}\right\}$$

Type 4:

$$A_7 = \frac{1}{4}\left\{\frac{\beta}{2} d_2^{\,2} + \frac{1}{2} d_2 d_3 \sin(\alpha - \beta) + \frac{1}{2}(c - d_3)^2 \tan\frac{\varphi}{2} - \frac{\pi}{4} d_3^{\,2}\right\}$$

Type 2:

$$A_7 = \frac{1}{4}\left\{\frac{\beta}{2} d_2^{\,2} - \frac{\pi}{4} d_3^{\,2} + \frac{1}{2}\left(b^2 - e^2\right)\tan\left(\alpha - \frac{\varphi}{2}\right) + \frac{1}{2} e^2 \tan\beta\right\}$$

Type 3:

$$A_7 = \frac{1}{4}\left\{\frac{\beta}{2} d_2^{\,2} - \frac{\pi}{4} d_3^{\,2} + \frac{1}{2} c^2 \tan(\alpha - \beta)\right\}$$

$$A_8 = \frac{\alpha}{8}\left(d_2^{\,2} - d_3^{\,2}\right)$$

Area of centre pole:

$$A_3 = \frac{\pi}{4}\left(d_3^{\,2} - d_4^{\,2}\right)$$

Mean length of flux paths at corners and mean areas associated with these:

$$l_4 = l_4' + l_4'' = \frac{\pi}{4}\left(h + \frac{1}{2} a - \frac{1}{2} d_2\right)$$

$$A_4 = \frac{1}{2}\left(A_1 + 2\beta d_2 h\right)$$

$$l_5 = l'_5 + l''_5 = \frac{\pi}{4}\left\{d_3 + h - \sqrt{\frac{1}{2}\left(d_3{}^2 + d_4{}^2\right)}\right\}$$

$$A_5 = \frac{1}{2}\left\{\frac{\pi}{4}\left(d_3{}^2 - d_4{}^2\right) + 2\alpha d_3 h\right\}$$

$$C_1 = \sum_{i=1}^{5}\frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5}\frac{l_i}{A_i{}^2}$$

This calculation ignores the effect of spring recesses and stud recesses. These can have some influence on the outcome of the calculation, especially for smaller cores.

5.8 Pair of EP-cores

Drawings of a pair of EP-cores are shown in Figure 8.

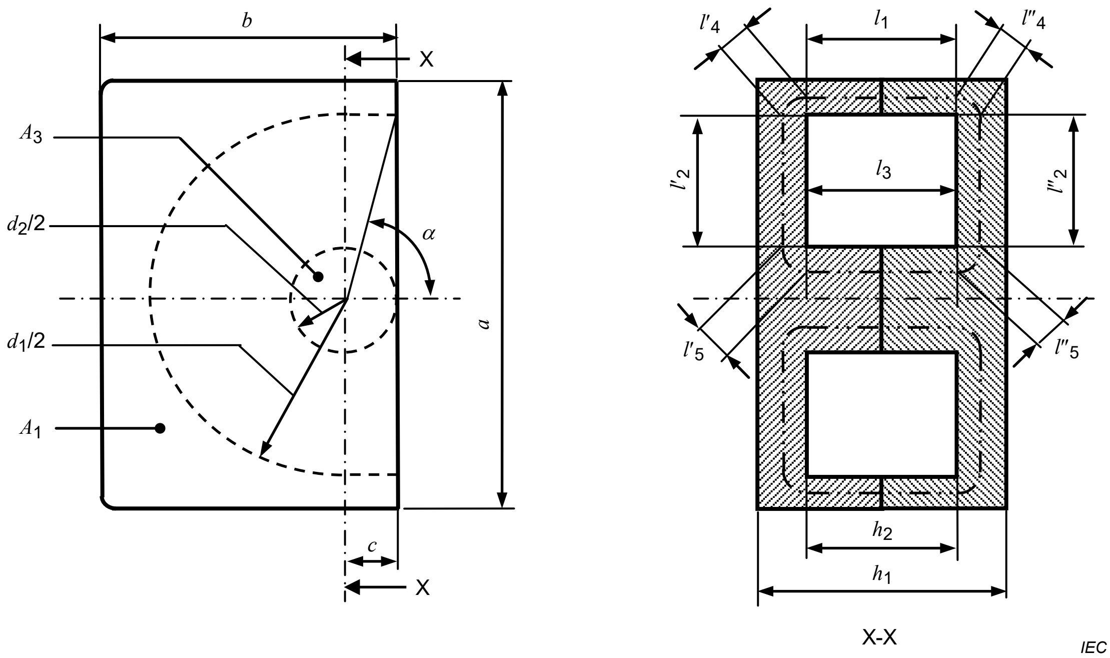


Figure 8 – Pair of EP-cores

As a pair:

$$\frac{l_1}{A_1} = \frac{h_2}{ab - \pi d_1^2 / 8 - d_1 c}$$

$$\frac{l_1}{A_1^2} = \frac{h_2}{(ab - \pi d_1^2 / 8 - d_1 c)^2}$$

$$\frac{l_2}{A_2} = \frac{2}{(\pi - \alpha)(h_1 - h_2)}\ln\frac{d_1}{d_2}$$

$$\frac{l_2}{A_2{}^2}=\frac{4(d_1-d_2)}{(\pi-\alpha)^2(h_1-h_2)^2 d_1 d_2}$$

$$\frac{l_3}{A_3}=\frac{h_2}{\pi\left(\frac{d_2}{2}\right)^2} = \frac{4h_2}{\pi d_2{}^2}$$

$$\frac{l_3}{A_3{}^2}=\frac{h_2}{\pi^2\left(\frac{d_2}{2}\right)^4} = \frac{16h_2}{\pi^2 d_2{}^4}$$

Areas associated with l_4 and l_5:

$$l_4=l_4'+l_4''=\frac{\pi}{2}\left(\gamma-\frac{d_1}{2}+\frac{h_1-h_2}{4}\right)$$

$$\gamma=\sqrt{\frac{(\pi-\alpha)d_1{}^2+2\left(ab-\pi d_1{}^2/8-d_1 d_2/2\right)}{4(\pi-\alpha)}}$$

where y is a hypothetical radius bisecting the cross-sectional area of the ring.

$$A_4=\frac{1}{2}\left\{ab-\frac{\pi}{8}d_1{}^2-\frac{d_1 d_2}{2}+(\pi-\alpha)d_1\left(\frac{h_1}{2}-\frac{h_2}{2}\right)\right\}$$

$$l_5=l_5'+l_5''=\frac{\pi}{2}\left(0{,}292\,89\frac{d_2}{2}+\frac{h_1-h_2}{4}\right)$$

$$A_5=\frac{\pi}{2}\left\{\frac{d_2{}^2}{4}+\frac{d_2}{2}(h_1-h_2)\right\}$$

$$C_1=\sum_{i=1}^{5}\frac{l_i}{A_i} \qquad C_2=\sum_{i=1}^{5}\frac{l_i}{A_i{}^2}$$

5.9 Pair of PM-cores

Drawings of a pair of PM-cores are shown in Figure 9.

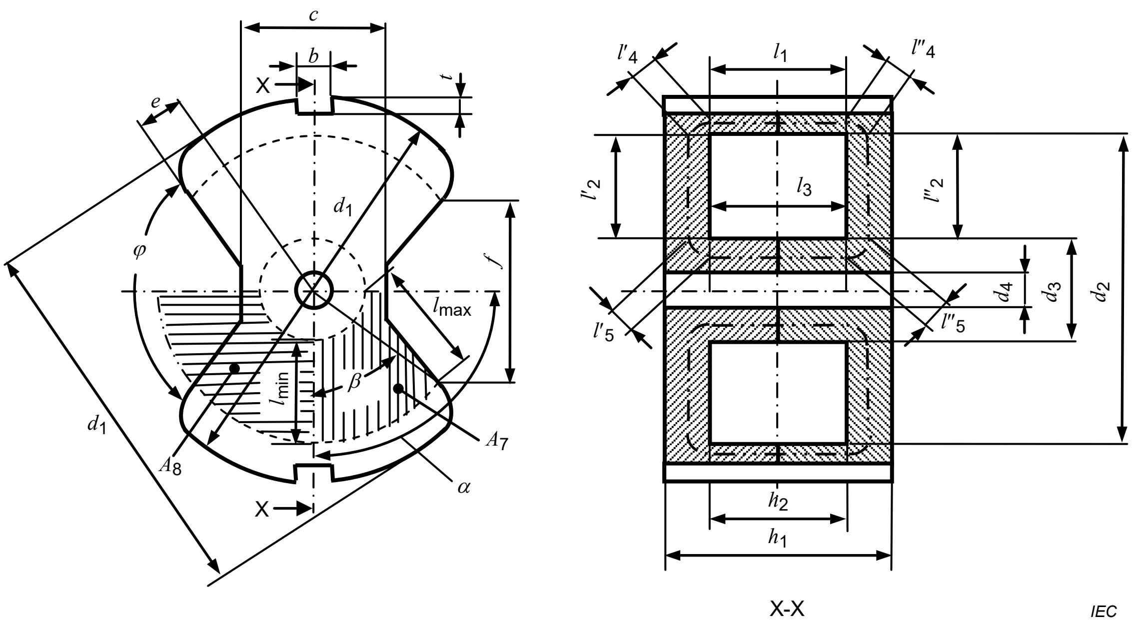


Figure 9 – Pair of PM-cores

Total area of the leg:

$$A_1 = \frac{\beta}{2}\left(d_1^2 - d_2^2\right) - 2bt$$

where $\beta = \alpha - \arcsin\frac{f}{d_2}$

Core factors associated with l_2:

$$l_2 = l_2' + l_2''$$

$$\frac{l_2}{A_2} = \frac{\ln\frac{d_2}{d_3}g}{D\pi\left(h_1 - h_2\right)/2}$$

where $g = \frac{l_{min} + l_{max}}{2l_{min}}$, $D = \frac{A_7}{A_8}$

$$l_{max} = \sqrt{\frac{1}{4}\left(d_2{}^2 + d_3{}^2\right) - \frac{1}{2}d_2 d_3 \cos(\alpha - \beta)}$$

$$\frac{l_2}{A_2{}^2} = \frac{\left(1/d_3 - 1/d_2\right)g}{\left\{D\pi\left(h_1 - h_2\right)/2\right\}^2}$$

$$A_7 = \frac{\beta}{8}d_2{}^2 + \frac{1}{8}f^2\tan\beta - \frac{1}{8}f^2\tan\left(\alpha - \frac{\varphi}{2}\right) - \frac{\pi}{16}d_3{}^2$$

$$A_8 = \frac{\alpha}{8}\left(d_2{}^2 - d_3{}^2\right)$$

Area of centre limb:

$$A_3 = \frac{\pi}{4}\left(d_3{}^2 - d_4{}^2\right)$$

Mean length of flux paths at corners and mean areas associated with these:

$$l_4 = l'_4 + l''_4 = \frac{\pi}{8}\left(h_1 - h_2 + d_1 - d_2\right)$$

$$A_4 = \frac{1}{2}\{A_1 + \beta d_2(h_1 - h_2)\}$$

$$l_5 = l'_5 + l''_5 = \frac{\pi}{4}\{d_3 + \frac{h_1 - h_2}{2} - \sqrt{\frac{1}{2}(d_3^2 + d_4^2)}\}$$

$$A_5 = \frac{\pi}{8}(d_3^2 - d_4^2) + \alpha d_3 \frac{(h_1 - h_2)}{2}$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{A_i{}^2}$$

5.10 Pair of EL-cores

Drawings of a pair of EL-cores and PLT(plate)-cores are shown in Figure 10 and Figure 11.

EL + PLT (plate)-cores use EL core formulae.

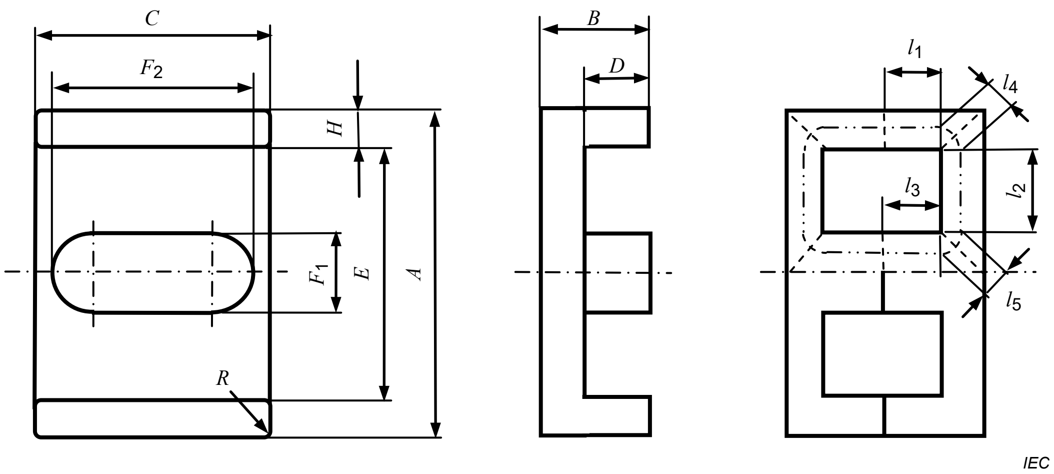


Figure 10 – Pair of EL-cores

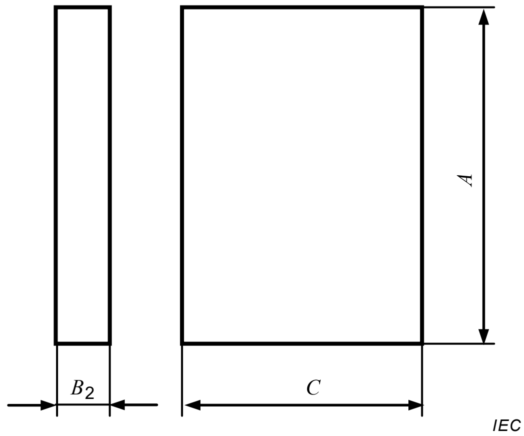


Figure 11 – PLT(plate)-cores

Area of outer leg:

$$A_1 = \frac{1}{2}(A - E)C - 4\left(R^2 - \frac{1}{4}\pi R^2\right)$$

Mean length of flux path at outer leg:

$$l_1 = D$$

Area of back wall:

$$A_2 = \frac{1}{2}\left(C + (F_2 - F_1) + \pi F_1/2\right)(B - D)$$

Mean length of flux at back wall:

$$l_2 = \left(\frac{E}{2} - \frac{F_1}{2}\right)$$

Area of centre limb:

$$A_3 = \frac{1}{2}\left\{\frac{1}{4}\pi F_1^{\,2} + (F_2 - F_1)F_1\right\}$$

Mean length of flux path at centre limb:

$$l_3 = D$$

Area of outside corner:

$$A_4 = \frac{A_1 + A_{21}}{2}$$

where $A_{21} = (B - D)C$

Mean length of flux path at outside corner:

$$l_4 = \frac{\pi}{8}\left(\left(\frac{A}{2} - \frac{E}{2}\right) + (B - D)\right)$$

Area of inside corner:

$$A_5 = \frac{A_{23} + A_3}{2}$$

where $A_{23} = ((F_2 - F_1) + \pi F_1/2)(B - D)$

Mean length of flux path at inside corner:

$$l_5 = \frac{\pi}{8}\left(\frac{A_3}{F_2} + (B - D)\right)$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{2A_i^2}$$

$$l_e = C_1^2/C_2 \qquad A_e = C_1/C_2 \qquad V_e = C_1^3/C_2^2$$

5.11 Pair of ER-cores (low profile)

Drawings of a pair of ER-cores (low profile) and PLT(plate)-cores are shown in Figure 12 and Figure 13.

ER + PLT (plate)-cores use ER core formulae.

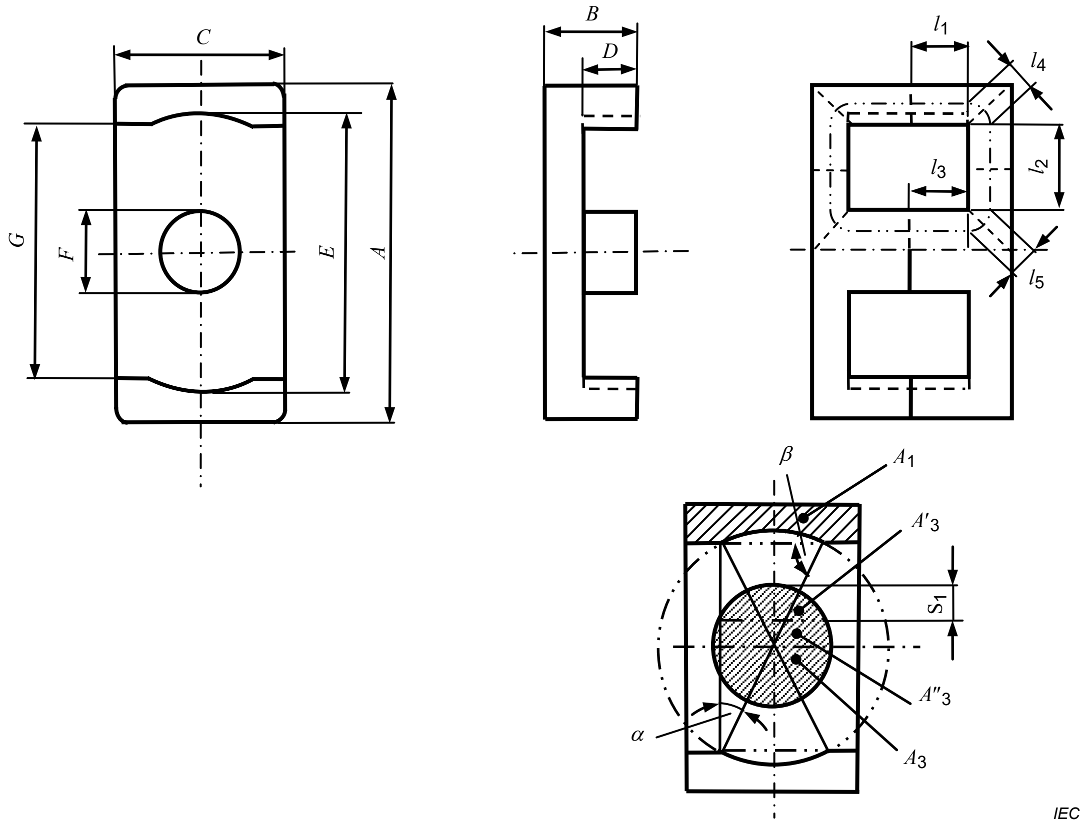


Figure 12 – Pair of ER-cores (low profile)

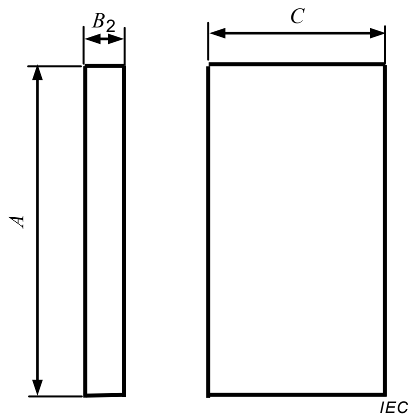


Figure 13 – PLT(plate)-cores

Area of outer leg:

$$A_1 = \frac{1}{2}C(A-G) - \left(\frac{\alpha E^2}{4} - \frac{EG}{4}\sin\alpha\right)$$

where

α = arccos (G/E)

Mean length of flux path at outer leg:

$$l_1 = D$$

Area of back wall:

$$A_2 = C(B - D)$$

Mean length of flux path at back wall:

$$l_2 = \frac{1}{4}\left(E + \sqrt{G^2 + C^2} - 2F\right)$$

Area of centre limb:

$$A_3 = \frac{1}{2}\left(\frac{1}{4}\pi F^2\right)$$

Mean length of flux path at centre limb:

$$l_3 = D$$

Area of outside corner:

$$A_4 = \frac{A_1 + A_2}{2}$$

Mean length of flux path at outside corner:

$$l_4 = \frac{\pi}{8}(p + h)$$

where

$$h = B - D \quad p = \frac{A}{2} - \frac{E}{2}$$

Area of inside corner:

$$A_5 = \frac{A_2 + A_3}{2}$$

Mean length of flux path at inside corner:

$$l_5 = \frac{\pi}{8}(2S_1 + h)$$

The condition to obtain $A'_3 = A''_3$ is

$$S_1 = \frac{1}{2}F(1 - \sin\alpha) = 0{,}298\,01\,F$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{2A_i^2}$$

$$l_e = C_1^2/C_2 \qquad A_e = C_1/C_2 \qquad V_e = C_1^3/C_2^2$$

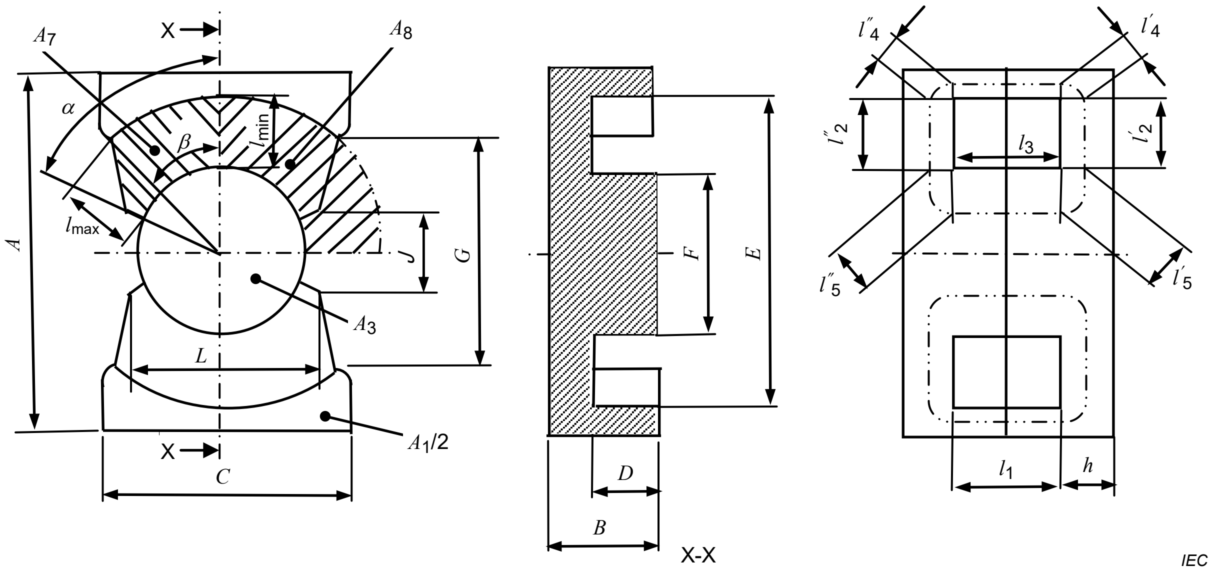
5.12 Pair of PQ-cores

Drawings of a pair of PQ-cores and PLT(plate)-cores are shown in Figure 14, Figure 15 and Figure 16.

PQ + PLT (plate)-cores use PQ core formulae.

NOTE 1 This calculation ignores the effect of spring recesses.

NOTE 2 The equations below are consistent with those given in IEC 62317-13.



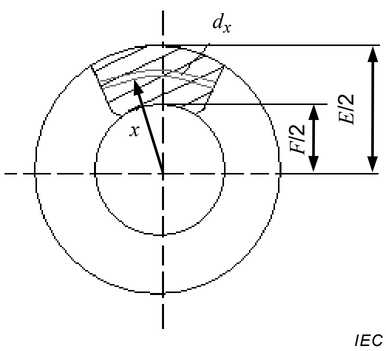


Figure 14 – Pair of PQ-cores

Area of outer leg:

$$A_1 = C(A-G) - \frac{\beta E^2}{2} + \frac{1}{2}GI$$

where

$$\beta = \arccos\left(\frac{G}{E}\right)$$

$$I = E \sin\beta$$

Mean length of flux path at outer leg:

$$l_1 = 2D$$

Core factors associated with l_2:

For l_2, A_2 the elemental radius dr shown in Figure 15 is the elemental length of the flux path in the integral below. The radius vector extends from $F/2$ to $E/2$ for the entire circle. The effective length l_{2i} for the section is multiplied by f. The area is the physical area multiplied by K.

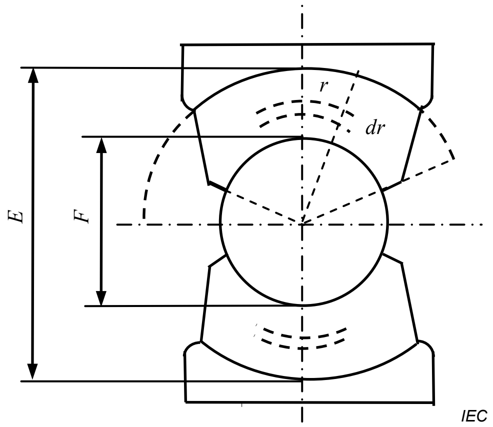


Figure 15 – PQ-cores

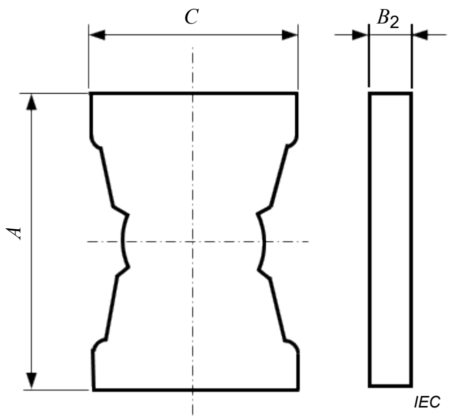


Figure 16 – PLT(plate)-cores

$$\frac{l_{2i}}{A_2} = \int_{\frac{F}{2}}^{\frac{E}{2}} \frac{f}{K 2\pi r(B-D)} dr = \frac{f}{2\pi K(B-D)} \ln\left(\frac{E}{F}\right)$$

$$\frac{l_2}{A_2^2}=\int_{\frac{F}{2}}^{\frac{E}{2}}\frac{2fdx}{\{2K[\frac{2\pi x}{2}(B-D)]\}^2}=\frac{2f}{[2K\pi(B-D)]^2}\int_{\frac{F}{2}}^{\frac{E}{2}}\frac{dx}{x^2}=f\frac{1/F-1/E}{K^2\pi^2(B-D)^2}$$

where

$$K=\frac{A_7}{A_8}=\frac{A_7}{\frac{\pi}{16}\left(E^2-F^2\right)}$$

$$A_7=\frac{1}{8}\left(\beta E^2-\alpha F^2+GL-JI\right)$$

$$\alpha=\arctan\left(\frac{L}{J}\right)$$

$$f=\frac{l_{min}+l_{max}}{2l_{min}}$$

$$l_{max}=\frac{\sqrt{E^2+F^2-2EF\cos(\alpha-\beta)}}{2}$$

Define the other two physical areas in the flux path at back wall.

$$A_9=2\alpha F(B-D)$$

$$A_{10}=2\beta E(B-D)$$

The mathematical area A_2 is given as $A_{10}>A_2>A_9$.

Area of centre limb:

$$A_3=\frac{1}{4}\pi F^2$$

Mean length of flux path at centre limb:

$$l_3=2D$$

Area of outside corner:

$$A_4=\frac{1}{2}(A_1+A_{10})=\frac{1}{2}\left[A_1+2E(B-D)\beta\right]$$

Mean length of flux path at outside corner:

$$l_4=l_4^{'}+l_4^{''}=\frac{\pi}{4}\left((B-D)+\frac{1}{2}A-\frac{1}{2}E\right)$$

Area of inside corner:

$$A_5 = \frac{1}{2}(A_3 + A_9) = \frac{\pi}{2}\left(\frac{F}{2}\right)^2 + F(B-D)\alpha$$

Mean length of flux path at inside corner:

$$l_5 = l_5^{'} + l_5^{''} = \frac{\pi}{4}\left((B-D) + \left(1 - \frac{1}{\sqrt{2}}\right)F\right)$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{A_i^2}$$

The minimum physical cross-section area A_{min} is given as:

$$A_{min} = \min(A_1, A_3, A_4, A_5, A_9)$$

$$l_e = \frac{C_1^2}{C_2} \qquad A_e = \frac{C_1}{C_2} \qquad V_e = \frac{C_1^3}{C_2^2}$$

5.13 Pair of EFD-cores

Drawings of a pair of EFD-cores are shown in Figure 17.

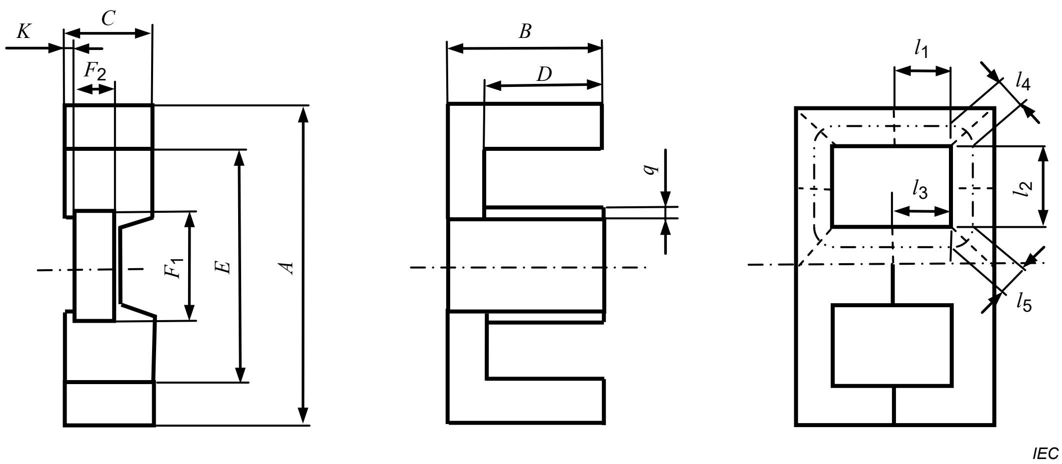


Figure 17 – Pair of EFD-cores

Area of outer leg:

$$A_1 = \frac{C(A-E)}{2}$$

Mean length of flux path at outer leg:

$$l_1 = D$$

Area of back wall:

$$A_2 = C(B - D)$$

Mean length of flux at back wall:

$$l_2 = \frac{E - F_1}{2}$$

Area of centre limb:

$$A_3 = \frac{F_1 F_2 - 2q^2}{2}$$

where q: chamfer

Mean length of flux path at centre limb:

$$l_3 = D$$

Area of outside corner:

$$A_4 = \frac{(A_1 + A_2)}{2}$$

Mean length of flux path at outside corner:

$$l_4 = \frac{\pi}{8}\left(\frac{A - E}{2} + (B - D)\right)$$

Area of inside corner:

$$A_5 = \frac{A_2 + A_3}{2}$$

Mean length of flux path at inside corner:

$$l_5 = \frac{\pi}{4}\left(\frac{F_1}{4} + \sqrt{\left(\frac{C - F_2 - 2K}{2}\right)^2 + \left(\frac{B - D}{2}\right)^2}\right)$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{2A_i^2}$$

$$l_e = \frac{C_1^2}{C_2} \qquad A_e = \frac{C_1}{C_2} \qquad V_e = \frac{C_1^3}{C_2^2}$$

5.14 Pair of E planar-cores

Drawings of a pair of E planar-cores and PLT(plate)-cores are shown in Figure 18 and Figure 19.

E planar + PLT (plate)-cores use E planar core formulae.

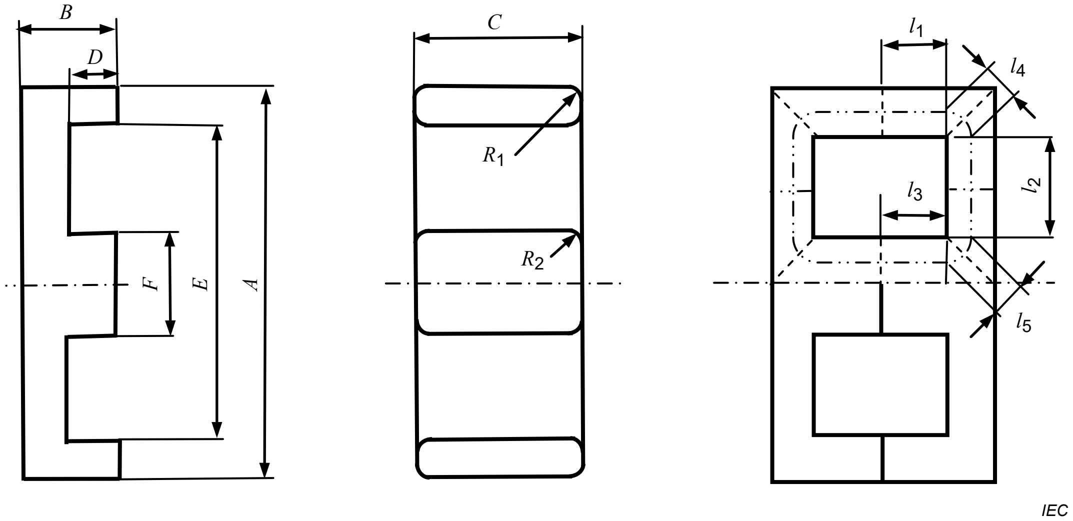


Figure 18 – Pair of E planar-cores

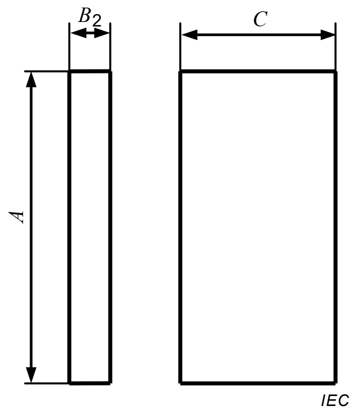


Figure 19 – PLT(plate)-cores

Area of outer leg:

$$A_1 = \frac{C(A-E)}{2} - 4\left(R_1^2 - \frac{\pi}{4}R_1^2\right)$$

Mean length of flux path at outer leg:

$$l_1 = D$$

Area of back wall:

$$A_2 = C(B-D)$$

Mean length of flux at back wall:

$$l_2 = \frac{E - F}{2}$$

Area of centre limb:

$$A_3 = \frac{FC}{2} - 2(R_2^2 - \frac{\pi}{4} R_2^2)$$

Mean length of flux path at centre limb:

$$l_3 = D$$

Area of outside corner:

$$A_4 = \frac{A_1 + A_2}{2}$$

Mean length of flux path at outside corner:

$$l_4 = \frac{\pi}{8}\left(\frac{A - E}{2} + (B - D)\right)$$

Area of inside corner:

$$A_5 = \frac{(A_2 + A_3)}{2}$$

Mean length of flux path at inside corner:

$$l_5 = \frac{\pi}{8}\left(\frac{F}{2} + (B - D)\right)$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{2A_i^2}$$

$$l_e = \frac{C_1^2}{C_2} \qquad A_e = \frac{C_1}{C_2} \qquad V_e = \frac{C_1^3}{C_2^2}$$

5.15 Pair of EC-cores

Drawings of a pair of EC-cores are shown in Figure 20.

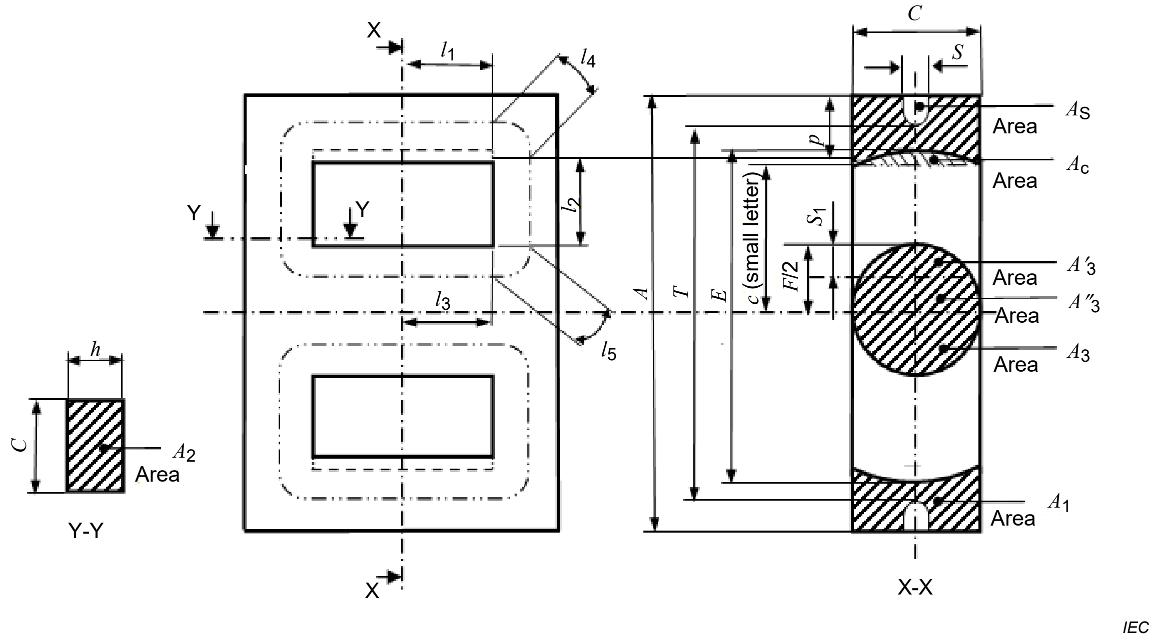


Figure 20 – Pair of EC-cores

A_1 is equal to the rectangle $C\left(\frac{1}{2}A - c\right)$ less the segment A_c and the segment A_s.

$$A_c = \frac{1}{4}E^2 \arcsin\left(\frac{C}{E}\right) - \frac{1}{4}C\sqrt{E^2 - C^2}$$

$$A_S = \frac{S(A-T-S)}{2} + \frac{\pi S^2}{8}$$

$$A_1 = \frac{1}{2}AC - \frac{1}{4}C\sqrt{E^2 - C^2} - \frac{1}{4}E^2 \arcsin\left(\frac{C}{E}\right) - \frac{S(A-T-S)}{2} - \frac{\pi S^2}{8}$$

Mean length of flux path at back walls:

$$l_2 = \frac{1}{4}\left(E + \sqrt{E^2 - C^2}\right) - \frac{F}{2}$$

NOTE l_2 is taken from the mean value of $\frac{1}{2}(E-F)$ and $(c - F/2)$.

Area of half the centre limb:

$$A_3 = A'_3 + A''_3$$

The condition to obtain $A'_3 = A''_3$ is

$$S_1 = 0{,}298\,0\ F$$

Mean length of flux path at corners:

$$l_4 = \frac{\pi}{8}(p + h)$$

where $p = \frac{A}{2} - l_2 - \frac{F}{2}$

$$l_5 = \frac{\pi}{8}(2S_1 + h)$$

Mean areas associated with l_4 and l_5:

$$A_4 = \frac{A_1 + A_2}{2}$$

$$A_5 = \frac{A_2 + A_3}{2}$$

$$C_1 = \sum_{i=1}^{5} \frac{l_i}{A_i} \qquad C_2 = \sum_{i=1}^{5} \frac{l_i}{2A_i^{2}}$$

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