Ferrites and accessories

Processing notes

Date: May 2017

1 Gapped and ungapped ferrite cores

Even with the best grinding methods known today, a certain degree of roughness on ground surfaces cannot be avoided, so that the usual term “without air gap” or “ungapped” does not imply no air gap at all. The A_L values quoted allow for a certain amount of roughness of the ground faces. The tolerance of the A_L value for ungapped cores is –20 to +30% or –30 to +40%. Closer tolerances are not available for several reasons. The spread in the A_L values of ungapped cores practically equal the spread in ring core permeability (±20% … ±30%), and the A_L value largely depends on the grinding quality of the matching surfaces.

The following are normally defined:

precision-ground/lapped cores	s_{resid}	≈ 1 µm
normally ground cores	s_{resid}	≈ 10 µm
gapped cores	s	≥ 10 µm

The residual air gap s_{resid} here is the total of the residual air gaps at the leg or centerpost contact surfaces.

With increasing material permeability the influence of the inevitable residual air gap grows larger. The spreads in the A_L value may also be increased by the mode of core assembly. Effects of mounting and gluing can result in a reduction of the A_L value. An appropriate wringing of cores with polished surface is used to improve reproducibility of the measurement (it is recommended to rub the mating surfaces themselves six times in a circular or elliptic arc that matches the core profile before measuring A_L).

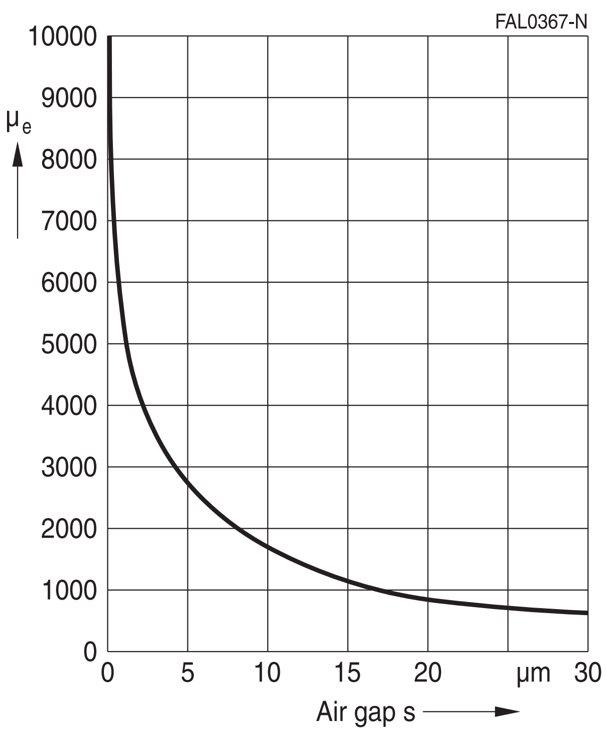


Figure 25
Relationship between permeability μ_e and air gap s for an RM 4/T38 ferrite core

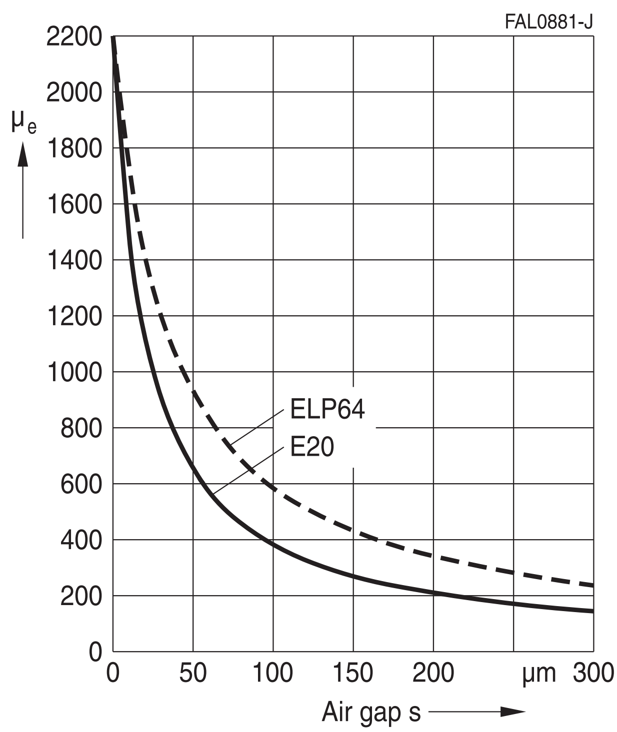


Figure 26
Relationship between permeability μ_e and air gap s for an E 20/10/11 N87 and ELP 64/10/50 N87 ferrite core

1.1 Air gaps and distributed air gaps in ferrite cores - E, EQ, ER, ETD, PM, PQ cores

Applications

- Power chokes
- Flyback converters

Technique

- The gap delays the core saturation
- The gap is required to increase the power handling capability
- The gap makes the core inductance independent of the material permeability and thereby narrows down the spread of inductance.

Benefits

- The core size can be reduced by one class due to lower winding loss (e.g. ETD 59 → ETD 54 or E 65 →E 55)
- Additional costs for creating the “triple gap” are compensated by the smaller core.

Core types

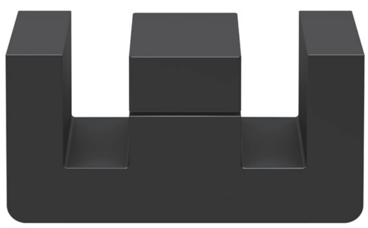


Figure 1: E Core

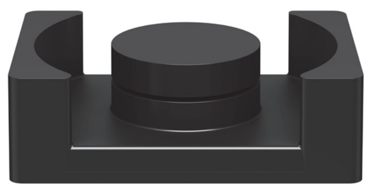


Figure 2: EQ Core

Figure 3: ER Core

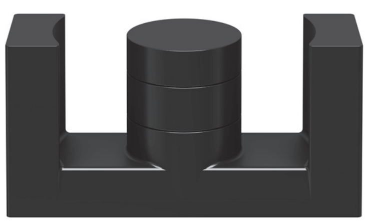


Figure 4: ETD Core

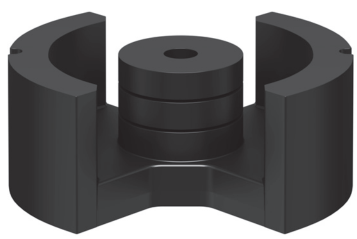
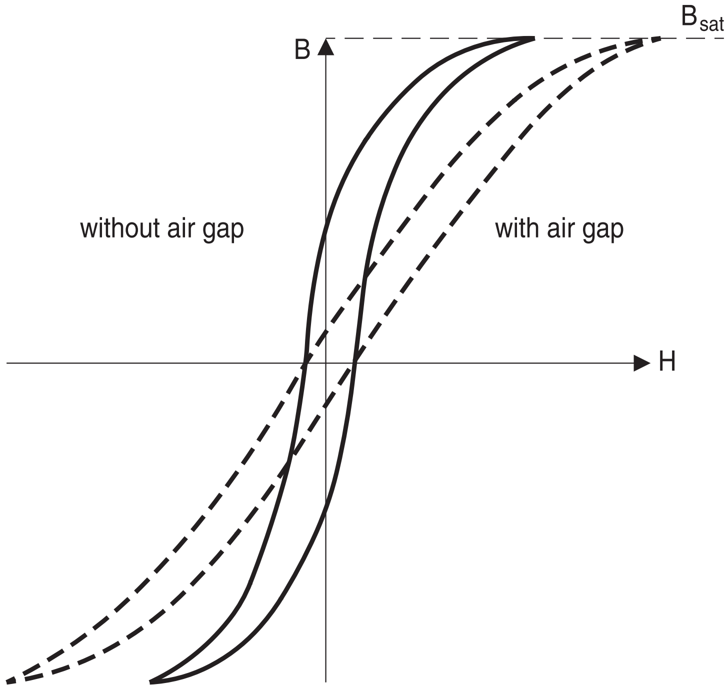


Figure 5: PM Core

Figure 6: PQ Core

Technique

The gap delays the core saturation.



$$I_{sat} = \frac{B_{sat} A_e}{n} (R_c + R_g)$$

R_c = Resistance of the core
R_g = Resistance of air gap
n = Number of turns

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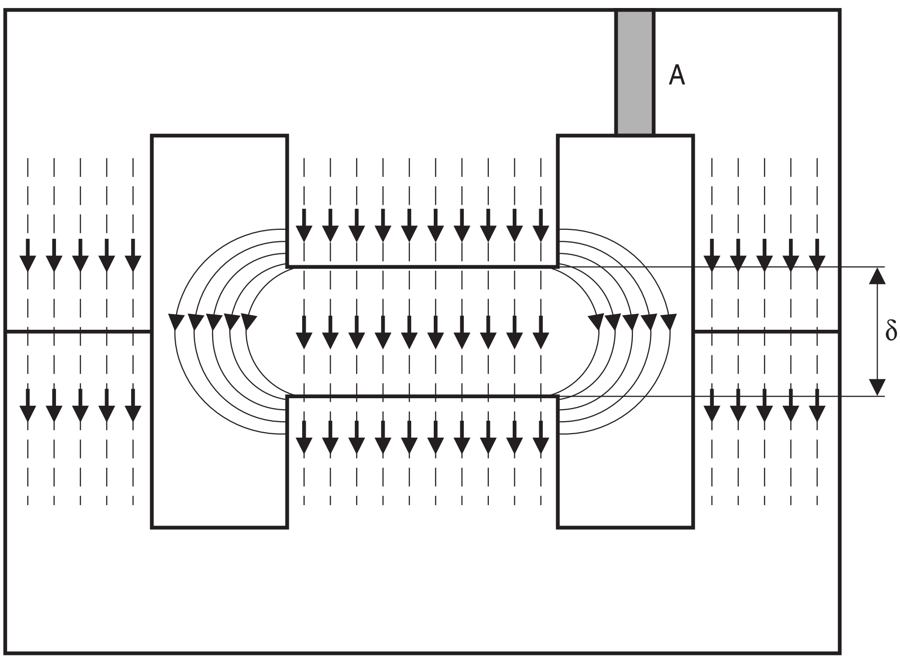
The gap is required to increase the power handling capabability.



$$W = \frac{1}{2} \frac{B^2}{\mu_0} \left(\frac{l_e}{\mu_r} + \delta\right) A$$

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The gap makes the core inductance independent of the material permeability.

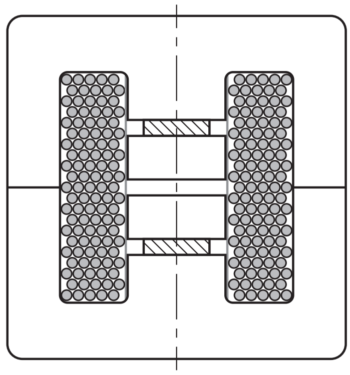
For more information, please read chapter „General – Definitions – 2 Permeability“

Processing notes

Simulation with ferrite cores E 55/28/25

The main effect of gaps of different sizes and locations will be changing the loss in the adjacent winding. The size of this effect depends on the stray field which enters the winding. The total gap remains identical, only the location and the individual size per gap are changed.

The average of the square of the local flux density in the winding is used for comparing the results, since they would induce eddy currents and lead to losses and heating governed by $P = R * I^2$.



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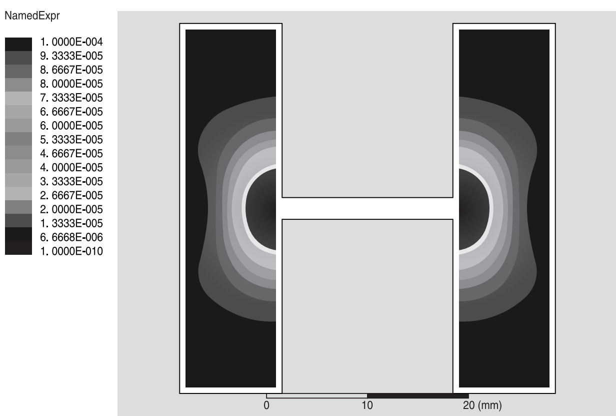
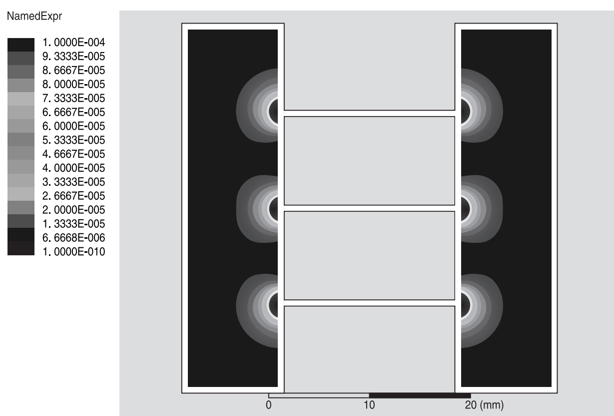
The worst effect is seen for a large single gap.



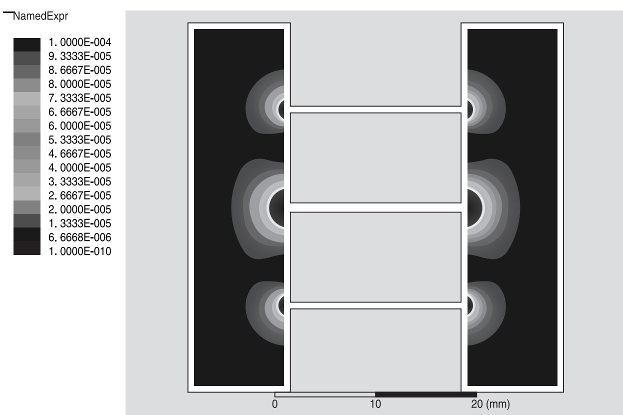
FEK0859-T

Creating more and smaller gaps improves the situation compared to the single gap.



FEK0860-W

Uneven distribution of gaps leads to the larger local losses close to the larger gaps.



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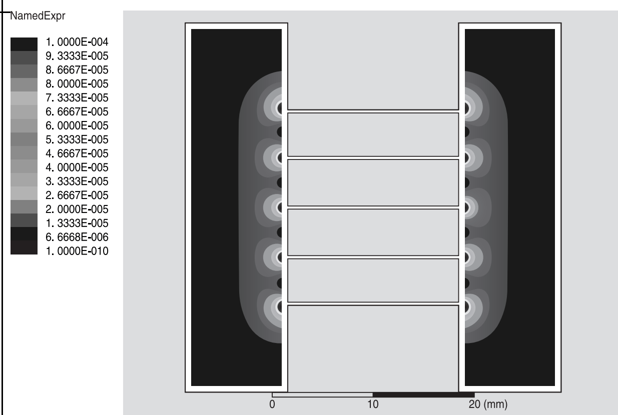
Five evenly distributed gaps.



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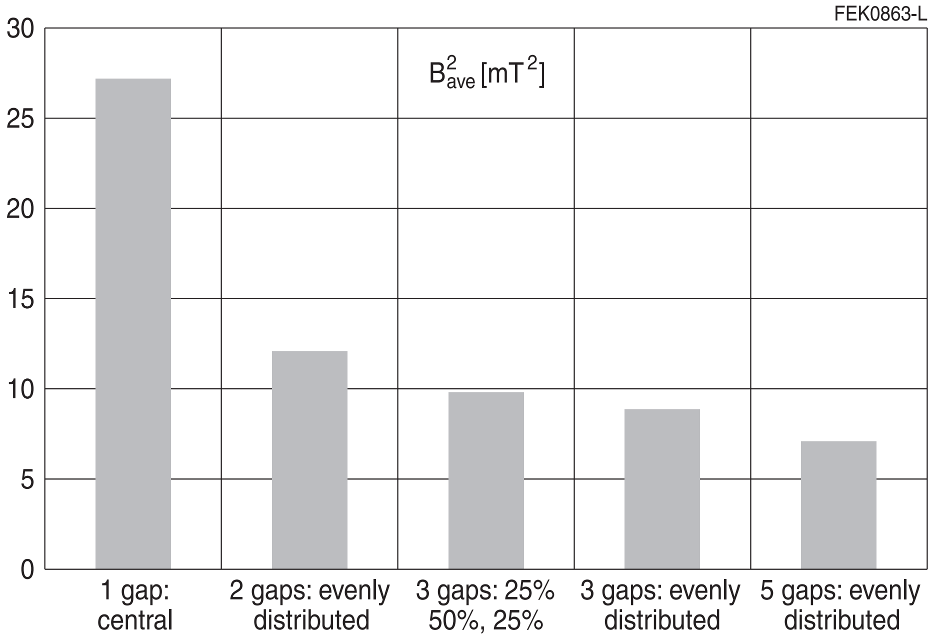
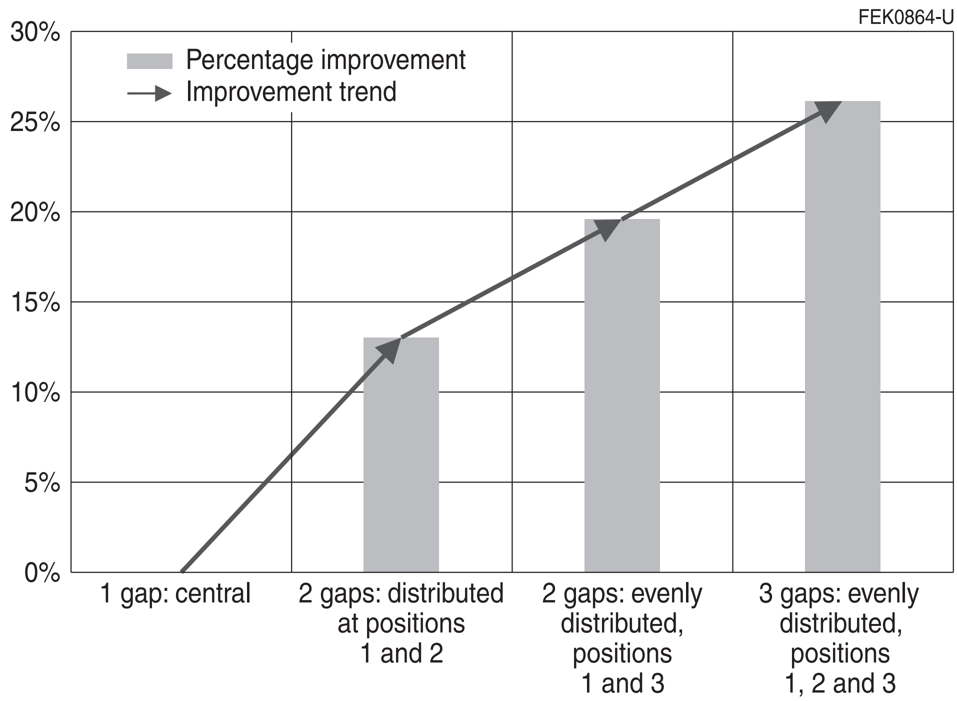
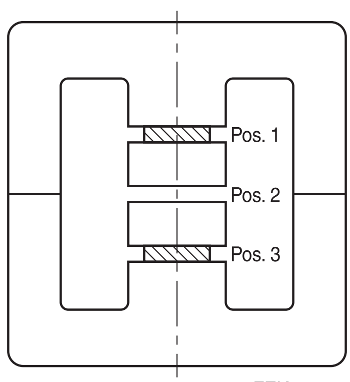
Average B^2 in winding depending on each gap size (total gap is same) and location.



Improvement in DC current for a 20% drop in initial Inductance for different gap sizes and structures (total gap is same).





Conclusion

In comparison between one gap and three evenly distributed gaps in the core it is seen that the square of the average flux B^2_{ave}, causing winding loss is lower in the later case.

In applications, there are consequently lower electromagnetic emissions and heating.

2 Processing notes for the manufacture of wound products for small-signal and power applications

2.1 Winding design

For the most common core types the maximum number of turns for the individual coil formers can be seen from the following nomograms. The curves have been derived from the equation

$$N = \frac{A_N}{A_{wire}} \cdot f_{Cu}$$

where

N	Max. number of turns
A_N	Winding cross section in mm^2
A_{wire}	Wire cross section in mm^2
f_{Cu}	Copper space factor versus wire diameter (f_{Cu} approx. 0.55 for wire diameter 0.05)

Common wires and litz wires are specified in the pertinent standards (IEC 60317).

As can be seen from Figure 26, as high a winding level as possible should be employed because at low μ_e values in particular a low winding level (h/H ratio) can cause an A_L drop of up to 10% compared to the maximum value with full winding. (By our standards, the A_L values are always related to fully wound 100-turn coils.)

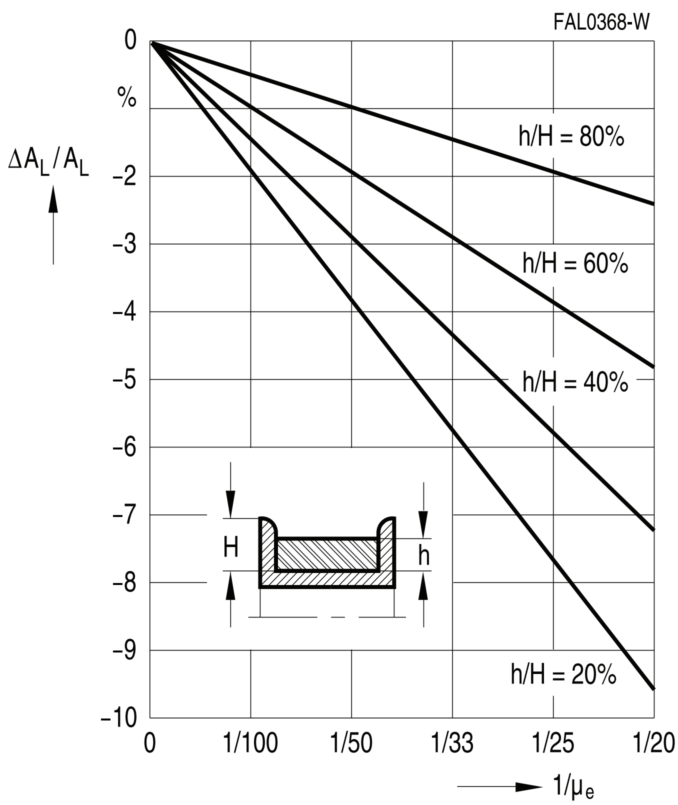
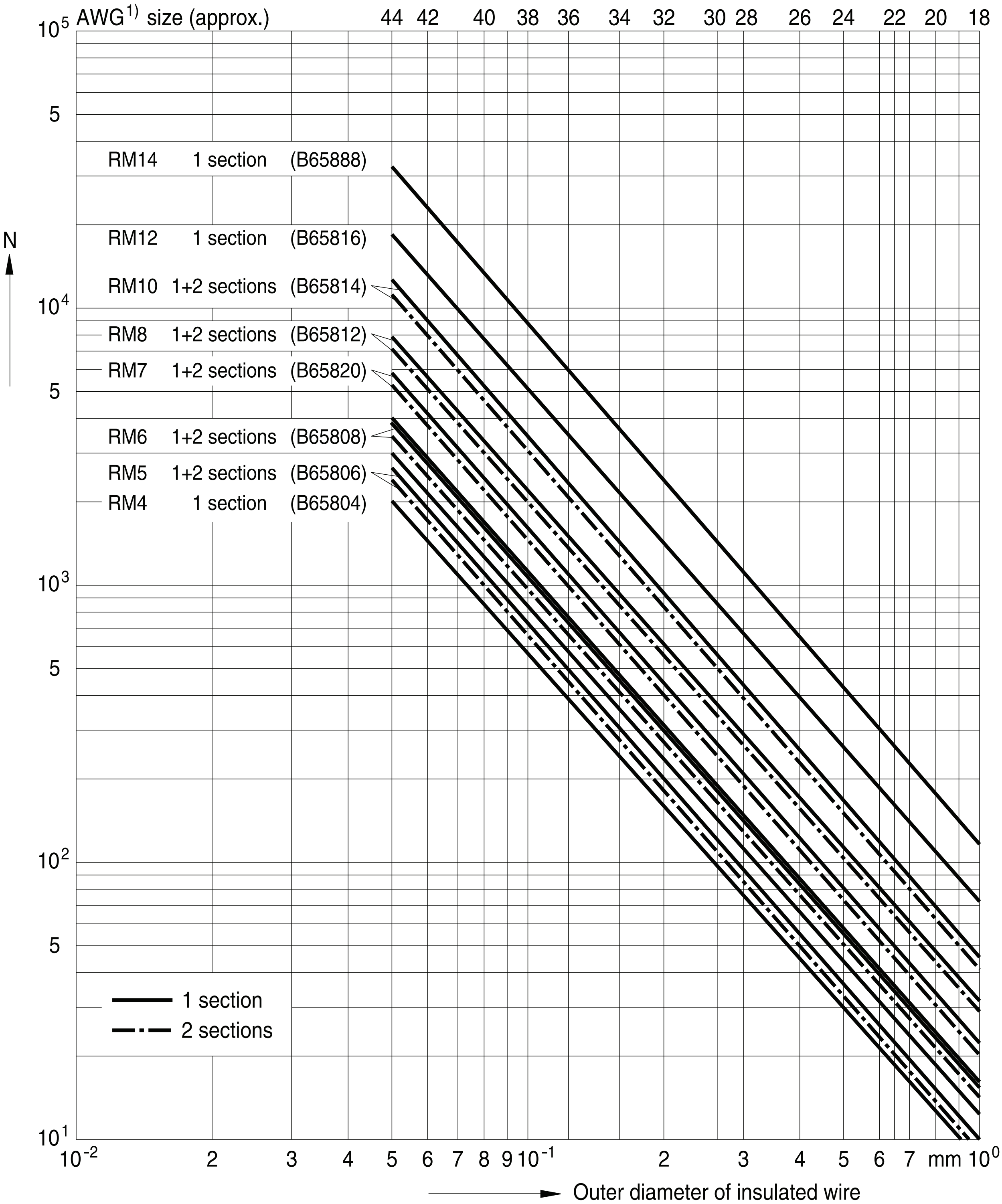


Figure 27
Percentage change in A_L value versus relative winding height h/H

RM cores

Maximum number of turns N for coil formers



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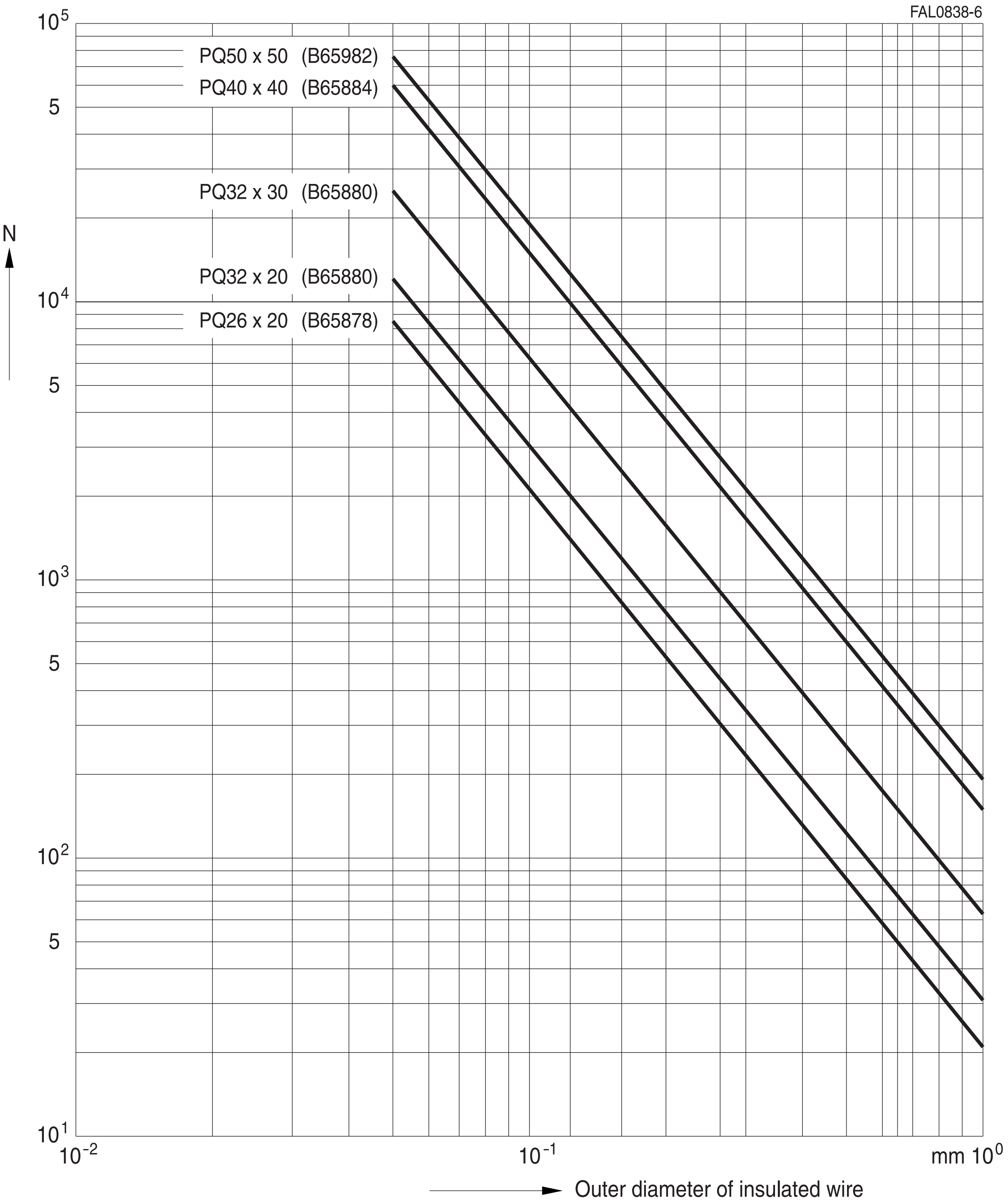
1) American Wire Gauge (AWG)

Processing notes

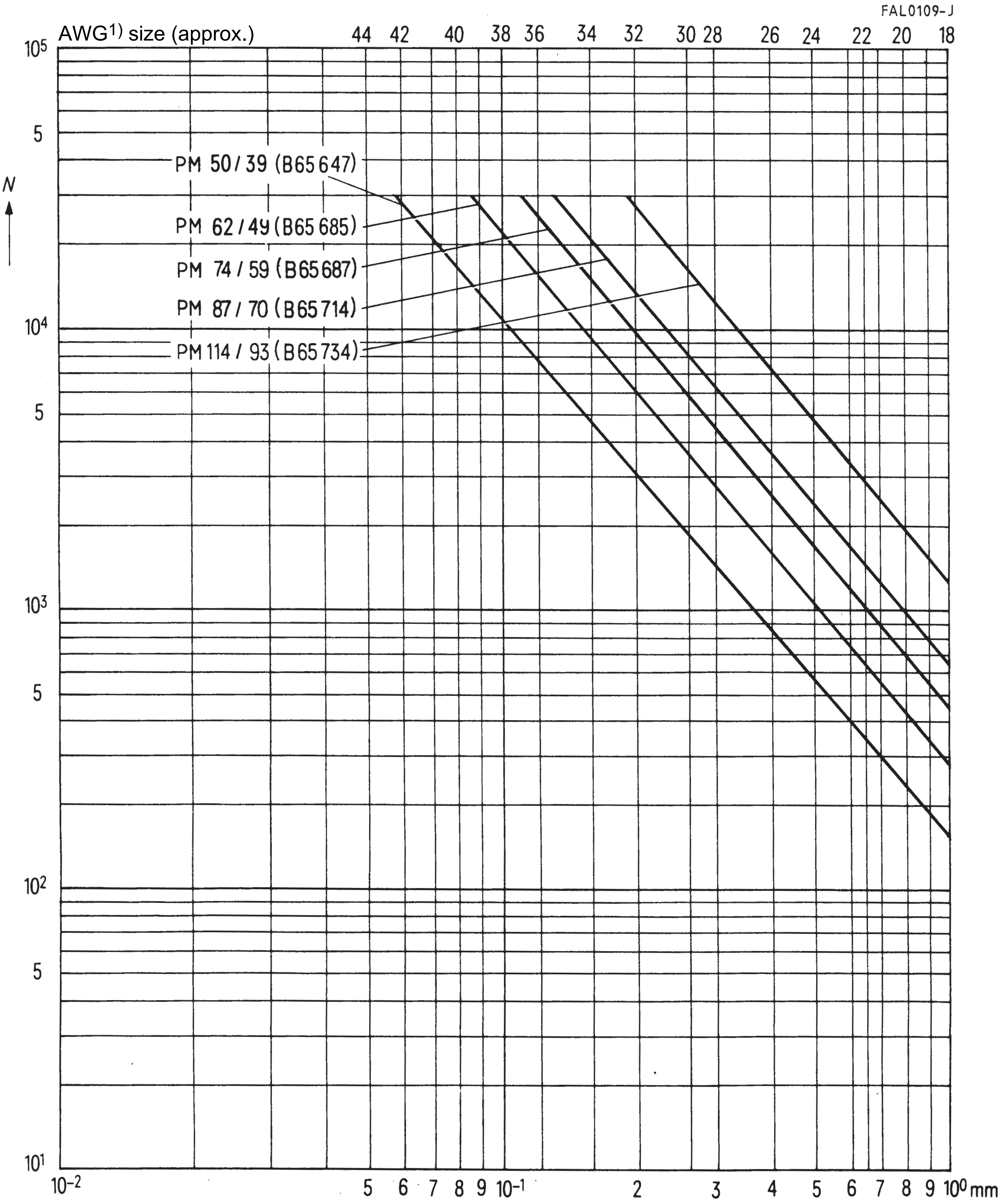
PQ cores

Maximum number of turns N for coil formers



PM cores

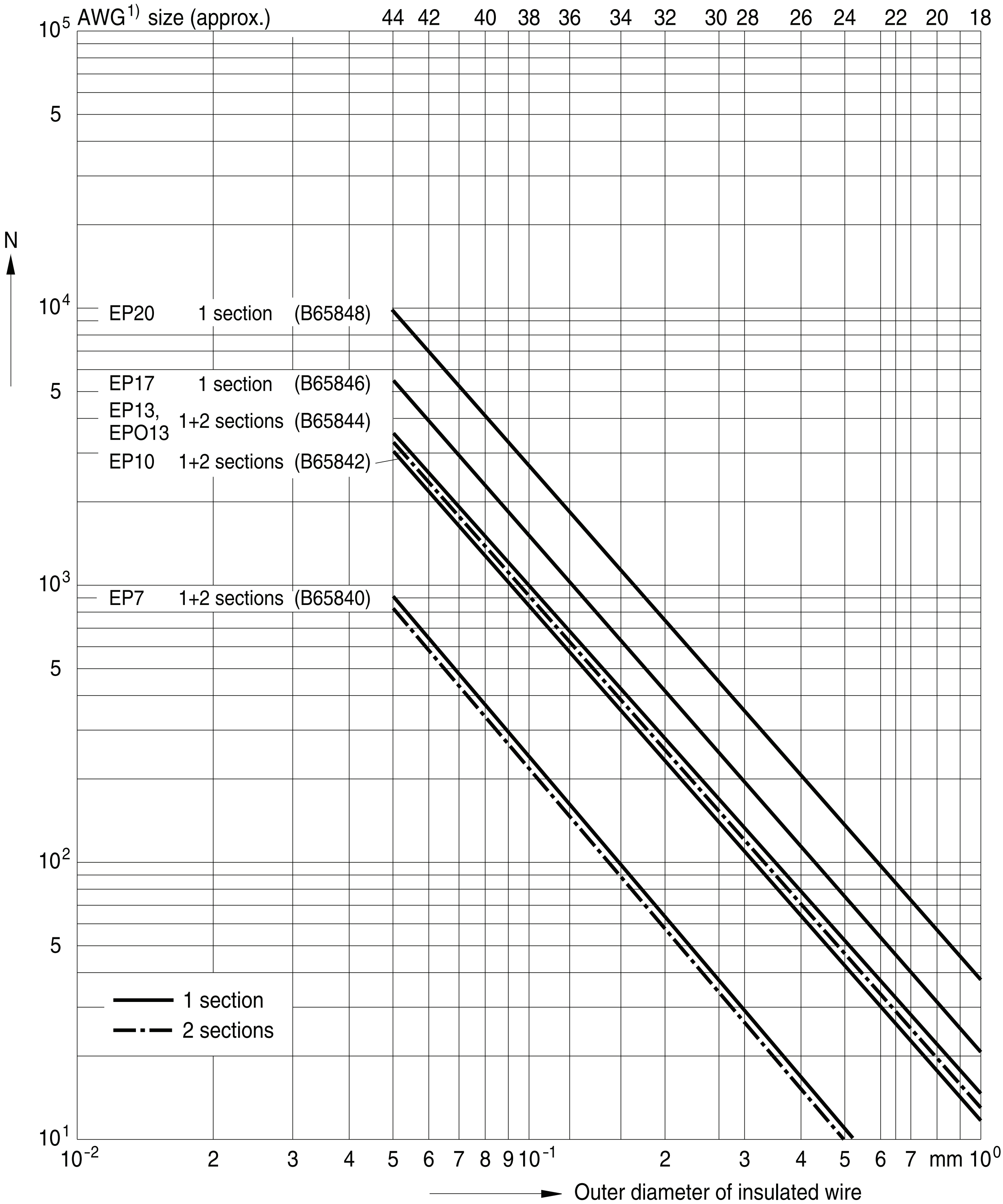
Maximum number of turns N for coil formers



1) American Wire Gauge (AWG)

EP cores

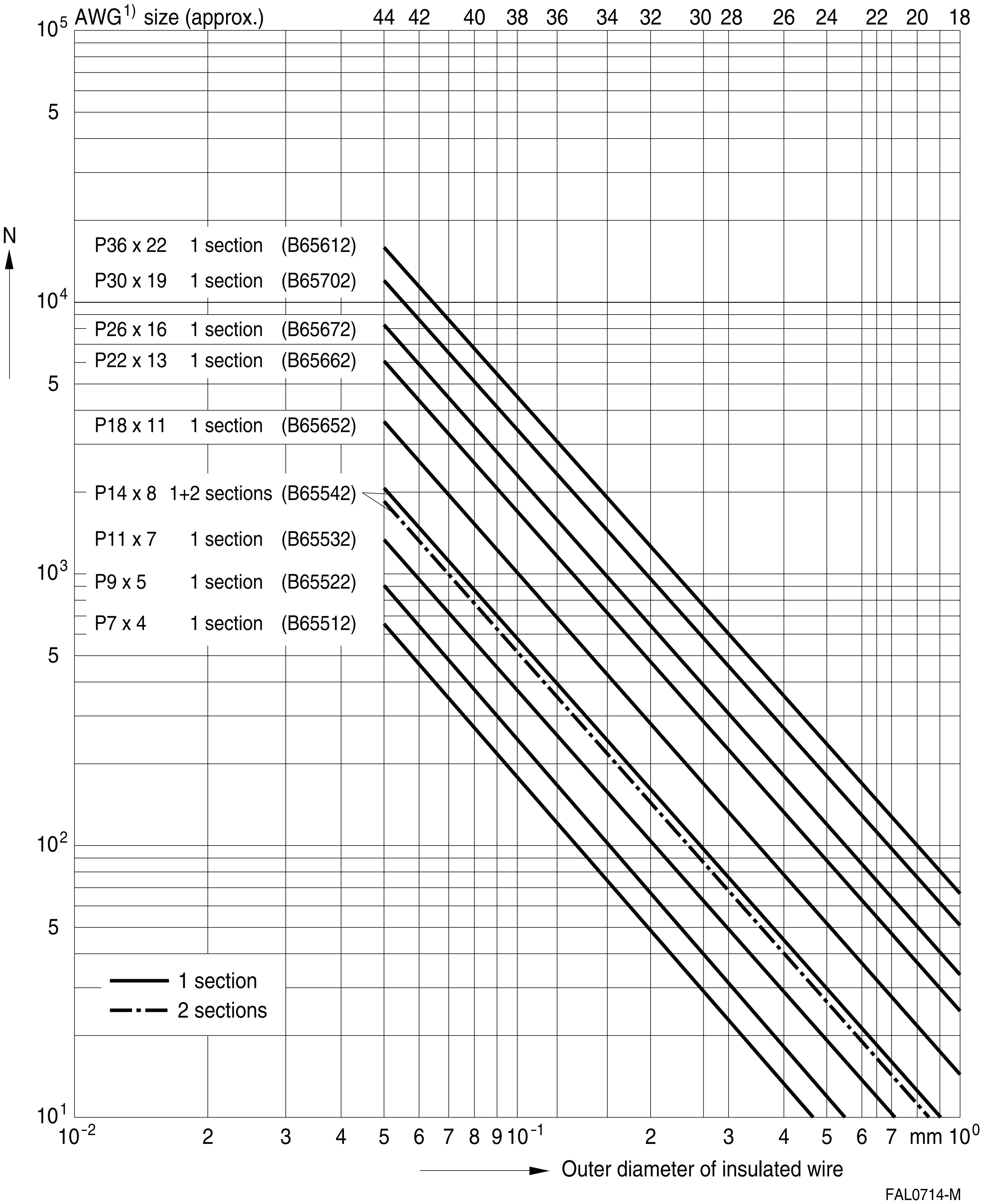
Maximum number of turns N for coil formers



1) American Wire Gauge (AWG)

P cores

Maximum number of turns N for coil formers



1) American Wire Gauge (AWG)

EFD cores

Maximum number of turns N for coil formers

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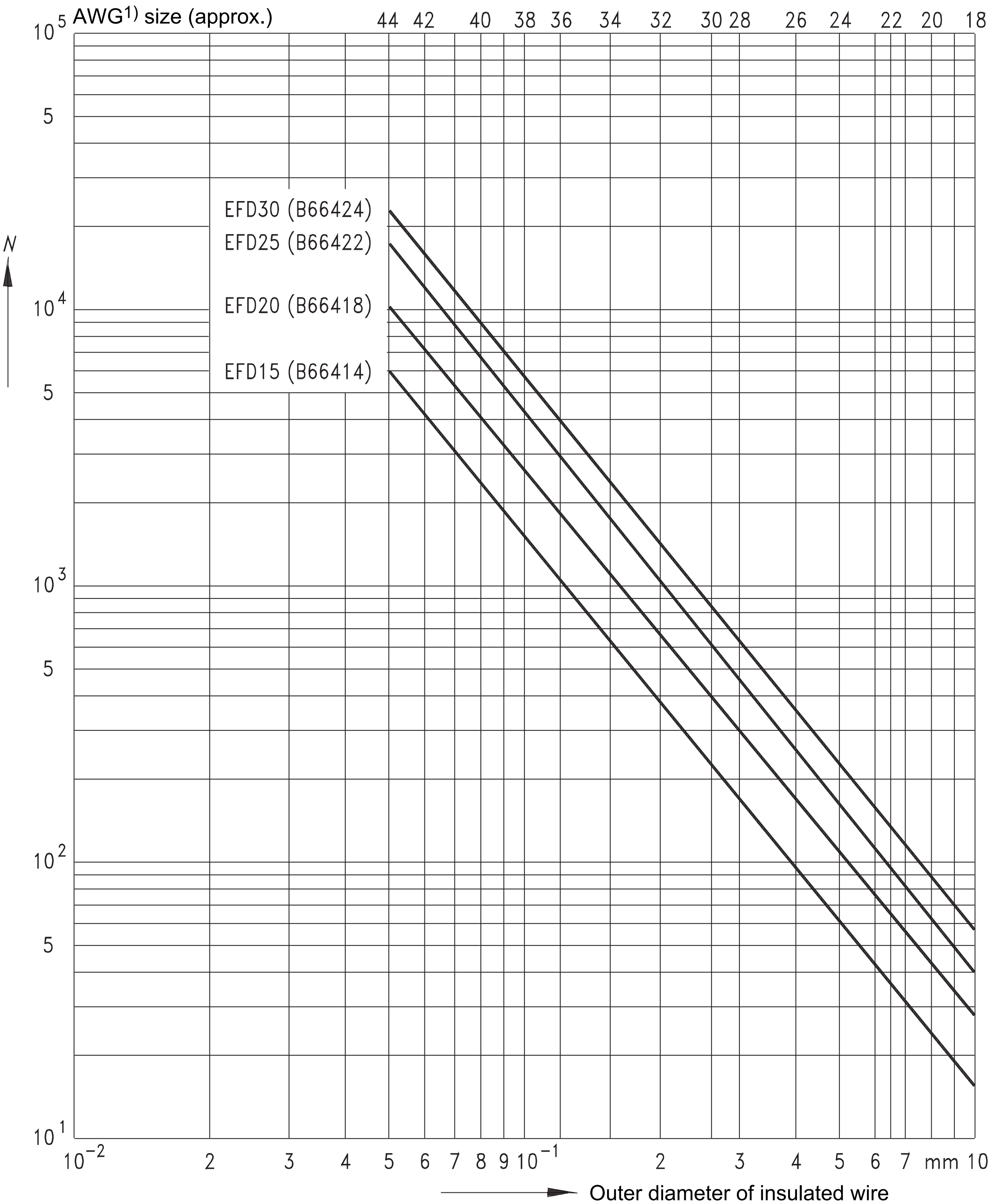
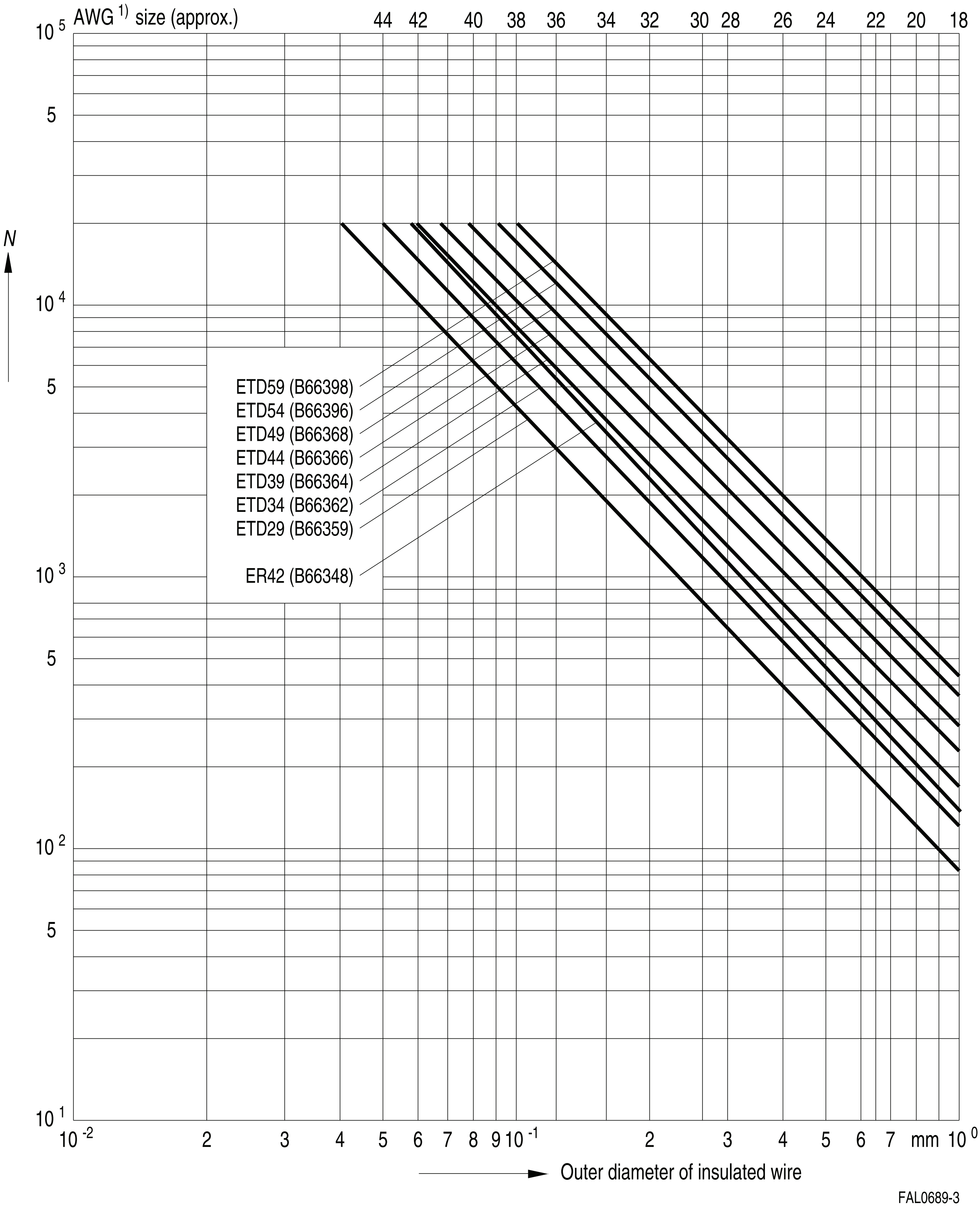


1) American Wire Gauge (AWG)

ETD and ER cores

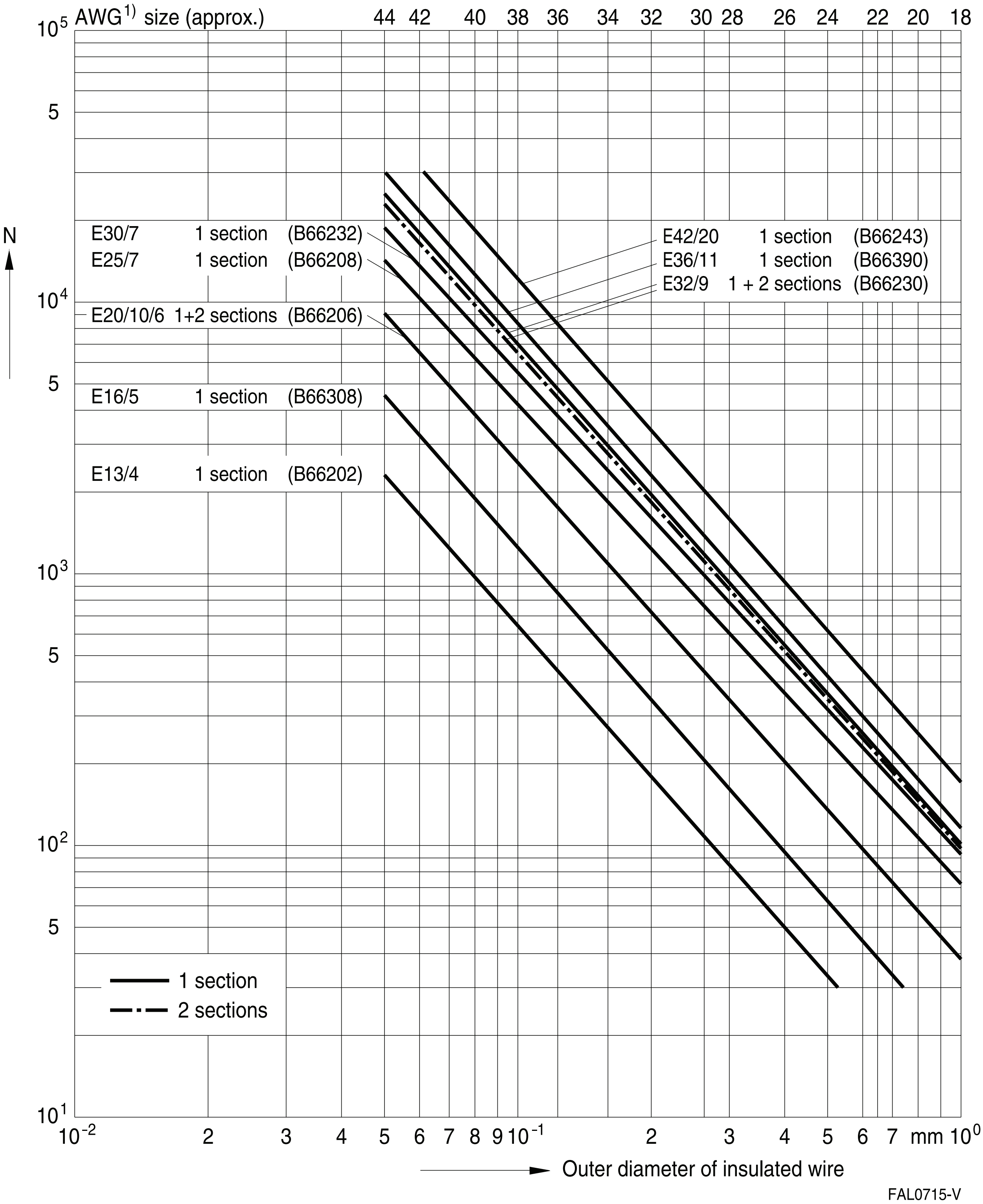
Maximum number of turns N for coil formers



1) American Wire Gauge (AWG)

E cores

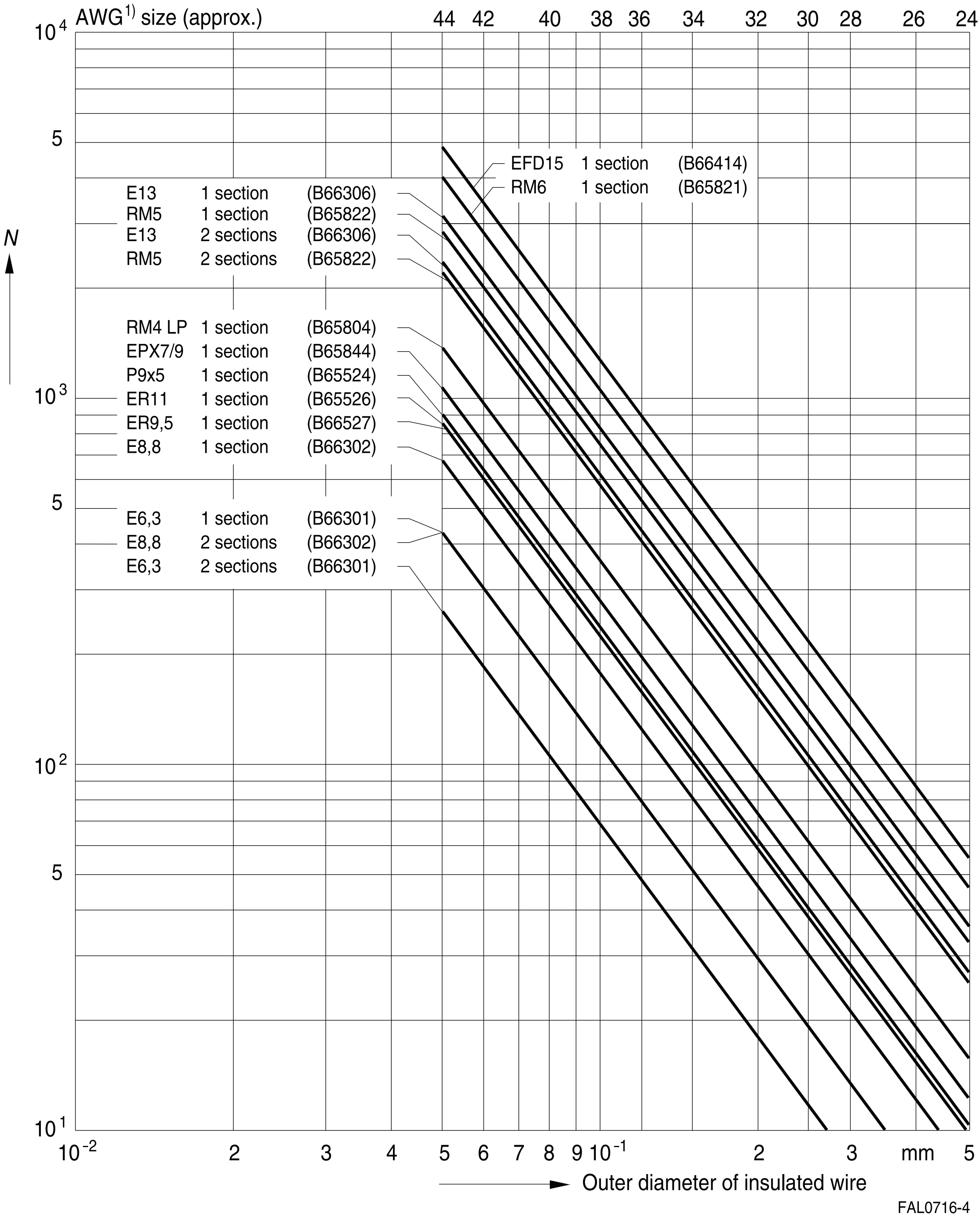
Maximum number of turns N for coil formers



1) American Wire Gauge (AWG)

SMD types

Maximum number of turns N for coil formers



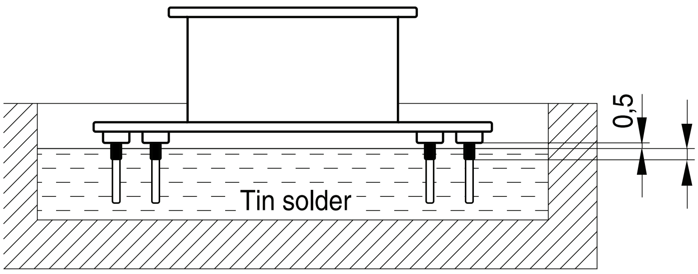
1) American Wire Gauge (AWG)

2.2 Soldering/Inductor assembly

The winding wires are preferably connected to the pins by dip soldering. Note the following when soldering:

- Prior to every dip soldering process the oxide film must be removed from the surface of the solder bath.
- 2 to 3 turns of the wire are dipped into the solder bath; the coil former must not be allowed to come too close to the solder or remain there for too long (see diagram).
- Typical values are: Bath temperature: 400 °C, soldering time: 1 s.

Soldering of PTH (pin through hole)



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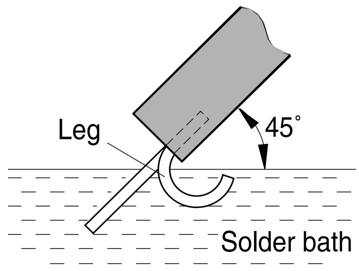
Soldering of J-leg



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For inductor assembly, it is advisable to clamp the cores with the associated relevant mounting assemblies for the coil formers and cores. In this way it is possible to avoid the effects of external mechanical stress.

2.3 Design and processing information for SMD components

2.3.1 Automatic placement

EPCOS ferrite accessories are suitable for automatic placement. Many automatic placement machines pick up the components with suction probes and pliers, so the inductive components should have simple and clear contours as well as a sufficiently large and flat surface. Ferrite cores with a perpendicular magnetic axis, e.g. RM and ER cores, have a smooth surface and the flange for the coil former is styled right for the purpose. For cores with a horizontal magnetic axis, e.g. E cores and toroids, we provide cover caps to meet these requirements.

2.3.2 Coplanarity

Coplanarity means the maximum spacing between a terminal and a plane surface. If inductive components are fabricated with coplanarity of <0.2 mm for example, then one or more terminals may be spaced maximally 0.2 mm from a plane surface.
Inductive components are fabricated to standard with coplanarity of <0.2 mm. Coplanarity is influenced by a number of factors:

a) Coil former specification
The coplanarity of the coil former is <0.1 mm for manufacturing reasons.

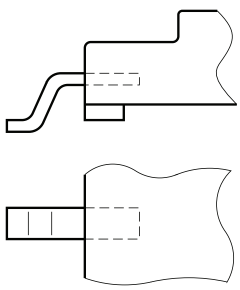
b) Winding wire
Use of thick winding wire (e.g. 0.25 mm diameter in model ER 11) leads to considerable mechanical strain on the terminal during winding, and this can degrade coplanarity.

c) Soldering temperature and duration
When winding wire is soldered to a terminal, the coil former is subjected to high thermal stress. If thick wires have to be soldered, the soldering temperature and/or duration increase and thus the thermal stress on the coil former too. This also degrades coplanarity.

Consequently the use of thick wires degrades coplanarity in two ways: greater mechanical strain when winding, and greater thermal stress during soldering.

If electrical requirements call for the use of thick wires, either the manufacturing effort is greater (it takes longer and the costs are higher), or a terminal geometry has to be chosen that is suitable for the use of thick wires. EPCOS offers two different SMD lead geometries: gullwings and J terminals.

Gullwing terminals



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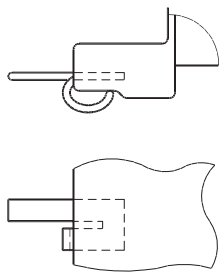
Molded-in J terminals



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With gullwings the wire is wound direct on the terminal, which is then soldered on the circuit board. With J terminals the wire is wound on a separate pin, and the J terminal is soldered to the circuit board.

So gullwings are suitable for applications with thin wire (up to approx. 0.18 mm in diameter), and J terminals for use with thick wire (upwards from 0.18 mm in diameter). These figures for wire diameter are only intended as guidelines. Depending on wire diameter, the winding arrangement, the pinning and electrical requirements, one has to decide from case to case which solution is best for the particular application.

2.3.3 Solder paste application

Coplanarity has to be considered when determining the thickness of the solder paste. If coplanarity is <0.2 mm for example, the solder paste has to be applied at least 0.2 mm thick to ensure proper soldering.

2.4 Adhesive application and core mating

A quantity of adhesive appropriate to the area in question is applied to the cleaned surface of the core’s side walls. The centerpost must remain free of adhesive. The two core halves without coil former are then placed on a mandrel and rotated against each other two or three times to spread the adhesive. A slight ring of adhesive exuding around the edges indicates that sufficient adhesive has been applied.

On porous, low-permeability SIFERRIT materials (K) the adhesive should be applied and spread twice.

The next step should follow immediately since the adhesive film easily attracts dust and absorbs moisture. Therefore, the core pair with adhesive already applied is opened for a short time and the wound coil is inserted without touching the mating surfaces.

The wound coil is then fixed into position. This can be done by using resilient spacers which must be inserted before applying the adhesive. Appropriate spacers are available on request.

The coil former can also be fixed by gluing, e.g. using adhesive d), but only at one spot on the core bottom to avoid any mechanical stress caused by the difference in thermal expansion of core and coil former.

Adhesive e) is suitable for external gluing, which implies only four dots of adhesive at the joints on both sides of the openings. Because of the somewhat lower torsional strength, it should be noted that this kind of gluing should only be used with mounted cores.

2.5 Holding jigs

The core assembly is cured under pressure in a centering jig. The core center hole – where present – is used for centering, and two to eight coils can be held in one jig with a pressure spring. Spacers will ensure that the pressure is only exerted on the side walls of the core.

Single jigs facilitate the coil inductance measurement, which has proved useful for checking cores with small air gaps before the adhesive has hardened. Small inductance corrections can be made by slightly turning the core halves relative to each other.

2.6 Final adjustment

(possible only with adjustable cores)

With all assembled ferrite cores, a magnetic activation takes place as a result of mounting influences such as clamping, gluing and soldering, i.e. a disaccommodation process commences. Therefore the final adjustment for high-precision inductors should take place no earlier than one day after assembly; preferably, one week should first elapse.

2.7 Hole arrangement

For drilling the through-holes into the PC board we recommend the dimensions given in the hole arrangement for each coil former, which depend on the distance of the pins on the pin outlet level.

2.8 Creepage and clearance

For telecom transformers the clearance and creepage distances and the thickness of insulation must be considered acc. EN 60950 subclause 2.9.

Mechanical stress and mounting

Ferrite cores have to meet mechanical requirements during assembling and for a growing number of applications. Since ferrites are ceramic materials one has to be aware of the special behavior under mechanical load.

As valid for any ceramic material, ferrite cores are brittle and sensitive to any shock, fast temperature changing or tensile load. Especially high cooling rates under ultrasonic cleaning and high static or cyclic loads can cause cracks or failure of the ferrite cores.

For detailed information see data book, chapter *"General - Definitions, 8.1"*.

Effects of core combination on A_L value

Stresses in the core affect not only the mechanical but also the magnetic properties. It is apparent that the initial permeability is dependent on the stress state of the core. The higher the stresses are in the core, the lower is the value for the initial permeability. Thus the embedding medium should have the greatest possible elasticity.

For detailed information see data book, chapter *"General - Definitions, 8.1"*.

Heating up

Ferrites can run hot during operation at higher flux densities and higher frequencies.

NiZn-materials

The magnetic properties of NiZn-materials can change irreversible in high magnetic fields.

Ferrite Accessories

EPCOS ferrite accessories have been designed and evaluated only in combination with EPCOS ferrite cores. EPCOS explicitly points out that EPCOS ferrite accessories or EPCOS ferrite cores may not be compatible with those of other manufacturers. Any such combination requires prior testing by the customer and will be at the customer‘s own risk.

EPCOS assumes no warranty or reliability for the combination of EPCOS ferrite accessories with cores and other accessories from any other manufacturer.

Processing remarks

The start of the winding process should be soft. Else the flanges may be destroyed.

– Too strong winding forces may blast the flanges or squeeze the tube that the cores can not be mounted any more.
– Too long soldering time at high temperature (>300 °C) may effect coplanarity or pin arrangement.
– Not following the processing notes for soldering of the J-leg terminals may cause solderability problems at the transformer because of pollution with Sn oxyde of the tin bath or burned insulation of the wire. For detailed information see chapter *"Processing notes"*, section 2.2.
– The dimensions of the hole arrangement have fixed values and should be understood as a recommendation for drilling the printed circuit board. For dimensioning the pins, the group of holes can only be seen under certain conditions, as they fit into the given hole arrangement. To avoid problems when mounting the transformer, the manufacturing tolerances for positioning the customers' drilling process must be considered by increasing the hole diameter.

Display of ordering codes for EPCOS products

The ordering code for one and the same product can be represented differently in data sheets, data books, other publications and the website of EPCOS, or in order-related documents such as shipping notes, order confirmations and product labels. **The varying representations of the ordering codes are due to different processes employed and do not affect the specifications of the respective products**. Detailed information can be found on the Internet under www.epcos.com/orderingcodes.

Symbols and terms

Symbol	Meaning	Unit
A	Cross section of coil	mm^2
A_e	Effective magnetic cross section	mm^2
A_L	Inductance factor; $A_L = L/N^2$	nH
A_{L1}	Minimum inductance at defined high saturation ($\triangleq \mu_a$)	nH
A_{min}	Minimum core cross section	mm^2
A_N	Winding cross section	mm^2
A_R	Resistance factor; $A_R = R_{Cu}/N^2$	$\mu\Omega = 10^{-6}\ \Omega$
B	RMS value of magnetic flux density	Vs/m^2, mT
ΔB	Flux density deviation	Vs/m^2, mT
$\hat{B}$	Peak value of magnetic flux density	Vs/m^2, mT
$\Delta\hat{B}$	Peak value of flux density deviation	Vs/m^2, mT
B_{DC}	DC magnetic flux density	Vs/m^2, mT
B_R	Remanent flux density	Vs/m^2, mT
B_S	Saturation magnetization	Vs/m^2, mT
C_0	Winding capacitance	F = As/V
CDF	Core distortion factor	$mm^{-4.5}$
DF	Relative disaccommodation coefficient $DF = d/\mu_i$	
d	Disaccommodation coefficient	
E_a	Activation energy	J
f	Frequency	s^{-1}, Hz
f_{cutoff}	Cut-off frequency	s^{-1}, Hz
f_{max}	Upper frequency limit	s^{-1}, Hz
f_{min}	Lower frequency limit	s^{-1}, Hz
f_r	Resonance frequency	s^{-1}, Hz
f_{Cu}	Copper filling factor	
g	Air gap	mm
H	RMS value of magnetic field strength	A/m
$\hat{H}$	Peak value of magnetic field strength	A/m
H_{DC}	DC field strength	A/m
H_c	Coercive field strength	A/m
h	Hysteresis coefficient of material	10^{-6} cm/A
h/μ_i^2	Relative hysteresis coefficient	10^{-6} cm/A
I	RMS value of current	A
I_{DC}	Direct current	A
$\hat{I}$	Peak value of current	A
J	Polarization	Vs/m^2
k	Boltzmann constant	J/K
k_3	Third harmonic distortion	
k_{3c}	Circuit third harmonic distortion	
L	Inductance	H = Vs/A

Symbol	Meaning	Unit
$\Delta L/L$	Relative inductance change	H
L_0	Inductance of coil without core	H
L_H	Main inductance	H
L_p	Parallel inductance	H
L_{rev}	Reversible inductance	H
L_s	Series inductance	H
l_e	Effective magnetic path length	mm
l_N	Average length of turn	mm
N	Number of turns	
P_{Cu}	Copper (winding) losses	W
P_{trans}	Transferrable power	W
P_V	Relative core losses	mW/g
PF	Performance factor	
Q	Quality factor ($Q = \omega L/R_s = 1/\tan \delta_L$)	
R	Resistance	Ω
R_{Cu}	Copper (winding) resistance (f = 0)	Ω
R_h	Hysteresis loss resistance of a core	Ω
ΔR_h	R_h change	Ω
R_i	Internal resistance	Ω
R_p	Parallel loss resistance of a core	Ω
R_s	Series loss resistance of a core	Ω
R_{th}	Thermal resistance	K/W
R_V	Effective loss resistance of a core	Ω
s	Total air gap	mm
T	Temperature	°C
ΔT	Temperature difference	K
T_C	Curie temperature	°C
t	Time	s
t_v	Pulse duty factor	
$\tan \delta$	Loss factor	
$\tan \delta_L$	Loss factor of coil	
$\tan \delta_r$	(Residual) loss factor at $H \rightarrow 0$	
$\tan \delta_e$	Relative loss factor	
$\tan \delta_h$	Hysteresis loss factor	
$\tan \delta/\mu_i$	Relative loss factor of material at $H \rightarrow 0$	
U	RMS value of voltage	V
$\hat{U}$	Peak value of voltage	V
V_e	Effective magnetic volume	mm^3
Z	Complex impedance	Ω
Z_n	Normalized impedance $\|Z\|_n = \|Z\| / N^2 \times \varepsilon\ (l_e/A_e)$	Ω/mm

Symbols and terms

Symbol	Meaning	Unit
α	Temperature coefficient (TK)	1/K
α_F	Relative temperature coefficient of material	1/K
α_e	Temperature coefficient of effective permeability	1/K
ε_r	Relative permittivity	
Φ	Magnetic flux	Vs
η	Efficiency of a transformer	
η_B	Hysteresis material constant	mT^{-1}
η_i	Hysteresis core constant	$A^{-1}H^{-1/2}$
λ_s	Magnetostriction at saturation magnetization	
μ	Relative complex permeability	
μ_0	Magnetic field constant	Vs/Am
μ_a	Relative amplitude permeability	
μ_{app}	Relative apparent permeability	
μ_e	Relative effective permeability	
μ_i	Relative initial permeability	
μ_p'	Relative real (inductive) component of $\overline{\mu}$ (for parallel components)	
μ_p''	Relative imaginary (loss) component of $\overline{\mu}$ (for parallel components)	
μ_r	Relative permeability	
μ_{rev}	Relative reversible permeability	
μ_s'	Relative real (inductive) component of $\overline{\mu}$ (for series components)	
μ_s''	Relative imaginary (loss) component of $\overline{\mu}$ (for series components)	
μ_{tot}	Relative total permeability derived from the static magnetization curve	
ρ	Resistivity	Ωm^{-1}
$\Sigma l/A$	Magnetic form factor	mm^{-1}
τ_{Cu}	DC time constant $\tau_{Cu} = L/R_{Cu} = A_L/A_R$	s
ω	Angular frequency; $\omega = 2\,\Pi f$	s^{-1}

All dimensions are given in mm.

SMD Surface-mount device

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