

Introduction

As power supply output current requirements continue to increase, it is important for the design engineer to pay close attention to inductor power losses and their affect on overall power supply **efficiency**.

The demand for an improvement in power supply efficiency, and therefore, inductor efficiency has increased quite rapidly. This demand has come as a result of an increase in power supply output current. At the same time, there has been a renewed effort to reduce the amount of heat that power supplies have to dissipate, which has a direct effect on overall power supply efficiency. The reduction in heat creation is especially important to laptop users.

Since heat creation and inductor power loss are directly related, it is extremely important to reduce inductor power losses. To reduce these losses, it is necessary to understand where they come from.

There are several main inherent losses associated with inductors, they are:

- Copper Wire DC Loss
- Copper Wire AC Loss (Skin Effect, Proximity Effect)
- Core Hysteresis Loss
- Core Eddy Current Loss

Each of these losses and the primary causes of them are listed below, the results of these losses are to lower efficiency and to produce heat, which further increases the losses in the inductor.

Types of “Losses ”	The Major Causes
Copper Wire DC Loss	DC resistance of winding wire.
	Heat energy assumed $Q=I^2 *R*t$
Copper Wire AC Loss	The skin and proximity effects lead to eddy currents in winding conductors, which increase copper loss under high current high frequency magnetic conditions.
Core Hysteresis Loss	Hysteresis loss varies directly with applied frequency, is directly proportional to applied frequency.
	Dependence on maximum flux density:
	How does area of B-H loop depend on maximum flux density?
Core Eddy Current Loss	Especially metallic material, small current loop occur on the surface of metallic materials, according to Lenz’s law, the eddy currents tend to prevent flux from penetrating the core.
	Eddy current power loss varies with square of excitation frequency.

The power loss of an inductor is defined by the basic formula: $P_{loss} = P_{core} + P_{copper}$

Each component of this formula is discussed below.

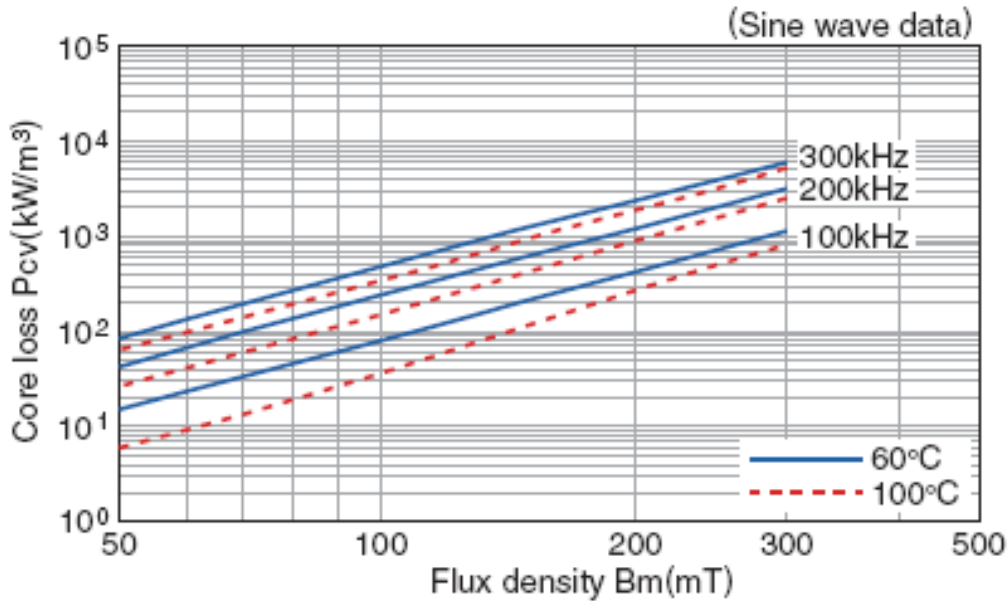
1.Core Loss(P_{core})

Core loss includes Core Hysteresis Loss and Core Eddy Current Loss,that is,

P_{core} = Core Hysteresis Loss+Core Eddy Current Loss,

Core Loss can be calculated by the formula: $P_{core}=P_{cv}*V_e$

- (1) P_{cv} is core loss consumed in unit volume, which can directly be got from the master data curve of core raw material in core supplier’s catalogue, P_{cv} varies with Flux Density and Frequency.(Example:TDK Core PC47).



Before you use the above curve to look up P_{cv} , you must calculate *Flux Density B* first from the Formula as follows:

$$\text{Flux Density: } B = [L \cdot I / A_e] \cdot N_p$$

Where:

B: Maximum magnetic flux density in hysteresis loop B(T)

L :Inductance(μ H)

I : Current(A),rated current is often used.

A_e :Effective cross-sectional area(mm²),can be got from core specification or core catalogue.

N_p :Winding turns

(2) V_e is effective volume which can be got form the core specification(based on No Gap core).

$$V_e = A_e \cdot L_e$$

Where:

A_e : effective cross-sectional area, L_e : effective magnetic length.

In International Standard IEC60205 "Calculation of effective parameters of magnetic piece part", Uniform rules for the calculation of effective parameters of ferromagnetic material is provided for some core types(No drum core,drum core+ring core are included).

An example is given to describe how to calculate P_{core} for Magcoils Part Number : 30S1045S-0R8M:

· $L_s = 0.8 \mu$ H, $I = 15.5$ A (supposed) , $N_p = 3$

· A_e of Core PC44 (supplier:TDK): =14.3mm² **from TDK's catalogue.**

The Flux Density B can be calculated from the following formula:

$$\begin{aligned} B &= [L \cdot I / A_e] \cdot N_p \\ &= [0.8 \cdot 15.5 / 14.3] \cdot 3 \\ &= 0.261 \text{T} = 261 \text{mT} \end{aligned}$$

From TDK PC47 Flux Density B(mT) curve, P_{cv} is about 850 kW/m³ at B=261mT and F=100kHz,

From Core material specification: $V_e = L_e \cdot A_e = 14.3 \cdot 12.63 = 180.6 \text{ mm}^3$

$$P_{core} = P_{cv} \times V_e = 850 \text{ kW/m}^3 \times 180.6 \text{ mm}^3 = 153.5 \text{ mW}$$

Core Losses of 30S1045S-0R8M can be calculated at different frequencies shown below:

f	P _{cv}	A _e	L _e	V _e	Core Loss
(kHz)	(Kw/m ³)	(mm ²)	(mm)	(mm ³)	(mW)
100	850	14.3	12.63	180.6	153.5
200	1900	14.3	12.63	180.6	343.1
300	3100	14.3	12.63	180.6	559.8

There is another way to calculate the core loss. Measuring core loss and getting repeatable results can be a tedious

task depending on the test frequency. A general form of the core loss formula for ferrite cores is:

$$P_{core} \text{ (mW)} = K_1 f^x B^y \times V_e$$

Where:

K_1 = Constant for core material

f = Frequency in kHz

B = Peak Flux Density in kGauss

x = Frequency exponent

y = Flux Density exponent

V_e = Effective core volume (cm³)

The core loss can be calculated by entering the K_1 coefficient and the frequency and flux density exponents, which are unique to each core material.

2. Copper Loss (P_{copper})

Copper loss includes Copper Wire **DC** loss and Copper Wire **AC** loss, that is, $P_{copper} = P_{dcr} + P_{acr}$

(1) P_{dcr}

The wire loss caused by dc resistance is easy to calculate. It is defined by this basic formula:

$$P_{dcr} \text{ (W)} = I_{rms}^2 \times DCR$$

Where:

I_{rms} = The rms value of the peak current applied to the inductor

DCR = The dc resistance of the inductor

(2) P_{acr}

The wire loss caused by ac resistance is more difficult to calculate since ac winding resistance values are not always readily available from magnetics vendors. P_{acr} is defined by the following formula:

$$P_{acr} \text{ (W)} = I_{rms}^2 \times ACR$$

Where:

I_{rms} = The rms value of the peak-peak ripple current applied to the inductor

ACR = The ac resistance of the inductor

The inductor power loss information can be often be provided by inductor suppliers for most of their products.

Conclusion

The following points are abstracted from IEC standard 60205 “**Calculation of the effective parameters of magnetic piece parts**”

- All calculation of the effective parameters of magnetic piece parts are using uniform rules.
- Calculations are only applicable to the component parts of a closed magnetic circuit.
- All irregularities in the outline of the core, such as small cut-outs, notches, chamfers, etc. shall be ignored unless specifically referred to in the other sections
- 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 jointing the centers 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.
- When the winding is uniformly distributed over a toroidal core, it may be expected that, at all points inside the toroidal core, the flux lines will be parallel to its surface
- No leakage flux will therefore leave or enter the toroidal core. This justifies the use of a theoretically more correct derivation of the effective parameters which do not make use of the assumption that the flux is uniformly distributed over the cross-section.

From the above points, we can see that all the parameters are roughly calculated based on an ideal model. In fact, the core types DRUM, DRUM+RING, EP types which are mainly used in inductors are very different from what are stated in IEC60205. At least they are not of a closed magnetic circuit.

As a conclusion, We think

- ① All the core losses can only be much roughly calculated.
- ② All the core loss calculation is only of reference meaning, not of absolute meaning.
- ③ For core types DRUM, DRUM+RING, No international standard of core loss calculation are available.