

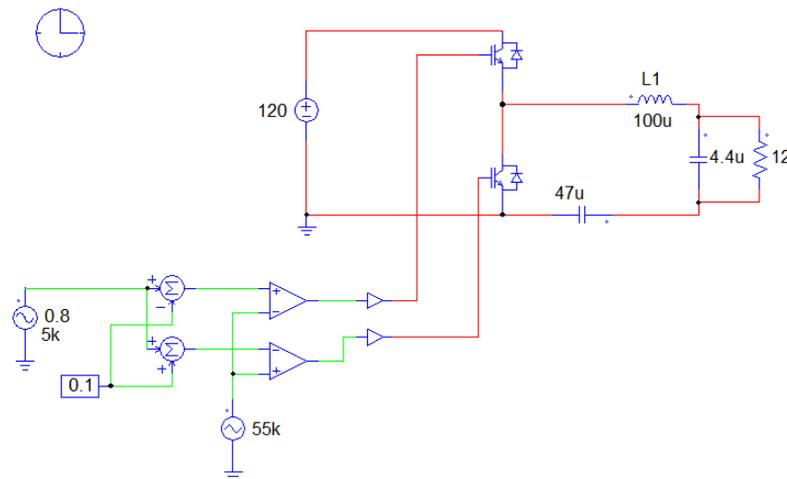
TUTORIAL

Inductor Loss Calculation in Thermal Module

October 2018

The Thermal Module provides the capability to calculate the winding losses, core losses, and temperature rise of inductors based on standard manufacturer cores and wires. This tutorial describes how an inductor is defined and calculated is performed.

To illustrate the process, the following inverter circuit example is used.



The losses of the inductor L1 will be calculated. The inductor has the following specifications:

Inductance: 100uH

Core:

Manufacturer: Ferroxcube

Core: E42/21/15

Material: 3C90

Winding:

Wire: Round; AWG18; 2 enamel layer insulation

Number of Turns: 25

Air Gap: 1.35mm

In general, the calculation involves the following steps:

- Entering core material information to the database
- Entering core and bobbin information to the database
- Entering wire information to the database
- Creating the inductor in the database
- Defining the inductor in the schematic

Both the core material and core and bobbin information is obtained from the manufacture datasheet. In this example, it will come from Ferroxcube's "Soft Ferrites and Accessories - Data Handbook - 2013" (file "www.ferroxcube.com/FerroxcubeCorporateReception/datasheet/FXC_HB2013.pdf").

Entering Core Material Information:

The core material database requires the following information:

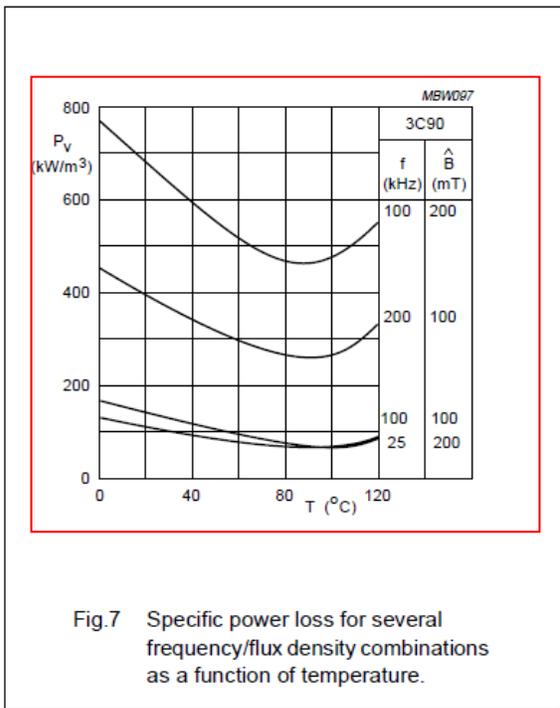
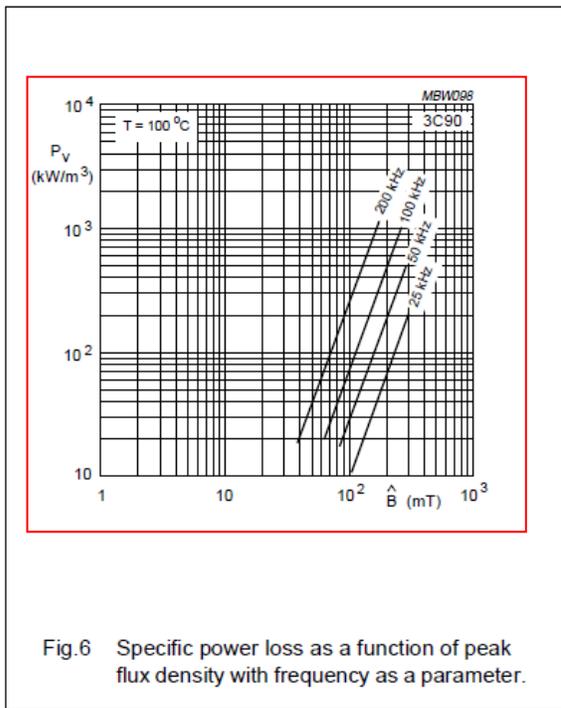
- Manufacturer: Name of the manufacturer (e.g. Ferroxcube)
- Type: Material type (e.g. Ferrite)
- Material: Material name (e.g. 3F3, 3C90)
- μ_r : Relative permeability μ_r of the material
- Ploss vs. Bpk: Graph of power loss Ploss vs. peak flux density Bpk
- Ploss vs. Tc: Graph of power loss Ploss vs. core temperature Tc

The value μ_r can be obtained from Page 84 of the Ferroxcube datasheet, and the graphs Ploss vs. Bpk and Ploss vs. Tc can be obtained from Page 85 of the datasheet, as shown below (highlighted in the red boxes).

3C90 SPECIFICATIONS

A low frequency power material for use in power and general purpose transformers at frequencies up to 0.2 MHz.

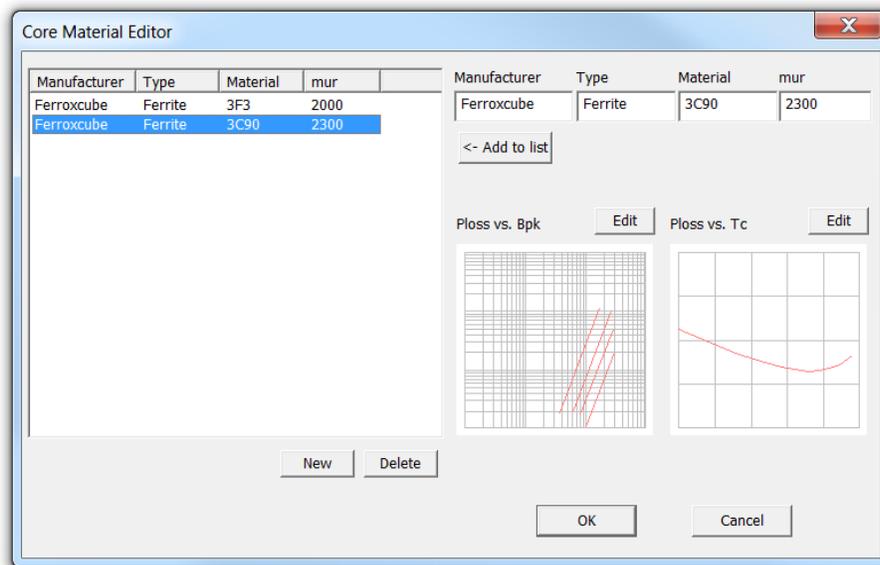
	CONDITIONS	VALUE	UNIT	
μ_r	μ_i	25 °C; ≤ 10 kHz; 0.25 mT	2300 $\pm 20\%$	
	μ_a	100 °C; 25 kHz; 200 mT	5500 $\pm 25\%$	
	B	25 °C; 10 kHz; 1200 A/m	≈ 470	mT
		100 °C; 10 kHz; 1200 A/m	≈ 380	mT
	P_v	100 °C; 25 kHz;	≤ 80	kW/m ³



To start, in PSIM, launch the **Device Database Editor** from the **Utilities** menu. In the Device Database Editor, select **Device >> Edit Core Material Database**. Enter the following:

- Manufacturer: Ferroxcube
- Type: Ferrite
- Material: 3C90
- mur: 2300

Capture all the four curves of Ploss vs. Bpk. For the graph Ploss vs. Tc, capture the middle curve that corresponds to frequency of 200kHz and Bpk of 100mT. The database editor dialog will appear as follows:



This completes the entry of the core material to the database.

Entering Core and Bobbin Information:

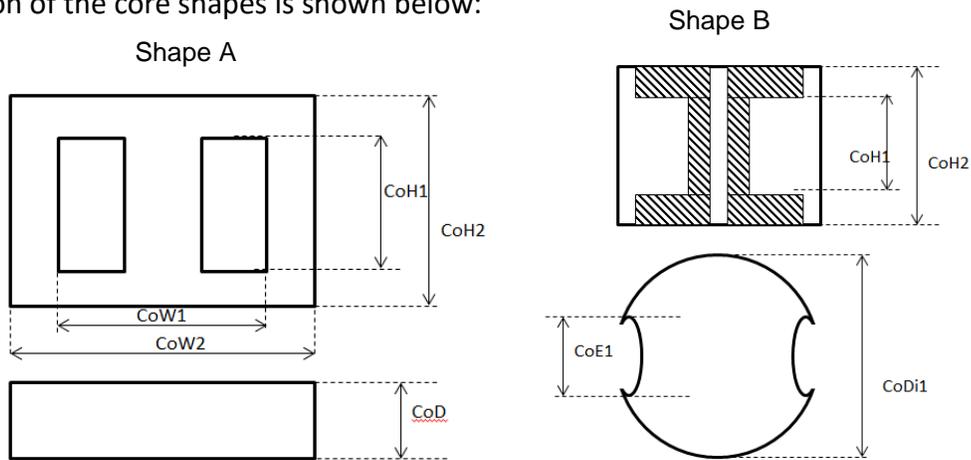
The core and bobbin database requires the following information:

- Manufacturer: Name of the core and bobbin manufacturer (e.g. Ferroxcube)
- Type: Core type (e.g. E, RM)
- Model: Core model (e.g. E42/21/15, RM8)
- Column Type: Shape of the center column. It can be: 0 for round, or 1 for rectangular.
- Shape Type: Shape of the core. It can be: 0 for Shape A, 1 for Shape B; and 2 for Other Shape.
- Material: Supported materials by this core (i.e. 3F3, 3C90, etc.)
- Ae: Effective area, in mm²
- Ve: Effective volume, in mm³
- Le: Effective length, in mm
- N_col: Number of column of the core
- Diameter1: Bobbin diameter of a round core, in mm
- Diameter2: Bobbin diameter of a round core, in mm

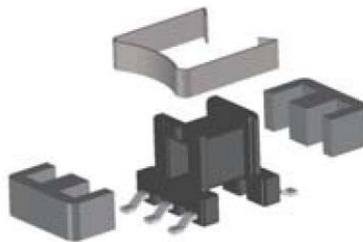
- Diameter3: Bobbin diameter of a round core, in mm
- Height1: Bobbin height H1, in mm
- Height2: Bobbin height H2, in mm
- Width1: Bobbin width of a rectangular core, in mm
- Width2: Bobbin width of a rectangular core, in mm
- Width3: Bobbin width of a rectangular core, in mm
- Depth1: Bobbin depth of a rectangular core, in mm
- Depth2: Bobbin depth of a rectangular core, in mm
- Depth3: Bobbin depth of a rectangular core, in mm
- CoH1: Core Height 1, in mm
- CoH2: Core Height 2, in mm
- CoW1: Core Width 1 of a Shape A core, in mm
- CoW2: Core Width 2 of a Shape A core, in mm
- CoD: Core depth of a Shape A core, in mm
- CoDi1: Core diameter of a Shape B core, in mm
- CoE1: Core space of a Shape B core, in mm
- Clip Vertical: Percentage of the clip area in the vertical direction
- Clip Horizontal: Percentage of the clip area in the horizontal direction

Note that, depending on the type of the cores, not all the parameters are required.

The definition of the core shapes is shown below:



In this example, the core is E42/21/15. The image of the E core is shown below:

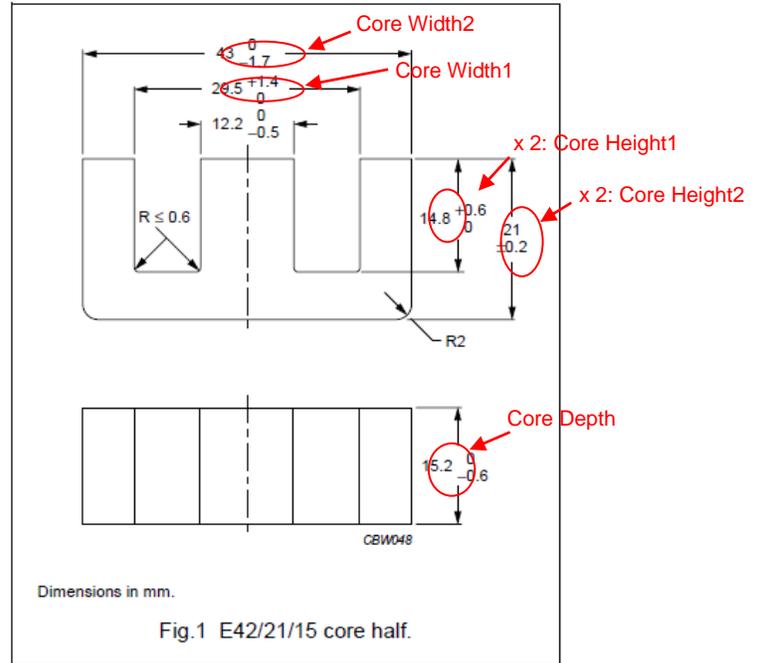


The core information is obtained from Page 270 of the Ferroxcube datasheet. The required parameters are highlighted by the red boxes.

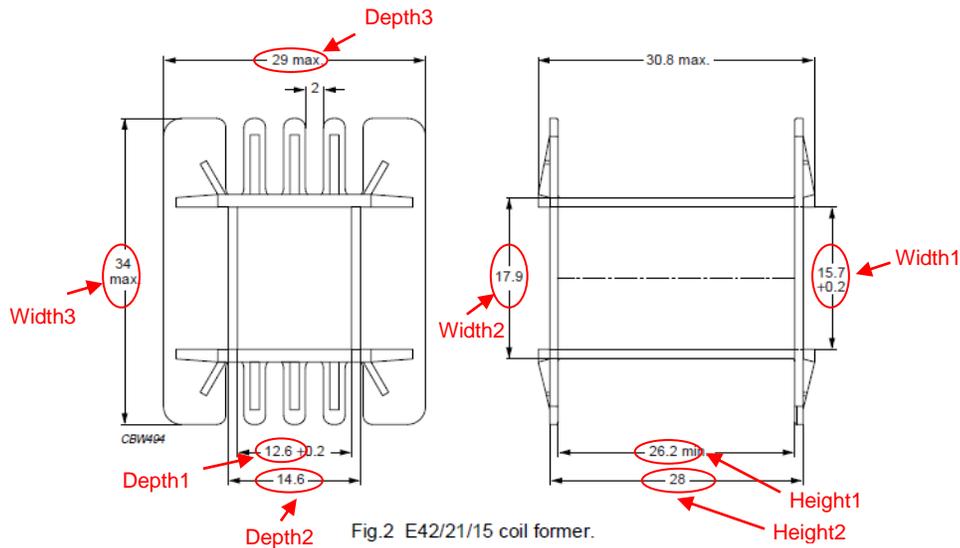
CORE SETS

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.548	mm ⁻¹
V_e	effective volume	17300	mm ³
l_e	effective length	97.0	mm
A_e	effective area	178	mm ²
A_{min}	minimum area	175	mm ²
m	mass of core half	≈ 44	g



The core bobbin information is obtained from Page 272 of the Ferroxcube datasheet. The required parameters are highlighted by the red boxes.



Assume that the core clip covers 50% of the core area in both vertical and horizontal directions.

To launch the core database editor, in the Device Database Editor, select **Device >> Edit Inductor Core Database**. The entry for the EE42/21/15 core and bobbin to the database is as follows:

- Manufacturer: Ferroxcube
- Type: E
- Model: E42/21/15
- Column Type: 1 [1 for rectangular]
- Shape Type: 0 [0 for Shape A]
- Material: 3C81, 3C90, 3C91, 3C92, 3C94, 3C95, 3F3
- Ae: 178
- Ve: 173000
- Le: 97
- N_col: 1
- Height1: 26.2
- Height2: 28
- Width1: 15.7
- Width2: 17.9
- Width3: 34
- Depth1: 12.6
- Depth2: 14.6
- Depth3: 29
- CoH1: 29.6
- CoH2: 42
- CoW1: 29.5
- CoW2: 43
- CoD: 15.2
- Clip Vertical: 0.5
- Clip Horizontal: 0.5

This completes the entry of the core material to the database.

Entering Winding Information:

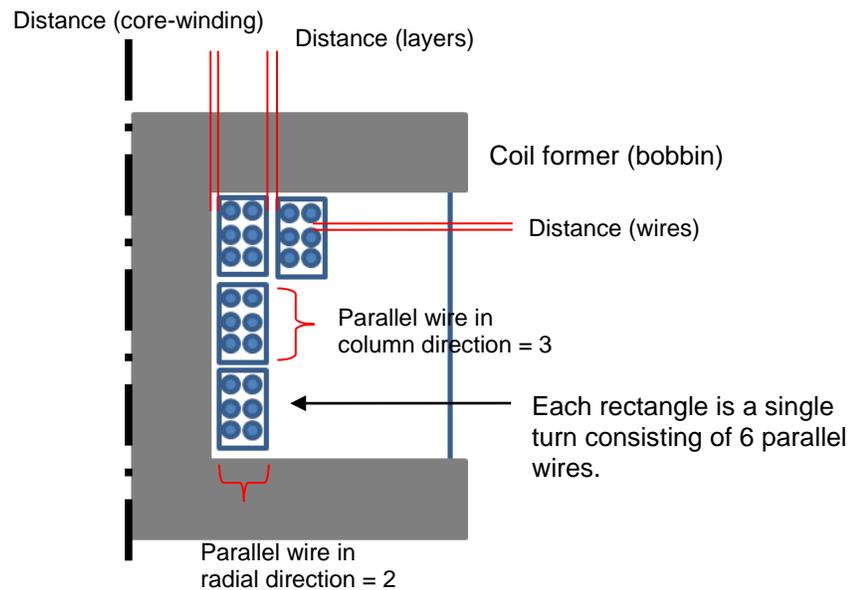
The inductor uses round AWG18 wire. The information of this wire is already in the database in PSIM.

Creating the Inductor in the Database:

With the required material, core, and wire already in the database, the inductor can be created and saved to the database. In the Device Database Editor, select **Device >> New Inductor**, the following dialog will appear.

Under the **Core** tab, the core shape and size as well as the core material are specified.

Under the **Winding** tab, the wire type and size, number of turns, and how the wires are wound are defined. When the current for a single wire is too high, it is common to use winding with parallel wires so that current can be distributed among the wires. The figure below shows the definition of the parameters for a winding consisting of 6 parallel wires.



The parameters are defined as:

Distance (layers):

Distance (core-winding):

Distance between two adjacent layers of windings

Distance between the bobbin and the inner most layer of the winding.

- Distance (wires): Distance between two adjacent wires
- Distribution of Parallel Wires in Radial Direction: Number of parallel wires in a winding in radial direction
- Distribution of Parallel Wires in Column Direction: Number of parallel wires in a winding in column direction

Under the **Gap** tab, the air gap is defined.

In this example, the inductor uses Ferroxcube E42/21/15 core with 3C90 core material. It has 25 turns, and uses a single AWG18 round wire with 2 insulation layers. The distance between wire layers is 0.05mm. Assume that the distance between the bobbin and the inner most wire layer is zero, and the distance between two adjacent wires is also zero. The air gap is on the center leg, with a length of 1.35mm. With this information, the inductor dialog window is shown as below.

The screenshot shows the 'Inductor' dialog window with the 'Gap' tab selected. The 'Core' tab is also visible. The configuration includes:

- Manufacturer:** Ferroxcube, **Part Number:** L_100uH
- Package:** Basic
- Electrical Characteristics:** L (uH) 100, L (estimated) (uH) 100.45
- Maximum Ratings:** I_{rms,max} (A)
- Core Type and Size:** Core Manufacturer: Ferroxcube, Core Shape: EE, Core Size: EE42/21/15
- Core Material:** Material Manufacturer: Ferroxcube, Material Type: Ferrite, Material Name: 3C90
- Graphs:** Ploss vs. Bpk and Ploss vs. Tc

The screenshot shows the 'Inductor' dialog window with the 'Winding' tab selected. The configuration includes:

- Winding Type and Size:** Conductor Type: Round, Conductor Size: AWG18, Isolation Type: 2 layers
- Winding Distribution:** Number of Turns: 25, Distance (layers) (mm): 0.05, Distance (core-winding) (mm): 0, Distance (wires) (mm): 0
- Distribution of Parallel Wires:** In Radial Direction: 1, In Column Direction: 1

The screenshot shows the 'Inductor' dialog window with the 'Gap' tab selected. The configuration includes:

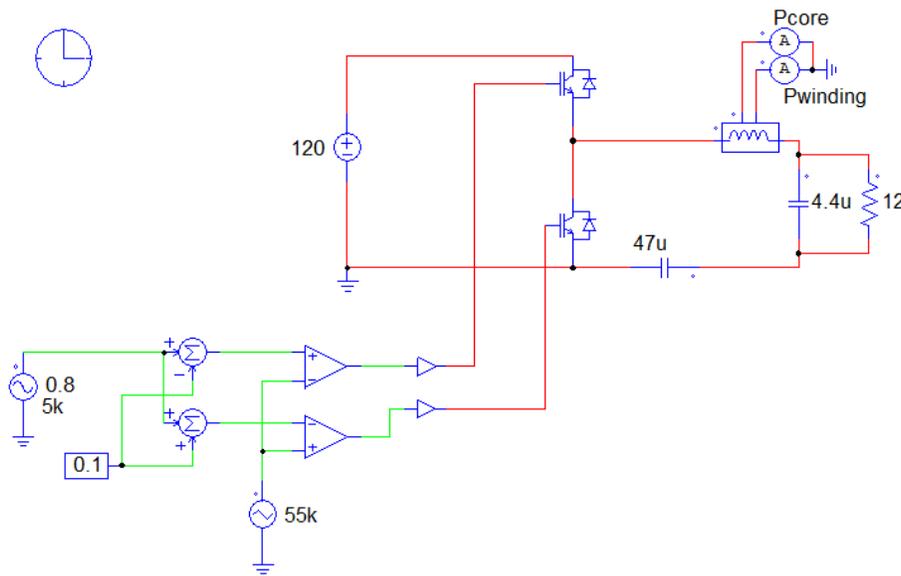
- Gap Data:** Gap Number: 1 (center leg), Gap Length (mm): 1.35

Once all the information is entered, click on the **Save** icon, or choose **Device >> Save Device** to save the inductor into the database. This inductor is ready to use in the simulation.

The value “L (estimated) (uH)” is the calculated inductance based on the entered values. This should be close to the desired inductance “L (uH)”. If there is a big difference, please double check if entered core/winding/gap values are correct.

Defining the Inductor in the Schematic:

To use this inductor in a circuit schematic, in PSIM, select **Elements >> Power >> Thermal Module >> Inductor (database)**. Connect the inductor in the schematic as shown below.



The inductor has two additional nodes for the inductor losses. The node with a dot is for the core loss, and the other node is for winding loss. The losses will flow out of these nodes in the form of a current, and an ammeter will give the reading of the losses.

In the inductor dialog, next to the **Device** parameter field, click on the ... button, and select L_100uH. The inductor dialog has the following parameters:

Frequency:	Fundamental frequency of the inductor, in Hz
Temperature Flag:	It can be either <i>Calculated</i> or <i>Fixed</i> . When it is <i>Calculated</i> , core temperature will be calculated. When it is <i>Fixed</i> , this temperature will be used to calculate the core losses.
Ambient Temperature:	Ambient temperature, in °C.
Convection:	Cooling method. It can be either <i>Natural</i> or <i>Forced</i> .
Air Speed:	If the cooling method is forced, set the air speed in m/sec.
Estimated Core Temp.:	If the Temperature Flag is fixed, set the estimated core temperature in °C.
Estimated Winding Temp.:	If the Temperature Flag is fixed, set the estimated winding temperature in °C.

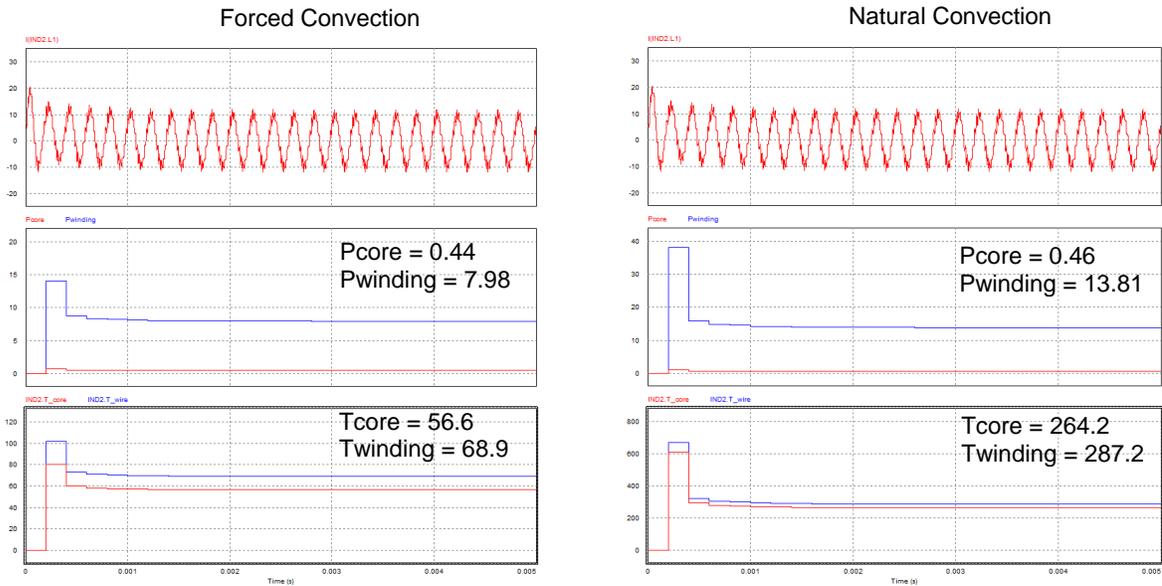
- Loss Calculation Flag: It can be set to either 0 or 1. When set to 0, the loss calculation will be performed from the very beginning of the simulation. When set to 1, the loss calculation will be performed for the last fundamental period only, and this will speed up the simulation.
- Current Flag: The current display flag of the inductor.

In this example, the inductor has the main ac component of 5kHz and switching harmonics at multiples of 55kHz. The fundamental frequency should be set to 5kHz. If the inductor were used in a dc circuit with dc component and switching harmonics only, the frequency would be equal to the switching frequency.

The core temperature will be calculated, with the ambient temperature of 25 °C. Two cases will be studied, with forced convection of 5 m/sec. air speed, and with natural convection. The inductor dialog with forced convection is shown below.

Parameter	Value	Display
Name	IND2	<input type="checkbox"/>
Device	Ferroxcube L_100uH	<input type="checkbox"/>
Frequency	5000	<input type="checkbox"/>
Temperature	Calculated	<input type="checkbox"/>
Ambient Temperature	25.0	<input type="checkbox"/>
Convection	Forced	<input type="checkbox"/>
Air Speed	5	<input type="checkbox"/>
Estimated Core Temp.		<input type="checkbox"/>
Estimated Winding Temp.		<input type="checkbox"/>
Loss Calculation Flag	0	<input type="checkbox"/>
Current Flag	1	<input type="checkbox"/>

Simulation results of these two cases are given below, with the forced convection results on the left, and the natural convection results on the right.



The results show that, with the forced convection, the losses are lower and the core and winding temperatures are within the acceptable range. But with the natural convection, the winding loss increases greatly, resulting unacceptable core and winding temperatures.