GeckoMAGNETICS Getting Started – Inductor Model Tutorial

GeckoMAGNETICS – Modeling Inductive Components

GeckoMAGNETICS is a tool that enables fast, accurate and user-friendly modelling and pareto-optimal design of inductive power components.

The key modelling features of Gecko-MAGNETICS are:

1) An easy-to-use user interface that guides the user through the design process. Based on the user-specified desired inductance, application, and cooling conditions GeckoMAGNETICS finds an optimum design with respect to losses or volume.

2) Sophisticated and accurate models for loss, thermal and inductance calculation, including:

- A very accurate inductance calculation based on a novel air gap reluctance calculation approach.
- Different winding loss effects, such as Skin effect, Proximity effects (including the influence of an air-gap fringing field).
- Many core loss effects such as e.g. a DC premagnetization, re laxation effects, etc. Neglecting for instance a DC premagneti zation, may lead to a loss underestimation by a factor of more than two.

3) A link to the circuit simulator GeckoCIRCUITS, enabling multi-domain modelling and extraction of waveforms from circuit simulations.

4) A material and core database (GeckoDB), which is a part of the GeckoMAGNETICS tool, for accurate core loss modelling.

This tutorial shows how an inductor can be modeled and how core materials and cores can be added to the above mentioned database GeckoDB. This is shown on the example of the core C055104A2 from Magnetics (www.mag-inc.com).

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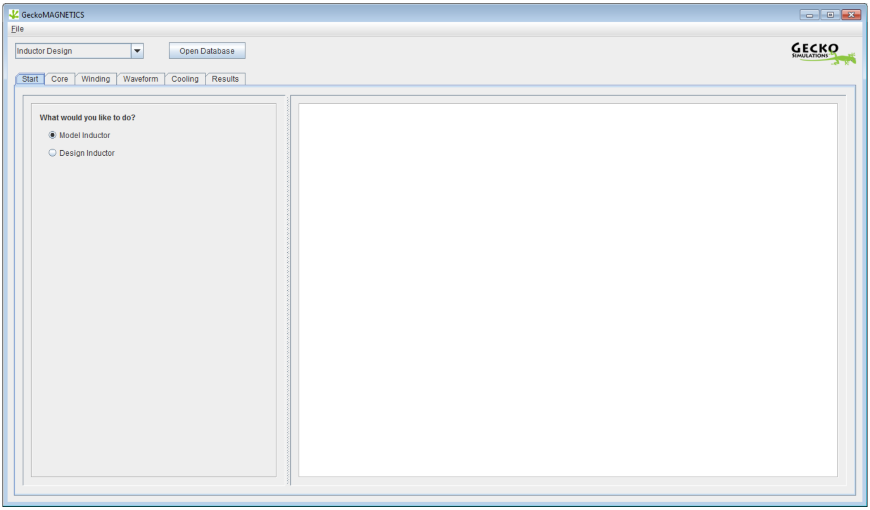
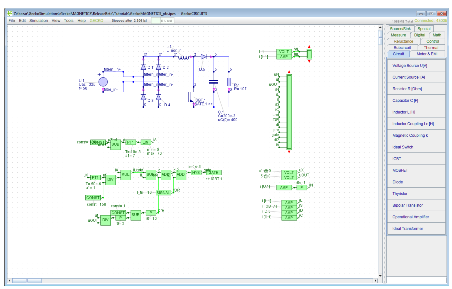


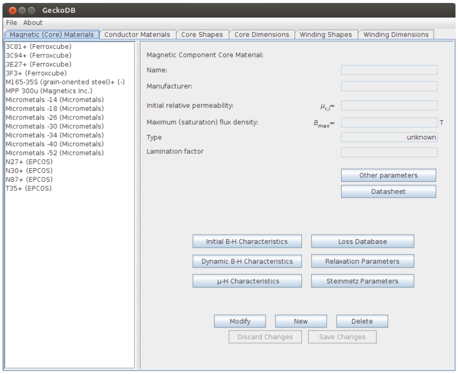
After GeckoMAGNETICS is started, the tab "Start" is active.

The user can either model the losses and temperature of a single pre-defined inductor or the tool can help in finding an optimum inductor for a particular design problem. In this tutorial, we would like to model the temperature and the losses of a pre-defined inductor with help of GeckoMAGNETICS; **accordingly, "Model Inductor" has to be selected.**

The considered example is a single-phase boost-type PFC rectifier with nominal power 750 W, mains frequency 50 Hz, DC voltage 400 V, and mains voltage 230 V (cf. figure on the right). The boost inductor is made of solid round wire ($N = 62$, diameter 2.4 mm) and the core is C055104A2 from *Magnetics*. It has an inductance of 1.5 mH.

The material as well as the particular toroid is not yet available in the database. Accordingly, we have to add it into the DB first. Therefore, we press the button "**Open Database**".





The database opens as illustrated in the figure above. The user has the possibility to add, remove, or change core materials, conductor materials, cores, and windings. In the example at hand, we would like to add the material MPP 300µ from Magnetics into our database.

We go to the tab “Magnetic (Core) Materials” and press the button “**New**”. Now we can enter the basic parameters as:

Name: “**MPP 300u**”,
Manufacturer: “**Magnetics Inc.**”,
Initial relative permeability: “**300**”,
Maximum (saturation) flux density: **0.8 T**,
Type: “**Iron Powder**”.
Lamination factor: “**1.0**”

Please note: if you use the trial version of GeckoMAGNETICS, it is important that the material name is exactly as written above.

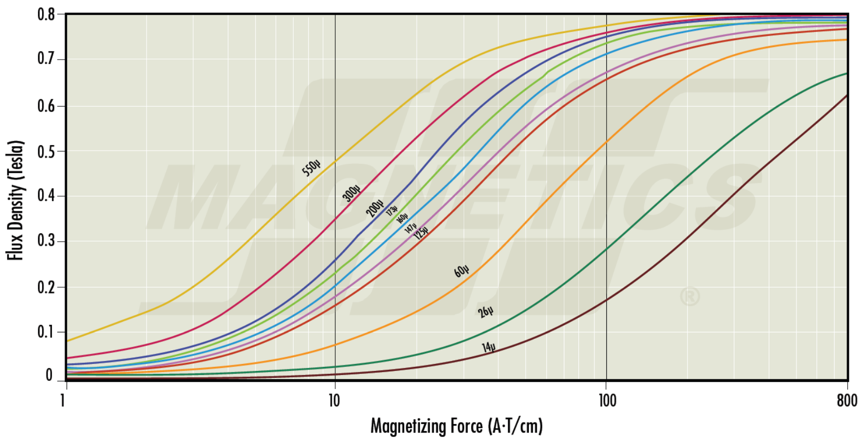
With “**Save Changes**” the parameters are confirmed. The physical meaning of most of the parameters used above is easy to understand. The maximum (saturation) flux density was extracted from the “Normal Magnetization Curves MPP” within the data sheet, as can be seen in the figure on the next page.

A material has two important non-ideal properties: its non-linear behavior (i.e. the non-linear *B-H* curve) and the core losses that occur in the material. Both of these characteristics have to be specified for an accurate loss model.

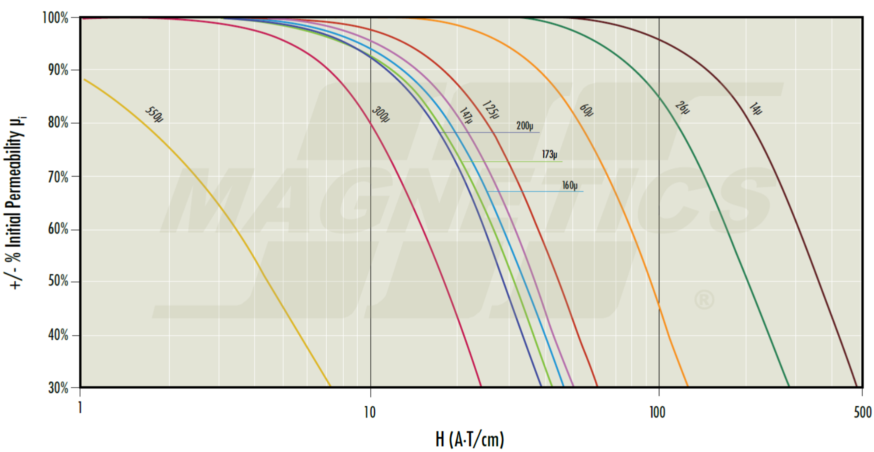
There are three ways of how to define the *B-H* curve in GeckoDB: we can specify an initial *B-H* curve, a dynamic *B-H* curve, and a *µ-H* characteristic. Under “Dynamic *B-H* curve” we understand a measured *B-H loop* that is extracted based on an *alternating* core excitation. The “Initial *B-H* curve” is the statically measured curve when the material is magnetized for the first time. In data sheets often the initial curve is given; it is recommended to use this curve. If the initial curve is specified, a dynamic curve is not necessary (and vice-versa). If both are specified, GeckoMAGNETICS will use the initial curve.

Based on the *B-H* curve, GeckoMAGNETICS can extract the *µ-H* characteristic (i.e. the relative *µ* at a certain DC magnetic field strength *H*). However, this approach has some inherent inaccuracy. Therefore, often, the material manufacturer specifies the *µ-H*

Initial *B*-*H* characteristics (© Magnetics)



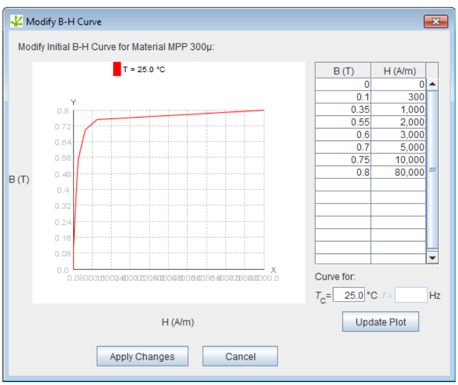
μ-*H* characteristics (© Magnetics)



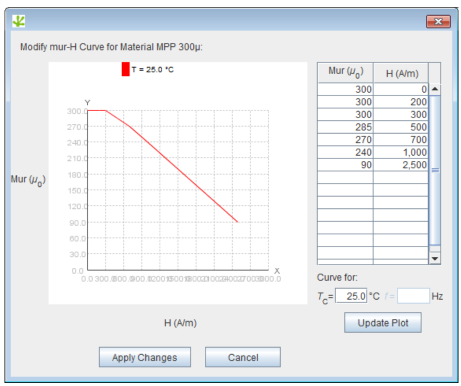
characteristic in a separate plot. It is recommended to add this plot, if available, into GeckoDB. GeckoDB allows the definition of different characteristics for different temperatures, which increases the model accuracy. However, often this information is not provided. In this case, it is sufficient to use the available curves (mostly measured at room temperature).

On the previous page, both required data sheet curves are shown. These curves can now be added to the database. The "Initial B-H Characteristics" and "Initial μ-H Characteristics" windows have to be opened by pressing the according buttons. The resulting screenshot of GeckoDB are given below.

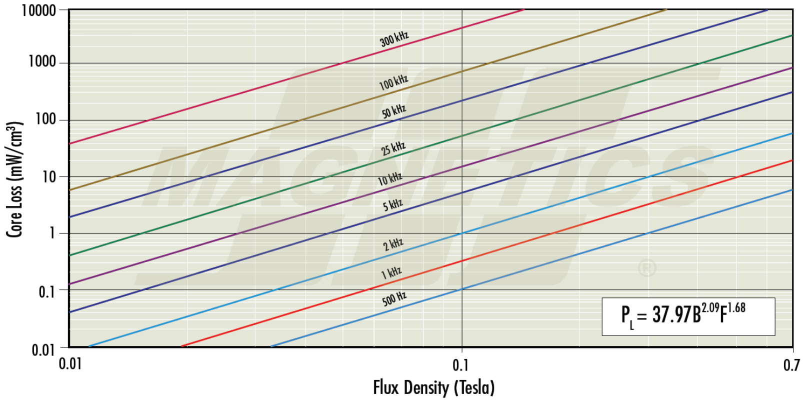
Initial *B*-*H* curve



μ_r-*H* curve



Core Loss characteristics (© Magnetics)



Above, the core loss characteristics of the material MPP 300μ are given. One can specify the core losses via a Loss Database or via Steinmetz parameters (cf. according buttons in GeckoDB).

The most accurate way is to set up a core loss database. The loss database stores losses per unit volume of a particular material at different operating points defined by the flux density ΔB, frequency f, temperature T, and DC bias H_{DC} at which the measurement is made. From these measurements, GeckoMAGNETICS interpolates the losses for an operating point being simulated by the user. The best results are achieved when the core loss database for a particular material is *complete*. A complete database is one which contains a measurement at each possible combination of ΔB, f, T, and H_{DC} stored in the database. For example, if losses of a particular material were measured at flux densities ΔB_1, ΔB_2, frequencies f_1, f_2, temperatures T_1, T_2, and DC pre-magnetizations H_{DC1}, H_{DC2}, a complete database would contain a measurement at each combination of these values, 16 in total: $(\Delta B_1, f_1, T_1, H_{DC1})$, $(\Delta B_1, f_1, T_1, H_{DC2})$, $(\Delta B_1, f_1, T_2, H_{DC1})$, $(\Delta B_1, f_1, T_2, H_{DC2})$, $(\Delta B_2, f_1, T_1, H_{DC1})$, $(\Delta B_2, f_1, T_1, H_{DC2})$, etc.

If a complete set of measurements is not available, the next best option is a *partially complete* database: one which would contain all combinations of measured ΔB and f, but not necessarily all combinations of measured T and H_{DC}. In the above example, a partially complete database would need at least 4 points, covering all $(\Delta B_i, f_i)$ pairs, for example $(\Delta B_1, f_1, T_2, H_{DC1})$, $(\Delta B_2, f_1, T_1, H_{DC1})$, $(\Delta B_1, f_2, T_2, H_{DC2})$, and $(\Delta B_2, f_2, T_2, H_{DC2})$.

Generally, a partially complete database will most likely yield less accurate accounting of the effect of temperature and DC bias on core losses than a complete database containing the same (ΔB_i, f_i) pairs. A database satisfying neither completeness condition is *incomplete*, and is likely to yield much less accurate results when used for core loss calculations.

For all core materials that are marked with a cross (+), a core loss database has been set up by Gecko-Simulations.

In the case at hand, the Steinmetz formula (including the necessary parameters) in order to calculate core losses is given (cf. the legend of the plot above). The user can directly set these Steinmetz parameters into the tool. The parameters are defined as $P_L = k\, f^{\alpha}\, B_{peak}^{\beta}$, where the units Tesla T, Hertz Hz, and W/m^3 are used.

Here, we set the Steinmetz parameters as:

$\boldsymbol{k} = 0.0091 \cdot 37.97 = 0.35$
$\boldsymbol{\alpha} = 1.68$
$\boldsymbol{\beta} = 2.09$

The factor '0.0091 = 1000 · 1/(1e3)$^{1.68}$' is required for a proper unit translation: kHz -> Hz and mW/cm^3 -> W/m^3.

If a core loss database is available, this has always priority compared to the Steinmetz parameters. In other words, if the Steinmetz parameters are set, they are used for the core loss calculation only if the core loss database is empty.

Furthermore, there is a button "Relaxation Parameters". In most cases relaxation parameters can be neglected and the relaxation parameter is not within the scope of this tutorial. For more information on relaxation effects, the reader is referred to the publication

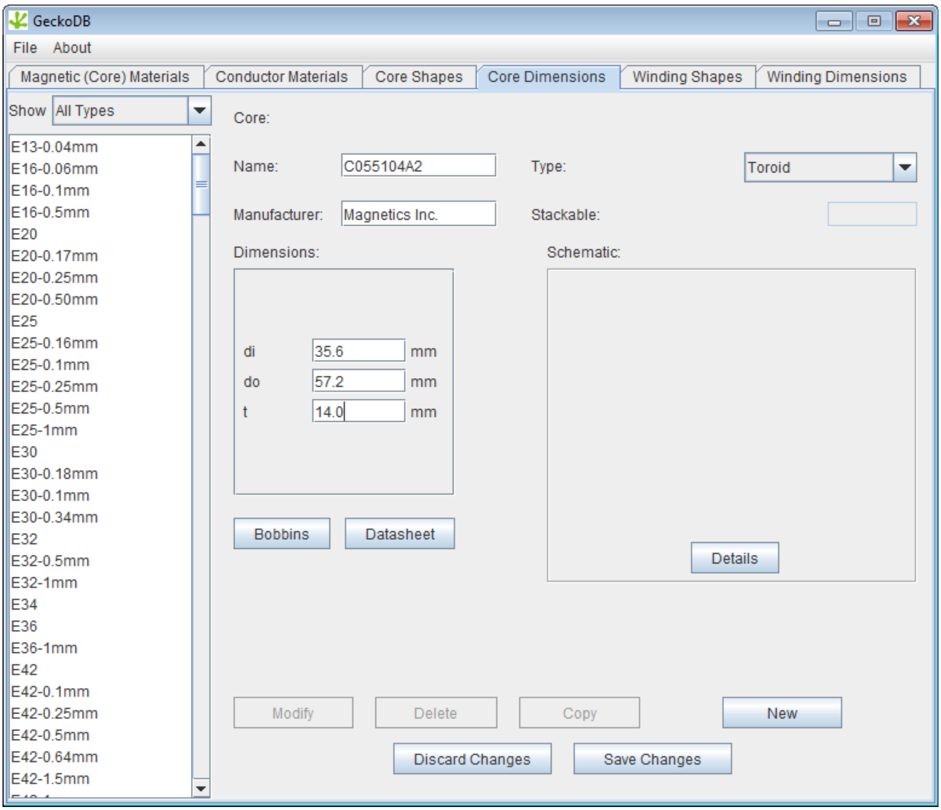
J. Mühlethaler, J. Biela, J. W. Kolar, A. Ecklebe, Improved Core-Loss Calculation for Magnetic Components Employed in Power Electronic Systems, IEEE Transactions on Power Electronics, Vol. 27, No. 2, February 2012.

Now, the core material is fully specified and can be used for designing and modeling of inductors.

Besides the material, the geometric dimensions of the core are not yet defined in database. Accordingly we add a new core under the tab "Core Dimensions".

We press the button "**New**", define the core as illustrated in the print screen below, and press "**Save Changes**".

In GeckoMAGNETICS, toroid cores are modeled without bobbins; hence the core characterization is finished.

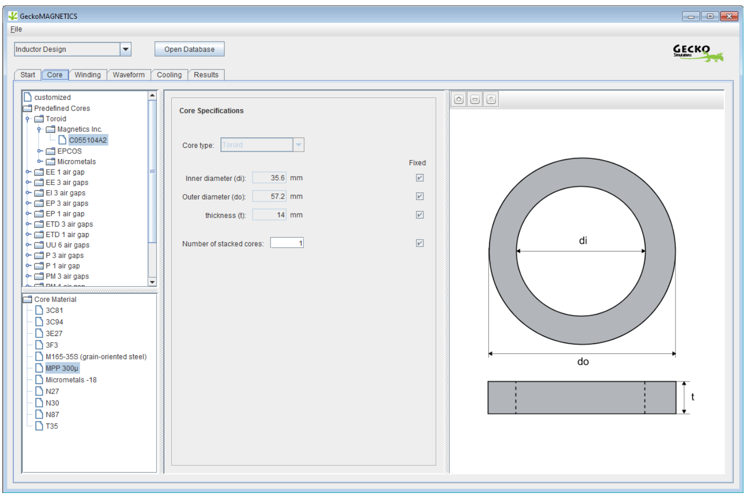


After closing GeckoDB, the new core and material are visible in the tab "Core". Now, the inductor can be modeled in GeckoMAGNETICS.

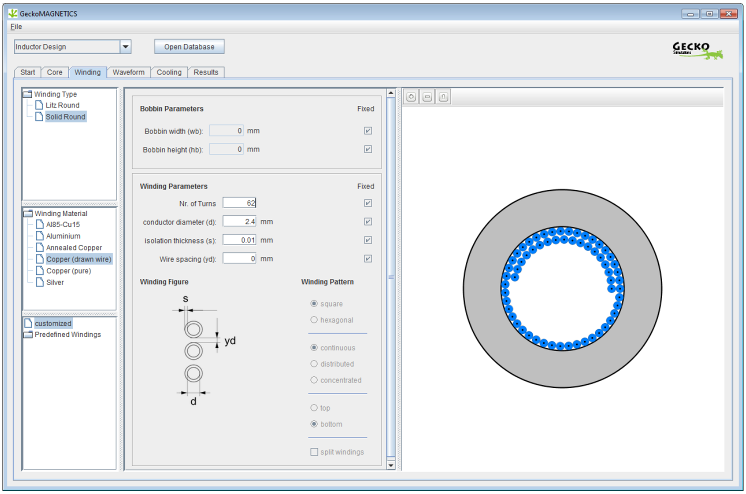
We set the inductor parameters in the tabs "**Core**" and "**Winding**", as given below:

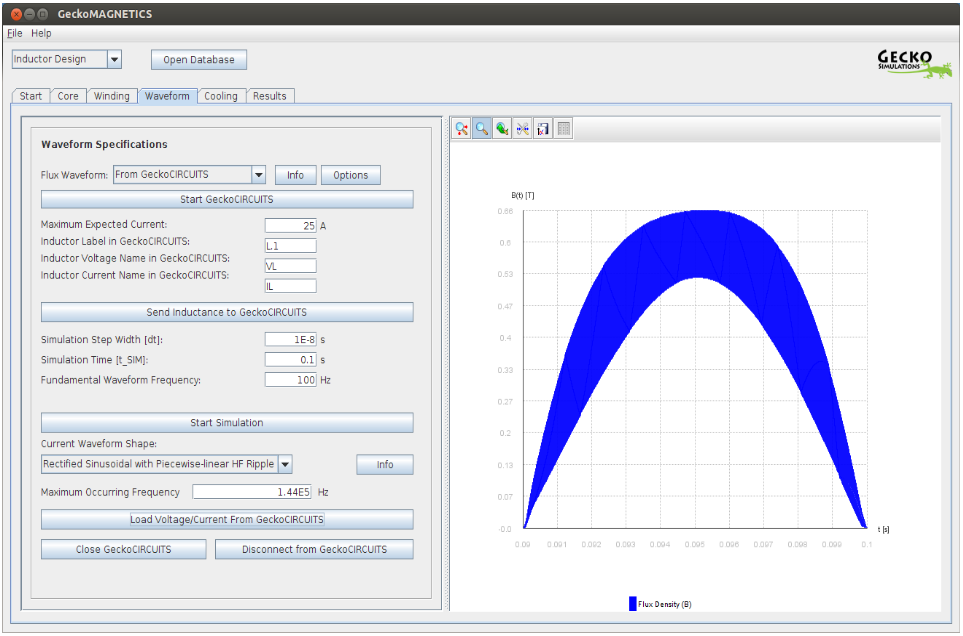
Core: "**C055104A2**",
Core Material: "**MPP 300u**",
Nr. of Turns: "**62**",
Conductor Diameter: "**2.4 mm**",

Core Tab Parameters:



Winding Tab Parameters:



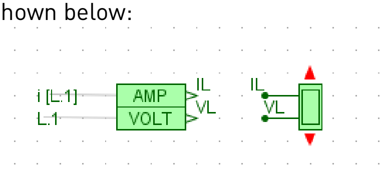


The user can select from different standard waveforms, such as sinusoidal, triangular, or trapezoidal flux waveforms. However, the highest accuracy is achieved when setting up a link between GeckoMAGNETICS and GeckoCIRCUITS (or any other circuit simulator).

GeckoCIRCUITS is a powerful circuit simulator that allows a power electronic system to be described on a system level. GeckoCIRCUITS is distributed as an open-source project (for more information, please visit www.gecko-simulations.com). In the tab "**Waveform**", we select "**From GeckoCIRCUITS**" and then press the button "**Start GeckoCIRCUITS**".

After GeckoCIRCUITS is started, we open the model "**GeckoMAGNETICS_pfc.ipes**".

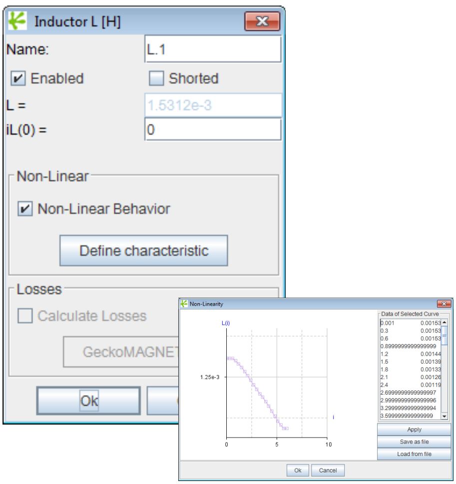
In the tab "Waveform", the inductor as well as its current and voltage label has to be specified. For it, it is very important to have the labels specified properly in GeckoCIRCUITS (including the scope), as it is shown below:



Note: to select more than one inductor in GeckoCIRCUITS, enter e.g. "L.1;L.2;L.3".

The maximum expected current is an important value in case a non-linear inductance characteristic is transferred to GeckoCIRCUITS, where in GeckoCIRCUITS the non-linear inductance is then characterized up to this current. We select **6 A** as the maximum expected current**.**

After the button "**Send Inductance to GeckoCIRCUITS**" has been pressed, the non-linear inductance characteristic is visible in GeckoCIRCUITS. It can be found in the inductor property window under "**Define characteristic**":



Now, some parameters that are related to the GeckoCIRCUITS settings have to be defined. The tool assumes steady state in the analyzed operating point (which means the average voltage during the analyzed fundamental period should be approximately zero). Steady state is reached after approximately 0.1 s; hence, we set the **simulation time to 0.1 s**. A waveform frequency of **100 Hz** should be selected (since twice the mains frequency is the fundamental flux frequency). The simulation time step of **1e-8 s** is a good choice for this example. If this value is too low, GeckoMAGNETICS becomes very slow, if the value is too big, GeckoCIRCUITS might not be accurate enough.

The maximum occurring frequency defines up to which frequency the tool is taking current harmonics into account for the winding loss calculation. The maximum occurring frequency in the example at hand is set to **144E3 Hz**.

The current waveform in the example at hand is "**Rectified Sinusoidal with HF Ripple**" and should be selected accordingly. After the button "Start Simulation" is pressed, GeckoCIRCUITS simulates the active circuit model. The waveforms can be loaded with "**Load Voltage/Current From GeckoCIRCUITS**".

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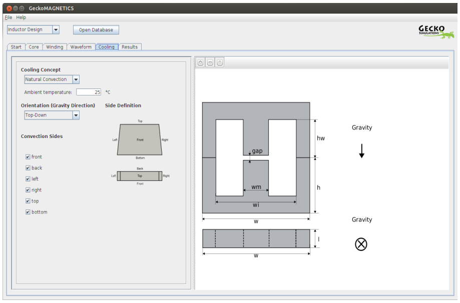

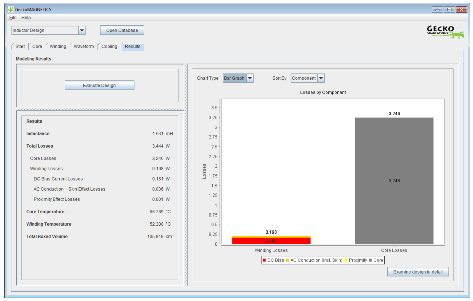

Another important aspect in the design phase of inductive components is the expected temperature of the component. This is not only important to avoid overheating; it also influences the loss modeling accuracy, since the losses are influenced by the temperature. Hence, a thermal model is indispensable for an accurate loss model.

In the tab "**Cooling**" the thermal boundary conditions can be defined. The user can select between natural convection, forced convection, and a user specified fixed temperature. How the component is positioned in the space (i.e. the gravity direction) as well as the air stream direction can be specified too. Furthermore, a fixed R_{th} can be defined for each side.

Here, we select "**Natural Convection**" with inductor orientation "**Top-Down**".

Now, all the required information for a proper inductor modeling is defined and the losses can be calculated.

After pressing the button "**Evaluate Design**", the simulated losses and the loss distribution due to different physical effects is shown within the tab "**Results**". Additionally, the simulated core and winding temperatures are displayed.

GeckoMAGNETICS – Modeling Inductive Components

In this tutorial, a step-by-step introduction to the tool GeckoMAGNETICS was given. It has been shown how a given inductor can easily be modeled.

A particular focus was put on how to add materials and cores to the database GeckoDB. Also, we showed the possible coupling between GeckoMAGNETICS and the circuit simulator GeckoCIRCUITS.

This tutorial example gives a good starting point to the reader to GeckoMAGNETICS. Generally, the tool is designed to be as self-explanatory as possible. However, if questions arise, or you would like to have a feature which is not available at the moment, please do not hesitate to contact us. Please also consider visiting our bug reporting platform

www.bugs.gecko-simulations.org

Contact Information / Feedback

Dr. Jonas Mühlethaler

Gecko-Simulations AG
Physikstrasse 3
CH-8092 Zürich, Switzerland

Phone +41-44-632 6576
Fax +41-44-632 1212

www.gecko-simulations.com
contact@gecko-simulations.com

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