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Measuring methods of losses in magnetic component

Abakar Mahamat Tahir[1], Rousseau Jean Jacques[3], Amir Mougache[1], Mahamat Barka[1], Ligot Dominique[2], Pascal Bevilacqua[2] and Mahamat Seïd Ali[1]

[1]Faculté des Sciences Exactes et Appliquées de l'Université de Ndjaména, Ndjaména Tchad
[2]Laboratoire Ampère INSA-Lyon 20, avenue Al. Einstein 69621 Villeurbanne Cedex, France
[3]Laboratoire LT2C (ex DIOM 2), rue du Dr Paul Michelon 42023 St Etienne Cedex, France

ABSTRACT

We present the principles of measurement of the losses in the magnetic component retained then the measuring equipment, we specify his constitution, his originality and its principal functions and we justify our approach starting from the objectives of modelling. And finally the result of many tests will be presented, thus making it possible to determine the parameters of our model.

Keywords: Thermal modelling, magnetic component, copper losses, core losses, connecting losses, magnetic core.

INTRODUCTION

Modeling of magnetic components requires knowledge in addition to different temperatures of electromagnetic losses which they are registered. These are losses due to current flow in the windings ("copper losses"), losses due to the temporal variation of the magnetic field in the magnetic cores ("iron losses") and losses due to link ("connection loss "). The detailed assessment of these losses is quite complex in practice because all of them depend on factors such as the frequency, the "amplitude and shape of" electromagnetic wave magnitudes and the nature of materials and geometry.

The magnetic basic material for the realization of numerous magnetic components used in power electronics relies on soft ferrites. These materials allow covering a wide field of application in the conversion of energy. We find magnetic materials in lot of case from the transformers, the inductances and in applications for which the frequencies of use vary from a few kHz to MHz and even in [1] [2] [3].

Losses in materials are mainly of two types:
- Losses by hysteresis which come from material.
- Losses by current of Foucault which occur in variation of flow.

Globally, a phenomenon of slowing down of the variations Bx(H) more or less important can be observed on the dynamic magnetic characteristics according to the importance of the induction current. The currents of Foucault are all the most important than the variations of B(t) are it.

Indeed, they provide unimportant losses which establish an important part of dynamic losses in the applications of the electronics of power.

Of course, we are interested in the losses of iron:

$$P_{fe_r} = P_{hysteresis} + P_{cfoucault} \qquad \textbf{[1]}$$

For the determination of the elements of the model, "to prop up" certain parameters or to validate the model, it is suitable to measure the losses in the magnetic material and in the winding with accurateness. It is also advisable to carry out the measure of the temperature according to the various zones of the components. It includes the temperature of the magnetic material, the temperature of the rolling-ups and the temperature of the connection.

By the way, we chose an indirect measure of the average temperatures obtained from measurement tools In order to avoid any modification of the magnetic component under test. We also pay a particular attention to the measure of the losses in order to minimize the springs of error.

In a first part, we show the selected principles of measure. In a second part, we describe the used equipment. Then, we specify its constitution, its originality and its main functions.

And at the end, we estimate the precision of the measures.

Objectives

The aim of this work is to get practical models that can provide working temperatures of a magnetic component versus both copper and magnetic losses. Mean temperatures of coil and magnetic core have to be computed by the means of simplifying assumptions i.e. within each of these parts, temperature is assumed uniform. For the user it is not very important to know all temperatures at each point of the component, only few given areas are interesting. The counterpart of it is that temperature will have to be determined from core and copper losses with a few degrees error at the most. Figure 1 shows the model and input/output variables.

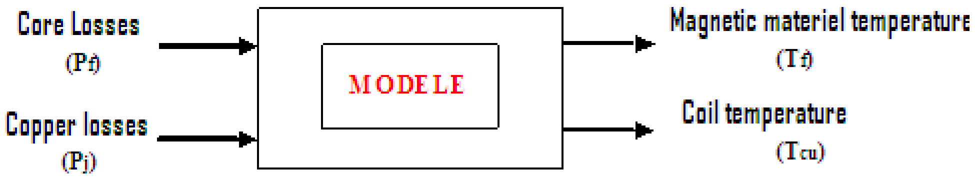


Figure 1: Model Overview

Which method do we have to choose?

In this section, different modelling methods are introduced and discussed. Interests, advantages and drawbacks of each method are defined and a method is choosen. First of all, it is necessary to remind heat transfers.

Heat transfer mode

Temperature quantity is classified as a 'stress' quantity. It means that there exists another variable that can define the 'flow' that occurs when there is a temperature difference between two points: the 'flow variable' that responds to any temperature gradient is called 'heat'. There are three different ways of heat transfer: conduction, convection and radiation.

a- Conduction: This mode is characterized by energy transfer (heat) from warm locations to cold ones without matter displacement. Such a mechanism is governed by Fourier's Law that links temperature gradient to heat flow:

$$P_{conv} = -\lambda . S . \frac{dT}{dx} \qquad [2]$$

Where S is the area through which the heat flow occurs and λ represents the thermal conductivity of the material.

b- Convection: Fluids movements are responsible for another kind of heat transfer, which is called convection and described by Newton's Law:

$$P = h.S.\Delta T \qquad [3]$$

S is the surface through which the phenomenon happens and h is a specific coefficient for convection flow.

c- Radiation: The last way of heat transfer is caused by electromagnetic radiations. The wavelengths mainly correspond to visible and infrared spectra. Stefan-Boltzmann's Law describes heat flux between two elements at temperature T_1 and T_2 respectively:

$$P = \varepsilon_{12}.\sigma.S.(T_1^4 - T_2^4) \qquad [4]$$

Where ε_{12} is the emissivity compared to one of a blackbody, σ the Stephan-Boltzmann constant and S the radiation surface.

Modelling method

Heat transfers can be variously described within a system and working temperatures can be variously estimated. Some methods can lead to detailed temperature mapping whereas others only give temperature at given points of the component. Methods are classified in three categories:

a- Conventional analytic methods: They calculate heat transfers for the system with enough complexity so that the system's description is correct. However, they require precise evaluation of rather fuzzy coefficients such as thermal conductivity, convection coefficient, emissivity...

b- Numerical methods: Finite elements methods which demand heavy memory resources and high calculation times are not compatible with our approach as we see the component in its environment, integrated in a converter. The 'multi-physics' aspect of the study (electrical, magnetic and thermal) increases even more the complexity of the model.

c- Nodal methods (also called Lumped-elements methods): This method is more adapted to our approach which is an experimental one. The component is separated into isothermal parts which are connected together via thermal resistances. Each isothermal part is represented as a 'node' associated to a temperature. At every node are also affected a 'thermal capacity' and a 'heat source' (see figure 2). The union of each thermal balance referring to each node makes the set of differential equations necessary to solve the problem. The thermal resistances may at first approximation be taken constant (for better precision, they can be modelled by analytical relations).

For magnetic components used in power electronics, equivalent circuit is only composed of few resistances and capacities, the values of which can be either calculated or measured (better precision). This last method adapts well to our specifications.

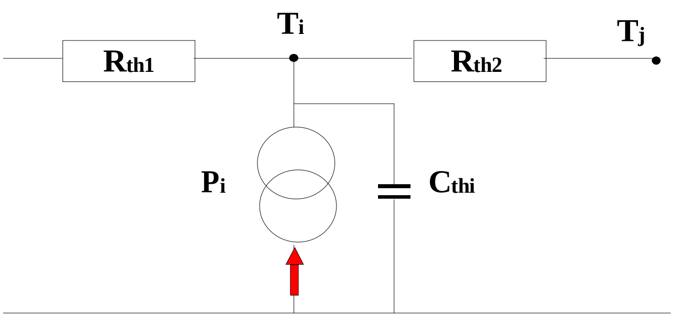


Figure 2: Nodal Method

Thermal model of a magnetic component

In this section, our approach for the design of magnetic component thermal models is described.

The first step consists in defining a simple, realistic and equivalent thermal diagram that comprises the main couplings. That piece of work follows the physical description of the component (materials, geometry, heat sources and localisation...) and some simplifying assumptions.

The second stage corresponds to the determination of thermal elements, resistors and capacitances. Their values can either be calculated or deduced experimentally from continuous mode measurements for resistive elements and from some tests performed in transient mode for capacitive elements.

Finally, the last phase is the model validation. Experiments and simulation are compared both in continuous mode and in transient mode.

As for the demonstrator, we picked a component of elementary shape, anyway realistic, used in power electronics. It is a coil made with a toric magnetic core and a single coil, as it is shown on Figure 3.

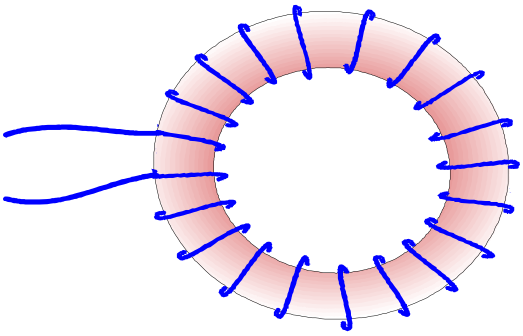


Figure 3: The demonstrator

The ring-core has an effective section area S_e and an effective length L_e and is surrounded by a single coil of N_1 non-joined and equally distributed turns. Coil is made of copper.

Conception of the model

The first simplifying assumption is related to inner and outer surface temperature of the component. According to geometric dimensions, one can assume that both temperatures are equal. That is a realistic approximation that leads to the study of a simple (cylindrical) shaped component, which by the way has a symmetry axis (see Figure 4).

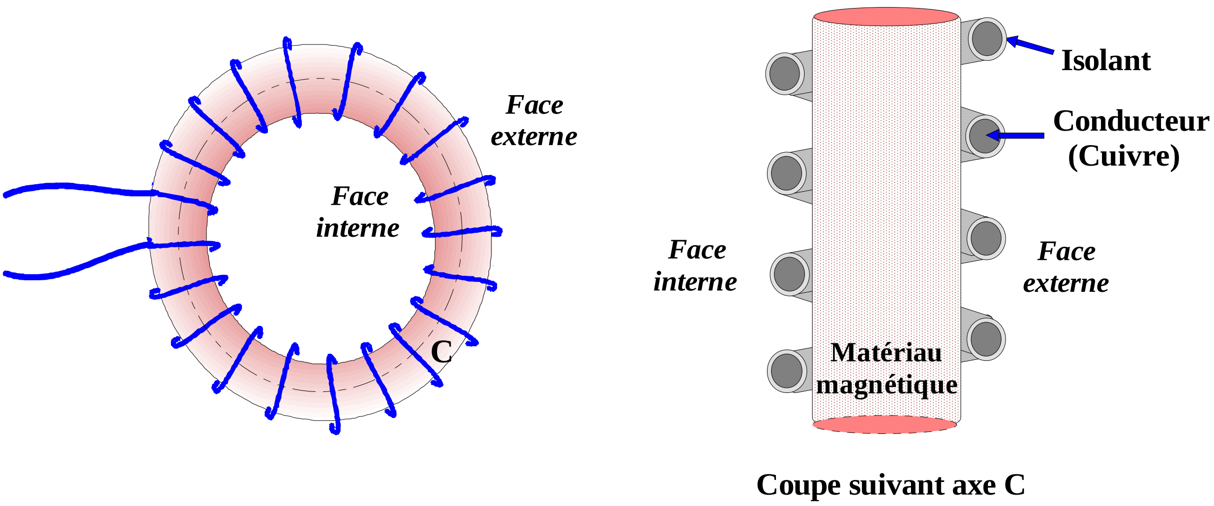


Figure 4: Component symmetry

In order to have a model that is not too complicated (Figure 5), we define two isothermal areas, which are: 1-the magnetic core, 2-the coil. That is the second simplifying hypothesis. These two isothermal areas are locations of heat diffusion caused by copper losses in conductive material and core losses in the magnetic material.

⇨ We allocate to each area a node as well as a source representing the losses (P_f and P_j). Two thermal capacitances, associated with those two elements, describe the storage of thermal energy in the materials C_{th1} and C_{th2} refer to stored energy in the magnetic material and in copper respectively. Concerning the magnetic material, thermal transfers can either exist directly towards ambient air or through the winding:

⇨ Thermal flux between ferrite and ambient air occurs through resistor R_{th3}, which nature is mainly convective (indeed, radiative transfers are weak assuming ferrite temperature).

⇨ Heat transfer between magnetic material and copper takes place across three resistors, R_{fe} (between center and surface of the ferrite), R_{insu} (due to wire insulator that makes the winding) and $R_{cu/2}$ (between centre and surface of the conductor). Dissipated energy in (or through) the winding is drained either directly towards ambient air or towards IC through connexion slots. One cannot neglect thermal flux through connexions, as copper thermal conductivity is high.

⇨ Heat flux between copper and ambient air forwards through three resistors, $R_{cu/2}$ and R_{insu} which copy the ones introduced lately, as well as R_c which represents the convective resistance between isolation part and ambient air.

⇨ Connexion terminals are the second location where the calories that are produced in the winding are drained. One can distinguish two resistors: r_1 of convective nature, between winding end and connexion terminal (i.e. connexion wire resistance); r_2 which represents conductive and convective heat transfers between soldering point and ambient air. Finally, stored energy in the connexion is modelled by capacitor C_{co}.

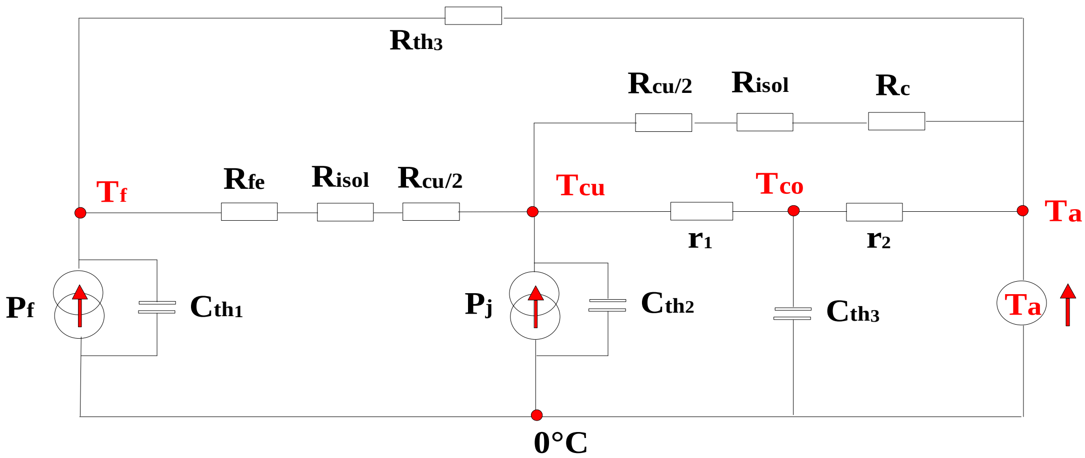


Figure 5: Complete thermal model of the component

Some elements of the previous diagram can be precisely calculated. For instance, C_f and C_{cu} as well as $R_{cu/2}$ and r_1. On the contrary, due to a lack of precision on thermal coefficients and dimensions of the component, it is hard to evaluate some other elements of the diagram. Only we can rely on the measurements and thus it is possible to determine resistance R_{th1} as the sum of each individual R_{fe}, R_{insu} and $R_{cu/2}$. Similarly, resistances $R_{cu/2}$, R_{insu} and R_c are grouped in resistance R_{th2} that can be deduced from measurements.

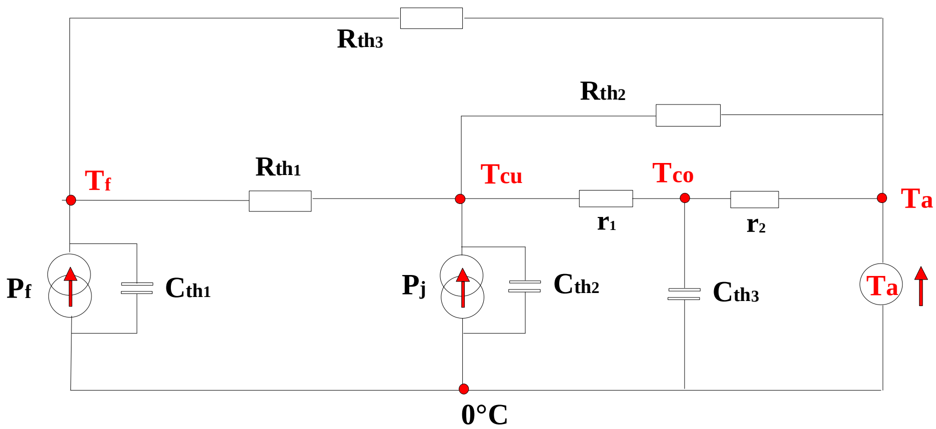


Figure 6: Simplified model

The thermal behaviour of the above-modelled magnetic component is ruled by the three following differential equations that describe heat fluxes balance at each node:

$$m_f.C_f.\frac{dT_f}{dt}=P_f-\frac{T_f-T_{cu}}{R_{th1}}-\frac{T_f-T_a}{R_{th3}} \quad (1)$$

$$m_{cu}.C_{cu}.\frac{dT_{cu}}{dt}=P_{cu}-\frac{T_{cu}-T_f}{R_{th1}}-\frac{T_{cu}-T_a}{R_{th2}}-\frac{T_{cu}-T_{co}}{r_1} \quad (2)$$

$$m_{co}.C_{co}.\frac{dT_{co}}{dt}=-\frac{T_{co}-T_{cu}}{r_1}-\frac{T_{co}-T_a}{r_2} \quad (3)$$

Pointing out that working temperatures variation domain is relatively narrow (working point at 70°C and variations of ±50°C), we will consider that thermal resistances are constant. That is an acceptable approximation regarding required precisions. There is however no problem considering thermal capacitances as constants. Finally, in the retained example, thermal model is only composed of five resistances and three capacitances.

In the second and last part of this article, we will identify experimentally every element in the model. We will thus introduce our characterization workbench. We will also present the tests that were performed as well as the results we obtained. We will conclude talking about the model validity domain.

Measuring methods of losses

General principles of measurement

The accurate measure of the losses that is essential to the determination of the value from the parameters of the model is equal to the measure of the temperature. That will be also the same during the validation phase of the model as well as when we shall have to determine the limits of validity of the model. The defined model had been previously creating two sources of losses, there exist losses by effect Joule in the rolling-up and losses of iron in the magnetic material. So, it will be advisable to determine separately these two types of losses. We will put into practice separated method though it is hard to tackle one global measure of the losses. The measure of the losses and particularly the one in high frequency is very delicate.

In fact, components are generally submitted to forms of non-sinusoidal waves in electronics of power. That is done by harmonious of high ranks which it is impossible to neglect. These high-frequency spectral components complicate strangely the measures. Furthermore, the magnetic components, the inductances or vacuous transformers get hold of a very weak power factor which increases considerably the difficulties [1] [2] [5]. The precision of the measures realized by means of a wattmeter is often insufficient in such conditions. It would be necessary to have a device possessing a bandwidth very superior to MHz, capable of making measures with a precision better than 1 % for factors of power which are lower than 0,05. Unfortunately, we do not get any kind of equipment. The measure of the losses stays a problem which is difficult to solve. But, several authors were interested in the measure of the losses in the magnetic components.

⇨ Feirrera and Van Wyk [5] suggest a method which helps to determine exactly the losses of Joule in the windings after having identified the causes of error in the measures using a wattmeter. The component to be characterized is inserted into an oscillating circuit. The statement of the signal in the borders of the condenser is positive to determine the value of the inductance and the resistance of the component. This method is well adapted to components without magnetic circuit (inductance with air for example). But, it does not seem easy for components with magnetic circuit when we separate the losses of iron to the losses of Joule.

⇨ Bowman and al. try out a calorimetric method by measuring the average power dissipated in a transformer with the various springs of error. They even propose a compensated procedure [6]. This original method is hardly operated and cannot separate losses anyway. So, we dump it.

⇨ Batista and al [7] chose an automated measurement system of the losses from the magnetic cores linked to sinusoidal and square excitements. This method is particularly more applied to circuits torques equipped with a primary winding and with a secondary winding. The losses are calculated by integrating the cycle of hysteresis obtained by finding the current of primary excitement and the tension in the borders of the secondary rolling-up. A digital oscilloscope makes the simultaneous acquisition of these two sizes (greatnesses), which are then transferred towards a computer for treatment (processing). The method is successful because springs of error were identified and minimized when sinusoidal excitements set to be until 100 kHz. Unfortunately, anyone dare not to experiment it in higher frequencies and for other forms of waves yet.

⇨Imre and al. [8] [9] test the various possible approaches for the measure of the losses in an inductance to planar. Among the five experimented methods including direct measure by means of a wattmeter, immediate acquisition of the sizes (greatnesses) u (t) and i(t), calculation of the average value of the product ie over a period, calorimetric and method discolor capacitive. , only, the latter happens to give an acceptable precision. The component to be characterized is placed in a surrounding wall which is heat-fully isolated and fulfilled by a fluid. The temperature increases to stabilize when the component is supplied by a converter. The same operation is repeated when the inductance is supplied by a source of continuous tension which is adjusted to obtain the similar temperature. The equality of the temperatures found on AC and DC indicates that the losses are identical. So, we can obtain the value of the losses with the very accurate measure of the losses in DC. This original method is unfortunately not easy to put into practice. Moreover, it does not allow separating the losses of Joule from the losses in the magnetic material.

⇨P.M. Gradzki and F.C Lee [10] developed a method of measure of the losses in ferrites for frequencies included between 100 kHz and 100 MHz. That method of characterization uses an analyzer of impedance associated with an amplifier of power. The component under test is submitted to a sinusoidal excitement of strong amplitude (until 0.5A-150V). The signals (tension and current) are taken by means of probes and then transmitted in the analyzer of impedance. The authors calculate the losses in the component by the equivalent plan parallel RL. They specified the useful procedure of calibration which is necessary to the obtaining of a correct measure. But, they are unable to make a report on it.

⇨*The work of Leon HAVEZ JCGE2013 [18] for the consideration of 3D geometric effects for the evaluation of iron losses in magnetic materials such power electronics ferrite used. The design of magnetic components requires knowledge of electromagnetic losses which they are registered. These are losses due to current flow in the windings (" copper losses ") and losses due to the temporal variation of the magnetic field in the magnetic cores (" iron losses "). The detailed assessment of these losses is quite complex in practice because they frequency, amplitude and waveform of the electromagnetic and the nature of the material and geometry dependent variables. L.HAVEZ team relied on two computational models currently used iron losses in power electronics, coupled with a code for calculating electromagnetic fields finite element COMSOL Multiphysics. The non - linear behavior of the magnetic induction is considered. This new method shows that even in the case of a toroidal geometry sine wave power , the differences between the results from the application of the standard formula SE and those obtained by the method differ in the order of 25%. It takes even more sense for more complex geometries in which the effects of geometry strongly influence the distribution of the magnetic induction and therefore the distribution of losses.*

⇨ Jonas M¨uhlethaler and all [19]. Recounts voltages across inductors or transformers generally show rectangular shapes, including periods of zero voltage. In the stage of zero applied voltage (constant flux), core losses are not necessarily zero. At the beginning of a period of constant flux, losses still occur in the material. This is due to relaxation processes. A physical explanation about magnetic relaxation is given and a new core-loss modeling approach that takes relaxation effects into consideration is introduced. The new loss model is called improved-improved generalized Steinmetz equation (i2GSE) and it has been verified experimentally.

⇨ Dimitrakakis, G.S. show [20] Copper losses in magnetic coils depend on several geometrical parameters, as well as on frequency, in a way that makes their analytical modeling a quite difficult task. In this paper, he describes how we use finite-element-analysis software to investigate a series of issues critical to the accurate determination of high-frequency copper losses in layered coils. Some of the issues we investigate are the impact of the edge effect and the winding pitch on the overall copper losses. He examines the effective resistance of windings with a hexagonal conductor arrangement and the validity range of the classic models for copper losses in windings with round solid wire. The results of this work help us to fully understand the real impact of two-dimensional effects in layered windings of real rather than ideal magnetic. They constitute a tool for the accurate calculation of losses, which is necessary for an optimized magnetic component design in power electronics applications.

⇨ Dimitrakakis, G.S [21]: this paper establishes a new semi empirical model for the accurate determination of HF copper losses in windings with the random conductor distribution, a case that cannot be treated by any analytical method. This model is based on the statistical treatment of numerical results coming from a large number of simulations carried out with finite-element analysis software, and incorporates only three easily determinable parameters. The selected range for each of these parameters ensures that the model is suitable for the majority of practical applications. The theoretical analysis is verified by experimental measurements on different forms of winding geometries. A detailed investigation of the new formula reveals its inherent advantages on copper loss calculation when designing no layered coils.

⇨ M. Valentin COSTAN : [22] in thesis, In transformers, as in all electrical machinery, energy conversion is not perfect, is the seat of losses classified in different ways. it is possible to differentiate depending on how fonctionnement or physical intervention area. In the first, we talk about the no-load losses and load the SECOND case we speak of iron losses and copper losses. Iron losses significat occupy a place in the machines.

⇨ Boggetto J.Mand all. IAS 2002. [23]: This paper gives drawbacks and advantages of three integrated on Si inductors topologies dimensioned for low power DC/DC converters. It has been shown that the 0LT inductor structure (copper spiral sandwiched by two magnetic plates) presents the best tradeoff regarding to efficiency. To confirm this result, a new method of copper losses determination based on the Dowell method has been developed. This method gives accurate results in this case because of the planar geometry of our inductor. We are able to obtain the same result for copper losses determination in these structures, using this formulation or 2D results will give help for all integrated converter analytical pre-dimensioning, avoiding 2D and 3D FEA simulations and so reducing the computing time.

⇨ SALLES Alain [24]: This thesis is in the context of supply of mobile electronic systems operating at low voltage and low current. The design and implementation of passive magnetic elements integrated to the energy storage across the switching is approached to reflect the size, position of the power supply from the power system as well as its performance and power density. The study of physical phenomena related to the inductive and resistive nature of planar spirals from equations and a normalized geometrical definition of component led to the development of tools Digital study to analyze the relationship between the geometric parameters and settings Electrical component. It then appeared that the geometric dimensions necessary for the performance specifications previous charges (including the goal of very low resistance), faced with the limits opportunities for technological achievement (form factor drivers, spatial resolution). In the end, to exceed these limits, we are interested in the combination series / parallel inductors magnetically coupled. Simulations have shown that flexibility existed, allowing optimizing electrical performance of the components.

Chosen solutions

As a result, there is not any general solution that is efficiently accurate to allow measuring and separating in any conditions the losses in a magnetic component. The measure is particularly delicate and the precision of measure limited when the forms of waves are bare in accountancy with the actual available equipments. Measures in pure sinusoidal regime or in direct current allow obtaining the desired precision alone. So, for the determination of the elements of the model we shall favor trials by implementing the following two types of excitement:

Continuous trial: the area of losses by effect Joule in the windings remains by itself the sample which is supplied with a source of direct current.

Trial in sinusoidal regime: the sample under test is excited by a signal as close as possible of the ideal sinusoid. It is the area of losses in the winding and losses in the magnetic material. Frequency is set according to the rapport losses copper/ losses wished iron. And the losses iron will be important as soon as the frequency of functioning is more and more brought up.

Continuous trial

In statics, the losses of iron are worthless so that winding is only set to be the area of losses. These losses of joules are obtained by the following relation: $P_{cu} = R_{DC}.I^2$. (R_{DC} is being the continuous moderate resistance of the winding and **I** the direct current of excitement which crosses it).

The resistance of the winding varies during a trial because of the high temperature. In that case, it is suitable to take into account those variations for a better precision. Indeed, the resistance of the winding is determined from each stage by a four wire volt metrical measure. This value of moderate resistance allows calculating the temperature of this one in addition to the losses in the winding.

Trial in sinusoidal regime

Here, we measure the total losses by means of a wattmeter. After that, we divide these losses into two categories:

- ✓ Losses in the winding (the copper losses).
- ✓ Losses within the magnetic material (the iron losses)

The losses of iron become very superior to the losses by effect Joule in the winding when frequency is raised. For a pure sinusoidal excitement, the losses of copper are calculated from the relation:

$$P_{cu} = R_{ac}.I^2 \quad [5]$$

(R_{ac} is being the resistance of the winding with the frequency of the signal of excitement and I the effective current which crosses it). The measure of the resistance of the winding R_{ac} can be made in an impedance meter by choosing an equivalent model (R, L) put into series. The following figure 7 indicates the variations of these various resistances according to the frequency for three samples which were used in the various tests (bobbins of material B_1 of different sizes and lengths of winding).

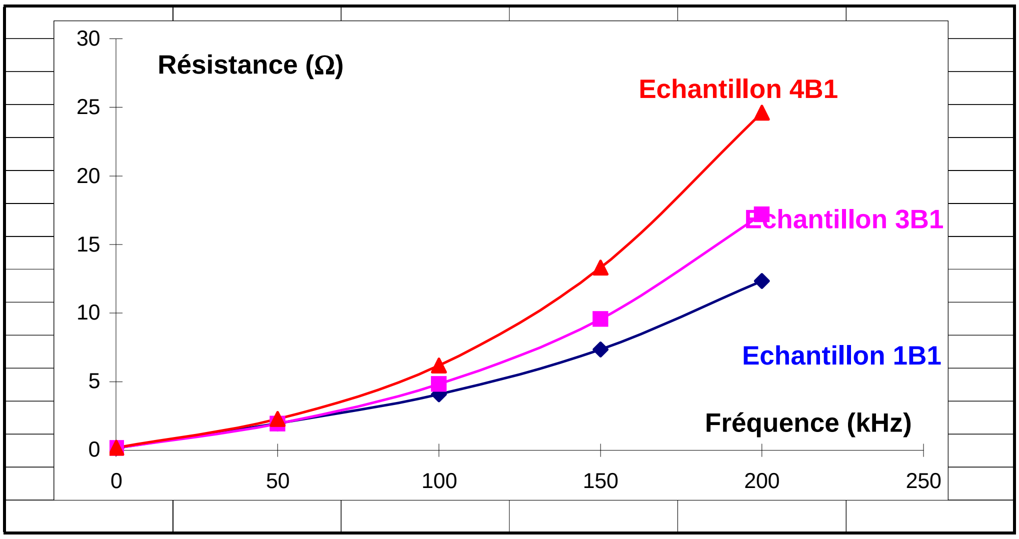


Figure 7: evolution from the resistance of the winding according to the frequency

The previous curves show that it is essential to take into account the evolution of the resistance of the winding according to the frequency. Indeed the effects of skin and closeness are translated by a considerable increase of the resistance of the winding with the frequencies of use. We observe a power upper to 20 between the continuous resistance (R_{DC}) and the resistance in 100 kHz (R_{ac100k}).

The signal of excitement being not perfectly sinusoidal, the question is to know if distortions can significantly influence the calculation of the Joules losses.

Two solutions are possible:

⇨**Solution$_1$**:
We proceed to the Fourier 's mass decomposition of the signal and we use the values of the resistance of the winding with the frequencies f, 2f, 3f to calculate the losses of Joule which is: $P_{cu} = \sum_{i=1}^{\infty} R_{aci} . I_i^2$

R_{aci} stands for the resistance of the winding for the harmonious of row i, Ii represents the effective value of the spectral component of row i.

⇨**Solution$_1$**:
We simply calculate the losses of Joules with the value of the resistance from the frequency F. it is calculated by :

$$P_{cu} = R_{ac1} . I^2 \quad \textbf{\textit{[6]}}$$

R_{ac1} symbolizes the resistance of the winding from the frequency of the fundamental and I stands for the effective value of the current.

The first solution is hardly found because we have necessarily to proceed first of all with the acquisition of the signal by means of a digital oscilloscope, then secondly to calculate the specter by means of a tool of signal processing. We can finally proceed to the calculation of the losses of Joule. The second method is immediate because we just measure the effective value of the current feeding the component under test with an ammeter.

In order to estimate the errors of the second method, we have to proceed to a comparison of these two methods on a real signal.

The following table shows the amplitude of the various spectral components that establishes the real signal circulating in the winding supplied by the amplifier of power of which we have in quasi-sinusoidal regime.

Table 1: spectral decomposition of the current finds in the winding

Frequency (kHz)	100	300	500	700
Harmonics	Fondamental	3	5	7
Amplitude of the nth harmonic (mA)	100	5	2	1
Resistance value R_{AC}(Ω)	6.2	54	152	300
Winding loss (mW) for each of the spectral components	6.2	1.3	0.6	0.3

The calculated losses of the first method rise in 64.2mW while the second method gives 62.2mW. There is an error of the order of 3 %. This error is not at all useless taking into account the losses of copper. In reality, the losses of copper represent in themselves the one part of the total losses (less than 10 %) with these particularly raised frequencies of functioning. The all losses made error is so very weak that the second method only remains for its simplicity. We will calculate the losses of copper that we found during the trial in quasi-sinusoidal regime by $P_{cu} = R_{ac1}.I^2$

Iron losses

Iron losses (P_{fer}) are obtained from the global measured losses (P_{tot}) by removing the losses of copper calculated (P_{cu}) as indicated previously:

$$P_{fer} = P_{tot} - P_{cu} \quad [7]$$

The following figure 8 clarifies conditions in which the measures of power can be carried out. We observe that the component under test is not directly connected to the wattmeter. The connection is made by means of a card of connection which is essential to the bench of thermal characterization and which the interest will be justified in the following paragraph. This configuration imposes a relatively long cabling of which the influence on the measure of the losses can turn out important. Losses in the component under test are added on losses in the elements of connection (wires, relay, printed circuit, etc.…).

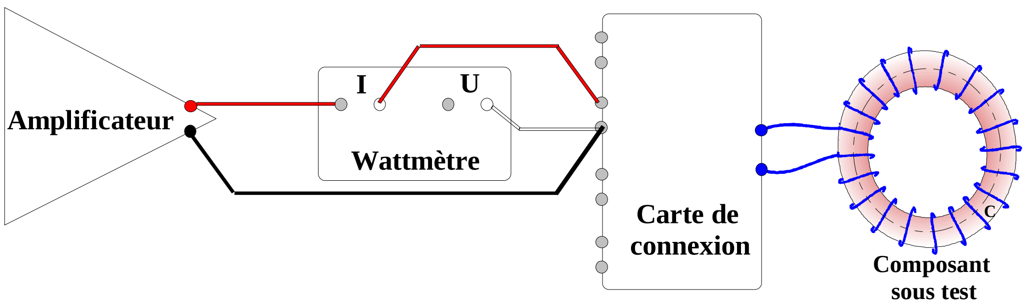


Figure 8: measure of power
Amplifier AP-400B RF to Amplify - BP: 80 kHz to 2.7 MHz - P = 400 W
Wattmeters Clarke-hess Model 255/256 Volt-Ampere-Watt meter-BP DC in 400 kHz in sine and up to 100 kHz in square signal

In order to estimate these additional losses which are measured by the wattmeter, we proceeded to two kinds of measure:

- ✓ A first measure on the bench by way of relays and other elements of connection.
- ✓ A second measure except thermal bench by connecting the sample as closely as possible to the wattmeter.

The results of these measures are recorded in the chart which is below. The measures show that there is no difference between both trials for frequencies which are lower than some tens of kHz.

Table 2: Error of x in per cent made upon the measure of losses

Echantillon	**4B1**
F=50kHz	5.4%
F=100kHz	15.6%

50 kHz beyond, the moderate losses are superior to the losses in the component of itself, then the elements of connection being not the field of reluctant losses. The use of the bench of thermal characterization is translated by the measure of additional losses which increase with the frequency. It will thus be advisable to correct the measures during the trials like it is in the following way:

Ptot = Pmes (1-x) ***[8]***

X is being the percentage of error committed on the measure of the global losses of the component.

Software of trial conduct

The software allowing the piloting of the bench of measure was developed with the software TESTPOINT. This software is helpful to perform and to use programs of tests, of measure and of acquisition of data. All the acquisitions are managed through a P.C. using an analogical card and a digital card. This program allows besides the acquisition of the measures, the processing, the display and the storage of the data. Various relative parameters on approval are supplied by the operator, these stages involve:

✓The choice of the relative parameters to the progress of the trial (number of test point, frequency).

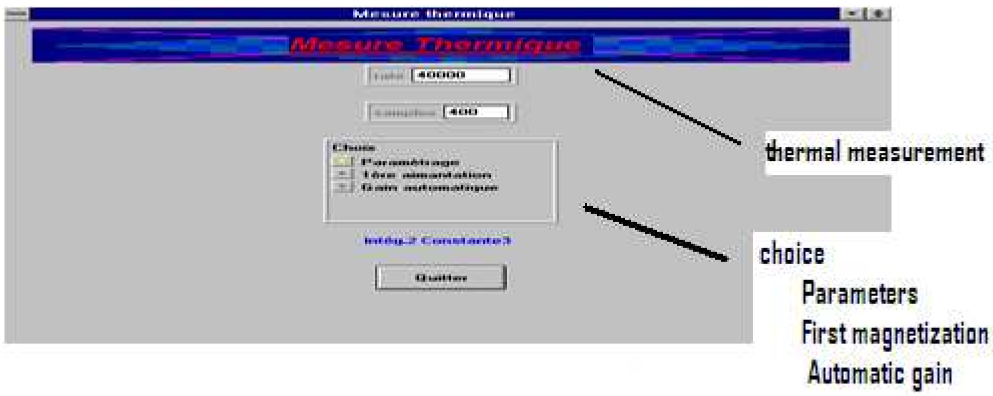
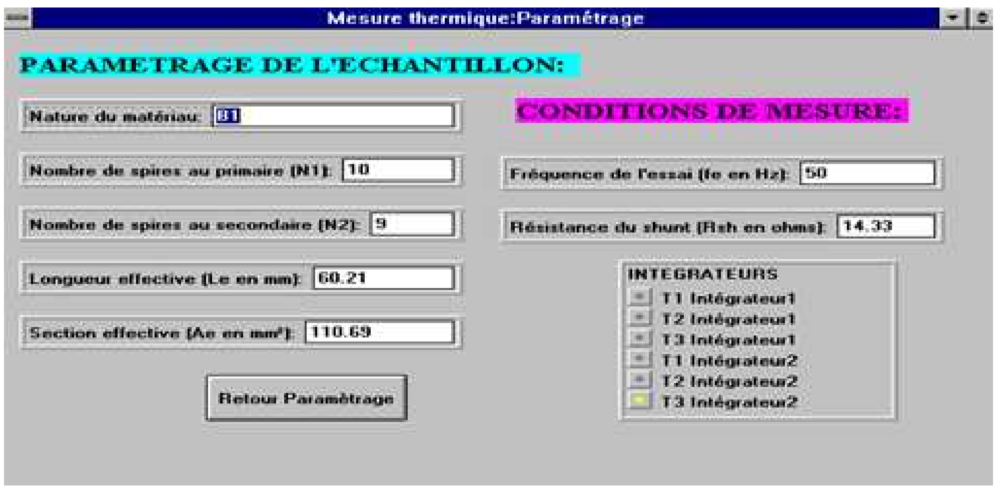


Figure 9: Test parameters

✓The regulation of the parameters for the acquisition of the curve of first magnetization (constant time of the integrator, the frequency of sampling, value of the shunt used for the measure of the current, the data concerning the sample: number of effective turns of the windings, the section and the length).



sample parameters	
Nature of the material	Measurement condition
Number of turns on the primary N1	Test frequency (f_e (Hz))
Number of secondary turns N2	Shunt resistor (R_{sh} (□))
Effective Length (Le (mm))	
Effective area (Se (mm^2))	

Figure 10: Parameters related to the extent of the initial magnetization curve

✓The semiautomatic determination of the earnings of the amplifiers of instrumentation according to the current chosen as the measure of the resistance of the winding (manual choice of the current 0.5, 1.25, 2.5 and 5A). Below the window guide the user in his choice as regards the amplitude of the current and the gain of the instrumentation amplifier associated with the measurement of the voltage across the shunt.

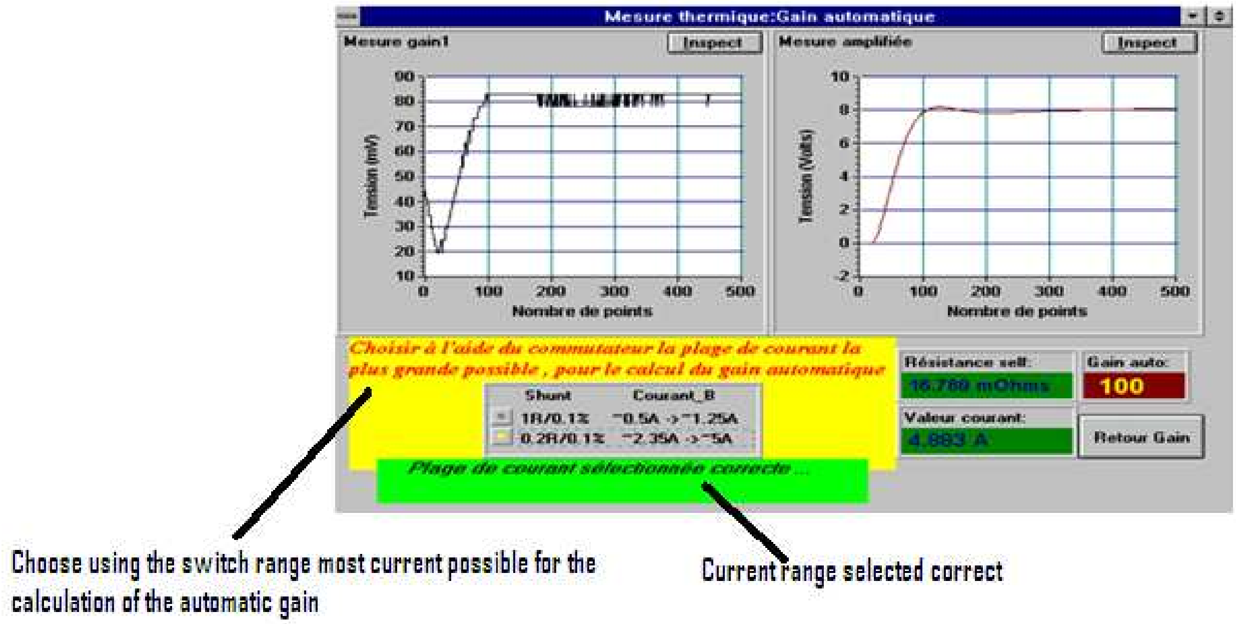


Figure 11: Choosing parameters for the measurement of the winding resistance

✓Then the choice regarding the amplitude of current and gain of the instrumentation amplifier associated with the measurement of the voltage in borders of the shunt. So, acquisition is automatically proceeding until the complete display of curves giving the evolution of the various temperatures according to time.

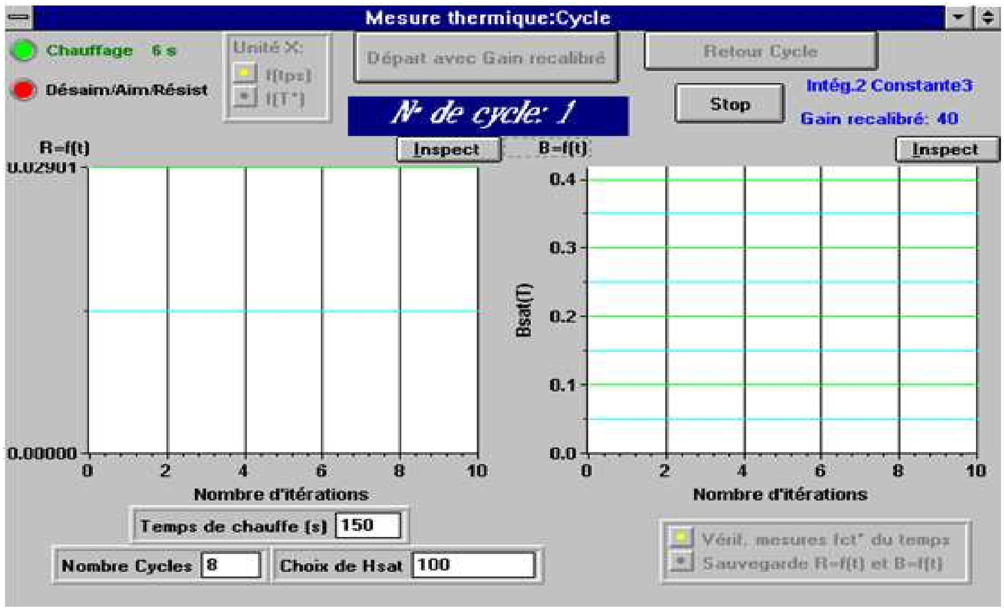


Figure 12: Followed by the acquisition

Validation of the measuring bench

various trials had been carried in order to validate the measures obtained by means of the device previously described. But, we have set to:

⇨Verify that the various measures did not modify the heat of the component under test.
⇨Analyze the validity of the measure of the temperature of connection realized by means of a thermocouple.
⇨Study the repeatability and the precision of the measures of the average temperatures of the winding and the magnetic material

CONCLUSION

The quality of the model depends mostly on the precision of the measures of the losses and on the temperatures. We developed a methodology which allows determining exactly the various losses in the magnetic component for a frequency band extending of the continuous until the maximal frequencies of use is several hundreds of kHz. The precision of the measures established a permanent concern in our approach.

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