Measurement of magnetic characteristics of transformer-cores and coil materials

Precision loss power measurement of sheet iron- and ferrit cores with high signal frequency: exact, easy and realtime!

With the precision power meter LMG it is possible to get access to other magnetic characteristic values in addition to the precise loss power measurement. So the peak values of the magnetic flux, the magnetic field strength and the permeability of a core can be determined at low and also at high frequencies. In the quality control of magnetic materials already wraped coils can be used. Many measuring proceedings require sinusodial field strength or flux. This simplified way of thinking leads to expensive and complicated signal sources. Because the point of interest is especially the saturation range, there is a high demand on the source in this range. It is more elegant and cost saving to use "intelligent" measuring equipment and allow arbitrary curve forms of the voltage and the current with better mathematical formulas. So that low cost power sources can be used. Even the line voltage with it's high harmonic disturbance can be used.

Measurement of the loss power

The dissipation of a ferrite core is directly proportional to the area marked off the hysteresis loop and so it is a function of the temperature, the frequency, the flux density, the ferrite material and also of the core form. By supplying an arbitrary signal at the primary side of a wrapped core and the measurement of the open - circuit voltage at the secondary side the measurement of the dissipation may be realised very easily with a LMG. The primary peak current (I_{pk}) is proportional to the magnetic field strength (H_{pk}) and the rectification value of the open - circuit voltage (U_{rect}) on the secondary side is proportional to the magnetic flux density. The integration of the hysteresis loop is equivalent to the measured true power.

The total dissipation of a wrapped core consists of a P_{loss} of the hysteresis, a P_{loss} of the eddy current, a P_{loss} of the winding and a P_{loss} of the rest. Measuring the ferrite core dissipation the copper losses should not be measured, what may be realised with the following measurement circuit:

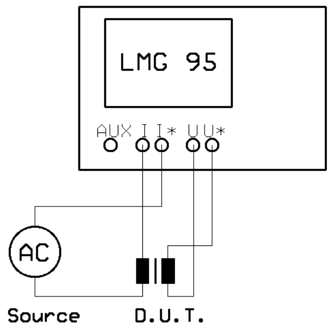

Fig. 1. Measurement circuit "core dissipation".

In this case the loss power is calculated like: $P_{loss} = U_{trms} * I_{trms} * \cos\varphi$. Using this measurement circuit the voltage drop of the copper resistance at the primary circuit has no effect, because at the primary circuit only the current is measured. To measure the real magnetising voltage the secondary circuit

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runs currentless. Both primary and secondary copper losses are not included in the measured loss power. Because of the precise measurement of Utrms, Itrms and cos φ the integration and the dynamic run through of the hysteresis loop is not necessary and the dissipation may be measured, displayed and read directly in real time with the LMG.

To solve this demanding measurement problem the following details should be considered:

The computation of error of the dissipation is calculated:

$$\frac{\Delta \mathrm{Pl}}{\mathrm{Pl}} = \frac{\Delta \mathrm{Utrms}}{\mathrm{Utrms}} + \frac{\Delta \mathrm{Itrms}}{\mathrm{Itrms}} + \frac{\Delta \cos\varphi}{\cos\varphi} \quad (1)$$

The total error of the dissipation contains an amplitude error of the measured voltage and current and also a delay time difference error between these signals. The delay time difference is caused by the different delay times in each measuring path.

Normally the losses are very small and the phase shift nearly 90° and so the cos φ is nearly zero. The division of Δcos φ by cos φ will result a very high value and this error will be of great importance.

A numeric example:

At a measurement of the dissipation of a ferrite core cos φ is 0.06, the primary current is sinusoidal with a frequency of f = 50kHz. With the following formula: $\varphi = \mathrm{t} * 360° * \mathrm{f}$, a time delay of only 3.8ns leads to an error of: $\frac{\Delta \cos \varphi}{\cos \varphi} = 2\%$.

This means it is the delay time on a measurement lead shorter than 1m! Additional to this error also the amplitude errors $\frac{\Delta \mathrm{U}}{\mathrm{U}}$ and $\frac{\Delta \mathrm{I}}{\mathrm{I}}$ must be considered, measuring with a precision power meter they may be neglected.

For this measurement problem the selection of the measuring instruments is very important, not even a high amplitude accuracy is necessary, but a meter with a high power measurement accuracy should be elected. Also a carefully wired measurement circuit is important for a high accuracy of the measured values. The measurement leads should be very short and of a equal length.

The manufacture ZES ZIMMER Electronic Systems offers for this measurement problem a special delay time adjustment of the LMG, which realises a delay time difference between U and I channel typically < 4ns. Because of the versatility of the power meter LMG the user gets access to other magnetical characteristic values.

Determination of the magnetic field strength

The peak value of the magnetic field strength (Hpk): From the first Maxwell equation:

$$\oint_C \vec{H} d\vec{s} = \int_A \vec{J} d\vec{A} + \frac{d}{dt}\int_A \vec{D} d\vec{A} \quad (2)$$

follows with the secondary factor: quasi-stationary fields

$$\frac{\omega\varepsilon}{\kappa} \langle\langle 1 \quad (3)$$

$$H_{pk} = \frac{I_{pk} * n_1}{l_{magn}} \quad (4)$$

Hpk is the peak value of the magnetic field strength in the core, n1 the primary windings, Ipk the peak value of the primary current and lmagn the magnetic path length. Hpk is exactly determinied, independent of the signal curve form of

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the primary current, only requirement: the current must be symetrical, so: Ipk=Ipp/2. The equation in the notation of the formula editor in the LMG:
Hpk=Ipp/2*n1/lmagn (5)

Determination of the magnetic flux density

The peak value of the magnetic flux density (Bpk): From the second Maxwell equation:

$$\frac{1}{dA}\oint \vec{E}d\vec{s} = -\frac{d\vec{B}}{dt} \qquad (6)$$

follows also with the secondary factor (3) and the reception of equally distributed flux density in the core material:

$$-\frac{1}{n_2 * A} * u(t) = \frac{dB(t)}{dt} \qquad (7)$$

n2 are the secondary windings, A is the effective magnetic cross section of the core material, u(t) is the induced voltage at the secondary winding in time domaine.
B(t) is minimal/maximal with dB(t)/dt=0, so at the zero crossings of the induced voltage. The integration between two zero crossings of the induced voltage delivers the peak value of the magnetic flux density:

$$-\frac{1}{n_2 * A} * \int_{t0}^{t1} u(t)dt = Bpp \qquad (8)$$

Bpp is the peak-peak value of the magnetic flux density in the ferrit core, t0 the beginning of a cycle of the induced voltage, t1 is the moment of the zero crossing of the induced voltage in the same cycle.
Because the induced voltage contains no direct voltage part (Udc=0), follows:

$$\int_{t0}^{t1} u(t)dt = -\int_{t1}^{T} u(t)dt \qquad (9)$$

T is the cycle time of the induced voltage. With equation (9) follows:

$$\int_{t0}^{t1} u(t)dt = \frac{1}{2}\int_{t0}^{T} |u(t)|\, dt \qquad (10)$$

This integral is also included in the formula of the rectified (secondary) voltage Urect:

$$U_{rect} = \frac{1}{T}\int_{0}^{T} |u(t)|\, dt \qquad (11)$$

With the power meter LMG you have got access to the value of the rectified voltage. So the flux density is calculated from following equation:

$$B_{pk} = \frac{U_{rect}}{4 * f * n_2 * A} \qquad (12)$$

f=1/T is the signal frequency of the induced voltage. Bpk is also exactly determinated, independent of the signal curve form.
The equation in the notation of the formula editor in the LMG is:

Bpk=Urect/(4*f*n2*A) (13)

Determination of the relative amplitude permeability

With the already calculated peak values: magnetic flux and magnetic field strength, the relative amplitude permeabiliy is easyly calculated with:

$$\mu_a = \frac{B_{pk}}{\mu_0 * H_{pk}} \qquad (14)$$

In the notation of the LMG:

ua=Bpk/Hpk/1.2566e-6 (15)

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Determination of the core losses

The dissipated loss power in the core is the measured P multiplied with n1/n2.
In the notation of the LMG:

Pfe=P * n1/n2 (16)

Realisation of the measurement with the LMG95

The precision power meter is connected with the power source and the unit under test according Fig. 1. After programming the equations in the formula editor (Fig. 2) the calculated values can be read out in realtime (Fig. 3), can be plotted graphicaly (Fig. 4) or printed out.
Especially the magnetic values Hpk, Bpk and ua wich can not be mesured directly are shown in realtime on the display

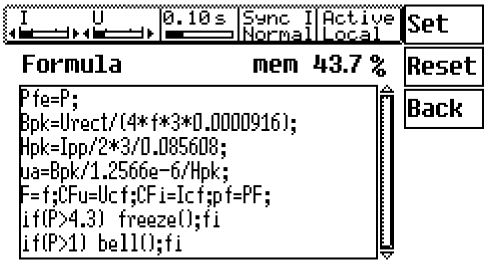

Fig. 2. Programming of the formula.

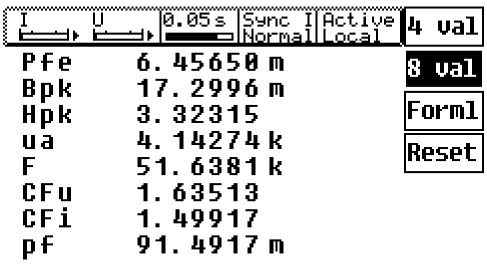

Fig. 3. Custom-defined measuring values.

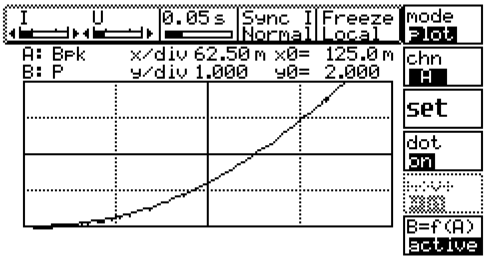

Fig. 4. XY-representation of the core losses vs. magnetic flux.

Conclusions

With the direct measured values: the rectified value of the induced voltage, the frequency, the peak value of the primary current and the user supplied geometrical values of the ferrit core, it is possible to determine the magnetic flux, the magnetic field strength and the relative amplitude permeability of the ferrit core. These values can be evaluated in realtime and can be displayd together with the directly measured loss power.

Fig. 5. LMG95.

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Development and Application

Literature

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