Power Meter Yields Magnetic Characteristics of Transformer Cores and Coil Materials

Power meter provides real time precision loss measurements on sheet iron and ferrite cores operating at high frequencies.

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An effective transformer design requires a determination of the peak values of the magnetic flux, the magnetic field strength, and the permeability of a core at low and high frequencies. These measurements involve sinusoidal field strength or flux, but this leads to expensive and complicated signal sources. The point of interest is especially the saturation range, where there is a high demand on the signal source. A more elegant and cost-saving approach is to use “intelligent” measuring equipment with better mathematical formulas that allow arbitrary waveforms of the voltage and current. This allows the use of low-cost power sources. You can even use line voltage with a high harmonic content.

Ferrite core dissipation is directly proportional to the area of the hysteresis loop; therefore it’s a function of the temperature, frequency, flux density, ferrite material, and the core’s 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, you can recognize the measurement of the dissipation. 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. Integration of the hysteresis loop provides the 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. When measuring the ferrite core dissipation, you should not measure the copper losses.

In this case, the loss power is: $P_{loss} = U_{trms} \times I_{trms} \times \cos\varphi$. Using the measurement circuit in **Fig. 1**, the voltage drop of the copper resistance at the primary circuit has no effect, because you only measure the current in the primary circuit. To measure the real magnetizing voltage, the secondary circuit runs current-less. Primary and secondary copper losses are not included in the measured loss power.

ZES ZIMMER LMG95

Because of the precise measurement of U_{trms}, I_{trms}, and $\cos\varphi$, the integration and dynamic run through of the hysteresis loop is not necessary. A power measurement system may measure, display, and read directly in real time the dissipation. You can accomplish this by considering the computation of error of the dissipation is:

$$\frac{\Delta Pl}{Pl} = \frac{\Delta U_{trms}}{U_{trms}} + \frac{\Delta I_{trms}}{I_{trms}} + \frac{\Delta\cos\varphi}{\cos\varphi} \qquad (1)$$

The total error of the dissipation contains an amplitude error of the measured voltage and current with a delay time difference error between these signals. The different delay times in each measuring path causes the delay time difference. Normally, the losses are very small and the phase shift nearly 90°, and so the $\cos\varphi$ is nearly zero. The division of $\Delta\cos\varphi$ by $\cos\varphi$ will result in a very high value.

Numeric Example

At a measurement of the dissipation of a ferrite core $\cos\varphi$

is 0.06, the primary current is sinusoidal with a frequency of f = 50 kHz. With the following formula:

$$\varphi = t \times 360^\circ \times f\ ,$$

a time delay of only 3.8 nsec leads to an error of:

$$\frac{\Delta \cos \varphi}{\cos \varphi} = 2\%$$

This means it's the delay time on a measurement lead shorter than 1 m. Also consider the amplitude errors:

$$\frac{\Delta U}{U} \text{ and } \frac{\Delta I}{I}$$

For this measurement problem, the selection of the measuring instruments is important. An instrument measuring high amplitude accuracy isn't necessary, but you should select a meter with high power measurement accuracy. Also, a carefully wired measurement circuit is important for a high accuracy of the measured values. The measurement leads should be short and equal in length. The LMG95 is an instrument that satisfies these requirements with a special delay time adjustment that provides a delay time difference between U and I channel, typically <4nsec (see **Photo** on page 74).

The LMG95 power meter accesses other magnetic characteristic values, such as determination of the magnetic field strength. The peak value of the magnetic field strength is H_{pk}. From the first Maxwell equation:

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

follows with the secondary factor: quasi-stationary fields

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

$$H_{pk} = \frac{I_{pk} \times n_1}{l_{magn}} \qquad (4)$$

H_{pk} = Peak value of the magnetic field strength in the core

n1 = Primary windings

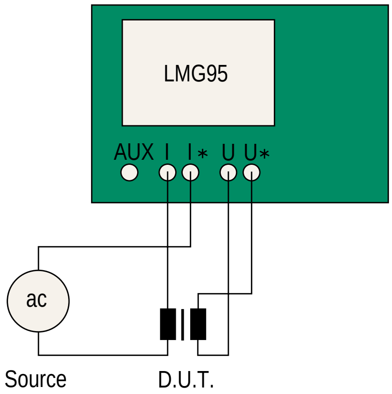

Fig. 1. *Measurement circuit "core dissipation."*

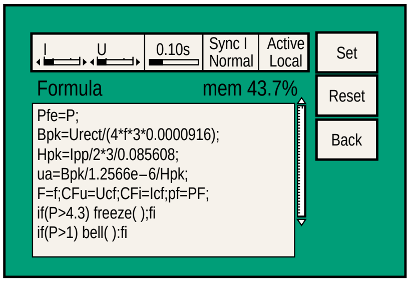

Fig. 2. *Programming of the formula editor.*

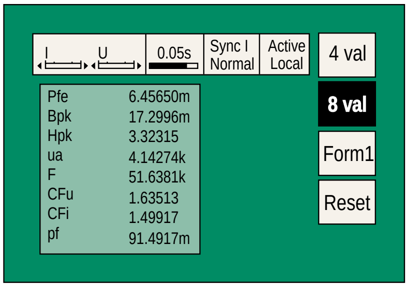

Fig. 3. *Custom-defined measuring values.*

Ipk = Peak value of the primary current

l_{magn} = Magnetic path length

H_{pk} is exactly determined, independent of the signal curve form of the primary current. The only requirement is that the current must be symmetrical, so $I_{pk} = I_{pp}/2$.

The equation in the notation of the formula editor in the LMG95:

$H_{pk} = I_{pp}/2 \times n1/l_{magn}$ (5)

Magnetic Flux Density

The peak value of the magnetic flux density (B_{pk}) from the second Maxwell equation:

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

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

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

n2 = Secondary windings

A = Effective magnetic cross section of the core material

u(t) = Induced voltage at the secondary winding in time domain

B(t) is minimal/maximal with dB(t)/dt = 0, which is 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:

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

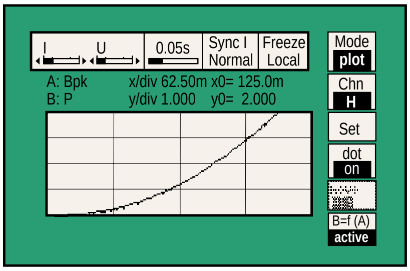

Fig. 4. *XY-representation of the core losses vs. the magnetic flux.*

B_{pp} = Peak-peak value of the magnetic flux density in the ferrite core

t0 = Beginning of a cycle of the induced voltage

t1 = Moment of the zero crossing of the induced voltage in the same cycle.

Because the induced voltage contains no direct voltage part ($U_{dc} = 0$), it follows that:

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

T = Cycle time of the induced voltage

With Equation (9) it follows that:

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

This integral is also included in the formula of the rectified (secondary) voltage U_{rect}:

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

With the LMG95 you have access to the value of the rectified voltage, so you calculate the flux density:

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

f = 1/T, the signal frequency of the induced voltage

B_{pk} is also exactly determined, independent of the signal curve form. The equation in the notation of the formula editor in the LMG95 is:

$B_{pk} = U_{rect}/(4 \times f \times n2 \times A)$ (13)

Relative Amplitude Permeability

Using the already calculated peak values, magnetic flux and magnetic field strength, the relative amplitude permeability is:

$$\mu_a = \frac{B_{pk}}{\mu_0 \times H_{pk}} \quad (14)$$

In the notation of the LMG95:

$u_a = B_{pk}/H_{pk}/1.2566\ e^{-6}$ (15)

The power meter connects to the power source and the unit under test according to **Fig 1**, on page 75. After programming the equations in the formula editor (**Fig. 2**, on page 75) the calculated values can be read out in real time (**Fig. 3**, on page 76), plotted graphically (**Fig. 4**, on page 76), or printed out.

Magnetic values H_{pk}, B_{pk}, and u_a that can't be measured directly are shown in real time on the display in **Figs. 2, 3,** and **4.**

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's possible to determine the magnetic flux, magnetic field strength, and the relative amplitude permeability of the ferrite core. These values can be evaluated in real time with LMG95 and displayed together with the directly-measured power loss. PCIM

References

1. *Küpfmüller, K.: Einführung in die theoretische Elektrotechnik. 13. Aufl., Berlin/Heidelberg: Springer 1990.*

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