Advance set-up for high-frequency measurements of magnetic materials and components in electronics

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Abstract – **High frequency loss measurements in magnetic materials and magnetic components need specialized equipment, especially in power electronics where the square voltages and currents are typical. A practical set-up for high accuracy loss measurements is proposed and used for measuring under wide band frequency and voltage waveforms. Manufacturers give information for losses only under sine voltages, so the proposed set-up is quite necessary for the design of components in other conditions, especially square voltages with variable duty ratio.**

Keywords – ***Measurements, soft magnetic materials, modelling.***

I. The Need of Measurements in Power Electronics

In order to model and investigate the properties of soft magnetic materials, we need a reliable set-up by which we can measure different parameters such as: voltage, current, frequency, temperature, magnetic flux and power losses.

Losses in magnetic components have been studied because of their particular significance to the component design in power electronics [1, 2]. The main components of the losses in magnetic components are the core losses and the winding losses.

High frequency measurements of power losses need special equipment. Moreover in power electronics voltages and currents are rather square than sine, so the conventional measuring equipment is not suitable for high accuracy measurements in these conditions.

Traditionally, the peak induction is used to determine the losses of magnetic materials and it is derived for sine waves:

$$P_{avv} = k f^{\alpha} \hat{B}^{\beta} \qquad (1)$$

where $\hat{B}$ is the peak induction, P_{avv} is the average power loss per unit volume and f is the frequency of the sinusoidal excitation.

For square waves of 50% duty ratio the equation (1) looses in accuracy, but remains still a good approximation. But but with a duty ratio of 5% (or 95%), quite different losses are measured and underestimated by the model - more than two times.

The purpose of the paper is to present a practical set-up of devices, intended to provide high accuracy measurements of losses in magnetic materials and components under quite wide frequency and waveforms conditions.

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II. Proposed Set-up – Main Components

The set-up has 7 main components:

- Half/full bridge platform
- Digital storage oscilloscope with specialized wide band probes
- Calorimeter
- Thermometers
- Function generator
- Power supply & heater

A. Half/full bridge platform

The platform, which is used [4], is designed for testing magnetic components as well as for development of resonant converters. A practical ferrite power loss measurement set-up is shown in Fig.1. A bridge converter is used to feed the measured magnetic component. The converter should have possibility of high frequency, high voltage output and regulation of the duty ratio and peak-to-peak voltage.

Having measured the current *I* and the voltage *V*, we obtain the ferrite losses after subtraction of the copper losses. Using Litz wire, the copper losses are low. The order of magnitude can be estimated by doing a test without the core.

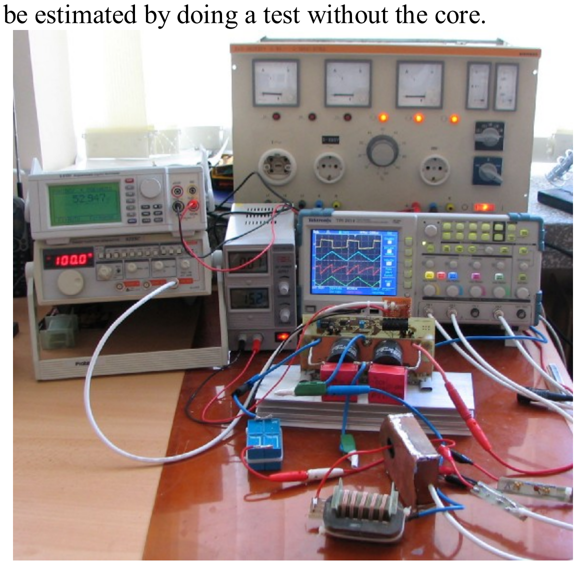

Fig. 1. The measurement set-up

B. Digital storage oscilloscope with specialized probes

It is important that the power measurement has *a wide bandwidth* and especially a *negligible phase shift between current and voltage* measurement. The phase shift should correspond with a time, for example, less than 10 times the rise time of the edges. Thus, the practical problem is to have wide band voltage and current probes and, in the same time, with a low relative phase shift between their measurements.

At high frequency and high permeability materials, the copper losses can be kept low using an appropriate litz wire. This allows to use a simple total power loss measurement and afterwards to subtract the copper losses.

We use the Tektronix TPS2014 digital storage oscilloscope.

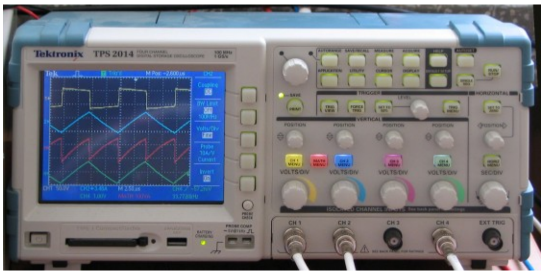

Fig. 2. Tektronix TPS2014

Wide Band Current Probe

The actual operating frequencies for ferrites are about 20 kHz to 1 MHz. However, due to the fast voltage edges, it is good to extend the measuring characteristic of the current and voltage probes up to 50 MHz. For a wide band current probe, the use of a current transformer is preferred as mass currents to the oscilloscope (resulting in ghost signals) can be reduced. Thus, an increased accuracy is provided at equal signal levels, compared to shunt measurement.

The electrical scheme of the current probe is shown in Fig.3. The high number of the resistors used is imposed by two reasons: the need for a low parasitic inductance of the equivalent resistor; the need of sufficient power dissipation ability. The input of the scope is 1 MΩ, 25pF. The current probe was constructed using a ring core TX36/23/15-3E25. The secondary side contains two windings of 20 turns, two 0.8 mm diameter copper wires in parallel. The current transformer is loaded with a 2 Ω resistance. This results in a 0.1 V/A transfer impedance. The low resistance results in a low cut off frequency below 150 Hz. The probe is designed to accept primary currents up to 20 A RMS value.

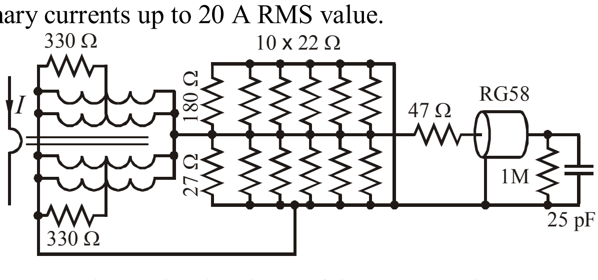

Fig. 3. Electric scheme of the current probe

Voltage Probe

The electrical scheme of the voltage probe is shown in Fig.4. The probe has a 1:100 ratio.

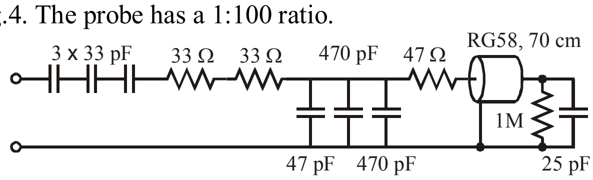

Fig. 4. Electric scheme of the voltage probe

A small damping (33 Ω + 33 Ω) is added to give some 'low pass' characteristic at high frequency and to compensate the phase delay of the transmission line behavior of the current probe.

The combination of both probes was tested for a sine wave voltage. The obtained phase difference between the presented current and voltage probes is sufficient for measuring square wave forms in the range of 1 kHz to 1 MHz.

Flux Measurement Probe

Here we present a passive integrator that can be used to estimate the flux linkage of the core, see Fig.5.

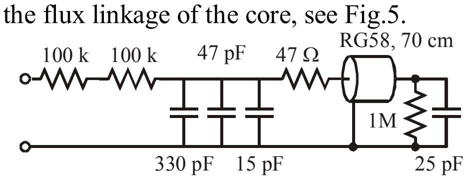

Fig. 5. Electric scheme of the flux probe

The integrating time constant is 100 µs. The cut off frequency is 845 Hz. This cut off frequency is already low enough to result in a negligible error at 20 kHz square waves. A high accuracy of the peak-to-peak flux measurement is required as 1% error generates about 2.5% error in the core losses. The parasitic inductance of the leads between the flux measurement place and the device under test (D.U.T) has also to be taken into account.

The combination of the voltage and current probes is tested with sine wave. The frequency response is shown in fig. 6. Current with peak value of 100 mA generates 0.25 W losses in 50 Ω resistor.

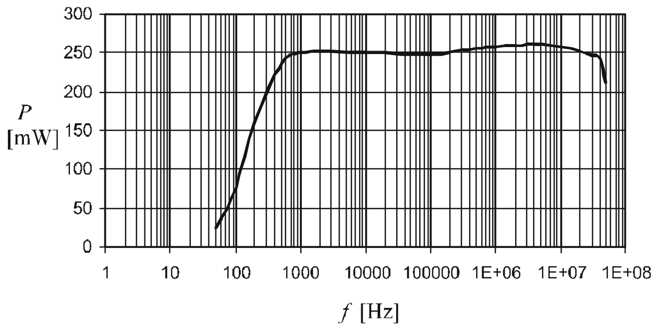

Fig. 6. Combined results from the probes

C. Calorimeter

Measurement methods, which tend to measure the dissipated heat directly, are among the most accurate means to measure losses. The calorimetric method is well suited for magnetic components and for entire circuits.

In a flow calorimeter, the device under test (dut) is thermally insulated from the environment but cooled with a mass flow of a cooling fluid. This principle has the advantage of reducing the settling time constant of the system. Moreover, there are no fan losses inside the test chamber. In steady state, the loss of the device under test is the product of the mass flow of the cooling fluid, the temperature rise of the cooling fluid and the specific heat capacity of the cooling fluid.

Tests with the proposed calorimeter show an absolute error better than 0.5% of the full power 200W and a relative error better than 3% of the measured power [3].

In a flow calorimeter, a continuous mass flow is used. With the temperature rise and the mass flow, the power loss of the device under test can be obtained. The heat transfer medium can be air, water or another fluid.

However, it is not so easy to measure a mass flow accurately. This mass flow measurement can be substituted by a temperature rise measurement together with a given known power in a dissipating resistor. The easiest implementation for low powers it to use air as a moving fluid.

Fig. 7 Flow calorimeter principle

$$P = \dot{m} \cdot c_p \cdot Td \qquad (2)$$

$$Td = T_2 - T_1 \qquad (3)$$

Where T_1 the temperature before the DUT. T_2 , the temperature after the DUT and Td the temperature difference. The c_p of air is quite independent of the air temperature and is 1.006 KJ/kg·°C at 30°C

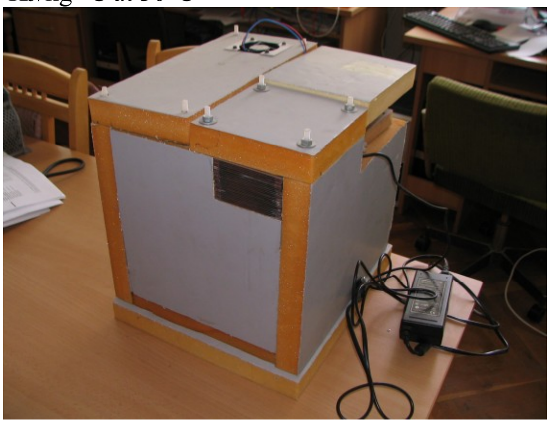

Fig. 8. Constructed calorimeter

The temperature measurements and the dissipating resistor for the flow stabilization are located in a labyrinth path. This labyrinth structure improves the mixing of the air in order to measure average temperatures and to hide the sensors for infrared light coming from the device under test or the hearing resistor. The fan is a brushless DC type, which is easy to control by the input voltage. The mass flow is stabilized to a constant 5K temperature rise. At the inlet, a stack of iron sheets is used to make a thermal low pass filter to reduce the micro temperature changes, which are present in the usual rooms.

D. Thermometers

Most of the properties of the magnetic materials depend on the temperature. This is especially true for ferrites, which have very strong dependence of power losses versus the temperature. In order to have correct and valid measurements the exact temperature must be known. Three different methods for measuring the temperature are used:

Infrared surface temperature measurement

This technique is quite easy to use. Care should be taken to have surfaces with known infrared emission coefficient. Windings should be accessible directly without insulation foil.

Thermocouple measurement

Thermocouples are mechanically and thermally robust and not subjected to self-heating. The temperature range of a thermocouple is more than large enough: -200°C to +1250°C. The thermocouples however, use a very low voltage and are subjected to disturbances of the power converter, so that the measured values are sometimes not valid during operation of the converter. This method is used to find the infrared emission coefficient.

Alchol or mercury thermometer measurement

This is the simplest of all methods and the one with 100% protection from EMI. The disadvantage is that only the fluid temperature can be measured. This method is used only for verification of the air temperature inside the thermal chamber.

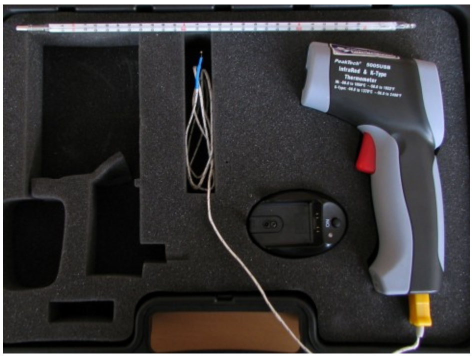

Fig. 9. Infrared thermometer with the thermocouple and the alcohol thermometer.

E. Function generator

We use two different function generators HP - 8116A and Protek 9205C. One of the requirements is the ability to change the duty ratio in the range 5-50%.

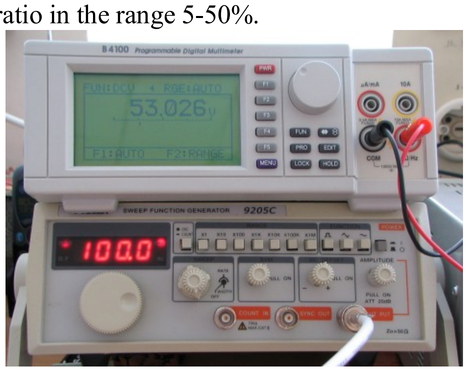

Fig. 10. Function Generator with the precision multimeter

F. Power supply and Heater

We use two different power supplies, one for powering the control module and protection (15V/3A) and another one for powering the platform and performing the power loss measurements (500V/10A).

An air heater with thermal chamber is used to heat up the materials under test to the desired temperature.

Fig.11 Power supply Siemens - 500V/10A

III. Applications of the Set-up

The proposed setup is tested with several magnetic materials: Ferrites [5] - 3F3, N67, N87; Nanocrystalline [6, 7] – Vitroperm 500F, Finemet F3CC.

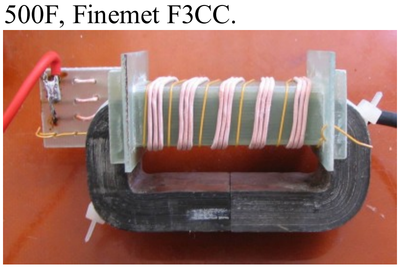

Fig. 12. Nanocrystalline material – Finemet, core F3CC016B

Different duty ratios are realized (5-50%), thus providing complete information for the behavior of the investigated material Vitroperm 500F

The results from the carried out measurements are shown in the next table.

TABLE I
RESULTS FROM THE MEASUREMENTS OF NANOCRYSTALLINE CORE VITROPERM 500F 50X40X20 W516-02, FULL BRIDGE - 100KHZ, B=0.100T, ROOM TEMPERATURE

Duty	Uin	Up-p	Ip-p	P	Pspecific
%	*V*	*V*	*mA*	*W*	*kW/m3*
50	16.5	39.1	117.8	0.397	37.0
45	17.9	43.8	121.9	0.443	41.3
40	19.8	49.3	128.8	0.493	45.9
35	22.0	54.4	136.6	0.541	50.4
30	25.2	66.2	149.1	0.608	56.7
25	29.7	81.2	166.4	0.692	64.5
20	36.1	96.7	186.5	0.799	74.5
15	47.2	120.2	215.0	0.962	89.7
10	69.3	184.8	309.0	1.292	120.5
5	131.1	370.4	356.3	1.954	182.3

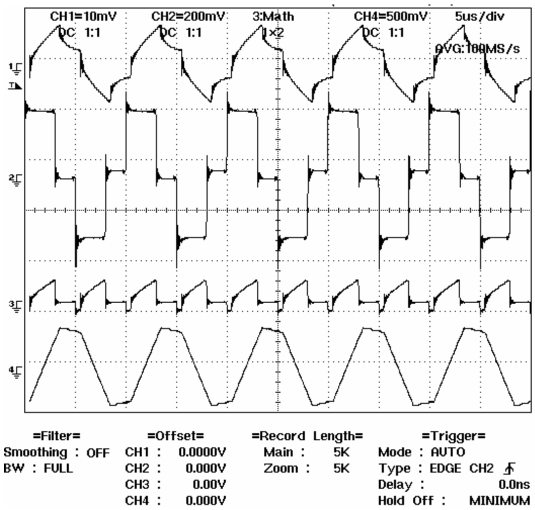

Fig. 13. Captured waveforms

IV. Conclusion

In this paper a complete set-up is presented intended for measurements and tests of magnetic materials and components under quite wide frequency and waveforms conditions. Specialized wideband oscilloscope probes are constructed. The results from the oscilloscope measurements are verified by calorimetric ones. Applications and experimental results obtained by using the set-up are shown in the paper.

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References

[1] Vencislav C. Valchev, Georgi T. Nikolov, Alex Van den Bossche, Dimitre D. Yudov, "Power losses and Applications of Nanocrystalline Magnetic Materials", ICEST 2007, 24-27 June, 2007, Ohrid, Macedonia, pp. 731-734.

[2] Van den Bossche A., D. Van de Sype, V. C. Valchev, 'Ferrite Loss Measurement and Models in Half Bridge and Full Bridge Waveforms', *Power Electronics Specialists Conference, PECS'05*, Recife, *Brasil*, June 12 -16, 2005, pp.1535-1539.

[3] Van den Bossche A., D. Van de Sype, V. C. Valchev, 'Flow calorimeter for Equipment Test', *IEEE Industry Electronics Society Annul Conference, IECON'05*, 2005, *North Carolina, USA*, pp. 860-864.

[4] Van den Bossche A., T. A. Filchev, V. C. Valchev, D. D. Yudov,, 'Test Platform for Resonant Converters', 10th European Power Electronics and Applications Conference, *EPE'03, Toulouse, France*, 2-4 September 2003, cd-rom.

[5] Philips, "Data handbook: Soft-ferrite and accessories", Book MA01, Philips components, magnetic products, 1998.

[6] Hitachi Metals, Ltd., Nanocrystalline soft magnetic material "FINEMET®", 2005

[7] Vacuumschmelze GmbH & Co. KG., *Cores and Components, Databook* (2000).