Journal of ELECTRICAL ENGINEERING, VOL 61. NO 7/s, 2010, 137-140

MAGNETIC PROPERTIES OF TYPES OF CORE FOR TOROIDAL TRANSFORMERS MADE FROM THIN LOW-LOSS SHEETS AND THERMAL INFLUENCE ON RESULTING TRANSFORMER IDLE CURRENT

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The paper presents the results of independent experimental analysis aimed at determining the magnetic properties of the selected type of toroidal transformer cores made from thin silicone alloyed sheets with a low loss number used in our case in the manufacture of toroidal transformers for higher class audio power amplifiers. Another part of the paper deals with the results of the experimental analysis aimed at determining the effect of temperature on size and type parameters of the current loading of small toroidal and conventional transformers. The aim of this measure was to assess the effect of temperature and voltage values at no load current of the selected type of toroidal and conventional transformers put in a climatic chamber. Furthermore, our attention was drawn to the observations of the effect of temperature and magnetic saturation on voltage transformer cores and to approximate formulation of magnetic properties of metal core type transformers in the form of BH hysteresis characteristics.

The samples were analysed and the waveforms U_{10}, I_{10}, U_{20} were measured and recorded. The measured values were then used for calculation of additional quantities of toroidal transformers (magnetic flux density, magnetic field intensity) that specify the magnetic properties of the measured samples. Finally, the measured results of both the toroidal and conventional transformers were compared.

The temporal analyses of saturation of cores are the outcome of extensive and time-consuming measurements and registration of signals in no-load state for various levels of supply voltage. The measurements were based on common knowledge of the properties of soft ferromagnetic materials.

Keywords: toroidal transformer, idly current, *BH* characteristics, climatic chamber, temperature

1 INTRODUCTION

The aim of this exploratory analysis was to assess the effect of temperature and voltage values of the selected type of toroidal and conventional transformers under no load condition, *ie* for no-load current. The influences of temperature and voltage values of magnetic toroidal transformers were then described and theoretical findings were verified.

The samples were analysed and waveforms U_{10}, I_{10}, U_{20} were measured and recorded. The measured values were then calculated for other quantities of the toroidal transformer characterizing the magnetic properties of measured samples (magnetic flux density, magnetic field intensity).

The final part deals with the implementation of the comparison of the measured results for the toroidal and current transformers.

During actual measurements, the knowledge of ferromagnetic properties of soft magnetic materials used for production of transformer cores was employed.

2 THEORETICAL PART

2.1 General and brief notes to the given issue

An idle transformer is characterized best by its idle current. The size and shape of the current describes substantially the resulting properties of design, structural and magnetic characteristics of the transformer core material. In the known geometric dimensions and parameters of the transformer windings, the timing of this current together with the induced voltage signal can then be used for the analysis of magnetic parameters and ratios of magnetic core transformer. Such an analysis can then be used both for determination of the magnetic properties of the metal core and for the control analysis of the resulting saturation and losses as a result of the design and construction of the transformer.

2.2 Calculation of values in the idle state

The test sample 92 902-P1S4 CD 5× the power supply voltage 235 V:

- number of turns in primary winding N_1= 1300
- number of turns in secondary winding N_2 = 66, (U_{20} = 11.68 V)
- amplitude of idle current I_{10} = 0.0118 A, (U_{10} = 235 V)
- sample size 92 × 50 × 25 mm

Magnetic field strength of the sample

$$l_{mean} = 2\pi\frac{(r_2+r_1)}{2} = 2\pi\frac{(4.6+2.5)}{2} = 22.3 \text{ cm} \tag{1}$$

$$H_m = \frac{F_m}{l_{mean}} = \frac{N_1 I_{10}}{l_{mean}} = \frac{1300\times 0.0118}{0.223} = 68.78 \text{ A/m} \tag{2}$$

Magnetic induction field of the sample

$$S = v(r_2 - r_1) \tag{3}$$

$$S = 2.5\times(4.6-2.5) = 5.25 \tag{4}$$

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ISSN 1335-3632 © 2010 FEI STU

$$U_i = N_2 \frac{d\Phi}{dt} = N_2 \frac{d(BS)}{dt} = N_2 \frac{SdB}{dt} \Rightarrow dB = \frac{u_i dt}{SN_2} \qquad (5)$$

3 EXPERIMENTAL PART

In all, four toroidal transformer samples supplied by Talema s.r.o. were used for measurements.

These transformers were intended for power audio-amplifiers in higher classes.

These transformers were placed in climatic chamber Vötsch 4018 for measurement.

Following samples were used for measurement:

92 902 – P1S4 CD 5×, supply voltage 230V (small transformer)

92 166 – P2 S6 DGR 1053/3, supply voltage 230V (middle-size transformer).

(a) (b)

Fig. 1. Example of individual samples: (a) - TR1A/B small, (b) - TR2A/B middle-size

The cores were made of the same material and with the same production technology. But they had different final technological finish.

The core transformer 1A was subject to a thermal finish and varnished, the other cores are not treated for final production.

Fig. 2. Example of measured core samples 1A/1B

Both of these cores were winding of electrical sheet made by ORB Steel Cogent, type M111 with a thickness of 0.30 mm, maximal loss of 1.11 W/kg.

The following samples were used for further measurement:

(a) TR1 – 230/24V; 160VA
(b) TR2 – 230/24V; 22VA
(c) TR3 – 230/18V; 10VA
(d) TR4 – 230/15V; 3VA

This is the standard employment of transformers for various applications. The objective of these measurements on the transformers is, in particular, from the current value of nothing. Subsequently, these values are compared with the results measured on toroidal transformers designed for power audio amplifiers of a higher class.

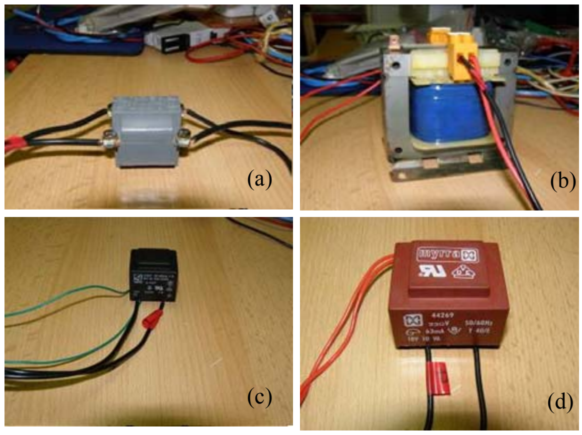

Fig. 3. Example of individual samples

3.1 Design and preparation of the workplace

To analyse the effect of temperature on the idle current of selected transformer types, the measuring workplace has been prepared; refer to the block diagram in Fig. 4

The transformers put in climatic chamber had primary and secondary windings brought out to the terminal placed outside the climatic chamber. The individual windings are successively connected to the measuring site, where the required quantities were registered.

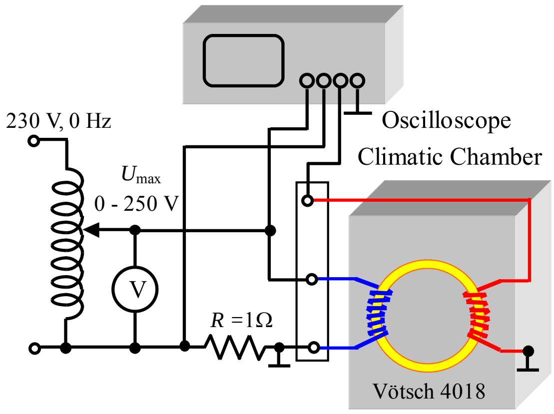

Fig. 4. Experimental setup

The power for analysed samples was supplied by an autotransformer and the value of voltage for each type of transformer was adjusted in the range from 50 to 250 V. The individual toroidal transformers were put into the Vötsch VC 4018 climatic chamber.

The climatic chamber was always set to the required temperature before start of each measurement. The temperature set points for the climatic chamber: -40˚C, -35˚C, -30˚C, -20˚C, -10˚C, 0˚C, 10˚C, 20˚C, 30˚C, 40˚C, 50˚C, 60˚C, 70˚C, 80˚C, 90˚C, 100˚C and 120˚C.

After reaching the desired temperature in the chamber, the measured transformers were left at standstill for half an hour so as to reach the temperature stability of the measured transformers and all of their volumes.

4 MEASUREMENT RESULTS

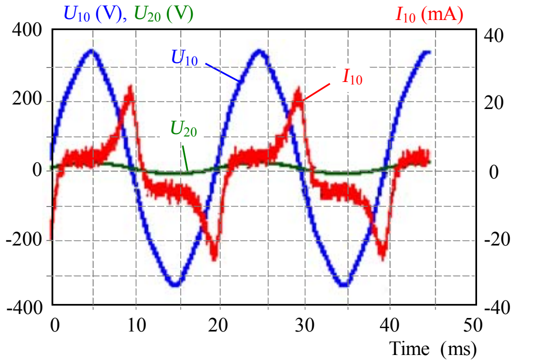

Fig. 5. Samples of resulting U_{10}, I_{10}, U_{20} waveforms for measurements on toroidal transformer, load -40°C, TR1A

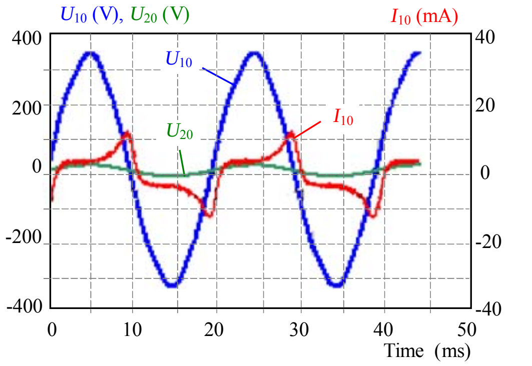

Fig. 6. Samples of resulting waveforms U_{10}, I_{10}, U_{20} for measurements on toroidal transformer at 120°C, TR1A

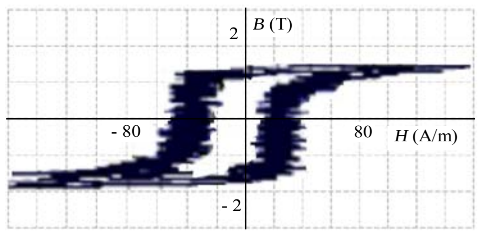

Fig. 7. Samples of resulting waveforms B, $H = f(t)$ for toroidal transformer at U = 235V;-40°C, TR1A

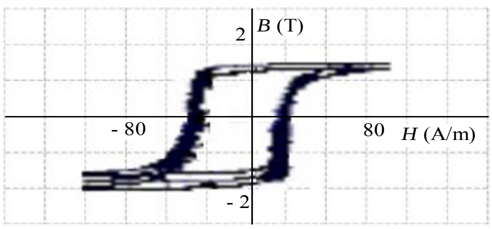

Fig. 8. Samples of resulting B,H =f(t) waveform for measurements on toroidal transformer at U=235V;120°C, TR1A

The records of the idle current signal and the induced primary voltage were performed using a Tektronix digital oscilloscope with GPIB communication interface and PC.

WaweStar v.2.4 was used to convert the readings into a text format and these were then imported into Microsoft Excel to be processed further.

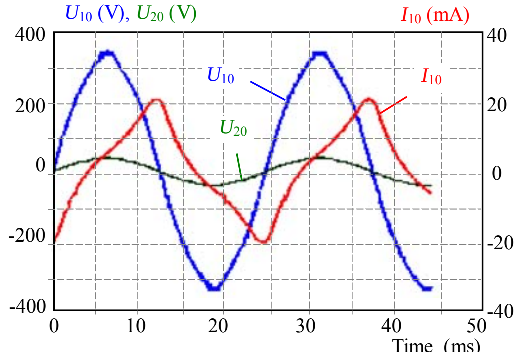

Fig. 9. Samples of resulting U_{10}, I_{10}, U_{20} waveforms for measurements on conventional transformer at-40°C, TR1

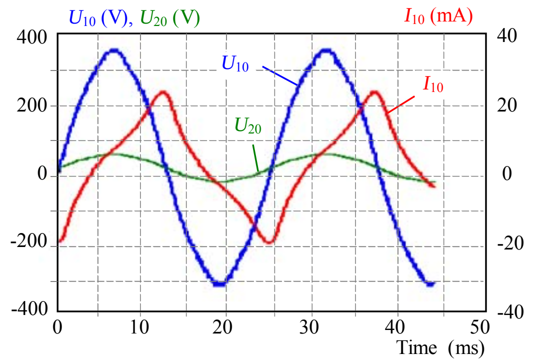

Fig. 10. Samples of resulting U_{10}, I_{10}, U_{20} waveforms for measurements on conventional transformer at 100°C, TR1

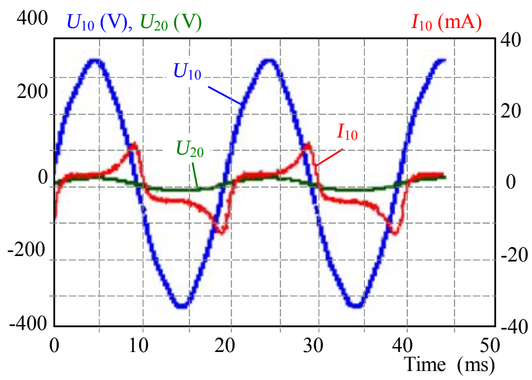

Fig. 11. Unvarnished toroidal core at 120°C,TR1A

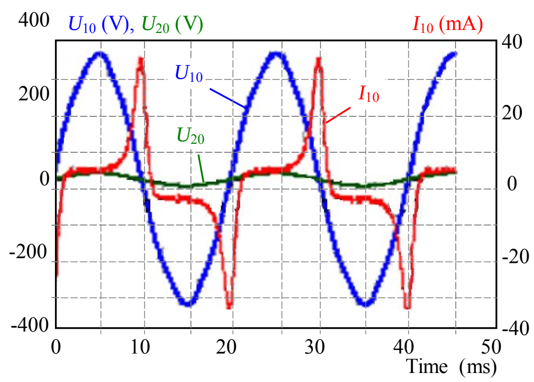

Fig. 12. Varnished toroidal core at 120°C, TR1B

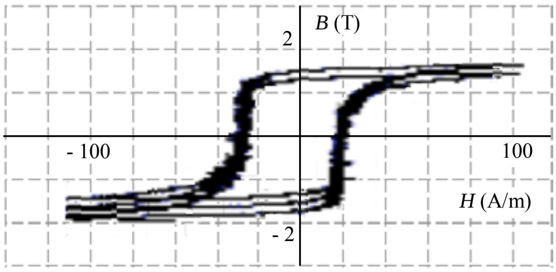

Fig. 13. BH=f(t)-Unvarnished toroidal core at 120ºC, TR1A

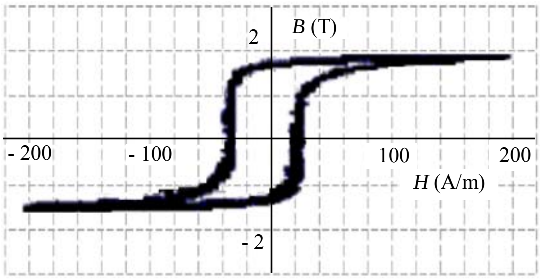

Fig. 14. BH=f(t) Varnished toroidal core at 120°C,TR1B

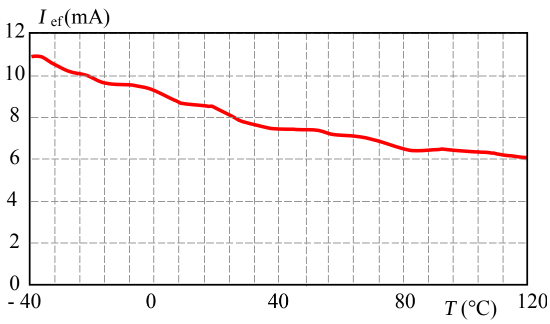

Fig. 15. Influence of temperature on the value of RMS idle current – toroidal transformer,TR1A

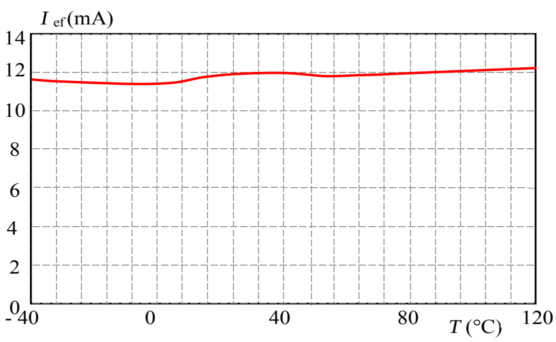

Fig. 16. Influence of temperature on the value of RMS idle current – conventional transformer,TR1

The actual experimental measurements were carried out in the Laboratory of Electrical Machines at the Department of Electrical Machines and Devices

5 CONCLUSION

From the measured results of the analysed samples results that the current load value in the range of set temperature range -40ºC to 120ºC is lower temperature in growing, whilst this effect on conventional transformers was almost imperceptible.

The measured results of the analysed samples indicate that the value of idle current of toroidal transformers in the range of set temperatures -40ºC to 120ºC decreased whereas this effect was almost imperceptible in conventional transformers.

The magnetization of toroidal transformers made from very thin metal sheets with a high maximum permeability value decreased with increasing temperature, the hysteresis loop narrowed down proportionally along with the losses ensuing rom it. This phenomenon can only be explained by a more profound description of the magnetization processes and magnetostrictive effects which were omitted from consideration in this paper.

Besides, it is evident from the measured results that the toroidal transformer denoted as Tr1A showed much smaller value than the sample 1B whereas both of them were made from the same material and with the same dimensions. The resulting difference in behaviour of otherwise identical transformers is given by intentionally different surface finish of the transformer cores. The magnetic core of sample 1A was unvarnished and thermally unhardened while the transformer core 1B was varnished and thermally hardened. The varnishing and hardening processes result in introduction of stress within the core and in enlargement of the transversal air gaps among individual layers of the transformer-core laminations and in deterioration of magnetic properties of all cores, making the idle current to rise.

Change of the transformer winding resistance by changing temperature has no effect on the resulting transformer idling current, because of insignificant value of the winding resistance with regard to high value of the inductive reactance.

As next it is obvious that the effect of temperature on the magnetic properties of the core is negligible with the normal quality of metal sheets. For very thin sheets of toroidal cores is the temperature effect significant due to their high permeability. At low temperatures magnetic properties of sheets turn to deteriorate, the current idling is increasing and at the same time the vibration and noise go up.

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Received 30 September 2010