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Demagnetization of instrument transformers before calibration

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This paper describes the influence of magnetization of an instrument current transformer (ICT) core on ICT errors, and presents a procedure for demagnetizing an ICT. The dependence of ICT errors on the magnetization of the ICT core for different magnetic materials is given in the paper, together with a detailed procedure for ICT demagnetization. The results of experiments are summarized, and conclusions are drawn on when ICT demagnetization is necessary, and on how to prevent the destruction of an ICT due to its winding being punctured.

Keywords: instrument current transformer, AC current, ratio error, phase displacement, magnetization

1 Introduction

Most ICTs are placed in circuits to make electrical energy measurements. ICT parameters must therefore be verified before they are set into operation. ICT verification is usually performed using a comparative method. The ICT under test is compared with a standard [1], [2]. ICT errors may be due to magnetization of their core, induced by the presence of a DC component in the primary current, as described in [3], [4], or by the primary current suddenly being switched off. This particularly concerns ICTs whose errors must correspond to required values in the range of 5% to 120%, or 1% to 120% of the rated primary current I_{R}. Magnetization of the core has a major impact on ICT errors, especially when the measuring currents are less than 10% of I_R. Instrument voltage transformers (IVTs) operate in the range of 80% to 120% of the voltage nominal value U_{R} and with induction in the core of between 0.6 T and 1 T. Their core is therefore demagnetized during operation. Standard ICTs with accuracy of 0.05% or better operate mostly with induction of 0.3 T or less (depending on the core material used), and they may also become partially magnetized relatively easily when the resistance of the secondary ICT winding is measured. This paper describes the procedure for demagnetizing an ICT. It focuses mainly on the demagnetization of standard ICTs before they are calibrated, with reference to the compliance of the insulation levels of the individual windings [5].

2 Errors of instrument current transformers

A detailed derivation of the dependence of ICT errors on the magnetic parameters of the core, its dimensions and the number of turns of the primary and secondary ICT windings can be found in [6]. The derivation is based on the phasor diagram in Fig. 1, which plots the end parts of the phasors of primary magnetomotive force with magnitude $N_1 I_1$ and secondary magnetomotive force with magnitude $N_2 I_2$ where (N_1, N_2 are the numbers of turns of the primary and secondary windings, while I_1, I_2 are the primary and secondary currents). The errors are caused by the magnetomotive force $N_1 I_{\mathrm{m}}$ where (I_{m} is the component of the primary current required to induce magnetic flux density B in the ICT core). According to the phasor diagram, the current ratio error can be expressed as

$$\begin{aligned}\varepsilon_I &= \frac{\Delta I_\varepsilon}{I_1} = \frac{I_{0\mathrm{m}} \sin(\delta+\Psi)}{I_1}\\ \varphi_I &\approx \operatorname{tg}\varphi_I = \frac{\Delta I_\varphi}{I_1} = \frac{I_{0\mathrm{m}} \cos(\delta+\Psi)}{I_1} \qquad (1)\\ &\text{where: } I_{0\mathrm{m}} = \frac{B l_s}{\mu_0 \mu_{\mathrm{a}} N_1}.\end{aligned}$$

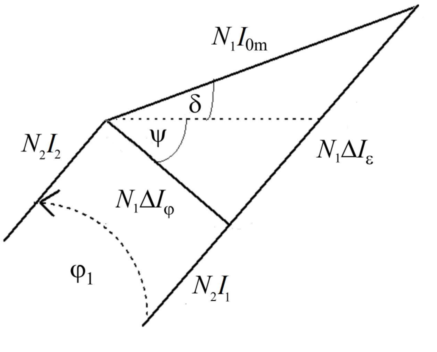

Fig. 1. ICT phasor diagram

The phase displacement (φ_I) may be expressed as in (1) for small enough angles only. Above, l_s - is the mean

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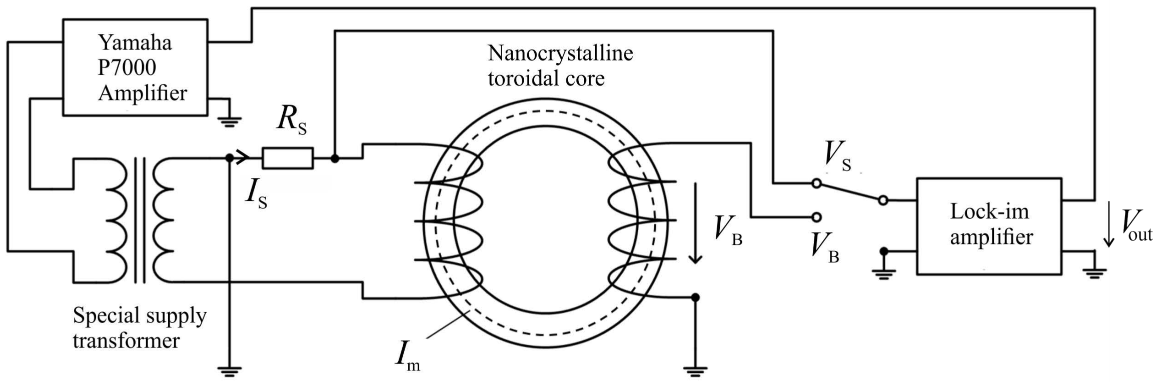

Fig. 2. Layout for measurements of (a) – apparent permeability, and (b) – the loss angle of a toroidal circuit

magnetic path in ICT core, $\mu_0 = 4\pi \times 10^{-7}$ H/mq is the magnetic constant, μ_a - is the apparent permeability pertaining to magnetic flux density B, δ - is the loss angle of the core, and Ψ - is phase displacement due the ICT burden.

Magnetization of the ICT core is the state when a DC magnetic flux is present in the toroidal ICT core at zero magnetic field intensity.

A small alternating magnetic field value induced by a measured current I_1 does not demagnetize the core, and this results in a change in the apparent permeability μ_a and in the loss angle of the ferromagnetic δ. According to (1), this corresponds to the change in the ratio error ε_I and the phase displacement δ_I.

3 Influence of magnetization on the values of the apparent permeability and the loss angle of ferromagnetics

The apparent permeability and the loss angle of ferromagnetics was measured in the layout shown in Fig. 2.

The toroid is magnetized by current I_S at a frequency (f) of 50 Hz from a supply transformer using a power amplifier. The amplifier is excited by the output voltage of the SR830 lock-in generator. The serial resistor $R_S = 0.1\,\Omega$, so the sine-wave magnetic flux density B is ensured with the use of a higher number of magnetizing turns N_1. The lock-in amplifier measures in the mode of voltage measurements V_{1B} or V_{1H} and their phase displacement related to the internal reference of the amplifier. The maximum value of the fundamental harmonic component of the magnetic field intensity H_{1m} can be expressed as

$$H_{1m} = \sqrt{2}\frac{N_1 V_{1H}}{R_s l_s} \qquad (2)$$

where V_{1H} is the RMS value of the fundamental harmonic component, measured by a lock-in amplifier in V_S mode. By measuring the fundamental harmonic component of voltage V_{1B} one can determine the apparent permeability

$$\mu_a = \frac{B_{1m}}{\mu_0} H_{1m} = \frac{V_{1B} R_S l_S}{4.44\mu_0\sqrt{2}V_{1H}N_1N_2fS} \qquad (3)$$

where S - is the cross section area of a (toroidal) core. Further, from phase displacement of measured voltages V_{1H} and V_{1B} one can directly determine the loss angle δ.

The dependence of the apparent permeability and the loss angle in ferromagnetics in demagnetized and magnetized state are shown in Fig. 3 to Fig. 6. The measurements were made for Trafoker and for a newly-used nanocrystalline material.

The results demonstrate that both materials show the effect of magnetizing on the decrease in apparent permeability μ_a, and on the increase in loss angle δ. This results in an increase in ICT errors when measuring small currents (*eg* up to 20% of I_N), when the core material is not demagnetized by the measured current. The influence of magnetizing is evident especially in the Trafoker material, and applies to a much less extent to the nanocrystalline material.

4 ICT errors caused by a magnetized core

Several sources can cause magnetization of the ICT core when it is used in a power network. The source may be magnetization due to a current pulse when there is a lightning strike, or when the measured current is switched off at the moment of the maximum magnitude of the magnetic flux density. The ICT may also be magnetized if its transformation ratio is selected incorrectly, or if the secondary circuit is suddenly disconnected, or if the current is suddenly switched off. In all these cases, the core remains magnetized to the value of the remanent magnetic flux density B_r on the dynamic hysteresis loop. The B_r value depends on the magnitude of the measured current and the shape of the dynamic hysteresis loop. If the measured current is small (*eg* 10% I_N), switching off need not be reflected in ICT errors. An example of the magnetizing effect of an ICT with a Trafoker material core is shown in Fig. 7 and Fig. 8. The ICT was magnetized to saturation by a DC current of 15 A into its secondary winding for 10 seconds. Then the current was gradually lowered to zero.

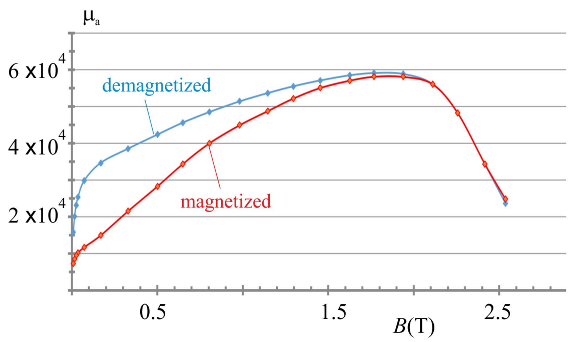

Fig. 3. Dependence of apparent permeability μ_a versus magnetic flux density B, material trafoker

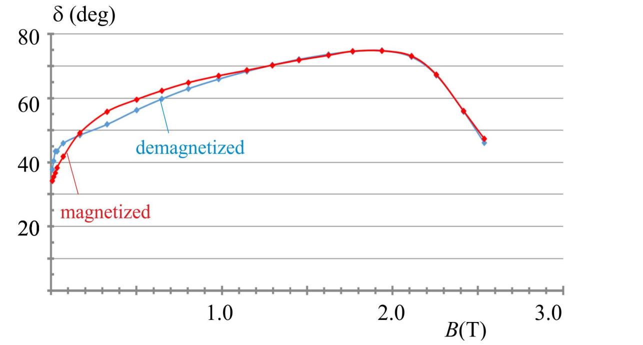

Fig. 4. Dependence of loss angle δ versus magnetic flux density B, material trafoker

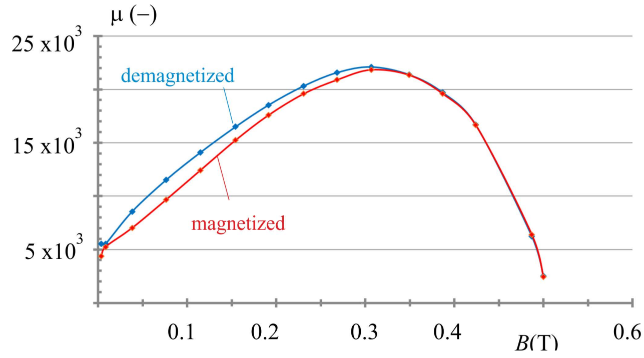

Fig. 5. Dependence of apparent permeability μ_a versus magnetic versus magnetic flux density B, nanocrystalline material

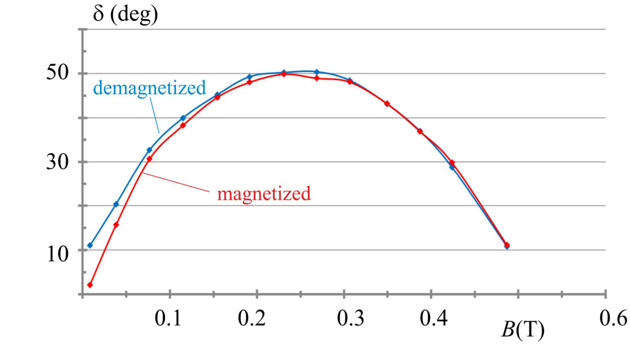

Fig. 6. Dependence of loss angle δ versus magnetic flux density B, nanocrystalline material

5 ICT demagnetization

The procedure recommends demagnetization of each ICT before it is calibrated. For different types of transformers, demagnetizing takes different lengths of time, because different current values are set. In standard verifications, an ICT is demagnetized when its errors are significantly different from the values specified by the manufacturer, or if its errors with a constant measured current are unstable. The demagnetization procedure is shown in the layout in Fig. 9. Two ICT windings are used.when demagnetization is carried out. Generally, the secondary winding N_S (or the winding with the biggest number of turns) is fed by demagnetization current I_S. Other ICT windings must be open, or must be loaded in such a way that the current passing through these winding is less than 1 mA.

5.1 Setting maximum magnetic flux density B_{max} in the ICT core

The maximum magnetic flux density B_{max} in the core is adjusted by increasing the magnetizing current I_1. When B_{max} is reached, it is indicated on primary winding N_B with a smaller number of turns. Excessively high induced voltage is lowered using the divider formed by resistors R_1 and R_2, which is designed in such a way that current $I_2 \leq 1$ mA. The saturation is reflected on an oscilloscope by a distortion of the harmonic course with a significant increase in the peak value. This indication is, however, only indicative. Better precision of the saturation indication can be achieved using the V_2 voltmeter, which is set to measure the arithmetic mean value of the U_{2m} voltage according to

$$B_{max} = \frac{U_{2m}}{4fSN_B} \tag{4}$$

where N_B - is the number of turns of the picking winding.

Saturation of the material is indicated when the magnitude of current I_1 increases and the mean value U_{2m} of voltage U_2 does not change, or the changes are very small. When current I_1 is increased by 10% of its existing value, voltage U_{2m} increases by less than 1% of its actual value.

5.2 Procedure for ICT core demagnetization

Demagnetization is performed in 3 steps. The first step is carried out with short-circuited resistors R_{S1} and R_{S2}, and current I_1 is set to achieve saturation of the ICT core. This means that voltage U_{2m} must be reached. Simultaneously, the effective value of current I_1 is measured so that the current loading of the winding N_H and the effective value of the voltage U_1 are not exceeded. The second step is performed by setting the value of resistor R_{S1} in such a way that half the value of magnetic flux density B_{max} is reached. This corresponds to voltage $U_{2m}/2$ at the same voltage U_1 of the source as in the previous step.

In the same way, resistor R_{S2} is set in such a way that the voltage of U_1 corresponds to the mean voltage $U_2 = U_{2m}/10$. After R_{S1} and R_{S2} have been set

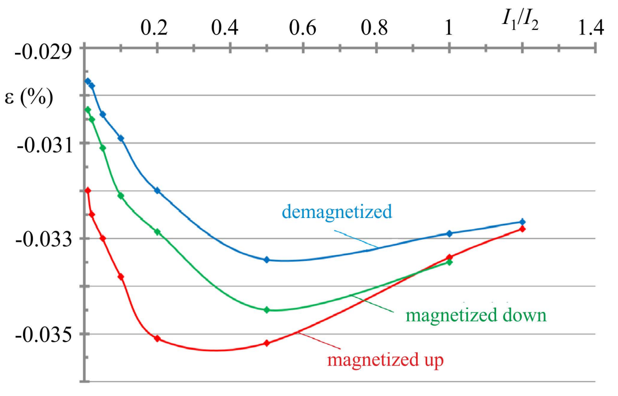

Fig. 7. Ratio error ε_I of an ICT with a trafoker core (ratio $I_{1N}/I_{2N}=4$, real burden $Z = 15$ VA) as a function of the applied primary current I_1 (measured in demagnetized state from 120% I_{1N} to zero and by magnetization up to remanence B_r from zero up to 120% of I_{1N})

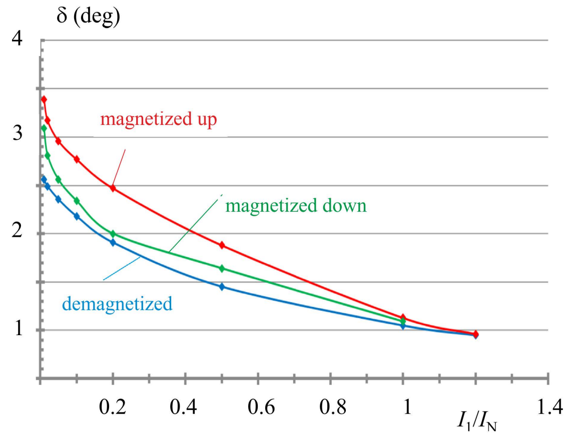

Fig. 8. Phase displacement δ_I of an ICT with a trafoker core (ratio $I_{1N}/I_{2N} = 4$, real burden Z=15 VA) as a function of the applied primary current I_1 (measured in demagnetized state from 120% of I_{1N} to zero and by magnetization up to remanence B_r from zero up to 120% of I_{1N})

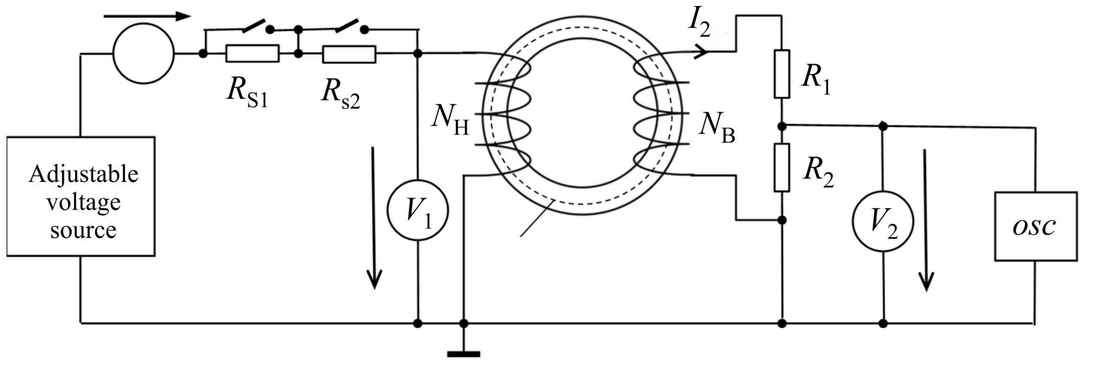

Fig. 9. Layout for ICT demagnetization

to the required values, demagnetization is gradually repeated in the steps described above. The same setting of the controllable voltage source U_1 enables a very slow and smooth decrease in the second and third step to the zero point of current I_1. Thus careful demagnetization is achieved.

6 Conclusion

- It is clear from the results that ICT magnetization always causes errors if the measured current lies in the area of (2 to 20)% of its nominal value, as the measured current does not demagnetize the ICT core.
- ICTs of accuracy class 0.2 or of accuracy class 0.5 mostly have cores made from a silicon steel, and they are designed in such a way that when 120% of rated current In is reached, the ICT is demagnetized, and not magnetization appears when it is being calibrated.
- ICTs of accuracy class 0.1 and better (laboratory and standard ICTs) usually have cores made from a high-quality soft magnetic material, and is not safe to demagnetize them by applying a measured current. It is therefore recommended to use the procedure described here, and to demagnetize their cores in three steps before they are used or calibrated.
- When demagnetizing, it is necessary to measure the voltage on the open winding with the largest number of turns in order to prevent it breaking down, and to prevent destruction of the transformer. For unloaded secondary windings, the peak output voltage must not exceed 4 kV.

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