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One option to determine electrical parameters of measuring transformers

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Abstract. *One challenge during the production, repair or even standard maintenance of measuring transformers is the use differential zero apparatus devices, which are costly and require second heavy current transformer with high class accuracy. To tackle this industry cost, while keeping robustness, this work focuses on presenting a method for automatic measurement of current transformer errors by personal computer and digital oscilloscope. The mathematical basis and an example program algorithm for the measuring process are also shown.. The principal electrical scheme of the worked out device is described. Finally, a validation experimental study is performed, the results are displayed and analyzed showing a good agreement with the reference zero apparatus device.*

Keywords: angle error, current error, current transformer, digital oscilloscope

1 Introduction

The current measuring transformer (CT) errors are essential for ensuring accuracy in transformer, their production, maintenance and daily usage. Traditionally, this process relies on differential zero apparatus devices, which require a high-precision second reference measuring transformer. While effective and very accurate, these methods are expensive, heavy and add complexity to testing procedures. This work proposes an automated approach to measuring CT errors using a personal computer and a digital oscilloscope, reducing costs while maintaining measurement robustness. The methodology is based on simple mathematical analysis, eliminating the need for additional reference transformers and their corresponding drawbacks. (Ernest, 2022), (Alessandro. 2020), (Ernest, 2022).

This works is structured as following – First, a detailed mathematical foundation and an example algorithm for the measurement process are presented, together with an example principal electrical scheme in Section 2-3 and the algorithm in Section 4. Last, in Section 5 an experimental study compares this approach to measuring values obtained from a standard differential zero apparatus and from their the conclusions are drawn. (Bessolitsyn,2017), (Sanlei, 2023), (Hongsen, 2024).

2 Background of Current Transformers

2.1 Current error ε_I

Represents the arithmetic difference between the actual secondary current and the primary current fed to the secondary circuit, expressed in percentages of the primary current fed into the secondary circuit. (Michal, 2022), (Bing, 2021), (Michal2020)

Current error $\varepsilon_{I\%}$ is defined by the formula:

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$$\varepsilon_{I\%} = \frac{I_2 - \frac{I_1}{K_I}}{\frac{I_1}{K_I}} .100 = \frac{K_I . I_2 - I_1}{I_1} .100\% \tag{1}$$

where:

I_2 - is the effective value of the current in the secondary circuit;
I_1 - is the effective value of the current in the primary circuit;
$K_I = \frac{\omega_2}{\omega_1}$ is the transmission factor determined by the condition $I_1 . \omega_1 = I_2 . \omega_2$
ω_2 - is the number of windings in the primary chain;
ω_1 - iz the number of windings in the secondary chain.

2.2 Angle error δ_I

The angular error is defined as the angle between the vector of the primary current and the vector of the secondary current rotated (phase shifted) π-radians. This occurs because the secondary current does not align exactly in antiphase with the primary current caused by the losses and the phase shift effects. The angular error is in the time range from 2 min to 120 min depending on the device accuracy class and the load. (Enrico, 2017), (Wath, 2016). The angular error is positive when the secondary current vector leads the primary current vector by 180°.

$$\delta_I = \frac{I_0}{I_1} \cos(\psi + \varphi_2) \tag{2}$$

where:

$\psi -$ angle of losses in the magnetic conductor:
$\varphi_2 -$ phase shift angle between current and voltage in the secondary circuit.

The errors of the current transformer depend on its magnetizing current I_0 :

$$I_0 = \frac{I_I\, \omega_1 + I_2 \omega_2}{\omega_1} \tag{3}$$

3 Proposed Testing Circuit

The proposed circuit diagram (see Fig. 1) includes an inductance L_1, load resistors R_1 and R_2, studied transformer CT and digital oscilloscope Velleman PC SCOPE PCS 500. A signal proportional to the current in the primary circuit is obtained as a voltage drop on R_{m1}, a of the secondary current on R_{m2}. The shunt resistors have parameters: R_{m1} - 600A, 60mV; R_{m2} - 15A, 60mV.

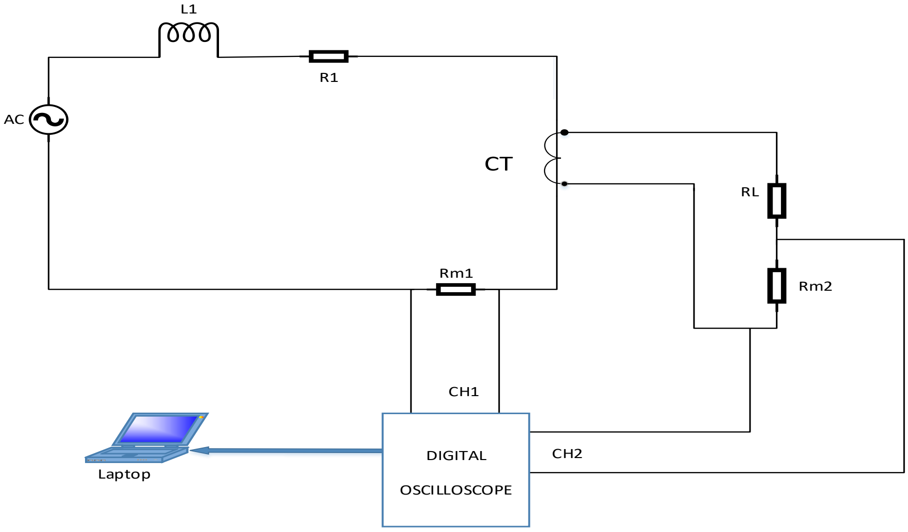

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Fig.1. Circuit diagram scheme for current transformer testing

The measurement of the voltage drops on R_{m1}, R_{m2} are stored in the memory of the personal computer. They are transformed as an oscillogram and in a discrete digital form. There are 500 samples stored for both channels per period. For the measurement, a software script was developed, which runs as the following sequence described in Section 4.

In the steady-state operation, the results for voltage drops on the shunt resistors are recorded. The measurements are performed at the following settings of the digital oscilloscope TIME/DIV-20ms,VOLT/DIV-15mv. In this case for 20 ms we have 125 reports.

4 Algorithm for determining the current error

4.1. Setting the maximum values $UR_{m\ 1\ max}$ и $UR_{m\ 2\ max}$

4.2. Setting the minimum values $UR_{m\ 1\ min}$ и $UR_{m\ 2\ min}$

4.3. Determining the range of voltages

$$U_{wing\ 2} = UR_{m\ 2\ max} - UR_{m\ 2\ min} \tag{4}$$

$$U_{wing1} = UR_{m\ 1\ max} - UR_{m\ 1\ min} \tag{5}$$

4.4. Determining of amplitude values of both voltages

$$U_{m1} = \frac{Uwing1}{2} \tag{6}$$

$$U_{m2} = \frac{Uwing2}{2} \tag{7}$$

4.5. Determining of the levels of the zeros of both voltages

$$U_{01} = U_{m1} + U_{Rm\ 1min} \tag{8}$$

$$U_{02} = U_{m2} + U_{Rm\ 2min} \tag{9}$$

4.6. Determining instantaneous voltage values of every measurement i

$$X_{i1} = |U_{i1} - U_{01}|_i \qquad i=[1:125] \tag{10}$$

$$X_{i2} = |U_{i2} - U_{02}|_i \qquad i=[1:125] \tag{11}$$

4.7. Determining of instantaneous current values of every measurement i

$$i_{i1} = Xi1.M1, \text{където } M_1 = \frac{Irm1}{Urm1} \tag{12}$$

$$i_{i2} = Xi2.M2, \text{където } M_2 = \frac{Irm2}{Urm2} \tag{13}$$

4.8. Determining the effective values of the currents in the primary and secondary winding

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$$I_{ef1} = \sqrt{\frac{1}{125}\sum_{i=1}^{125}(i_{1i})^2} \quad (14)$$

$$I_{ef2} = \sqrt{\frac{1}{125}\sum_{i=1}^{125}(i_{2i})^2} \quad (15)$$

4.9. Setting the transmission factor:

$$K_I = \frac{\omega_2}{\omega_1} \quad (16)$$

4.10. Determining the current error:

$$\varepsilon_{I\%} = \frac{K_I.I_2 - I_1}{I_1} x\ 100\% \quad (17)$$

5 Determining the angular error

The main problem in determining the angular error is to measure the phase difference between the primary and secondary currents and its measurement in the unit minutes. Present at the following sequence:

5.1. Determination of the current error according to the algorithm indicated in Section 4.

5.2. Defining a phase-out step

5.3. Determination of the number of phase shift steps

Second similar measurements are carried out at the following oscilloscope settings - TIME/DIV-0.1ms, VOLT/DIV-15mv. In this case we have 125 data samples for 0.1ms. At a frequency of 50Hz the wave period is T=20ms. The step of phase shift X_d between two reports in these settings is determined by the formula:

$$X_d = \frac{360^o.0.1ms}{125.20ms} = 0.0144^o = 0.864\text{min} \quad (18)$$

The digital oscilloscope records 5000 data samples of voltage drops on the shunt resistors U_{Rm1} and U_{Rm2}. At TIME/DIV=0,1 ms data are recorded for duration of 4 ms, or this is equal to 1/5 period T. The number of steps N are determined for the peaks $U_{Rm1\ max}$ and $U_{Rm2\ max}$, $U_{Rm1\ min}$ and $U_{Rm1\ min}$, the zeros of the voltages or the amplitude values.

5.4 The angular error is determined by the formula:

$$\delta_I = N.X_d\ \text{min} \quad (19)$$

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If U_{Rm2} leads U_{Rm1} the angular error is negative, and if U_{Rm1} leads U_{Rm2} the angular error is positive. If greater accuracy is needed, it is possible to work at the range TIME/DIV=50 us.

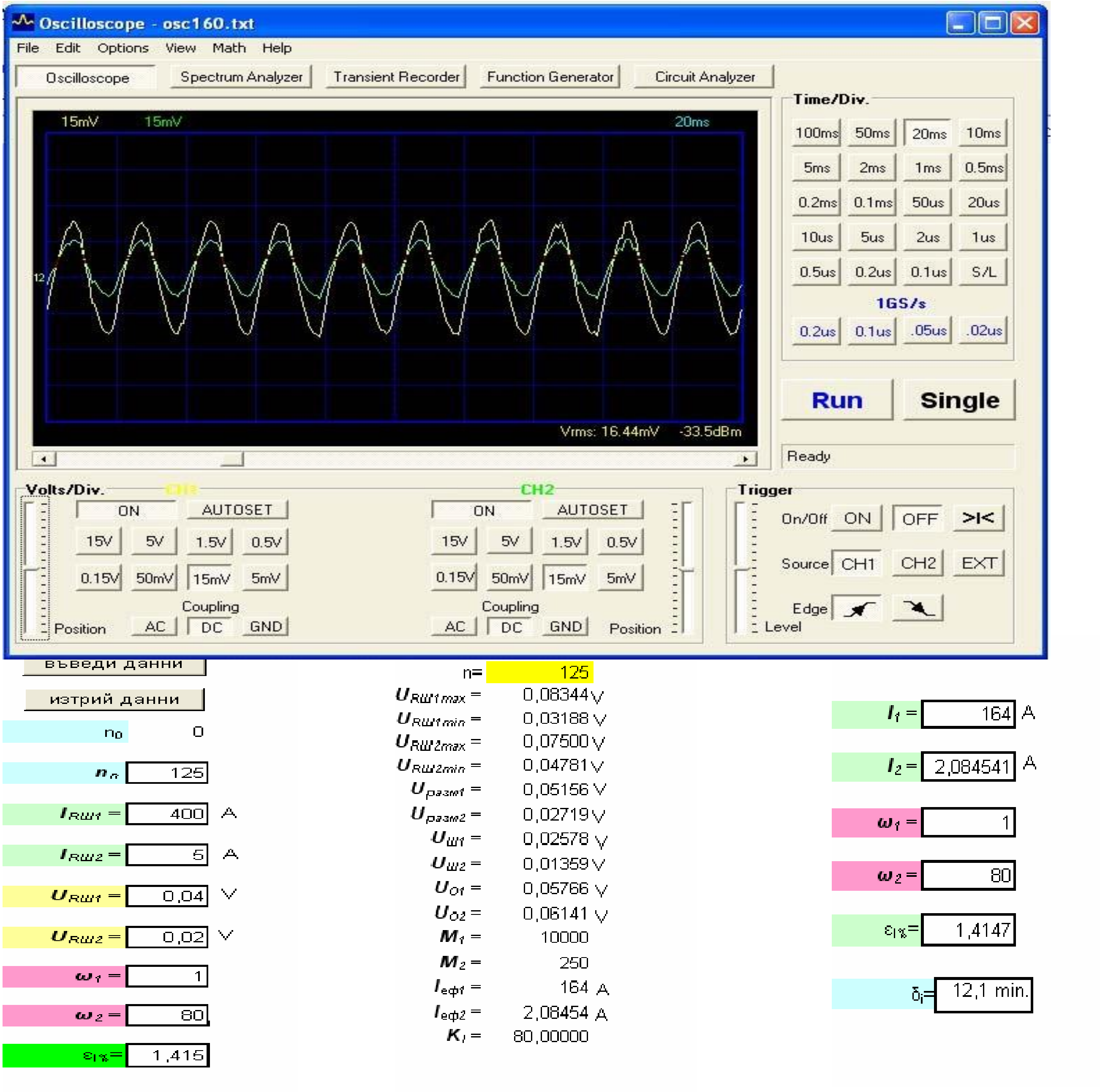

Fig.2. Experimental results 1

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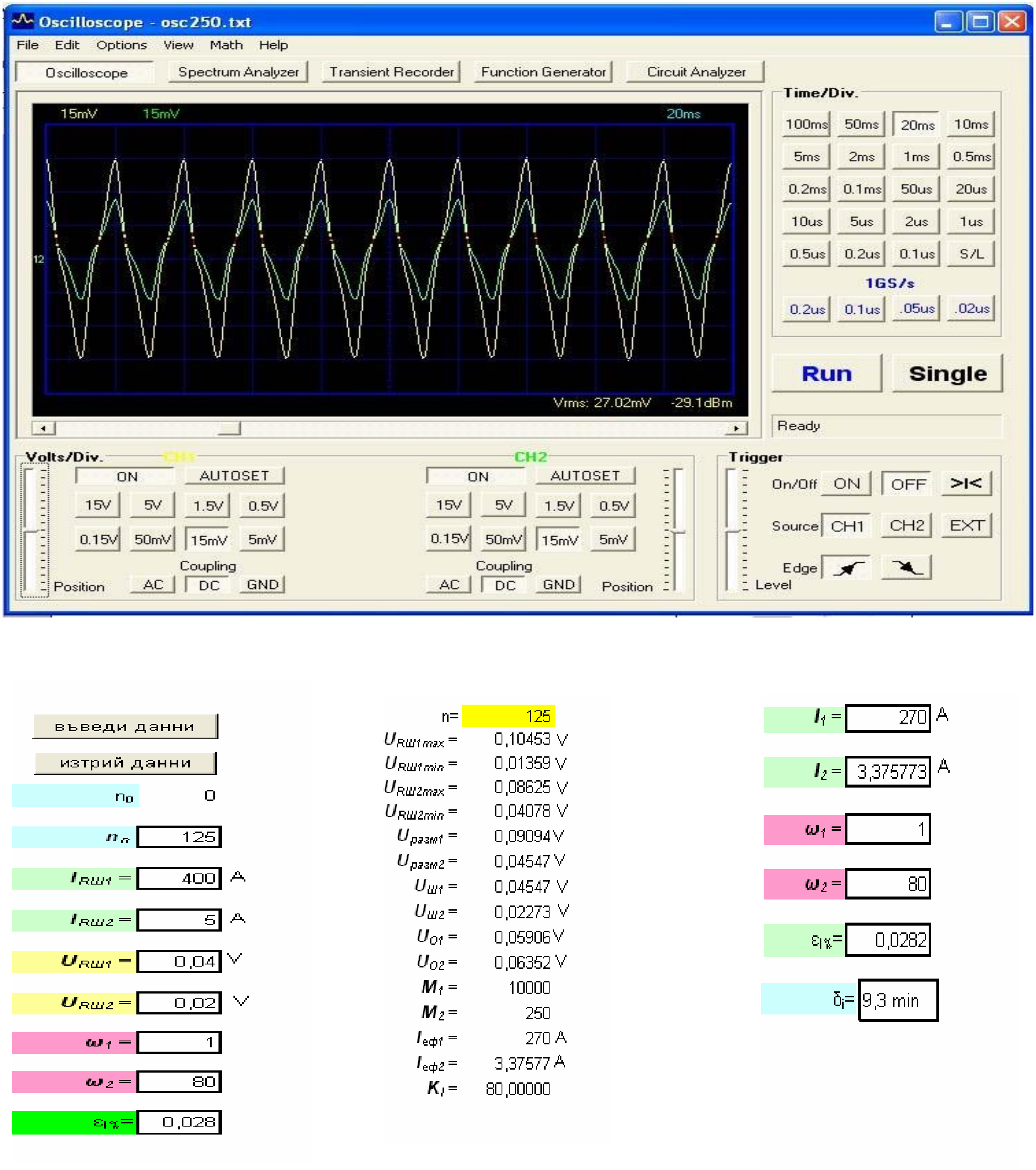

Fig.3 Experimental results 2 with another load

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6 Discussion

The method used to measure the errors of current transformers was compared with a differential zero method, in which the tested transformer is compared with a reference with a high accuracy range. The results showed a deviation for the current error of 4÷9% and for the angular error of 5÷9%.

The method was also checked with accurate ammeters with an accuracy class of 1%. The deviations from the comparisons made for current error were from 5 ÷ 9%.

The obtained comparative results are close to the expected and provide an opportunity for application in manufacturing enterprises, repair workshops and educational institutions.

7 Conclusion

A similar method can be used to measure the electrical parameters of voltage measuring transformers. The existing knowledge on current transformer research has been enriched and a new method for measuring current transformer errors in established mode has been synthesized using a digital oscilloscope and computer method. This method has the following advantages:

1. Good enough accuracy for application in industry and formation
2. Light weight of measuring equipment
3. The measuring process is facilitated, accelerated and energy efficient
4. The method can be applied outside laboratories in production conditions

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