Checks on a Toroidal Compensated Current Comparator with Additional Circuits

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Abstract- Methods for checking the sensitivity of a toroidal compensated current comparator and its inherent errors and auxiliary circuits are described in this paper. Results of the measurements are also given in graphical form.

I. Introduction

The toroidal compensated current comparator (CCC) is a very precise standard for AC current ratio. Its basic layout for instrument current transformer (ICT) calibration with burden ***Z*** is shown in Figure 1.

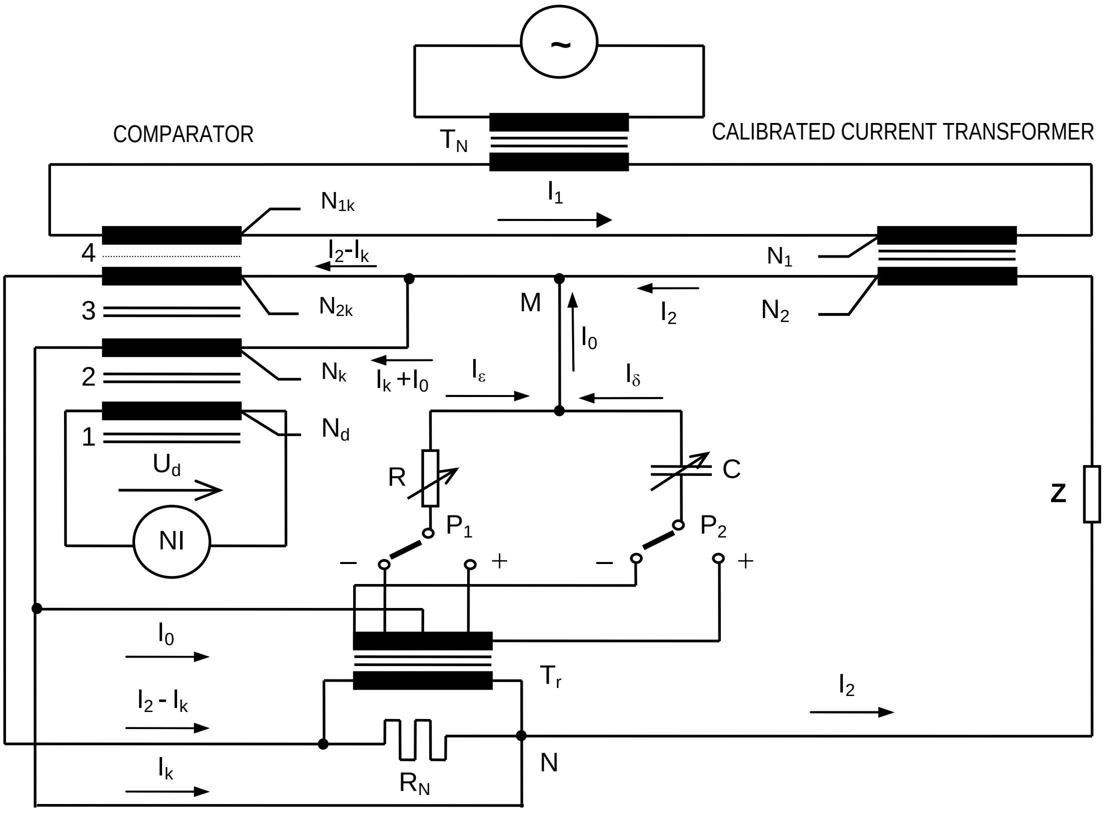

Figure 1. Layout for current transformer calibration using a current comparator

The CCC consists of a system of toroidal cores, where "1" is a detection toroid with a detection winding N_d, "2" is the magnetic shielding of the detection toroid, which decreases the magnetic error of the comparator. Compensation winding N_k is wound on to the magnetic shielding, "3" is the excited magnetic shielding with the primary and secondary ratio windings N_{1k} and $N_{2k,}$ and "4" is the electrostatic shielding between the primary and secondary winding. The magnetic shielding is formed by four toroids placed in such as way as not to form a shading ring. Compensating winding N_k decreases the ICT additional burden, which is represented by the CCC secondary winding N_{2k} and resistor R_N. For ICT turn numbers N_1, N_2 and CCC turn numbers N_{1k} and N_{2k} and compensation winding N_k the following equation must be satisfied

$$\frac{N_2}{N_1}=\frac{N_{2k}}{N_{1k}}=\frac{N_k}{N_{1k}}=\frac{I_1}{I_2}=p_I \qquad (1)$$

where p_I is the transformation ratio of the ICT under test.

ICT and CCC primary windings N_1 and N_{1k} are serially connected and are fed by current $\boldsymbol{I}_1$ from a supply transformer T_N.
If the ratio $\boldsymbol{I}_1/\boldsymbol{I}_2$ differs from the magnitude of the rated transformation ratio p_I (which corresponds to ratio error ε_I) or if the two currents are not in the same phase (which corresponds to phase displacement δ_I), the imbalance of the magnetomotive forces induces a magnetic flux in the detection toroid and voltage $\boldsymbol{U}_d$ in the detection winding. Voltage $\boldsymbol{U}_d$ is indicated by a null indicator NI.
The comparator is balanced by a variable magnetomotive force $N_k \boldsymbol{I}_0$. The current $\boldsymbol{I}_0$ or its components $\boldsymbol{I}_\varepsilon$ and $\boldsymbol{I}_\delta$ are adjusted using resistance decade R and capacitance decade C. The balancing circuit is fed by a voltage drop on resistor R_N matched by transformer T_r. Switching the winding of transformer T_r enables us to balance positive and negative errors. In the balanced state, ratio error ε_I and phase displacement δ_I can, after an adjustment, be expressed as

$$\varepsilon_I = \pm R_N \frac{n_\varepsilon}{n_1}\frac{1}{R}\,100\ \left(\%;\Omega;\Omega\right),\quad \delta_I = \pm R_N \frac{n_\delta}{n_1}\,\omega C\ \ (\text{rad};\Omega;\text{rad}\cdot\text{s}^{-1};\text{F}), \qquad (2)$$

where n_ε/n_1 a n_δ/n_1 are ratio of windings of auxiliary transformer T_r.

In ICT calibrations not only inherent CCC errors and methodological errors, which cannot be simply eliminated, but also errors due to inaccuracy of the elements of the balancing CCC circuit must be taken into account. This concerns standard resistor R_N and auxiliary transformer T_R, which are CCC parts, and also balancing decades R and C connected outside the CCC. According to (2), the relative value of the standard uncertainty u_ε of ratio error ε_I and uncertainty u_δ of phase displacement δ_I can be expressed as

$$u_\varepsilon=\sqrt{u_{R_N}^2+u_{p_\varepsilon}^2+u_R^2}\ ,\qquad u_\delta=\sqrt{u_{R_N}^2+u_{p_\delta}^2+u_\omega^2+u_C^2}\ , \qquad (3)$$

where $u_{R_N}, u_{p_\varepsilon}, u_R, u_{p_\delta}, u_\omega, u_C$ are the relative uncertainties of the individual elements in eq. (2).

Resistor R_N and Transformer T_r are CCC components, and their uncertainties are difficult to check. A ratio error and phase displacement simulation method was therefore designed. This method enables us to check all elements which, according to (2) and (3), influence measured errors and their uncertainties. A method for measuring the sensitivity of a CCC detection circuit and for assignment its inherent error is also described.

II. Checking the parameters of the comparator

The CCC inherent error is checked using a layout similar to that shown in Figure 1. Ratio windings N_{1k} and N_{2k} with the number of turns are series connected and fed by a common current so that the magnetomotive forces subtract. In an ideal case, zero voltage on the detection winding U_d corresponds to this state. In a real state, there are inherent CCC errors, and voltage U_d is not zero. After CCC balancing we obtain from (2) the magnitude of its ratio error ε_{IC} and its phase displacement δ_{IC}. Check on the sensitivity of CCC is carried out when the ratio windings have been disconnected by means of a magnetomotive force induced by a current passing through an additional conductor, which is encircled by the CCC core. The conductor must be fed from a current source in order not to decrease the CCC sensitivity. The sensitivity of the CCC detection circuit is given as

$$S_{KPK}=\frac{U_d}{N_P I_P}\ \ (\Omega, \text{V}, \text{A}), \qquad (4)$$

where U_d is the voltage on the detection winding induced by current I_P ,
N_P number of turns of the auxiliary winding,
I_p current passing through the auxiliary winding.

A check on the CCC additional circuits and the balancing elements is performed using the layout according to Figure 2. Ratio windings with the same numbers of turns $N_{k1} = N_{k2}$ are fed from the variable transformer T_{N1} by a common current $I_1 = I_2$. They are series connected so that their magnetomotive forces subtract. The auxiliary winding N_{aux} is formed by one or four turns. It is fed by a current $\boldsymbol{I}_S$ generated by a power amplifier excited by a signal from a lock-in generator phase locked on the 50 Hz mains. The generator enables continuous amplitude and phase adjustment of current $\boldsymbol{I}_S$, so that errors of both signs and with various magnitudes can be simulated. The value of the simulated ratio error ε_{IS} and phase displacement δ_{IS} is determined from the rectangular components of the phasor of current $\boldsymbol{I}_S$. The components are measured by means a lock-in amplifier, the reference voltage of which is picked-up from standard resistor R_{N2}. The phasor of current $\boldsymbol{I}_S$ is picked up as a voltage drop on standard resistor R_{N1} and is brought in to the lock-in amplifier input. The simulated ratio error and phase displacement can then be expressed as

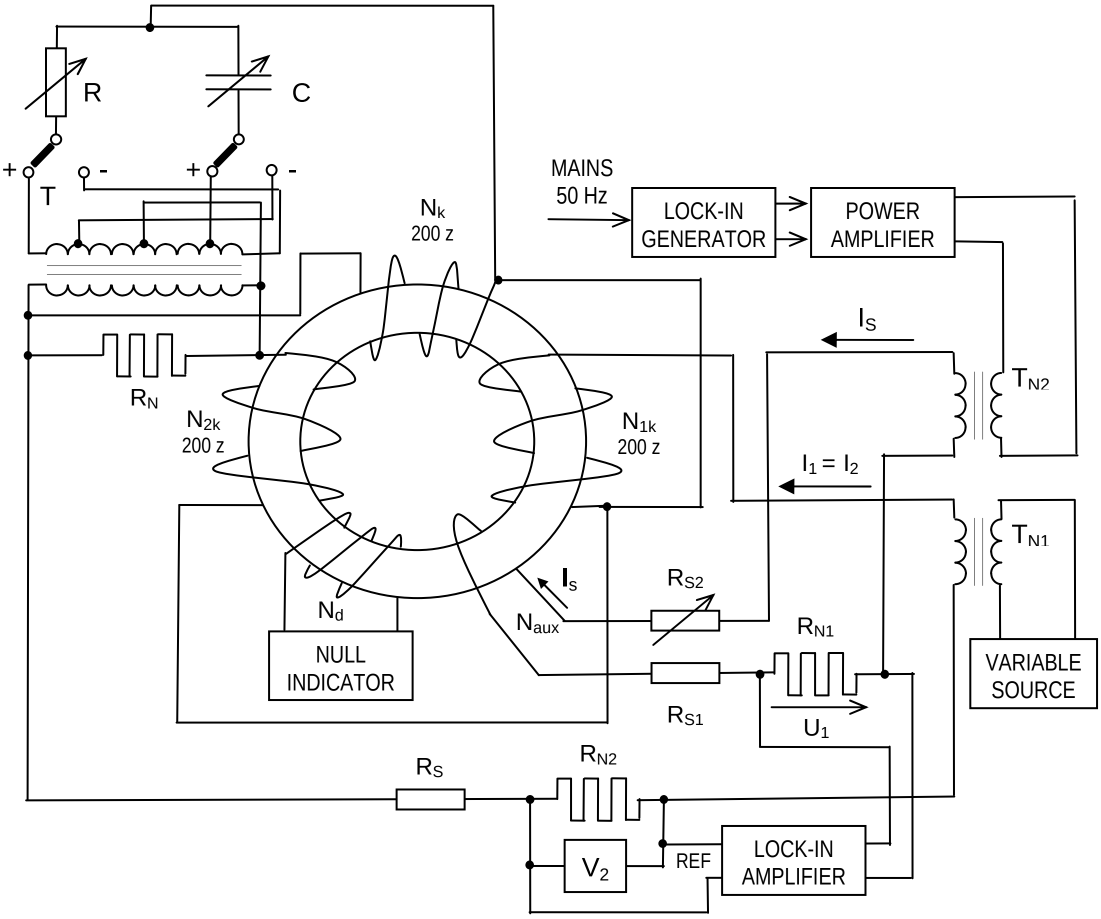

Figure 2. Layout for simulation of ratio error and phase displacement

$$\varepsilon_{IS} = \frac{N_{aux}\mathrm{Re}\left[\boldsymbol{I}_S\right]}{N_1 I_1}100 = \frac{N_{aux}}{N_1}\frac{R_{N2}}{R_{N1}}\frac{\mathrm{Re}\left[\boldsymbol{U}_1\right]}{U_2}100\,,\quad \delta_{IS} = \mathrm{tg}\delta_{IS} = \frac{N_{aux}\,\mathrm{Im}I_S}{N_1 I_1} = \frac{N_{aux}}{N_1}\frac{R_{N2}}{R_{N1}}\frac{\mathrm{Im}\left[\boldsymbol{U}_1\right]}{U_2}\,, \qquad (5)$$

where ε_{IS} is	magnitude of simulated ratio error (%),
δ_{IS}	magnitude of simulated phase displacement (rad),
N_1; N_{aux}	number of turns of primary and auxiliary winding (-),
R_{N1}; R_{N2}	value of standard resistor for measurement of currents (Ω),
$\mathrm{Re}[\boldsymbol{U}_1]$; $\mathrm{Im}[\boldsymbol{U}_1]$	measured real and imaginary component of the voltage U_1 (V).

If CCC and its auxiliary circuits are operating properly, the readings of the measured errors given by (2) must correspond to the readings of the calculated errors according to (5) in the balanced state.

III. Conclusion

The method described here was used for checking the parameters of the compensated current comparator which forms a basic part of the national standard for the AC current ratio at 50 Hz frequency at the Czech metrology institute in Prague. The results of the comparator sensitivity measurement are shown in Figure 3. The graph shows the dependence of the voltage on detection winding U_d versus the additional magnetomotive force $U_\mathrm{m} = NI$. The results show that the output voltage on detection winding $U_\mathrm{dt} = 1$ mV corresponds to deviation magnetomotive force $U_\mathrm{m} = 0{,}73$ mA. At the rated value of magnetomotive force 200 A up to 1 200 A the total relative error in the range ($3{,}65.10^{-6}$ up to $0{,}61.10^{-6}$) corresponds to this deviation magnetomotive force. Owing to that the sensitivity of the used null indicator is 50 nV/division the sensitivity of the comparator is therefore very adequate. The dependences of the inherent ratio error and phase displacement versus the measured current are shown in Figure 4 and 5. The inherent ratio error is clearly smaller than 0.5 ppm and the phase displacement is smaller than 0.01 angle minute. The parameters of the auxiliary circuits were checked in accordance with Figure 2. The relative difference between the simulated and measured ratio error in the range up to ±100 ppm was smaller than 2 %, and for the simulated phase displacement in the range up to ±30 angle minutes the difference was smaller than 1 %.

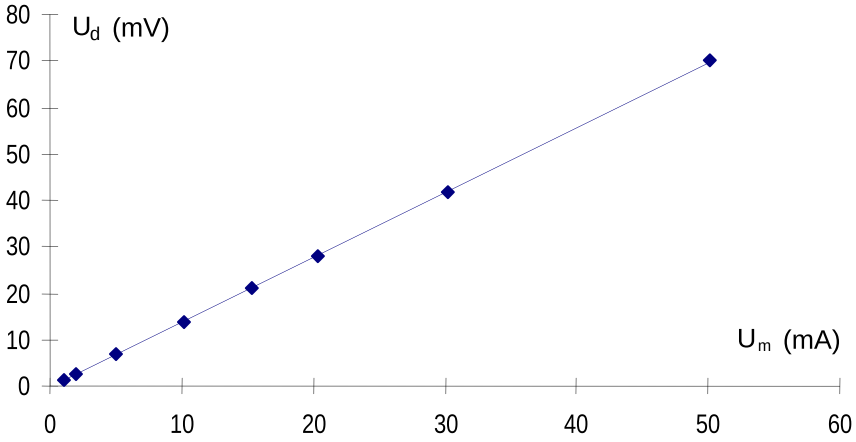

Figure 3. Results of measurement of CCC sensitivity

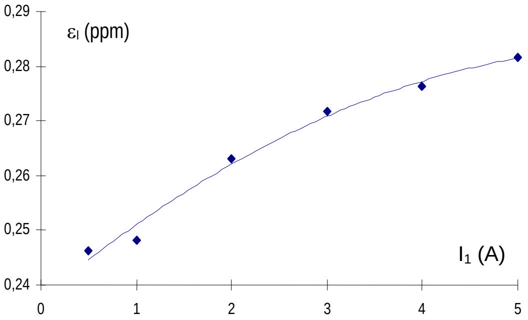

Figure 4. Dependence of inherent ratio error versus measured current

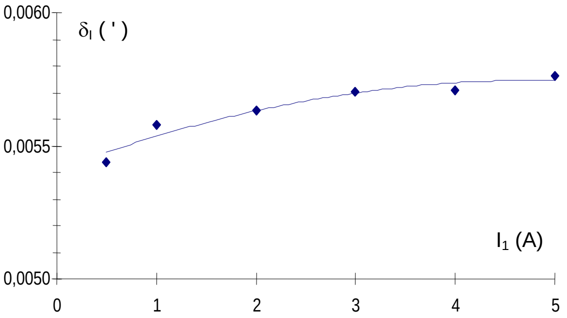

Figure 5. Dependence of inherent phase displacement versus measured current

Acknowledgments

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