CALIBRATION OF ROGOWSKI COILS

Karel Draxler
Czech Technical University
Faculty of electrical engineering
Technická 2
166 27 Prague 6
E-mail: draxler@fel.cvut.cz

Renata Styblíková
Czech Metrology Institute
Laboratory of fundamental metrology
V Botanice 4
150 72 Prague 5
E-mail: rstyblikova@cmi.cz

Abstract: *Calibration method of toroidal sensors for measurement of AC current at 50 Hz and wider frequency range based on Rogowski coil principle is described in the article. The constant determining dependence between output voltage and measured current is checked and also a phase displacement of these two quantities is measured. Analysis of measurement uncertainties is also presented.*

1. Introduction

Use of instrument current transformers (ICT) in protection systems is limited due to supersaturation of their magnetic circuits. Rogowski coils (RC) with toroidal shape with uniformly distributed pick-up winding can replace ICTs in this area. Mutual inductance between the conductor passed by measured current and pick-up winding does not contain any ferromagnetic parts, thus the sensor is linear in wide area of measured currents. The output voltage of RC must be though integrated to determine the magnitude and phase displacement of the measured current. Evaluation electronics must have high input resistance in order so that no error of measurement occurs. Spurious AC magnetic field may cause an error of measurement. Its magnitude depends on perfect fabrication of the toroid and homogeneity of the pick-up winding. The basic parameter of RC is its constant determining at certain frequency the dependence between output voltage and measured current and their phase displacement or its deviation from 90°. Problems of calibration methods of RC and spurious magnetic field influence on RC reading are discussed in the next text.

2. Calibration at 50 Hz main frequency

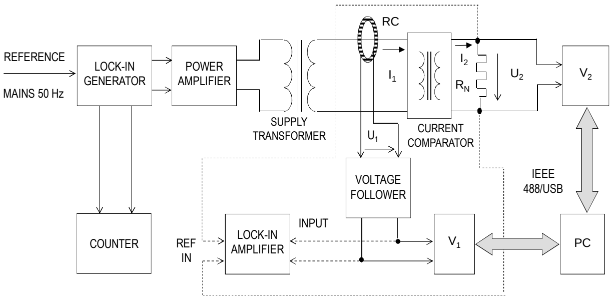

Fig. 1. Calibration of Rogowski coil at 50 Hz frequency

Notes to circuit diagram:

RC – Rogowski coil type KECA 80A1, man. ABB
LOCK-IN GENERATOR – sinewave phase locked on 50 Hz main frequency with adjustable amplitude an phase shift and minimum distortion
POWER AMPLIFIER – Yamaha P4500 1.5 kW
CURRENT COMPARATOR – Tettex 4764,range (5 – 5 000) A/(1, 5) A, accuracy 10 ppm and 0.05' at 50 Hz
R_N – standard resistor Guildline type 9222, 0.1 Ω, accuracy 0.1 %
V_1, V_2 – multimeters Agilent 34401A or 3458A
VOLTAGE FOLLOWER – FET operational amplifier AD 795, $R_{in} > 100\ \mathrm{M}\Omega$, $A_0 = 10^{6,}$ $f_T = 1$ MHz
LOCK-IN AMPLIFIER – Stanford Research RS 830
COUNTER – Agilent 54621A

Mathematical expression of K_{RC} constant for 50 Hz frequency

$$K_{RC} = \frac{U_1}{I}\frac{50}{f} = \frac{U_1}{U_2}\frac{R_N}{p_I}\frac{50}{f}$$

where $p_I = I_1/I_2$ is transformation ratio of current comparator.

Phase displacement Φ is given as a phase shift between measured current I_1 and induced voltage U_1.

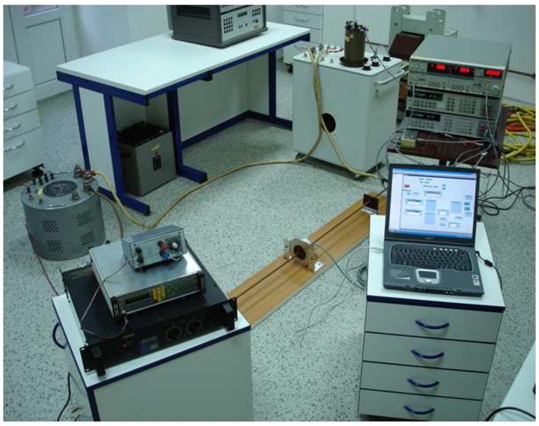

Fig. 2. Working place for Rogowski coil calibration

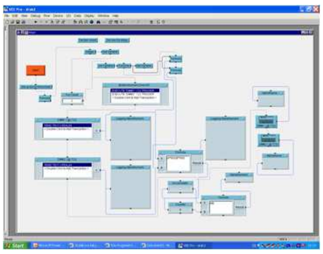

Fig. 3. Printscreen - HP VEE 6.0

Fig. 4. Detail of Rogowski coil with primary conductor

3. Results of measurements at 50 Hz frequency

number of measurement	1	2	3	4	5	6	7	8	9	10
K_{RC} 50 Hz [mV/A]	1.8673	1.8681	1.8674	1.8675	1.8676	1.8661	1.663	1.8659	1.866	1.8668

Table 1. Results of KRC measurement at 50 Hz frequency.

Mean value of K_{RC} at 50 Hz frequency = 1.8669 mV/A
Phase displacement Φ = 89.98°

Uncertainty of measurement:

Type B standard uncertainty of K_{RC} is given as

$$u_{K_{RC}}(B) = \frac{1}{\sqrt{3}}\sqrt{u_{U_1}^2 + u_{U_2}^2 + u_{R_N}^2 + u_{p_I}^2} = 0.061\%$$

Type A standard uncertainty of K_{RC} from 10 measurements (see Table 1) U_{KRC} = 0.013 %.
Combined uncertainty of K_{RC} is given as

$$u_{K_{RC}} = \sqrt{u_{K_{RC}}(A)^2 + u_{K_{RC}}(B)^2} = \sqrt{0{,}013^2 + 0{,}061^2} = 0.062\%$$

Combined uncertainty of measurement of phase displacement does not exceed 0.02°.

4. Calibration at wider frequency range

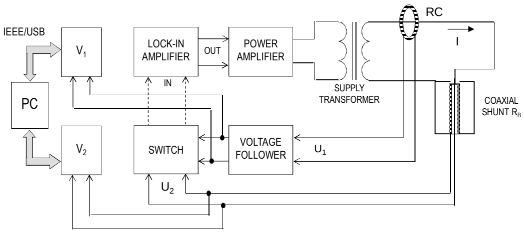

Fig. 5. Connection diagram for calibration of Rogowski coil in wider frequency range

$$K_{RC}(f) = \frac{K_{RC}}{f}.50 = \frac{U_1}{I}.\frac{50}{f} = \frac{U_1 R_B 50}{U_2 f}$$

RESULTS OF MEASUREMENTS

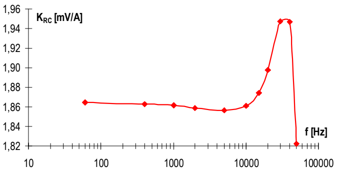

Fig. 6. Frequency dependence of the K_{RC} constant

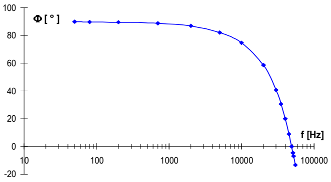

Fig. 7. Frequency dependence of phase displacement ϕ between measured current and induced voltage

5. Conclusion

Using the described method the constant of RC made by the ABB firm, type KECA 80A1 was measured. The RC are used in protection systems at medium voltage area. Very good agreement of measured parameters with parameters given by manufacturer was achieved by calibration. If both voltmeters Agilent 3458A measure in synchronously subsampled mode and their reading is close to the maximum of range (eg. 1 V) it would be possible to achieve standard type B uncertainty of K_{RC} 0.012 %. This uncertainty corresponds to measurement for the current I = 500 A, comparator transformation ratio p_I = 500 A/5 A using a standard resistor RN = 0.2 Ω.

ACKNOWLEDGMENTS

The work was supported by the research program No. MSM6840770015 "Research of Methods and Systems for Measurement of Physical Quantities and Measured Data Processing" of the CTU in Prague sponsored by the Ministry of Education, Youth and Sports of the Czech Republic.

REFERENCES

[1] J. D. Ramboz, D. E. Destefan, R. S. Stant: *The Verification of Rogowski Coil Linearity from 200 A to Greater than 100 kA Using Ratio Methods.* Proc. of IMTC 2002, Vol. 1, pp. 687 – 692.

[2] J. D. Ramboz: *Machinable Rogowski Coil, Design and Calibration. IEEE Trans. Instrum. Meas.*, Vol. 45, No. 2, April 1996.