EJTAS
ISSN 2786-7447
EUROPEAN JOURNAL OF THEORETICAL AND APPLIED SCIENCES
OPEN ACCESS
PEER REVIEWED

The Rogowski Coil Technology Advancements: A Review of High Current Applications

Rafiqullah Hamdard ✉
Physics Department, Education Faculty, Wardak Institute of Higher Education, Wardak, Afghanistan;
Faculty of Physics and Technology, Al-Farabi Kazakh National University, Almaty,050038, Kazakhstan

Anuar M. Zhukeshov
Faculty of Physics and Technology, Al-Farabi Kazakh National University, Almaty,050038, Kazakhstan

Mustafa Rahime
Physic Departsment, Education Faculty, Ghazni University, Ghazni, Afghanistan;
Faculty of Physics and Technology, Al-Farabi Kazakh National University, Almaty, 050038, Kazakhstan

Shir Agha Shahryar
Physic Departsment, Education Faculty, Kunduz University, Kunduz, Afghanistan;
Faculty of Physics and Technology, Al-Farabi Kazakh National University, Almaty,050038, Kazakhstan

Yama Aseel
Physic Departsment, Education Faculty, Farah Higher Education Institute, Farah, Afghanistan;
Faculty of Physics and Technology, Al-Farabi Kazakh National University, Almaty,050038, Kazakhstan

Suggested Citation

Hamdard, R., Zhukeshov, A.M., Rahime, M., Shahryar, S.A., Aseel., Y. (2024). The rogowski coil technology advancements: a review of high current applications. *European Journal of Theoretical and Applied Sciences, 2*(2), 724-729.
DOI: 10.59324/ejtas.2024.2(2).64

Abstract:

Rogowski coil (RC) also known as air-cored was suggested in 1912 and was introduced by German physician Walter Rogowski. This coil is developed for the measurement of alternating and transient high currents, it has the capability of measurement from a few milliamperes to more than 1MA. The advancement of technology and use of microprocessor-based modern signal processing devices have coursed improvement of the Rogowski coil and extended its applications in various places. This article will provide an overview of the theory of Rogowski coils and its high current applications. initially, the article discusses the principles and basics of high current Rogowski coils, explaining their design, construction, and operation. Besides, the research study explores the various high current applications of this coil. its uses overlap from laboratory testing to industrial equipment, Rogowski coils find Usefulness in fault detection, partial discharge measurement, and lightning current detection, surpassing traditional current sensing devices in aspects of speed, accuracy, and reliability. As a result, it is a valuable resource for academics, engineers, and practitioners looking to use this adaptive technology in a wide range of commercial and scientific activities.

Keywords: *Rogowski coil, High current measurement, Fault detection, Impulse current, Partial discharge.*

Introduction

Rogowski coil (RC) is also known air-cored that was proposed in 1912 and has been introduced by German physician Walter Rogowski (Khalid *et al.*, 2023; Nanyan *et al.*, 2018), it is designed for measurement of alternating and transient high currents, it is capable to measure from few milliamperes to more than 1MA (Liu *et al.*, 2011; Ramboz, 1996). The advancement of technology and use of microprocessor based modern signal processing devices have coursed improvement of the Rogowski coil and extended its applications in various places (Nanyan *et al.*, 2018). For measurements of high-impulse currents, three main methods have been used: resistive, inductive, and optical. The Rogowski coil having a B-dot probe connected in series wound on a toroidal former is one of the inductive methods (Metwally, 2010), because of a non-magnetic core Rogowski coil is Competence to measure large currents with Wide bandwidth between 0.1 Hz and 1 GHz without saturation and it is typically used for indirect measurement of very large pulsed currents (Nanyan *et al.*, 2018). Rogowski coil is easy to use compare to conventional CTs due to its lightweight and flexibility (Kojovic, 1997), its cost is also low, moreover it has excellent capability of transient response and it is possible to make its uncertainty better than 0.1%, additionally it is used without direct connection to the main circuit which ensures safety, (Liu *et al.*, 2011). The sourse (Solovev *et al.*, 2015) suggests that voltages lower than 1000 V, Rogowski coils consist of magnetic corees and air gap should be used. In such applications the coils size and weight can be minimized, the dimension is maximumly not being greater than 5 cm.

This paper provides a review of the Rogowski coil as a current sensor, concentrated on high current applications, this coil is categorized as a typical current sensor and is most suitable for high-voltage applications. (Skendzic & Hughes, 2013). The remaining parts of this paper are arranged as follows. Section II discusses the basics and concepts of high-current Rogowski coils. High current applications of the Rogowski coil are discussed in Section III. subsequently, this paper is a valuable resource for researchers, engineers, and practitioners aiming to maximize the prospect of this adaptive technology in a variety of industrial and scientific applications.

Principles and Basics of High Current Rogowski Coil

Rogowski coil is wounded on non-magnetic core (Nanyan *et al.*, 2018), it either could be wounded on a rigid toroidal core or a flexible belt-like core form. Unopenable cores are more reliable to provide better accuracy, because the openable ones are disposed to change their specifications because of the wire turns displacement when opened or closed (Argüeso *et al.*, 2005). The coil is placed around current flowing wire for measuring the current as shown in (Fig. 1) (Kawabata, *et al.*, 2013), due to the current flow a magnetic field is generated around the conductor, according to Faraday's induction law the field is converted into a signal, that is proportional to the derivative of the current change which is flowing in the conductor (Nanyan *et al.*, 2018). The rate of current change induces a voltage in the coil, given by

$$v_{coil} = M\frac{di}{dt} \qquad (1)$$

where $v_{coil}$is induced voltage in the coil by the current (i) due to the mutual inductance M between the main current and the coil(Argüeso *et al.*, 2005). For receiving the output signal voltage proportional to the current an integrating circuit is used (Naidu *et al.*, 2018). for integrating were various options considered: a) mathematic integration, that is integrating the signal v_{coil} received by oscilloscope or a data acquisition card. b) electronic integration, that is integrating with passive integration networks. c) self-integration, it is possible by development of a self-integrating Rogowski coil. Mathematic integration is limited for capacitance added by the oscilloscope probe, that reducing the bandwidth. Electronic integration is also overlooked, to make the circuitry as simple as possible so, the last option is chosen (Argüeso *et al.*, 2005). The bandwidths of output voltage received by electronic or active integrator circuit is large which is about 100 MHz, the response is affected by the skin effect at frequencies above 100 MHz Naidu *et al.*, 2018).

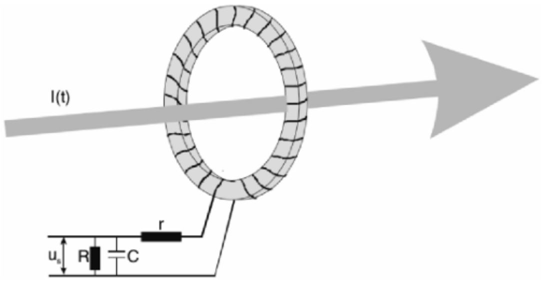

Figure 1. A sample Rogowski coil with an RC integrator.
Source: Samimi *et al.*, 2015.

Typically, the coil is wound around a non-magnetic core in shape of a toroid and has significant number of windings to have enough induced voltage for recording purposes. The winding in done in a criss-cross manner to minimize leakage inductance. If the number of turns of the coil is M, the coil area is A, and its mean length is lm, the mutual inductance can be determined by (Wadhwa, n.d.).

$$M = \frac{\mu_0 NA}{l_m} \tag{2}$$

Here μ_0 is the permeability of air, which equals to $4\pi \text{ x } 10^{-7}\ H/m$. For toroidal coils with a rectangular cross section, the mutual inductance, measured in MKS is given by:

$$M = \frac{\mu_0}{2\pi} nWln\frac{b}{a} \tag{3}$$

where n stands for the number of turns of the coil, W show the width or thickness of the toroid in meters, b is the outside a is the inside diameter in meters(Ramboz, 1996).

High Current Applications of Rogowski Coil

This section discusses the applications of Rogowski coils in high current measurements, considering the different shapes or types of Rogowski coils. The suitability of Rogowski coil for using it to measure high frequency currents like not saturation, good linearity, low price, Simple circuitry(Eriksson *et al.*, 2002.), non-geometric structure and ability of measuring high amplitude current and other advantages makes it the best choice in high current measurements, it has several applications in laboratory testing, industrial measuring instruments, and unconventional measuring systems. Conventional CTs are being used in the power system protection for decades, due to the large power requirements of relays for proper operation. CTs were necessary for these electromagnetic relay's operation, while relays are numeric and operate with low power signals properly (Samimi *et al.*, 2015), so that, Rogowski coils can be used instead of CTs to detect faults in electrical machines and transmission lines. The Rogowski coils made with printed circuit board (PCB) technology are flexible and very accurate in design and manufacture. PCBs are stable at high-temperature that are useful for industrial applications. The Rogowski coil also can be used for on-line monitoring by placing it around high-voltage bushings (Nanyan *et al.*, 2018). Thus, Rogowski coils have various applications due to their unique characteristics and advantages. Here are some major applications.

High Impulse Current Measurement

Rogowski coils are capable to accurately capture fast-changing current waveforms, thus they are widely used for measuring high impulse currents (Metwally, 2010). than capacity of measuring wide bandwidth (0.1 Hz to 1 GHz) currents with high amplitude, makes the Rogowski coil one of the best devices for measuring large sharp currents, that are Extremely used in pulsed power applications (Liu *et al.,* 2011). It is also suitable for measuring device in tests addressing impulse currents, it is employed in high-tech TOKAMAK fusion devices, for both normal and eddy current measurements. Additionally, it has applications in plasma setups, where current does not flow within a conductor but within a defined area in the air. Renowned for its accuracy, the Rogowski coil stands out as one of the premier measurement devices in plasma and pulsed power technology (Samimi *et al.*, 2015). PCB (Printed Circuit Board) is a sort of Rogowski coil with high accuracy due to precise winding size. In this coil, the top layer acts as one of the wrapping wires, while the bottom layer acts as the other wire. The two additional edges are inside the board, connecting the top and bottom layers through holes. This coil is used to measure impulsive currents. This kind is ideal for precision measuring applications requiring digital wiring and major automated production (Khalid *et al.*, 2023) This sort of coil does not have unequal density or altered windings, and its precise properties are derived analytically in the literature. Furthermore, PCB coils can be built in a way that ensures great temperature stability, which is critical for industrial applications. (Samimi et al., 2015).

Fault Current Detection and Protection

Regarding fault detection and protection, Rogowski coils surpasses traditional current sensing devices in properties of speed, accuracy, and reliability, that is making it better choice for assuring the safety and integrity of the system (Kojovic, 1997). high sensitivity and wide bandwidth make Rogowski coil suitable for detecting and measuring fault currents accurately and quickly. Its Linearity, no saturation nature and ability to endure large overloads even at high fault currents exceeding 100kA provides excellent protection security, makes it a preferred choice for fault current detection applications (Samimi *et al.,* 2015). Rogowski coils can quickly detect faults by measuring sudden changes in current magnitude, and responses rapidly to fault currents, for early fault detection and isolation to prevent equipment damage. Furthermore, the accuracy of the Rogowski coils in fault currents measurement, ensures that electrical systems are effectively protected (Kojovic, 1997).

Partial Discharge (PD) Measurement

Another important application for Rogowski coils is real-time PD (partial discharge) measurement in high-voltage components. Detecting defects in high-voltage elements and disconnecting them from the electrical network before they cause severe damage can save money and time for the power grid (Bull *et al.,* 2005). A wide-bandwidth device is required for measuring a high-frequency phenomena. PD measurement of instruments is and effective way for detecting defects in high voltage components. Due to breakdown in high voltage equipment, the rate of partial discharge typically increases. Thus, by monitoring the partial discharge, the equipment state can be determined. The Rogowski coil's wide bandwidth allows it to be utilized for both online and offline PD measurement (Samimi *et al.,* 2015). Harmonic current transformers that have a Rogowski coil and electronic circuits capable of converting the measurement to optical information fed to ground potential via an optical cable (Arrillaga, 2008) In some circumstances, such as power cables, PD detection based on voltage signals is challenging due to stray capacitances. In such cases, based on measured current signals, the Rogowski coil is an appropriate device for PD measurement, PCB is utilized for partial discharge because of the accurate size of windings, making it a very suitable device for precise measurement applications. (Samimi et al., 2015).

Lightning Current Detection

Lightning current has a large amplitude and a short rising time that can lead to overvoltage in the power system. To monitor the current flow over important portions of the structure under test, Lightning tests are necessary (Nanyan *et al.*, 2018). Therefore, an effective high-current sensor is necessary for this purpose. For measuring the lightning current Rogowski coil was tested, particularly for telecommunication towers and wind turbines(Kawabata *et al.*, 2013). by using Rogowski coil a shunt lightning current measurement device was developed for monitoring lightning current. The sensor is constructed using an integrating circuit hat has a low-frequency amplifier, and a low pass filter, it has better integration accuracy in (100 Hz-1 MHz) range. The measuring current range was up to 1 kA, confirming that the Rogowski coil could be utilized for measurements up to 2.4 MHz, which exceeds the maximum frequency of 1 MHz. Lightning currents has high frequency, hence with the Rogowski coil a combination of B-Dot sensor was proposed. likewise, the Rogowski coil has been tested to measure lightning current up to multiple kiloamperes. This sensor was designed to measure and locate lightning currents on transmission lines by using a Rogowski coil and an external integrator, and lightning currents up to 400 kA is detectable by it. However, undesirable electromagnetic interference will negatively impact the functionality of sensor. so, an electrostatic shielding of copper or aluminum is added which is usually wrapped around the coil. Similarly, a niche along the inner circumference should be created to ensure the shielding box is not closed to control the eddy current induced by the magnetic flux (Nanyan *et al.,* 2018). for output voltage below 50 V, the sensor can measure lightning current in a power grid up to 400 kA with 0.1144 V/kA sensitivity. by rising the number of turns and sectional area, the sensitivity of the coil linearly rises, and by increases the effective magnetic path, integral resistance or capacitance The sensitivity of the coil decreases exponentially (Nanyan *et al.,* 2018).

Conclusion

The article has conducted a comprehensive overview of the high current sensor Rogowski coil, which plays the role of the most suitable technology in high current measurements, it is preferred due to the aspects of its remarkable Flexibility, precision, and reliability across a range of applications. Moreover, The article has studied several applications of Rogowski Coil, includes the laboratory testing to industrial instrumentation. The capability of this coile to accurately sense and detect high-impulse and high-frequency currents with wide bandwidths, detection of faults, measurement of partial discharge, and monitoring lightning currents highlights their Importance in protecting critical infrastructure and confirming functional integrity. yet, the Rogowski coil represents not only a Testimony to the creativity of its inventor, Walter Rogowski, but also a testament to the enduring legacy of creation in engineering and technology.

References

Argüeso, M., Robles, G., & Sanz, J. (2005). Implementation of a Rogowski coil for the measurement of partial discharges. *Review of Scientific Instruments, 76*(6). https://doi.org/10.1063/1.1921427

Eriksson, T., Blomgren, J., & Winkler, D. (2002). An HTS SQUID picovoltmeter used as preamplifier for Rogowski coil sensors. *Physica C: Superconductivity, 368*(1-4), 130-133.

Kawabata, T., Yanagawa, S., Takahashi, H., & Yamamoto, K. (2013). A development of a shunt lightning current measuring system using a Rogowski coil. 2013 *International Symposium on Lightning Protection (XII SIPDA),* 283–286. https://doi.org/10.1109/SIPDA.2013.6729212

Khalid, K. A., Fahmi, M. I., Nanyan, A. N., & Bohari, Z. H. (2023). PCB Rogowski Coil sensor by using Saw blade pattern for arcing fault detection. *Journal of Physics: Conference Series, 2550*(1). https://doi.org/10.1088/1742-6596/2550/1/012016

Kojovic, L. (1997). Rogowski coils suit relay protection and measurement ~of power systems. *IEEE Computer Applications in Power, 10*(3), 47–52. https://doi.org/10.1109/67.595293

Liu, Y., Lin, F., Zhang, Q., & Zhong, H. (2011). Design and construction of a Rogowski Coil for measuring wide pulsed current. *IEEE Sensors Journal, 11*(1), 123–130. https://doi.org/10.1109/JSEN.2010.2052034

Metwally, I. A. (2010). Self-integrating Rogowski coil for high-impulse current measurement. *IEEE Transactions on Instrumentation and Measurement, 59*(2), 353–360. https://doi.org/10.1109/TIM.2009.2023821

Naidu, M. S., & Kamaraju, V. (n.d.). High-Voltage Engineering.

Nanyan, A. N., Isa, M., Hamid, H. A., Hafizi Rohani, M. N. K., & Ismail, B. (2018). The Rogowski Coil Sensor in High Current Application: A Review. *IOP Conference Series: Materials Science and Engineering, 318*(1). https://doi.org/10.1088/1757-899X/318/1/012054

Ramboz, J. D. (1996). Machinable Rogowski Coil, Design, and Calibration. *In Ieee Transactions On Instrumentation And Measurement* (Vol. 45, Issue 2).

Samimi, M. H., Mahari, A., Farahnakian, M. A., & Mohseni, H. (2015). The rogowski coil principles and applications: A review. *IEEE Sensors Journal, 15*(2), 651–658. https://doi.org/10.1109/JSEN.2014.2362940

Skendzic, V., & Hughes, B. (2013). Using Rogowski coils inside protective relays. *2013 66th Annual Conference for Protective Relay Engineers, CPRE*, 1–10. https://doi.org/10.1109/CPRE.2013.6822022

Solovev, D. B., & Shadrin, A. S. (2015). Instrument current transducers with Rogowski coils in protective relaying applications. *International Journal of Electrical Power and Energy Systems, 73,* 107–113. https://doi.org/10.1016/j.ijepes.2015.04.011

Wadhwa, C. L. (2006). *High voltage engineering*. New Age International.