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A Rogowski-Chattock coil: sources of error

Abstract. *The local magnetic field is measured by means of magnetic sensors, such as a Rogowski-Chattock coil. The main advantage of the Rogowski coil is its capability to measure the field strength directly at the sample surface because both ends of the coil can be installed very close to the specimen surface. However, the measurements are affected by numerous errors, which are comprehensively discussed in this paper.*
Key words**:** *Rogowski-Chattock coil, measurements errors, local magnetic measurements.*

Introduction

Rogowski coil, or Chattock coil (also known as magnetic potentiometer [1]), is a special kind of helical coil sensor uniformly wound on a relatively long non-magnetic, flexible strip, bent in such a way that its end faces are placed in close contact with the sample, as shown in Fig. 1 [2].

The principle of the Rogowski coil is based on the property that for any closed path not containing a current source ($L = C1 \cup C2$, see Fig. 1) the integral of the magnetic field $\boldsymbol{H}$ is zero. Therefore, a scalar magnetic potential difference exists between two points A and B, which can be determined by: $F_{mA} - F_{mB} = \int_{C1} \boldsymbol{H}.\boldsymbol{dl} = \int_{C2} \boldsymbol{H}.\boldsymbol{dl}$

If the magnetic field is uniform between point A and B, the line integral of the magnetic field $\boldsymbol{H}$ along path $C1$ can be calculated as:

(1) $$\int_{C1} \boldsymbol{H}.\boldsymbol{dl} = \boldsymbol{H}_{AB}\boldsymbol{l}_{AB}$$

where H_{AB} are l_{AB} the magnetic field component tangential to the path $C1$, and the distance between point A and B in the magnetic material, respectively.

When the magnetic field varies with time, the induced terminal output voltage of the Rogowski coil is the sum of voltages induced in each turn (all n turns are connected in series). Assuming that the cross sectional area S_i of the Rogowski coil is so small that the field value may be assumed to be constant over any given cross section S_i, although its direction and value may vary along $C2$.

(2) $$V_{Rogowski} = \frac{d\varphi}{dt} = \sum_{i=1}^{n} \mu_0 \boldsymbol{S}_i \frac{d}{dt}\boldsymbol{H}_i = \sum_{i=1}^{n} \mu_0 \boldsymbol{S}_i \frac{d}{dt}\boldsymbol{H}_i \times \frac{\Delta \boldsymbol{l}_i}{\Delta \boldsymbol{l}_i}$$

where φ is the total flux linkage, S_i is the coil turn cross sectional area, n is the number of coil turns, and Δl_i is the magnetic path length between two neighbouring coil turns.

Let us assume that the cross sectional area S_i and the magnetic path length Δl_i are constant for every coil turn, i.e. $S_i = S,\ \forall \boldsymbol{i}\ and\ \Delta l_i = \Delta l,\ \forall \boldsymbol{i}$, therefore $\Delta l = L_{c\text{-}average}/n$. By substituting (1) into (2) :

(3) $$V_{Rogowski} = \mu_0 \boldsymbol{S} \frac{\boldsymbol{n}}{\boldsymbol{L}_{c-average}} \frac{d}{dt}(\boldsymbol{H}_{AB}\boldsymbol{l}_{AB}) = \boldsymbol{K}_R \frac{d\boldsymbol{H}_{AB}}{dt}$$

where $K_R = \mu_0 Snl_{AB}/L_{c\text{-}average}$ is the Rogowski coil coefficient, which can be calculated from this equation, or determined by calibration using a Helmholtz coil. Therefore, the magnetic field strength H on the specimen surface can be obtained by the time integral of the potential difference $V_{Rogowski}$. A correctly designed and manufactured Rogowski coil should give the same output signal independent on the shape of the coil between points A and B.

Source of errors in Rogowski coil Measurements

The accuracy of the magnetic field measurements using the Rogowski coil can be affected by numerous errors, such as (i) faulty integration by the Rogowski coil and (ii) non-uniformity of the magnetic field in the specimen over the region of integration [3]. Here, we explain only the first source of errors "faulty integration by the Rogowski coil". The complete analysis is discussed in the full paper.

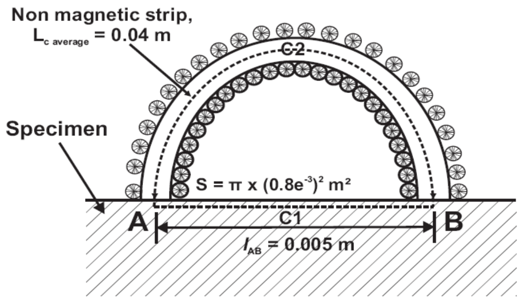

Fig.1. *Schematic* overview of the used Rogowski coil.

In the theory above, it has been assumed that S_i and Δl_i are constant over the length of the Rogowski coil. Unless these conditions are carefully observed in the winding of the coil, the integration is incorrect.

Inaccurate S_i: The error could happen, for example, when the coil cross sectional area S is not constant for every coil turn, i.e. $S_i \neq S, \forall \boldsymbol{i}$. Recalling equation (2), and assuming that β is the average cross sectional area of the coil, so:

(4) $$V_{Rogowski} = \sum_{i=1}^{n} \mu_0 \boldsymbol{S}_i \frac{d}{dt}\boldsymbol{H}_i = \mu_0 \beta \sum_{i=1}^{n} \frac{d}{dt}\boldsymbol{H}_i$$

where β is:

(5) $$\beta = (\sum_{i=1}^{n} \boldsymbol{S}_i \frac{d}{dt}\boldsymbol{H}_i)/(\sum_{i=1}^{n} \frac{d}{dt}\boldsymbol{H}_i)$$

which may give different results compared to equation (3) as β, and also K_R, may depend on the time dependent magnetic field to be measured. The effect of inaccuracy of Δl_i is presented in the full paper.

Therefore, the above discussions clarify the necessity of the coil calibration using the Helmholtz coil rather than calculating the Rogowski coil coefficient.

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