Electrical current coil metrological confirmation for current clamp meters calibration

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Abstract. This paper presents a strategy to evaluate metrological characteristics of current coils used in clamp meter calibration. Coil calibration results are analysed and then an uncertainty budget of a clamp meter is discussed.

1. Introduction
Current clamp meters are widely used in electrical utilities for critical and other electrical measurements. These instruments commonly measure currents from 500 A up to 1000 A or higher at power frequency and DC. Other clamps are suitable for measurement of few milliamperes or microamperes at higher frequency – sometimes a harmonic frequency. There are two main types of clamp meters: toroidal-wound and Hall Effect sensor clamps. Toroidal-wound clamp meters are effectively current transformers with the current carrying conductor to be measured forming the primary and a winding around a jaw and closing mechanism forming a secondary. The jaw is composed of a suitable magnetic core material which completes the magnetic circuit when closed. Toroidal clamps can measure only AC current. Hall Effect based clamps can measure AC and DC current and unlike current transformer clamp meters, the jaws are not wrapped by copper wires. Instead, the magnetic field generated by the conductor is focused across one or more gaps in the core after the jaws are clamped around the conductor [1].

Like all other measurement instruments, clamp meters need to be calibrated and certified in regular intervals. It is a well-established practice in calibration laboratories to use current coils for clamp meter calibrations – there are a small numbers of current sources capable of driving currents from 500 A to 1000 A. Many laboratories either build their own coil, or simply make several loops of a test lead for the purpose of increasing the current value sensed by the clamp meter. Some manufacturers provide current coils capable of clamp meters calibration up to 1000A or 1500A, as an optional of multifunction calibrators.

2. Current coil
When a current is passed through a single strand of wire, it produces a magnetic field. The force that produces the magnetic field is called magnetomotive force (mmf). The unit of mmf is defined as the ampere-turn (At). One ampere-turn is the amount of force that is generated by a direct current of 1 ampere flowing in a single loop turn in a vacuum. The total mmf that is produced is defined by the
product of the number of turns and the current. If a single strand of wire is looped into 50 turns (N), the current in the wire would be multiplied by 50 to obtain the mmf [2].

Toroidal-wound and Hall Effect clamp meters present different loads which the current coils and their source must be designed to cope with. Hall clamps are typically much higher inductance than the toroidal ones and are more sensitive to magnetic field non-uniformity and interference within the clamp area, the result of design differences needed to accommodate the Hall sensor within the jaw magnetic circuit [3].

3. Current coil calibration

To evaluate the characteristics of a current coil, it is necessary to calibrate it. This calibration is intended to ensure that there are no manufacturing defects, and that the mmf generated by each coil is equivalent to an ideal conductor. The calibration is performed at a low frequency AC value (50 or 60 Hz) because this is the typical use case for clamp meters.

A 50 turns current coil from Eletrobras Eletronorte Metrology Laboratory, that is specified for currents up to 20 A (effective current of 1000 A), was calibrated by an accredited Brazilian metrology laboratory, traceable to standards. Calibration results are shown in table 1 (k=2).

| Current (A) | Error (%) | Uncertainty (%) |
|------------|-----------|-----------------|
| 10         | 0.00      | 0.02            |
| 50         | -0.22     | 0.02            |
| 250        | -0.21     | 0.06            |
| 500        | -0.10     | 0.36            |
| 750        | -0.28     | 0.37            |
| 950        | -0.20     | 0.37            |

Calibration results were used to confirm that the current applied to the coil was multiplied by 50 turns instead of 49, 51, e.g. the aim is to prove that the coil is not 1 turn out. So, the conformance limit is 1 turn / 2 = 0.5 turn / 50 turns = 1%. Calibration results shown for all measurement point that the current applied to the coil is really multiplied by 50. Differences from 50 are due to the instruments and standards used in the calibration. The uncertainties on the certificate are suitable for performing this evaluation only. Figure 1 shows evaluation of coil calibration results at 60 Hz considering the defined conformance limit.
The reason that instruments are calibrated is because the physical properties of the instrument may drift over time (i.e. electronic components drift, physical standards like weights or gauge blocks wear). This is not the case of current coils, since they do not have components that degrade or drift during the years. For this reason, after initial calibration there is no need to recalibrate a current coil. However, intermediate verifications or checks can be performed to assure that the coil does not have defects due to mishandling or accidents. These verifications can be performed using a clamp meter, and must be able to confirm that the N turn coil remains with the same number of turns since calibration. The frequency of the verifications depends on the risk of damage to the coil, and must be evaluated by the end user. It can be annually, semi-annually or either every time the coil is used in clamp meters calibration, in a set just before calibration.

4. Clamp meters calibration

In clamp meters calibration, there is no uncertainty due to the number of turns, e.g., the number of turns is an exact number. The main uncertainty contributions come from the (1) uncertainty of the applied current (usually a multifunction calibrator) and the (2) uncertainty in the interaction between the coil and the clamp meter. This uncertainty depends on the type of the clamp being calibrated, current transformer or Hall sensor types. Typical values for this contribution stated by current coil manufacturers vary from 0.2% (current transformer) to 0.5% (Hall sensor) at DC or line frequency.

Table 2 shows an example of uncertainty budget for a low resolution Hall sensor clamp meter calibration, at 200 A (60 Hz), where:

- $I_X$ Indication of the clamp meter under calibration
- $\delta I_X$ Correction due to finite resolution of the clamp meter under calibration
- $I_S$ Current driven by the calibrator
- $\delta I_S$ Correction of the calibrator based on accuracy specification given by its manufacturer
- $\delta I_{S,C}$ Correction of the calibrator based on its last calibration certificate
- $N$ Number of turns of the coil (its uncertainty is related to the coil / clamp interaction)
Table 2. Uncertainty budget for clamp meter calibration at 200 A (60 Hz).

| Quantity | Standard uncertainty | Probability distribution | Sensitivity coefficient | Uncertainty contribution |
|----------|-----------------------|--------------------------|------------------------|-------------------------|
| $I_X$    | -                     | -                        | -                      | -                       |
| $\delta I_X$ | 0.029 A              | Rectangular              | 1                      | 0.029 A                 |
| $I_S$    | 0.00066 A             | Normal                   | -50                    | 0.016 A                 |
| $\delta I_S$ | 0.0044 A            | Normal                   | -50                    | 0.085 A                 |
| $N$      | 0.63 A                | Rectangular              | -1                     | 0.37 A                  |

Standard uncertainty $u (y)$ 0.38 A

5. Conclusions
This paper presented a strategy for electrical current coil metrological confirmation, in order to be used in clamp meters calibration. It was demonstrated it is necessary to calibrate a coil just once, before use it in clamp calibrations. To assure its metrological characteristics after calibration, only further verifications or checks must be performed, in order to detect any damages that could occur.

6. References
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