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Calibration of Rogowski Coils at High Pulsed Currents

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Abstract

The many applications of Rogowski coils include their use as current sensors in AC resistance welding. Weld quality depends on monitoring/controlling the welding currents. The accuracy of these current sensors matters, and so does the accuracy of their calibration. A high-accuracy system for calibrating Rogowski coils at continuous AC currents was previously developed at NRC. However, in AC resistance welding, high pulsed currents are used. A new calibration system was developed to calibrate current sensors and related equipment under high pulsed currents.

1. Introduction

A winding evenly placed on a non-magnetic former of constant cross-section, first described by A.P. Chattock [1] and later named after W. Rogowski [2]. The main applications of Rogowski coils are for the measurement of high AC currents, transient currents, impulse currents, and pulsed currents such as those used in AC resistance welding [3],[4].

Measurement and control of the welding current as the means for controlling heat in AC resistance welding are very important for achieving the consistency of the welds. This points to the need for accurate current sensors and weld current monitors, and traceability of their calibration. Numerous new coil designs and some calibration methods have been introduced over the years [3], [5]-[7]. A high-accuracy system for calibrating Rogowski coils at continuous AC currents was described in [5]. This paper describes the new calibration system developed at NRC Canada for the calibration of Rogowski coils and weld current monitors at high pulsed currents such as those used in AC resistance welding.

2. Description of the calibration system

The calibration system consists of a custom built high-current source and a current measurement system based on digital sampling. A block diagram of the calibration system is shown in Figure 1.

The high-current source is supplied from the power line at 60 Hz. It consists of a microprocessor-based weld sequence control with solid state contactors, a set of auto-transformers (AT), a high-current step-up transformer (ST), a coaxial copper cage in the high-current path, and a cooling subsystem. A heat exchanger, pump and a coolant tank form the

The weld control allows for control of the pulsed current duration in terms of the power line cycles, among its many functions. It also allows for the phase angle control of the output waveform through a pair of silicon controlled rectifiers (SCRs), i.e. control of the shape and time parameters of generated pulsed currents (e.g. heat, power factor, and other settings). The output high-current transformer is used as a current step-up transformer operating close to the short-circuit conditions and generating high-current at its secondary. The auto-transformers allow adjustment of the output current amplitude independently from the weld control. At the same time, this adjustment allows a fine control of the auto-transformers' input/primary current, which is measured by a current sensing coil designed for smaller currents. The coaxial copper cage is used for testing of current-sensors [4]. The current sensor under test, DUT, and the reference current sensor, REF, are placed in the coaxial copper cage around the center conductor during measurements, and the digital sampling meters are connected to the outputs of current sensors.

The copper cage is of circular coaxial design which provides a radially symmetrical magnetic field around the center conductor inside the cage. A close approximation is the magnetic induction, B, inside a long coaxial cable [8], represented by:

$$B = \begin{cases} \mu_0 \dfrac{i}{2\pi a^2} r, & r \le a \\ \mu_0 \dfrac{i}{2\pi r}, & a \le r \le b \\ \mu_0 \dfrac{i\,(c^2 - r^2)}{2\pi r (c^2 - b^2)}, & b \le r \le c \\ 0, & r \ge c \end{cases}$$

where i is the current, a is the center conductor radius, b and c are the cylinder inner and outer radii, and r is the distance from the center. The magnetic field B in the cage is shown in Figure 3, with the radial dimensions a, b and c proportional to those of the actual cage:

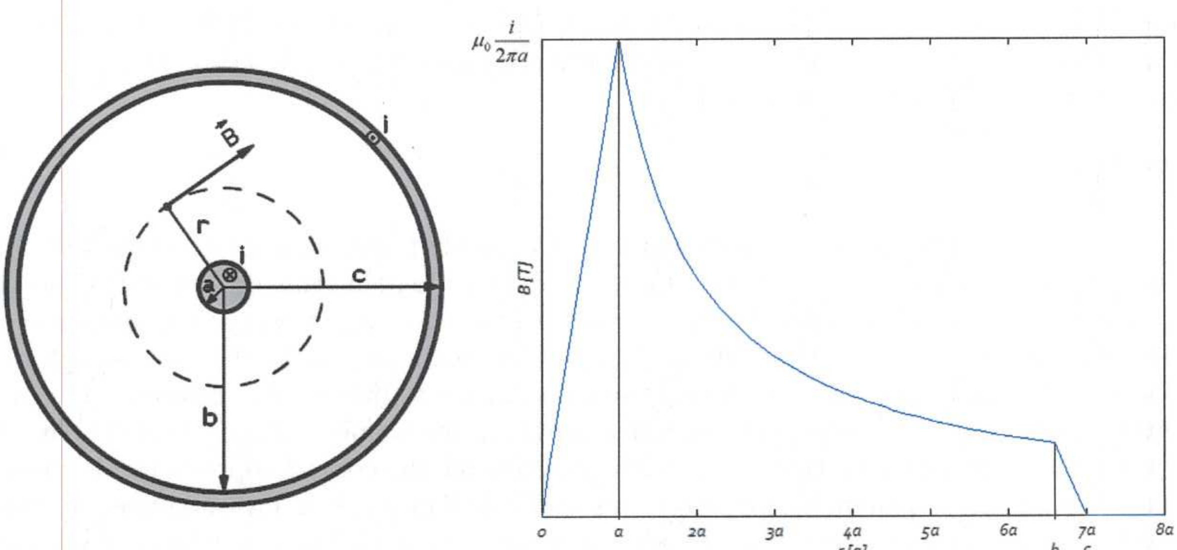

Figure 3. Magnetic field B around the current-carrying conductor inside a long coaxial cage

and recorded. It confirmed the validity of previously measured high current source impedance and other parameters. Due to the present limitations of the available service power, pulsed currents of up to 28 kA peak or 20 kA rms for a set number of power line cycles, in the total durations of up to 1.65 s, have been generated at the time of preparation of this paper. It is expected that higher currents will be possible in the near future as arrangements are being made to secure access to a power supply with a higher current rating.

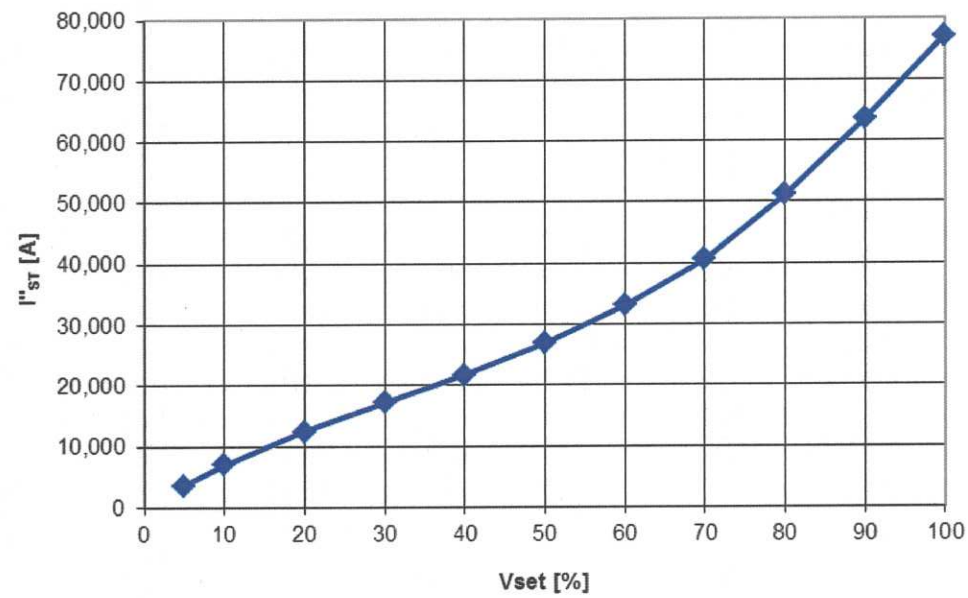

Figure 4. Step-up transformer secondary current, I''_{ST}, i.e. current through the cage, at the supply voltage of 600 V

Based on the dependence of the supply current and the step-up transformer output current on the auto-transformers setting, the current source capability of 70 kA peak or 50 kA rms, or greater, is expected for the duration in the order of 10 cycles. The actual value will depend on the current rating of the new service power, its output impedance, and the tolerance to short voltage dips of other customers supplied by the same service power. The maximum current that can be safely drawn from the power supply for a predetermined number of power line cycles will be verified experimentally. It is expected that the actual high current source capability will be known at the time of presentation of this paper at the conference.

5. Traceability and measurement uncertainties

Traceability for pulsed-current measurements has been discussed in [9]. The traceability to SI units of the new system for the calibration of Rogowski coils at high pulsed currents is derived from the traceability of the accredited NRC calibration of Rogowski coils at continuous AC currents [5] used for the calibration of the reference Rogowski coil.

The coil selected as the reference is a single-layered machined coil [10] similar to that described in [11]. The coil is characterized by low positional and temperature sensitivities. The coil uncertainty is determined by calibrating the coil at NRC calibration systems for continuous AC currents, and by determining its type A uncertainties, positional sensitivity, and temperature

8. B.D. Popovic, "Introductory Engineering Electromagnetics," Addison-Wesley Publishing Company, Reading, MA, USA, p. 261, 1971.
9. J.D. Ramboz and D.E. Destefan, "Establishment of Traceability for Pulsed-Current Measurements to Greater than 60 kA," Proc. NCSL Workshop and Symposium, pp. 31–39, 1998.
10. B.V. Djokic, J.D. Ramboz, and D.E. Destefan, "To What Extent Can the Current Amplitude Linearity of Rogowski Coils Be Verified?," *IEEE Trans. Instrum. Meas.*, vol. 60, no. 7, pp. 2409– 2414, July 2011.
11. J. D. Ramboz, "Machinable Rogowski Coil, Design, and Calibration," *IEEE Trans. Instr. Meas.*, Vol.45, No.2, June 2006, pp. 939 – 943.