Technical Note

AC Clamp Meter CM4141/CM4142

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***Abstract*—The AC Clamp Meter CM4141/CM4142 is a slim AC clamp meter engineered to be easy to insert into narrow gaps between cables. This paper provides an overview of the product, discusses its functions and features, and provides several examples of measurements carried out with it.**

I. Introduction

Clamp meters are instruments that measure current using a sensor that is clamped around one or more cables. Since there's no need to shut off the circuit, this type of instrument is widely used in maintenance inspections of electrical equipment that would be difficult to take offline and in electrical wiring work.

In recent years, wiring in distribution panels has become more closely spaced, making it impossible to use many conventional clamp meters. As a result, technicians have had to forcibly widen the gaps between cables or search for other locations where there was enough space to affix the instrument, degrading work efficiency.

To resolve this problem, Hioki developed the AC Clamp Meter CM4141/CM4142 series (hereafter called CM4141/CM4142) with sensor jaws whose small cross-sectional area allows them to fit into gaps between cables immediately above and below circuit breakers. Fig. 1 depicts the appearance of the product.

II. Overview

The CM4141/CM4142 is a clamp meter that can measure AC currents of up to 2000 A. The new model inherits the extensive measurement functionality, environmental resistance, and fast measurement speed of the previous model (the CM4370) while having a clamp sensor form that's easier to use.

Additionally, the CM4142 provides **Bluetooth**® communications functionality, allowing it to communicate with smartphones and tablets.

III. Functions and Features

The remainder of this paper describes the newly designed clamp (current) sensor of this clamp meter. For more information about other functions and features of the CM4141/CM4142, please see the Technical Note on the AC/DC Clamp Meter CM4370 series [1].

Fig. 1. Appearance.

A. Air Core Coil

The CM4141/CM4142 uses an air core coil to detect the magnetic flux produced by the current under measurement. Since the air core coil's output voltage takes the form of a current differential waveform, an integrator in the instruments' electric circuitry can reproduce the original waveform.

The magnetic flux Φ detected by the coil can be expressed by (1), where I indicates the current under measurement:

$$\Phi = \mu_0 \frac{S}{L} I \tag{1}$$

μ_0: Space permeability

S: Cross-sectional area of coil

L: Average flux path length

Based on the law of electromagnetic induction, the voltage V_{coil} output from the coil can be expressed by (2):

$$\begin{aligned} V_{\mathrm{coil}} &= -N \frac{d\Phi}{dt} \\ &= -\mu_0 \frac{SN}{L} \frac{dI}{dt} \end{aligned} \tag{2}$$

N: Number of turns in the coil

The integrator's output characteristics V_{out} can be expressed by (3):

$$V_{out} = -\frac{1}{CR}\int V_{in}\,dt \qquad (3)$$

C: Capacitance

R: Resistance

Based on (2) and (3), the coil's output voltage via the integrator, V_s, can be expressed by (4):

$$V_s = \frac{SN\mu_0}{L}\frac{1}{CR}I \qquad (4)$$

The instrument's electric circuitry includes an amplifier and has three ranges: 60.00 A, 600.0 A, and 2000 A. Consequently, a broad range of currents, from 1.00 A to 2000 A, can be measured with a single instrument (Fig. 2).

The product has a frequency band of 30 Hz to 1 kHz (Fig. 3).

B. *Sensor Shape*

The CM4141/CM4142's large-diameter sensor jaws are designed to be slim yet strong.

The jaws must be slim enough to fit between closely spaced cables inside distribution panels and other confined spaces. At the same time, they must open wide enough, and have a large enough diameter, to be easy to clamp around cables that are thick enough to carry 2000 A currents. Sensor jaws that satisfy these requirements must be large and yet must also have a small cross-sectional area. This trade-off threatens to make it impossible to provide enough strength to withstand repeated insertions between cables.

Hioki addressed this challenge by giving the sensor jaws as large a cross-sectional area as possible closer to the grip but gradually decreasing the jaws' cross-sectional area toward the tips. The tips of the jaws have the minimum necessary cross-sectional area. The part of the jaws where the cross-sectional area changes abruptly feature a curved surface to keep stress from becoming concentrated there (Fig. 4). This design makes possible a sensor shape that satisfies this product's goal. At the tips of the jaws, the cross-sectional area measures about 11 mm on the outside (Fig. 5). That area is about 30% less than the corresponding figure for the previous Hioki model with the same rated current (Fig. 6).

Fig. 7 depicts the product being used to measure a cable connected to a circuit breaker as seen from above. The two triangular marks on the surface of the sensor jaws indicate the point at which maximum accuracy can be achieved by positioning the conductor under measurement in the center of the jaws. There's no need to insert the sensor jaws so

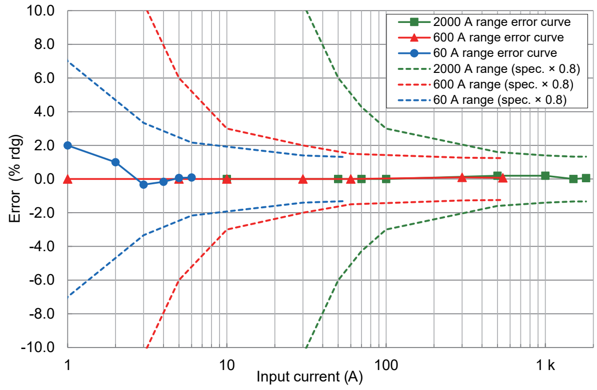

Fig. 2. Linearity.

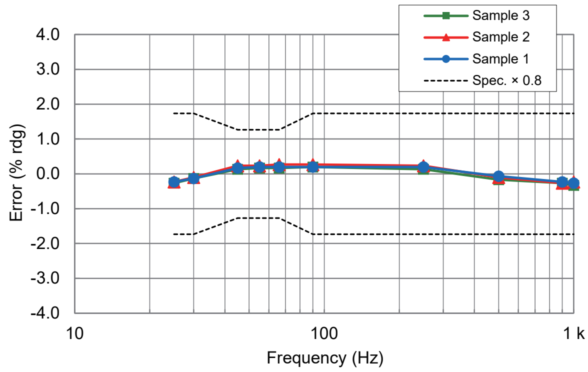

Fig. 3. Frequency characteristics.

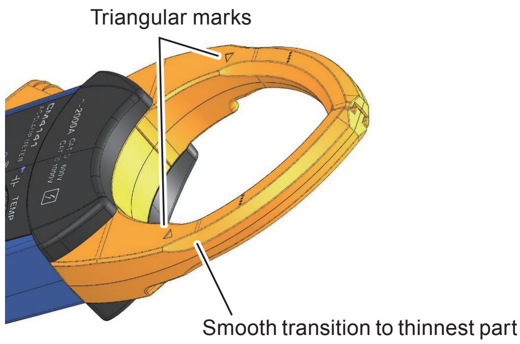

Fig. 4. Transition to thinnest part of jaws and triangular marks.

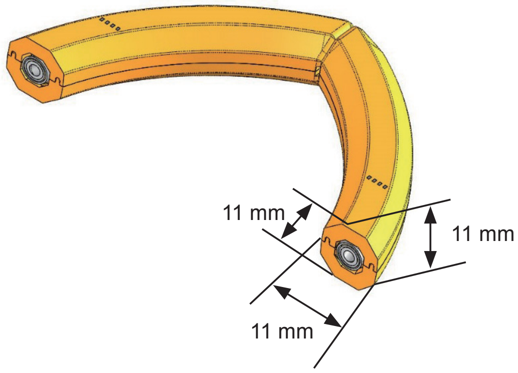

Fig. 5. Cross-sectional dimension at tip of sensor jaws.

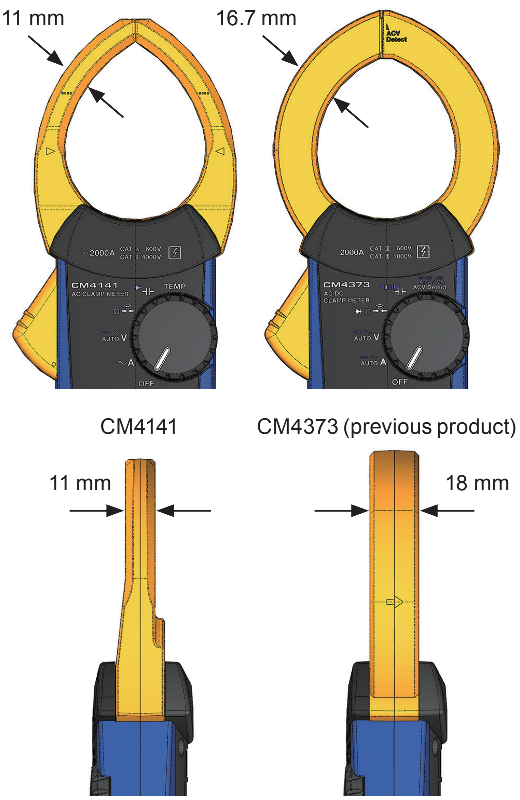

Fig. 6. Comparison of sensor jaw size.

far that the conductor under measurement is closer to the user than the imaginary line connecting these two marks. Consequently, the jaws only need to be thin beyond those marks since thickness on the user's side of the marks doesn't hinder clamping by the product.

C. Example Current Sensor Characteristics

Generally speaking, a perfectly round shape for the sensor (jaws) causes the conductor position to have less of an effect on measured values. However, jaws whose shape approaches that ideal cannot be clamped around conductors through the narrow spaces between cables. Hioki designed the coil so as to reduce the effect of conductor position on measured values, despite the jaws' divergence from the ideal shape. As a result, the product offers conductor position effects that are equivalent to those of a previous product that uses a round air core coil (the 3280-20F) (Figs. 8 and 9).

The clamp's open/close cycle count is one indicator of clamp sensor durability. Wear of the sensor's mating faces as the instrument is repeatedly opened and closed can adversely impact measurement accuracy. Hioki subjected the CM4141/CM4142 to a 50000-cycle open/close test, in excess of the 30000 cycles in the product specifications, and verified that there was no significant effect on accuracy specifications (Fig. 10).

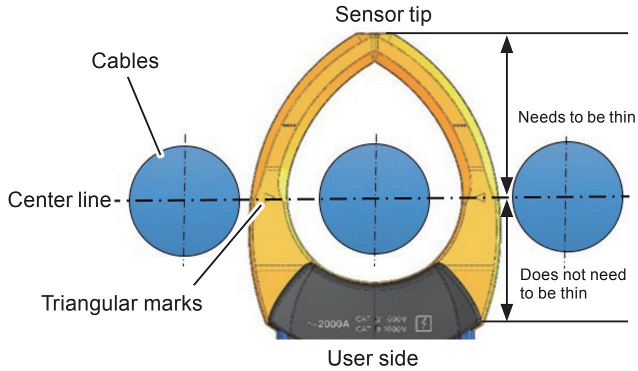

Fig. 7. Illustration of circuit-breaker measurement.

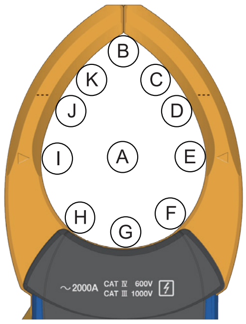

Fig. 8. Conductor position.

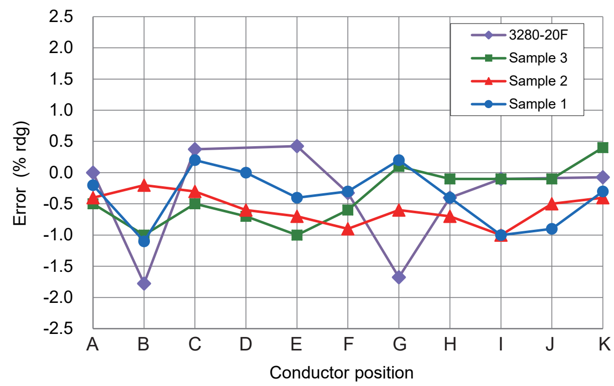

Fig. 9. Effects of conductor position.

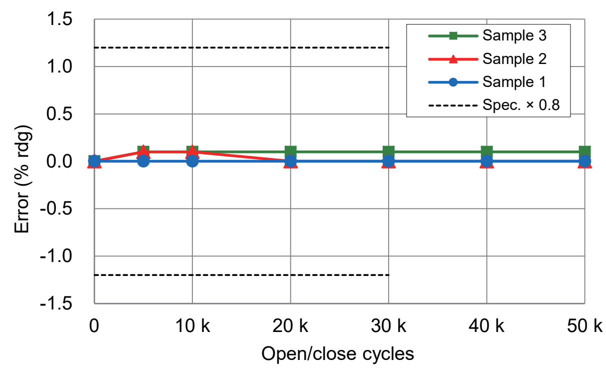

Fig. 10. Effect of clamp open/close cycles.

TABLE I. CLAMPABLE CIRCUIT-BREAKER/CABLE COMBINATIONS

✓: Clampable −: Not clampable

Conductor under measurement		CM4141/CM4142	Previous products	
Circuit breaker	Cables		3280-20F	CM4373
30AF	CV8	✓	✓	−
60AF	CV22	✓	✓	−
125AF	CV60	✓	✓	−
250AF	CV150	✓	−	−
400AF	CV325	✓	✓	−
600AF	CV150 (double wiring)	✓	−	✓
600AF	CV200 (double wiring)	✓	−	✓
600AF	CV250 (double wiring)	✓	−	✓

IV. Example Measurement Applications

The CM4141/CM4142 is designed to be clamped around conductors through gaps between adjacent cables immediately above or below a circuit breaker (Fig. 11).

TABLE I indicates whether the product is suitable for use with a variety of combinations of commercially available circuit breakers and cables. The table shows that the CM4141/CM4142 can even be used with combinations with which previous Hioki products could not be used.

The CM4141/CM4142 also provides an inrush function for measuring equipment's inrush current and other parameters. This function can be used to measure the inrush current's maximum crest value and RMS value to determine whether the cable being used to power the equipment has any additional current capacity. Inrush current waveforms can be displayed by using the instrument's Bluetooth communications functionality and GENNECT Cross, an original Hioki application (Fig. 12). The application also provides logging functionality, functionality for displaying measured values on photographs or drawings, and FFT functionality. The logging function can be used to measure changes in a piece of equipment's load current over time so that appropriate breakers can be selected based on the maximum load.

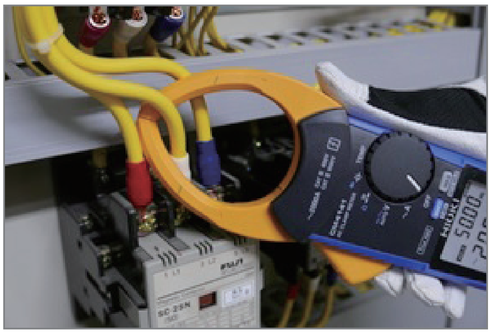

Fig. 11. Example of clamp use.

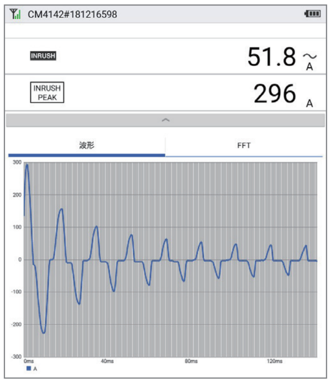

Fig. 12. Inrush current waveform.

V. Conclusion

The CM4141/CM4142 is an AC clamp meter developed based on customer feedback expressing a desire for an instrument that would be easy to insert into narrow gaps between cables. Rather than merely making the sensor jaws thinner, Hioki pursued ease of use without sacrificing durability and favorable electrical characteristics.

Hioki hopes that the CM4141/CM4142 will improve the efficiency of work in the field while contributing to the realization of a safe, secure society by facilitating maintenance of electrical equipment.

Kentaro Nakajima[1]

Reference

[1] T. Nakamura, "AC/DC Clamp Meter CM4370 Series," *Hioki Giho (Hioki Technical Notes)*, vol. 37, no. 1, pp. 73-78, 2016. (Japanese, also available in English).

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[1] MN Unit