Technical Notes

AC Flexible Current Sensor CT9667-01/-02/-03, CT7044/CT7045/CT7046

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***Abstract*—**The AC Flexible Current Sensor CT9667-00 series (which consists of the CT9667-01, -02, and -03) and CT7040 series (which consists of the CT7044, CT7045, and CT7046), are lines of current sensors that can measure large currents flowing in conductors in three diameter categories, packaged in enclosures that are smaller than those of previous products (except the CT9667-03). This paper introduces these products' features and functionality.

I. Introduction

The AC Flexible Current Sensor CT9667-00 series and CT7040 series are derivatives of the Flexible Clamp On Sensor CT9667, which was launched in 2012. These products are primarily used as current sensors with power meters and power quality analyzers.

The shrinking size of distribution panels and wiring components in recent years has made complex wiring installations in which it is difficult to install or place clamp sensors with a rigid core more common. There are an increasing number of places in which the previous CT9667 cannot be installed due to its sensor's thickness and size. At the same time, flexible-type sensors have become the go-to choice outside Japan for use with power meters and other instruments, creating the impetus for Hioki to expand its line of flexible sensors.

Hioki recently added two new types of small-diameter sensor that incorporate general-purpose BNC connectors along with a redesigned version of the previous CT9667 to the CT9667-00 series, for a total of three new sensors.

The company also launched the CT7040 series with three new small-diameter sensors featuring a dedicated Hioki connector that delivers a high level of convenience in the field, bringing the total to six sensors spanning two product series.

The expanded line enables end-users to choose sensors that are better suited to the requirements imposed by each installation location.

II. Overview

The new sensors, which are designed to be easy to install even in confined spaces, feature a narrower design so that they can be more easily inserted into such places along with a more compact junction that fits inside a standard distribution panel, which is where these sensors are most often used.

Appearance of the CT9667-01.

Appearance of the CT7045.

In addition, the CT7040 series supports automatic sensor detection functionality, which offers the convenience of being able to connect the sensor and use it right away.

The new sensors also deliver improved environmental performance compared to previous products, a fact that is evidenced by their IP dustproof and waterproof ratings and by their expanded operating temperature range, which allows them to be used in a variety of temperature environments.

III. Functions and Features

A. Measurement Functionality

The CT9667-01/-02/-03 offer two ranges (500 A AC and 5000 A AC) with a maximum rated current of 5000 A AC and a frequency band of 10 Hz to 20 kHz.

The CT7044/CT7045/CT7046 offer two ranges (600 A AC and 6000 A AC) with a maximum rated current of 6000 A AC and a frequency band of 10 Hz to 50 kHz.

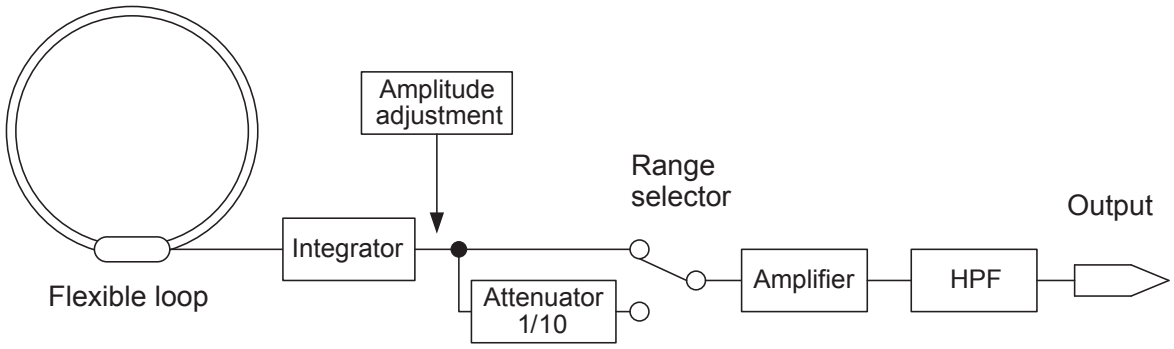

Fig. 1. Block diagram.

B. *Flexible Loop*

A Rogowski coil in the form of a cable with a diameter of 7.4 mm is used as the sensor, and the end cap, which is the thickest part of the coil, has been kept to a diameter of 9.9 mm so that the sensor can be inserted into a gap with a diameter of 10 mm (except the CT9667-03). Three variants are available to measure conductors in three diameter categories (100 mm, 180 mm, and 254 mm) and can be chosen based on the application in question.

C. *Safety*

The sensors are designed to ensure safety in CAT IV (600 V) and CAT III (1000 V) measurement applications.

D. *Environmental Performance*

The CT9667-00 series is rated IP54 for dust and water for the flexible loop (except the CT9667-03), while the CT7040 series is rated IP54 for the entire sensor. The sensors can be operated in environments ranging from −25°C to 65°C (−13°F to 149°F) (except the CT9667-03, which can be operated in environments ranging from −10°C to 50°C [14°F to 122°F]).

E. *Direct Plug-in Method (CT7040 Series)*

The sensors receive power from the instrument to which they are connected and support functionality provided by Hioki instruments to automatically detect the type of connected sensor using the sensor ID. This functionality eliminates the bothersome need to connect a power supply and set the output rate, allowing the sensor to be used simply by connecting it and helping reduce end-users' sensor setup time.

F. *Design*

The sensors feature a new distinctive design that updates the design of the previous CT9667 based on compactness, ease of use, and productivity considerations. In addition, they incorporate the Hioki Blue coloring, which Hioki is utilizing on other products, for the sleeve on the flexible loop junction to give the sensors an external appearance that makes them immediately recognizable as Hioki products.

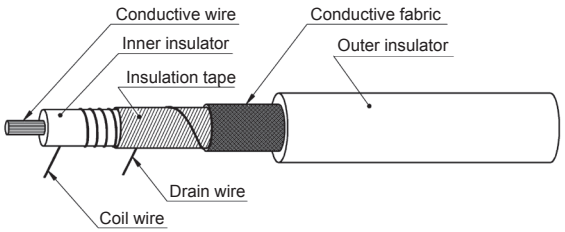

Fig. 2. Sensor construction.

IV. Architecture

A. *Hardware Architecture*

1) Overview: Fig. 1 provides a block diagram for these new AC flexible current sensors, all of which share the same basic architecture. Since the flexible loop generates and outputs a differentiated waveform of the current under measurement, the sensor's circuitry uses an integration circuit to reproduce the original waveform.

2) Sensor construction: Fig. 2 illustrates the construction of the sensor itself, which incorporates a coil wire consisting of copper wire wound around the innermost insulated wire, a layer of shielded tape that serves as insulation, a drain wire, and conductive fabric, all wrapped with an outermost layer of elastomer known as TPE in a seven-layer extrusion-molded design. Incorporation of an electrostatic shield that utilizes conductive fabric—a feature that the CT9667 lacked—has dramatically reduced the effects of common-mode voltage (except the CT9667-03).

B. *Characteristics*

1) Frequency characteristics: Fig. 3 illustrates the sensors' amplitude-frequency characteristics, while Fig. 4 illustrates their phase-frequency characteristics. The CT9667-00 series and CT7040 series limit measurement error to within ±3 dB across a frequency band of 10 Hz to 20 kHz or 10 Hz to 50 kHz, respectively.

In addition, the sensors deliver excellent phase-frequency characteristics, which are important in power measurement, in the commercial frequency band.

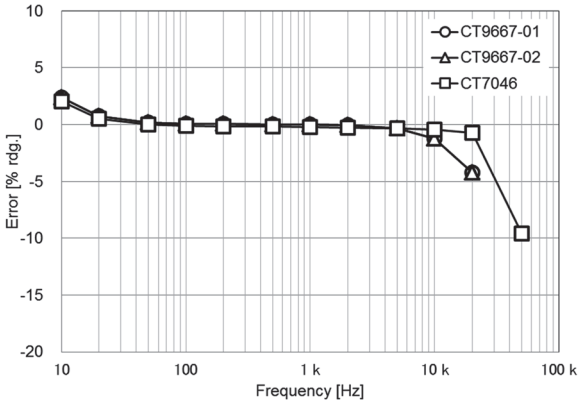

Fig. 3. Amplitude-frequency characteristics.

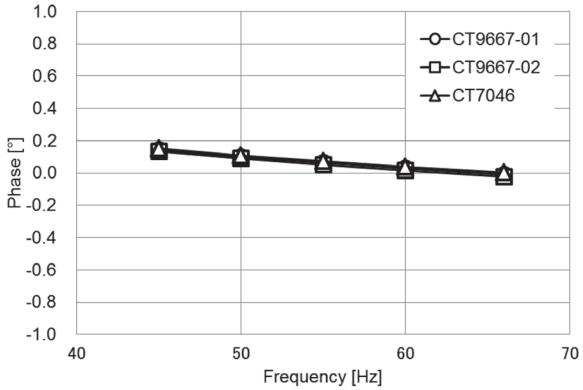

Fig. 4. Phase-frequency characteristics.

2) Intrinsic error of amplitude accuracy: Figs. 5 and 6 illustrate the CT7046's intrinsic error of amplitude accuracy, which is broadly representative of the new sensors' performance. The magnitude of the error is sufficiently small relative to the instruments' specifications.

3) Temperature characteristics: Fig. 7 illustrates the new sensors' temperature characteristics. The small magnitude of the effect of temperature means that the sensors are capable of stable measurement across the range of operating temperatures.

4) Effects of common-mode voltage: Fig. 8 illustrates the effects of common-mode voltage. The figure charts output values when a 1000 V rms conductor is placed in contact with the sensor. Since the new sensors incorporate an electrostatic shield, they exhibit improvement in terms of the magnitude of the effects of common-mode voltage compared to the previous CT9667. Consequently, they are less susceptible to the effects of external noise, even when measurement is performed in the vicinity of an inverter.

5) Effects of nearby conductor: Fig. 9 illustrates the effects of a nearby conductor on the CT9667-00 series and CT7040 series. (Fig. 10 illustrates the locations at which measurements were taken.)

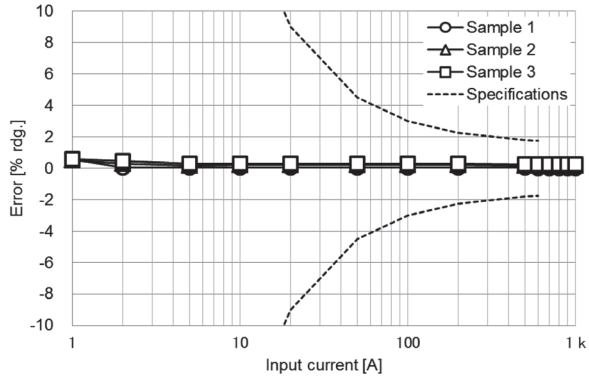

Fig. 5. Intrinsic error of amplitude accuracy (CT7046, 600 A range).

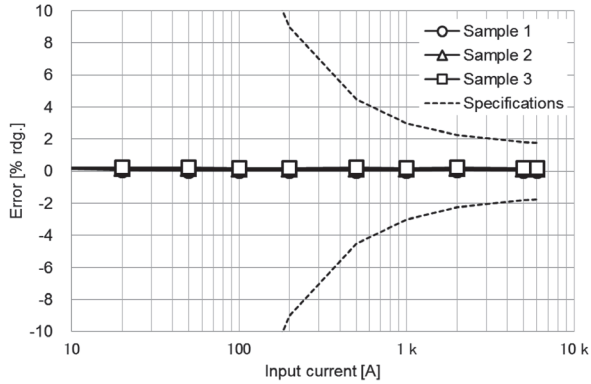

Fig. 6. Intrinsic error of amplitude accuracy (CT7046, 6000 A range).

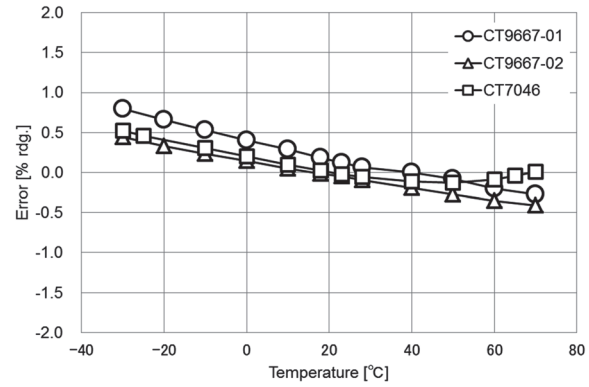

Fig. 7. Temperature characteristics.

The magnitude of the effects is less than −40 dB (1/100), indicating that the sensors can make accurate measurements even in locations with complex wiring since nearby wires will exert only a slight effect on measured values.

6) Effects of conductor position: Figs. 11 to 13 illustrate the effects of conductor position on CT7040 series sensors with a diameter of 100 mm, 180 mm, and 254 mm, which is broadly representative of the new sensors' performance. (Deviation is indicated relative to Position 1, and Fig. 14 indicates the locations at which measurements were taken.) The effect, which is most pronounced at Position 6, the sensor junction, is within ±1.5% for sensors of all diameters.

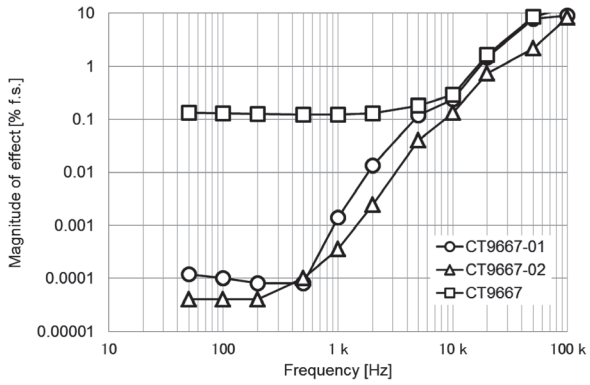

Fig. 8. Effects of common-mode voltage.

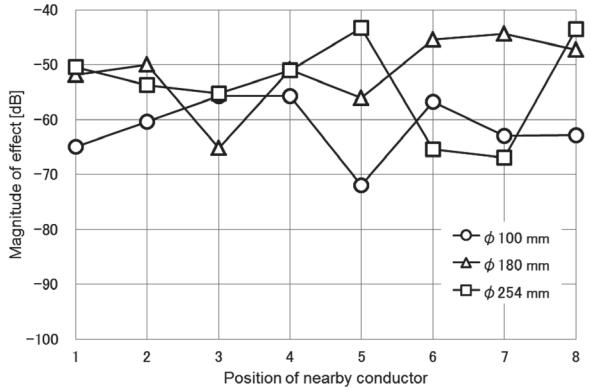

Fig. 9. Effects of nearby conductors.

Fig. 10. Effects of nearby conductors: Measurement locations (ø30 mm conductor carrying 600 A at 60 Hz).

C. Construction

1) Sensor junction: Fig. 15 illustrates the construction of the sensor junction. The method of affixing the sensor and of locking and unlocking it remains the same as in the previous CT9667 in order to provide consistency across models in the series while ensuring users can seamlessly transition to the new sensors.

The junction has been kept as small as possible by eliminating all wasted space while retaining enough space to ensure safety and facilitate the necessary wire connections. Hioki studied the construction of parts related

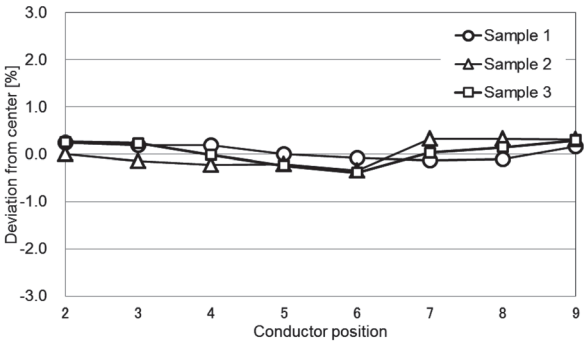

Fig. 11. Effects of conductor position (ø100 mm).

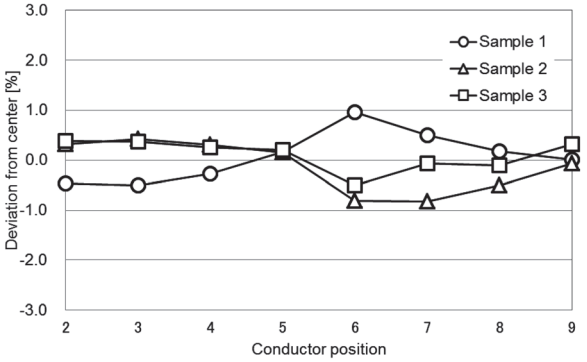

Fig. 12. Effects of conductor position (ø180 mm).

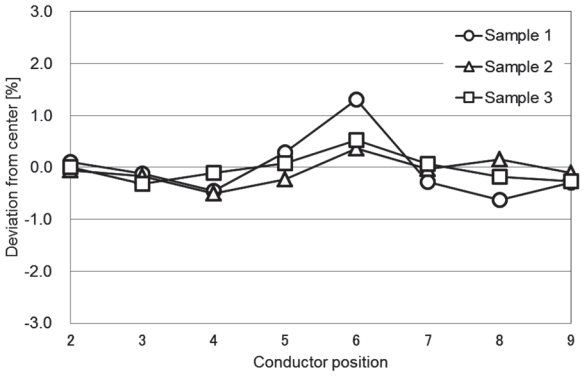

Fig. 13. Effects of conductor position (ø254 mm).

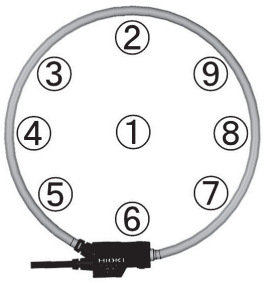

Fig. 14. Effects of conductor position: Measurement locations (ø30 mm conductor carrying 600 A at 60 Hz).

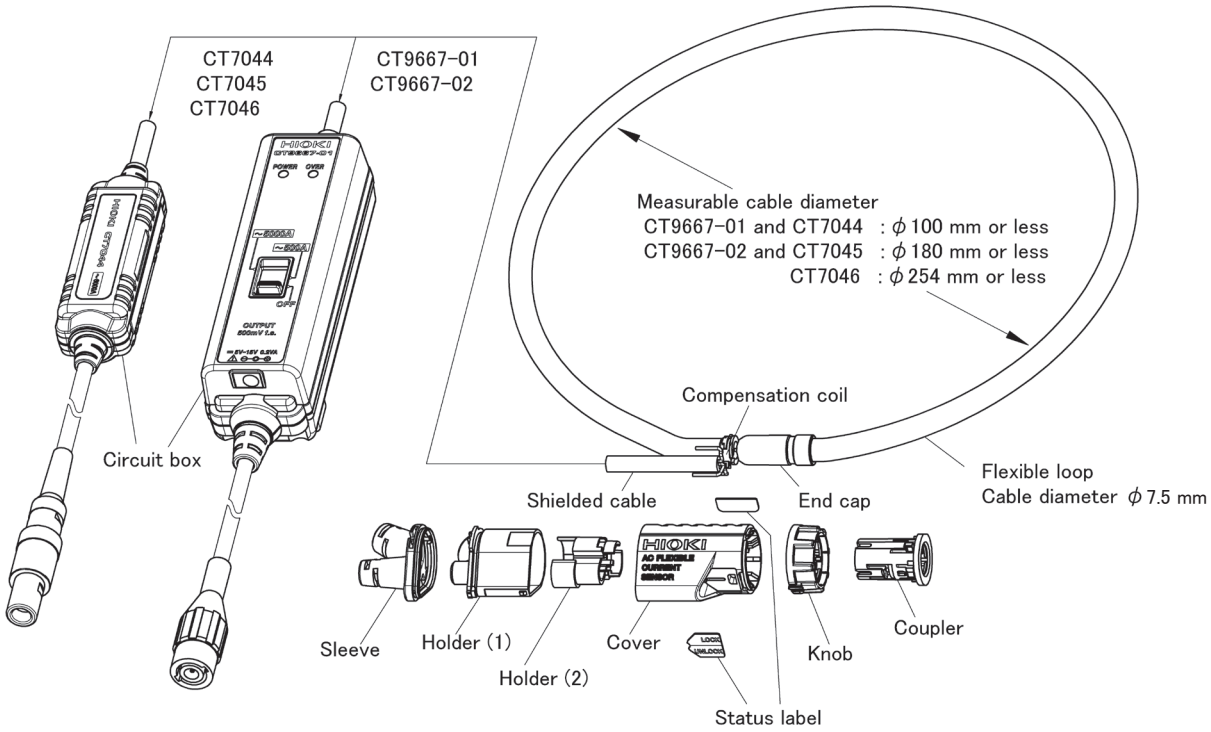

Fig. 15. AC Flexible Current Sensor construction (except the CT9667-03).

to the sensor's connection and locking function in order to minimize its size while simultaneously ensuring a reliable locking mechanism.

In addition, to ensure that the base of the sensor cable and shield cable deliver IP54-level dust and water resistance, integral molding has been used to fabricate the sleeve while embedded in the holder (1). Furthermore, the sleeve incorporates a protruding shape that fits into a groove in the cover to create a seal.

2) Circuit box (CT7040 series): Fig. 16 provides a detailed view of the construction of the circuit box. All sensors in the CT7040 series have an overall protection rating of IP54, including for the circuit box, whose size has been minimized in order to reduce each instrument's installation footprint. Thanks to packing between the upper and lower cases and packing around the holes through which the connection cables pass, the circuit box has the same IP54 rating.

To accommodate demand for a compact sensor and minimize the size of the sleeve, the cables connected to the circuit box feature a sleeve that has been fabricated by means of integral molding above crimped fittings.

Furthermore, Hioki addressed the issue of greater susceptibility to external noise of the electrical circuitry inside the circuit box—a downside of miniaturization—by applying conductive paint to the inside surface of the cases to create an electrostatic shield. In this way, the design

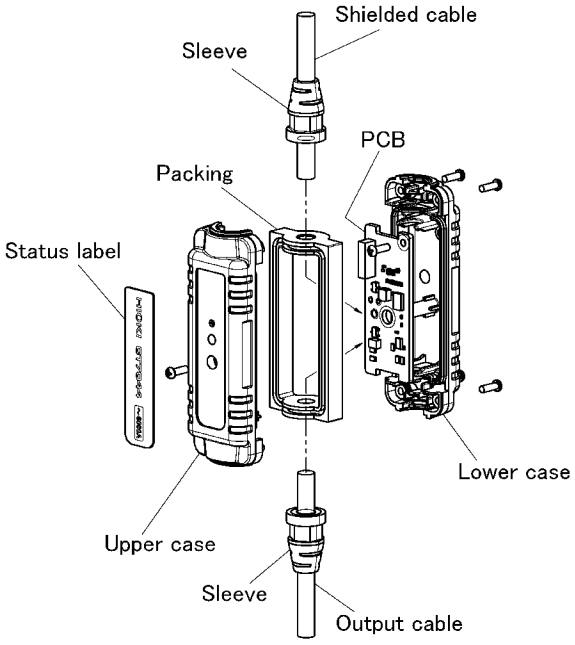

Fig. 16. Circuit box construction (except the CT9667-03).

maintains the necessary level of performance despite its smaller size.

This construction allows the size of the circuit box to be minimized while ensuring that it still delivers IP54 protection.

V. Conclusion

The CT9667-00 series and CT7040 series of current sensors can be used to measure current in confined locations and under harsh environmental conditions that were difficult to measure with previous designs. Hioki expects these devices to be broadly used to further streamline maintenance and inspections of electrical equipment.

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References

[1] T. Miyasaka, “Flexible Clamp On Sensor 9667,” *Hioki Giho*, vol. 23, no. 1, pp. 25-28, 2002. (Japanese).

[2] T. Inoue, “Clamp On HiTester 3280,” *Hioki Giho*, vol. 20, no. 1, pp. 67-72, 1999. (Japanese).

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