Technical Note

AC Leakage Clamp Meter CM4002/CM4003

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***Abstract*—The AC Leakage Clamp Meter CM4002/CM4003 is a current clamp meter that can measure currents from minuscule leakage currents to load currents with a high degree of accuracy. By connecting the optional Wireless Adapter Z3210, the wireless communication is enabled and the process of searching for electric leaks can be streamlined. This paper provides an overview of the product, discusses its functionality and features, and describes example measurement applications.**

I. Introduction

Leakage current measurement is carried out in order to prevent electric shocks and equipment issues caused by defective insulation. The international standard IEC/EN 61557-13 established in 2013 specifies the performance requirements for current clamp meters, which require high reliability.

Hioki developed the AC Leakage Clamp Meter CM4002/CM4003, which minimizes the effects of external magnetic fields and is capable of measuring extremely small leakage currents with a high degree of accuracy, to comply with the standard. Fig. 1 shows the appearance of the product.

II. Overview

The CM4002/CM4003 is a leakage clamp meter that can measure currents from leakage currents to load currents. Leakage clamp meters are used to check leakage currents in order to prevent fires and electric shocks and to search for locations where electric leaks are occurring. By reducing the effects of external magnetic fields by about 40% from the previous model, the Clamp on Leak HiTester 3283, The CM4002/CM4003 enables more accurate measurements. The instrument also complies with the performance standards of IEC/EN 61557-13, an international standard on leakage current clamp meters.

Additionally, by connecting the optional Wireless Adapter Z3210, **Bluetooth**® wireless communications with tablets and smartphones is available, enabling the use of various convenient functions by Hioki's mobile app GENNECT Cross. The app's new event recording function allows users to record intermittent electric leaks that occur at unpredictable timing.

Fig. 1. Appearance.

III. Functions and Features

A. Principal Specifications

- AC current measurement
  Accuracy guarantee range: 0.060 mA to 200.0 A
  Available measurement ranges:
  6.000 mA, 60.00 mA, 600.0 mA, 6.000 A, 60.00 A, 200.0 A
  Accuracy specifications:
  ±1.0% rdg ±5 dgt (6.000 mA, 60.00 mA, 600.0 mA, 6.000 A ranges)
  ±1.5% rdg ±5 dgt (60.00 A, 200.0 A ranges)
- Measurable conductor diameter: ϕ40 mm
- Filter function: −3 dB at 180 Hz ±30 Hz
- Complies with the performance standards of IEC/EN 61557-13.

B. Sensor Structure

The CM4002/CM4003 uses roughly the same sensor structure as the previous model (the 3283). Figs. 2 and 3 illustrate the magnetic core structure and comb tooth structure, respectively. The comb tooth structure with alternating magnetic cores made of high permeability magnetic material (78.5% Ni permalloy) enhances the contact between adjacent magnetic cores and minimizes the leakage of magnetic flux. Fig. 4 illustrates the shielding structure. A total of six shielding materials of four types are used: two on the sides where adjacent cores meet

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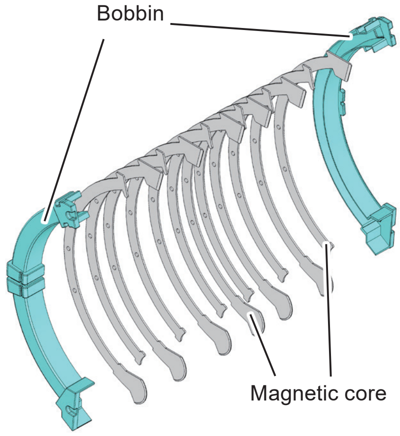

Fig. 2. Structure of magnetic cores.

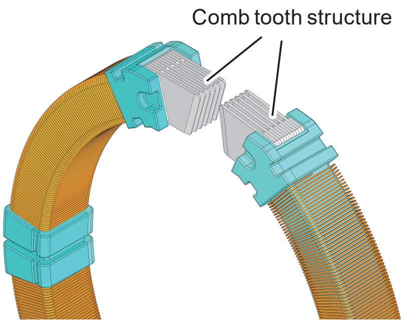

Fig. 3. Comb tooth structure.

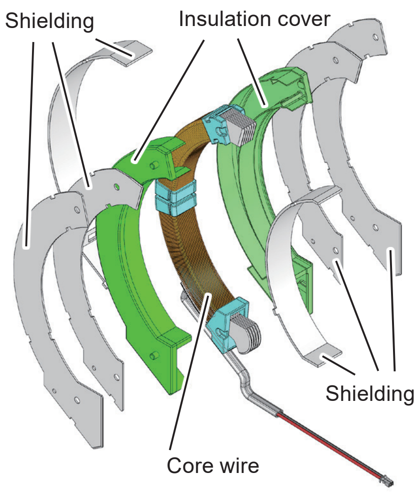

Fig. 4. Shield structure.

(t: 0.5 mm) and two covering the inside and outside of the cores (t: 0.8 mm).

Hioki made two principal changes in the sensor production method and structure from the 3283. The first change is in the processing method used for producing the magnetic cores and shielding elements. This change reduces the magnetic resistance of the magnetic circuit consisting of the magnetic cores and shielding elements.

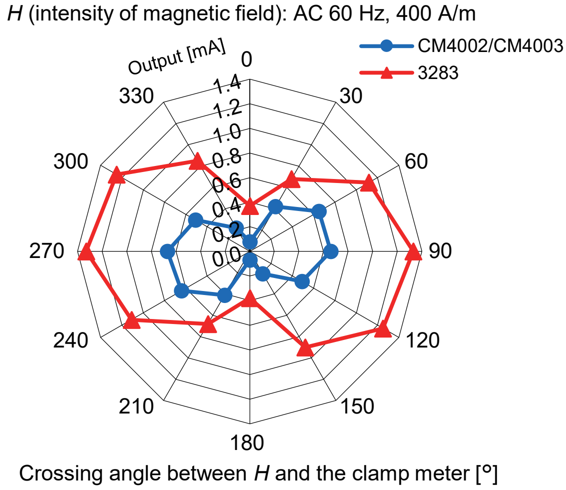

Fig. 5. Effects of external magnetic fields.

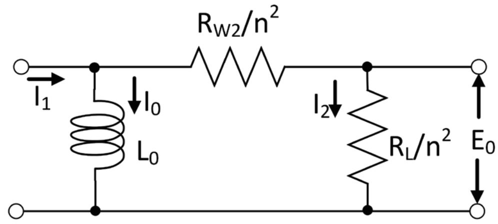

Fig. 6. Equivalent circuit (primary conversion).

The second change involves winding structure. The processing method used for windings has been changed to improve the noise resistance. Additionally, the amount of mechanical stress to which the magnetic cores are subjected during production has been reduced by adding a gap in the middle of the windings. It is desirable to minimize mechanical shocks during the sensor assembly process as mechanical stress could cause damage to the crystalline structure of the magnetic cores, degrading their magnetic characteristics.

Fig. 5 shows an example of the effects of external magnetic fields. Thanks to these two changes, the CM4002/CM4003 reduces the effect of external magnetic fields by 40% compared to the 3283. All outputs are shown in current equivalent values. The strength of the magnetic field applied in this measurement, *H*, is 400 A/m, which is equivalent to about 10 times the magnetic field of the earth.

C. Sensor Operating Principle

This section describes the current transformer (CT) operation. As the CM4002/CM4003 is a clamp-type CT with the conductor under measurement as the primary winding, the winding resistance and leakage inductance of the primary winding can be ignored. Additionally, core losses and magnetic flux leakages can be ignored

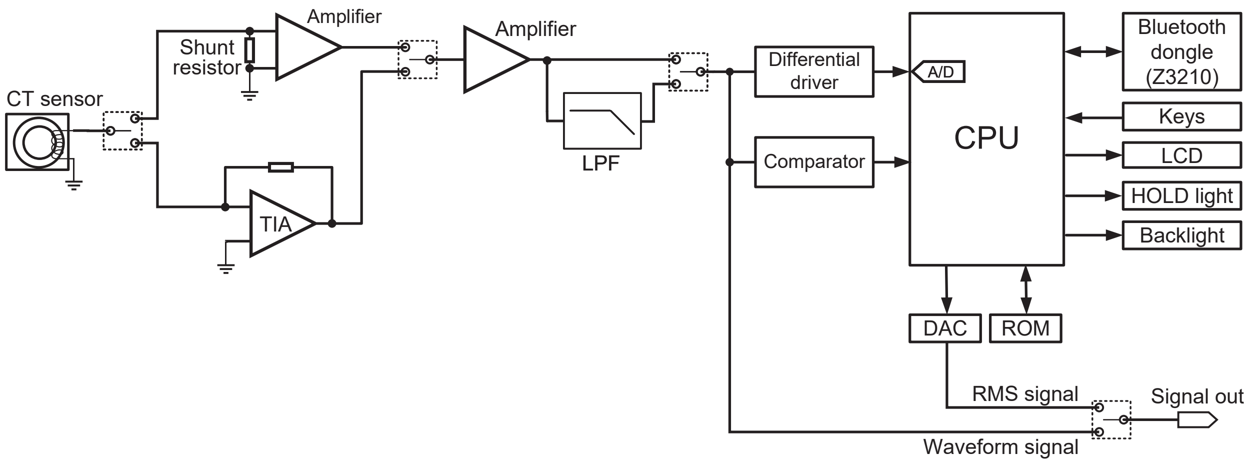

Fig. 7. Block diagram.

since they have been reduced sufficiently as a result of design considerations inherent in the sensor's structure. Consequently, Fig. 6 describes the CT by an equivalent circuit (primary conversion).

The output voltage, E_O, can be expressed by (1).

$$E_o=\left(\frac{R_L}{n^2}\right)I_2$$
$$=\left(\frac{R_L}{n^2}\right)I_1/\left(1+\frac{R_{W2}/n^2+R_L/n^2}{j\omega L_0}\right) \quad (1)$$

Consequently, under the conditions of (2), (3) is obtained. It indicates that the sensor operates as an ideal CT.

$$\omega L_0 \gg \frac{(R_{W2}+R_L)}{n^2} \quad (2)$$

$$E_o=\left(\frac{R_L}{n^2}\right)I_1 \quad (3)$$

The excitation inductance can be expressed by (4).

$$L_0=\frac{N_1{}^2}{R_c}=\frac{1}{R_c}=\frac{1}{\frac{1}{\mu_0}\int\frac{dl}{\mu_s S_c}}=\frac{\mu_0\mu_s S_c}{l_c} \quad (4)$$

N_1: Primary winding count
R_c: Core reluctance
μ_0: Space permeability (4π × 10^{-7})
μ_S: Core relative permeability
S_c: Core cross-sectional area (24 mm²)
l_c: Length of core's magnetic circuit (207 mm)
R_{W2}: Winding resistance (35 Ω)
R_L: Secondary load, 0 Ω or 2 Ω (varies with range)
n: Number of turns (2000)

Calculating the excitation inductance, L_0, using the above values, (5) is obtained.

$$L_0=15\times10^{-6}\ \text{H} \quad (5)$$

The excitation impedance, Z_0, at a frequency of 50 Hz, can be expressed by (6).

$$Z_0=\omega L_0=2\pi f L_0=0.005\ \Omega \quad (6)$$

Since (a) the CM4002/CM4003's winding resistance, R_{W2}, is 35 Ω; (b) the number of turns is 2000; and (c) the secondary load varies in the range of 0 Ω or 2 Ω, the conversion to the primary side is as shown in (7) and (8).

$$\frac{R_{W2}}{n^2}=8.4\ \mu\Omega \quad (7)$$

$$\frac{R_L}{n^2}=0\ \Omega\ (R_L=0\ \Omega)$$

or

$$\frac{R_L}{n^2}=0.5\ \mu\Omega\ (R_L=2\ \Omega) \quad (8)$$

Consequently, the calculation results satisfy (9), indicating that the CM4002/CM4003 CT operates under conditions close to those of an ideal transformer.

$$Z_0=\omega L_0 \gg \frac{(R_{W2}+R_L)}{n^2} \quad (9)$$

D. Circuit Architecture

Fig. 7 shows a block diagram for the CM4002/ CM4003's electrical circuitry.

Currents detected by the sensor is converted into a voltage by a shunt resistance or a transimpedance amplifier (TIA).

The voltage is amplified at an amplification rate that is suitable for each range with the gain amplifier in the next stage, and inputted to an A/D converter. The voltage inputted to the A/D converter is converted into a measured value, undergoing A/D conversion and calculation processing. When measuring currents at a commercial frequency of 50 Hz or 60 Hz, harmonic components can be eliminated with a low-pass filter. The output function outputs one of two signal waveforms as the user-selected signal. One is a wave output which outputs an AC voltage proportional to the measured current. The other is a RMS output which outputs a DC voltage proportional to the RMS value of the measured current.

The CM4002/CM4003 measures minuscule currents across a broad frequency band more accurately by using a TIA in the current-voltage conversion circuit. Whereas the previous model (the 3283) offered a minimum range of 20.00 mA, the CM4002/CM4003 realizes a 6.000 mA range with high single-digit resolution (Figs. 8 and 9). Additionally, whereas the 3283 provided guaranteed accuracy across a frequency range of 40 Hz to 2 kHz, the CM4002/CM4003 extends that range of 15 Hz to 2 kHz (Figs. 10 and 11). Converting a minuscule current into a voltage requires a high current-voltage conversion rate. If using a shunt resistance to convert the current into a voltage, that shunt resistance must have a high resistance value, which has the effect of increasing the CT sensor's secondary load. Equation (1) above indicates that the R_L value (load resistance) must be reduced in order for the CT to operate as an ideal transformer. When R_L is large, the denominator of the ideal transformer condition in (1) increases, especially in the low-frequency region, causing the CT sensor's output to decrease. The TIA lets the sensor operate as an ideal CT by allowing the load resistance to be virtually 0 Ω.

E. Enclosure Construction

The CM4002/CM4003's design follows in the footsteps of the CM series, which was launched in 2015.

Fig. 12 shows an exploded view of the CM4002. Fabricated by layering an elastomer onto a PC/ABS material base using two-color molding technology, the instrument's grip is shaped so that it fits the hand. Since the instrument is specifically designed for current measurement, there's no need to switch measurement modes with a rotary switch which the past CM series models had. Only the minimum necessary number of rubber keys have been included to ensure simplicity and ease of use.

Fig. 13 shows the appearance of the Connection Cable L9097, which is designed exclusively for the CM4003. The L9097 provides an insulated BNC connector for connecting the CM4003's output voltage to external devices as well as a USB connector for supplying power. The highly versatile Type C connector allows the use of a charging cable from a portable device.

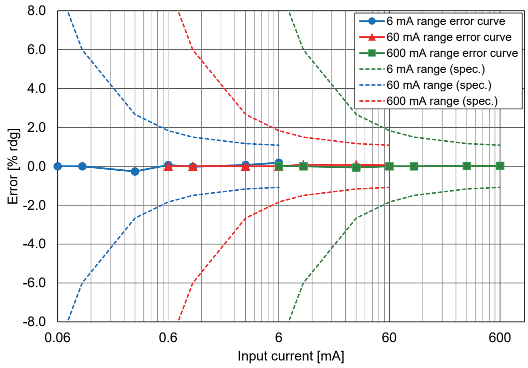

Fig. 8. Current measurement linearity (6 mA, 60 mA, 600 mA ranges).

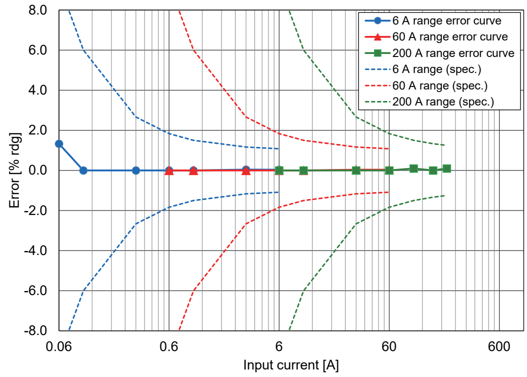

Fig. 9. Current measurement linearity (6 A, 60 A, 200 A ranges).

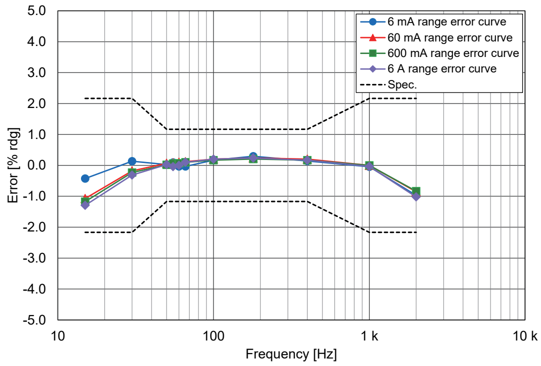

Fig. 10. Frequency characteristic (6 mA, 60 mA, 600 mA, 6 A ranges).

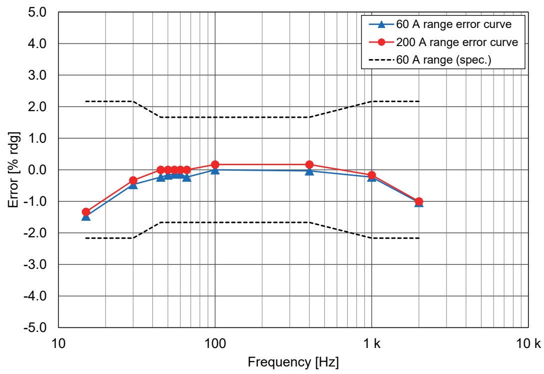

Fig. 11. Frequency characteristics (60 A, 200 A ranges).

F. Bluetooth® Communications

The CM4002/CM4003 is compatible with the Wireless Adapter Z3210, which enables Bluetooth communications function for connecting to GENNECT Cross, a free mobile app from Hioki. GENNECT Cross provides extensive features, including for waveform display, data logging, and harmonic analysis. The CM 4002/4003 can visualize measured values and phenomena more effectively and intuitively. It significantly goes beyond previous current clamp meters. These capabilities promise to dramatically improve work efficiency.

G. Event Recording Function

When paired with GENNECT Cross, the CM4002/CM4003 can be used to record events. The event recording function detects fluctuations in measured values that exceed preset thresholds and records them as events. Four pieces of information can be recorded for each event: the time and date at which the event occurred, the time and date at which the event stopped, the time and date at which the leakage current reached its maximum value, and the maximum current value. The CM4002/CM4003 can record up to 999 events during one recording session.

The instrument delivers gapless recording by dividing the input waveform into 100 ms intervals and continuously calculating the measured values. Consequently, the event recording function can capture even unpredictable, instantaneous fluctuations.

H. Output Function

The CM4003 provides two signal formats: the RMS output and the wave output.

The former outputs a DC voltage derived from CM4003's display value (measurement current RMS value). RMS output can be recorded by a logger to check variations in current values over time.

The latter outputs the measurement current waveform as an AC voltage signal. Wave output can be inputted to a recorder such as a Memory HiCorder or an oscilloscope to check measurement current distortion and harmonic components.

I. External Power Supply Function

The CM4003 can perform continuous measurement over an extended period of time by drawing power from an AC adapter.

As the CM4002/CM4003 has the event recording function and the output function, a long time measurement is required at times. When using batteries, continuous measurement time is limited by the amount of time that the instrument can operate on that power source. The CM4003 can avoid this constraint and perform continuous measurement over an extended period of time by drawing power from an AC adapter.

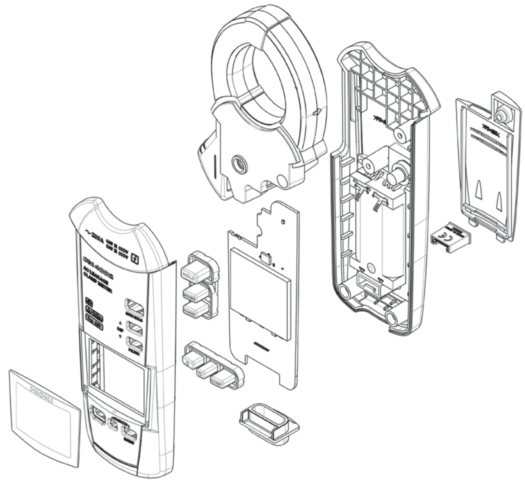

Fig. 12. Exploded view of the CM4002.

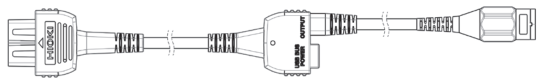

Fig. 13. Connection Cable L9097.

J. Other Functions

In addition to high levels of electrical and design reliability and safety, the CM4002/CM4003 provides a number of other features designed to enhance ease of use:

- Comparator function
- Statistical functions (maximum value, minimum value, average value, maximum crest value, minimum crest value)
- Inrush current measurement function
- Hold function

IV. Example Measurement Applications

A. Regular Leakage Current Inspections

In regular leakage current inspections, high accuracy of the measured values is required.

Thanks to the following features, the CM4002/CM4003 improves the quality of inspection works by accurately measuring minuscule leakage currents:

- Guaranteed basic accuracy of ±1.0 rdg ±5 dgt for measurement currents starting at minimum 0.060 mA
- Compliance with performance standards of IEC/EN 61557-13 (high noise resistance)

B. Investigation of Steady Electric Leaks

When a leakage current is confirmed during a regular inspection or by an electric leak monitoring system, an investigation for identifying where the leakage occurs is conducted. Leakage current measurements are conducted in the branch of the circuit where the leakage current was confirmed, moving from upstream to downstream.

Since such investigations involve repeating measurements in a large number of locations, the ability to record the measurement locations and values is directly related to improvement of work efficiency. By using photograph and drawing function provided by GENNECT Cross, the measured values can be recorded on photographs or drawings depicting measurement locations as follows:

1. Take a picture of the measurement location with a smartphone (Fig. 14).
2. Measure the leakage current.
3. Record measured values by tapping measurement locations on the smartphone's screen (Fig. 15).

C. Investigation of Intermittent Electric Leaks

It is extremely difficult to investigate intermittent electric leaks. Since it is unpredictable when the leak occurs, it is necessary to install electric leak loggers at multiple circuits.

By using the CM4002/CM4003 and the event recording function provided by GENNECT Cross, intermittent electric leaks can be efficiently investigated. This functionality can be used as follows:

1. Set a threshold for leakage current on the smartphone's screen (Fig. 16).
2. Set the CM4002/CM4003 to the circuit to be monitored and start recording.

In the event of a leakage current that exceeds the threshold set in Step 1, the instrument will record the time and date at which the leakage current occurred, the time and date at which it stopped, and the time and date at which the leakage current reached its maximum value and its maximum current value as event data. The smartphone connection need not be maintained during recording. Event data are stored in the instrument's memory.

3. Connect the instrument to GENNECT Cross, import the recorded data, and review it (Fig. 17).

As multiple instruments can be used to record event data for multiple circuits at the same time, the instrument is a powerful tool for investigating intermittent electric leaks.

Fig. 14. Photographing a measurement location.

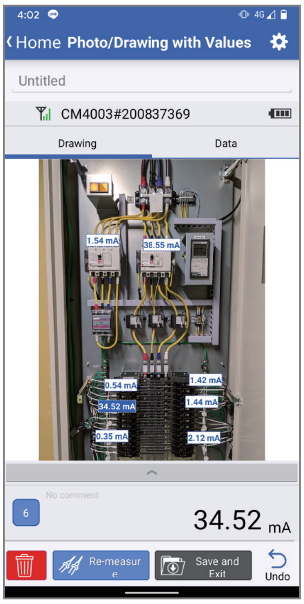

Fig. 15. Example record of measured values.

Fig. 16. Setting electric leak thresholds.

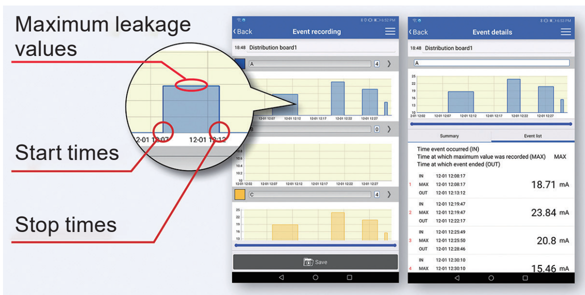

Fig. 17. Recorded event data.

V. Conclusion

The CM4002/CM4003 was developed as a leakage clamp meter that combines the ability to accurately measure minuscule leakage currents with outstanding noise resistance. Electric power comprises critical infrastructure for society, making it difficult to turn off the power in order to conduct an inspection or search for an electric leak. Since leakage clamp meters need only be clamped around wires to measure current, eliminating the need to shut off power, they can be used to reduce the impact of such work on people's lives and on manufacturing operations.

The 3283 has contributed to maintenance of plants and buildings over the many years since Hioki launched it in 1997. However, workers have had to spend time comparing handwritten measurement data on paper with the measurement locations, and the process of searching for intermittent electric leaks has required recorders and other equipment.

Used in combination with GENNECT Cross, the CM4002/CM4003 makes it easy to record the inspection results and search for intermittent electric leaks. Hioki hopes that the CM4002/CM4003 will improve the efficiency of work in the field while contributing to the realization of a safe, secure society by enjoying broad use in the area of maintenance.

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