Heat Flow Logger LR8432-20 and Heat Flow Sensor Z2012/Z2013/Z2014/Z2015/Z2016/Z2017

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Abstract**—**The need for heat flow measurement to augment temperature measurement as a new indicator in product development has been growing in step with technological advances such as better-insulated homes and improved performance of household electronics, residential-use fuel cells, and vehicle batteries. Hioki developed the Heat Flow Logger LR8432-20 to serve as a data logger that can measure thermal energy. The company has also boosted heat flow measurement capabilities by developing a number of new, flexible heat flow sensors as options for use with the LR8432-20. This paper describes the features and architecture of the LR8432-20 and these flexible heat flow sensors.

I. Introduction

Measurement of temperature at multiple locations is an important part of the development process for products such as refrigerators, televisions, multi-function printers and other household electronics and office equipment. Apart from household electronics, temperature measurement also plays an essential role in development of residential and environmental energy equipment and in testing of automotive engine compartments.

However, it is difficult to determine how heat is actually flowing by temperature measurement alone. Heat flow measurement is necessary in order to understand the movement of thermal energy, which is the principal cause of changes in temperature. To measure heat flows requires a heat flow sensor and a measuring instrument.

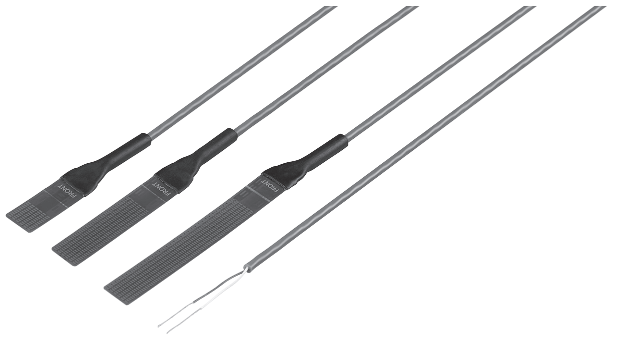
Hioki has developed a logger with the functionality required to measure heat flows. The company has also commercialized a number of optional heat flow sensors that can be used in a broader range of settings than previous designs.

II. Overview

A. Heat Flows

1) Definition: Heat is energy that changes temperature, and like water and electricity, and it moves from areas of high concentration to areas of low concentration. These movements of heat are known as heat flows, and the amount of heat energy that flows through a unit of area per unit of time is expressed in terms of watts per square meter (W/m^2).

Appearance of the LR8432-20.



Appearance of Hioki's Heat Flow Sensors.

2) Advantages of heat flow measurement: Temperature measurement using a thermocouple or thermography does not provide sufficient data with which to gauge the processes of temperature change (heat generation, heat absorption, magnitude, etc.). By measuring heat flows, it is possible to visualize the movement and magnitude of heat energy, which can be used as a leading indicator of temperature change.

3) Principle of heat flow measurement: Fig. 1 illustrates the principle of measurement with a heat flow sensor. If the thermal conductivity λ [W/(m·K)] and sensor thickness d [m] are known, it is possible to calculate the heat flow Q [W/m^2] by measuring the temperature on both surfaces of the sensor. By detecting the temperature difference between the top and bottom of the sensor with a high degree of precision, heat flow sensors output a voltage that is proportional to the heat flow rate.

B. Product Architecture

Despite its compact footpoint, the LR8432-20 provides a 10-channel terminal block with M3 screws. Its small size enables the logger to be used to observe heat flows in a variety of settings.

Measurement targets include voltage or heat flow data, temperature data (from thermocouples), and pulse data. The instrument's maximum sensitivity is 10 mV f.s., and it can accept the minuscule voltages output by heat flow sensors in applications such as insulation evaluation.

The LR8432-20 performs measurement by means of high-speed sampling of all channels at 10 ms, enabling it to track abrupt changes that outpaced previous models' 100 ms sampling speed.

The instrument supports use of CompactFlash (CF) and USB flash drives as external storage media. Since media can be "live-swapped" during measurement, it is possible to remove recorded data from the instrument while continuing measurement.

Optional heat flow sensors include the Z2012, Z2013, Z2014, Z2015, Z2016, and Z2017. Sensors are available in three sizes and two cable lengths, for a total of six models, so that users can choose the sensor that best suits their application.

III. Features

A. LR8432-20 Features

1) Simple heat flow sensor setup: Since heat flow sensors output a voltage that is determined by the heat flow rate (based on the sensor's sensitivity constant), the heat flow rate can be calculated by measuring the voltage value with the LR8432-20 and then multiplying the result by a coefficient. With the ordinary scaling method, it was necessary to calculate a conversion ratio since this sensitivity constant varies with the sensor. For example, if the sensitivity constant were 0.013 mV/W·m^{-2}, it would be necessary to enter the scaling value after calculating the inverse of 0.013×10^{-3}, or 76 923. This approach was time-consuming and posed the risk of calculation errors. The LR8432-20 offers completely automated scaling by allowing the user to enter the heat flow sensor's sensitivity constant directly, simplifying setup and eliminating the possibility of calculation errors.

2) Simultaneous display of heat flow and temperature scales: Because previous models could display only one graduated scale for the display waveform, it was difficult to compare waveforms. Reflecting users' frequent need to compare correlations between heat flow and temperature as part of heat flow measurement, Hioki has simplified that process by adding functionality for simultaneously displaying separate graduated scales for two user-specified channels. Fig. 2 provides an example of these scales. In this way, the user can check the scales for heat flow (CH2) and temperature (CH3) at the same time.

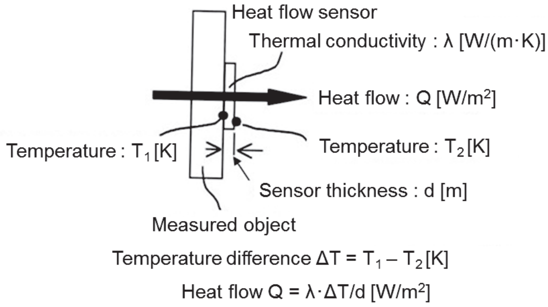


Fig. 1. Measurement principle.

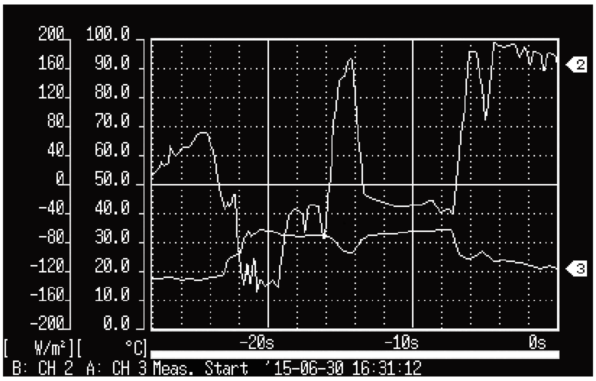


Fig. 2. Example graduated scales.

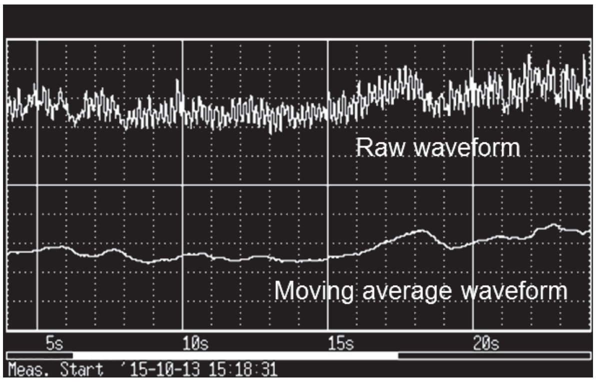


Fig. 3. Moving average waveform calculation.

3) Real-time waveform calculation functionality: The LR8432-20 provides five waveform calculation functions: the four arithmetic functions along with moving average, simple average, integration, and coefficient of overall heat transmission. It is typical to average readings from heat flow sensors since their output fluctuates greatly due to factors such as surrounding convection currents, making moving averaging functionality essential. Fig. 3 provides an example measurement waveform before and after moving average calculation.

B. Heat Flow Sensor Features

1) Method for affixing sensors: Hioki provides Thermally Conductive Tape Z5008 for use when affixing sensors to measurement targets. Use of the Z5008 tape to facilitates acquisition of more accurate heat flow values. In addition, the polarity of the output voltage varies with the orientation in which the sensor is affixed to the target surface. Consequently, the sensor's top surface has been labeled "FRONT" to make clear the proper orientation. Fig. 4 illustrates the relationship between output voltage and heat flow when the back of the sensor is affixed to the target surface.

2) Sensor architecture and principle of operation: As illustrated in Fig. 5, each sensor consists of P- and N-type semiconductors connected at multiple points. When different semiconductors are connected, temperature differences across the sensor's two surfaces trigger the Seebeck effect, giving rise to a voltage. This voltage is multiplied by the sensor's architecture, which includes a large number of connections and thereby allows accurate measurement of even minuscule heat flows.

3) High sensitivity: Until now, compact heat flow sensors yielded low output voltages, making it difficult to measure minuscule heat flows. The Z2012 and its counterparts implement high sensitivity by means of the architecture described above to enable measurement of minuscule heat flows to and from small components. High sensitivity makes it possible to detect minuscule heat flow rate variations.

4) Thin profile: When a heat flow sensor is affixed to a measurement target, the effects of thermal resistance and convection currents become sources of error in measurement. Hioki has implemented a thin, flexible heat flow sensor that is approximately 0.28 mm (0.01″) thick. This thin construction gives the sensor itself low thermal resistance and minimizes its effect on convection currents, enabling accurate measurement, including in environments characterized by intense convection currents. Fig. 6 illustrates the effects of sensor thickness as well as the effects of convection currents on the sensor.

5) Flexibility: Past heat flow sensors have been rigid, making it difficult to affix them to curved surfaces. Hioki's flexible heat flow sensors have a minimum radius of curvature of 30 mm (1.18″), enabling their use on measurement targets such as pipes that have been unmeasurable until now and making it possible to measure heat flows in a greater variety of locations.

6) Size: Since Hioki offers three sensor sizes (small, medium, and large), users can select the model that best suits their application. The small-size models have a heat flow sensor that is approximately 10 mm (0.39″) square, making them ideal for measuring small components such as semiconductors. The large-size models yield higher output than their smaller counterparts, which makes them useful when measuring minuscule heat flows. In addition, their long sensors can be wrapped around pipes and other objects.

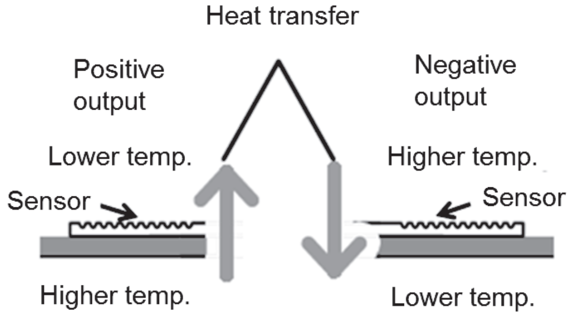


Fig. 4. Output voltages and heat flows.

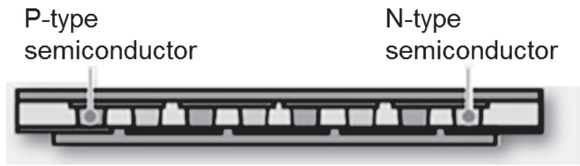


Fig. 5. Sensor architecture.

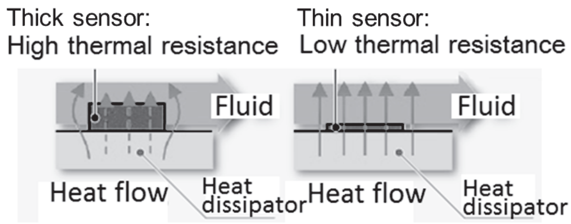


Fig. 6. Effects of thickness and convection currents.

7) Waterproofness: As reflected by their IP06 and IP07 International Protection Code ratings, Hioki's heat flow sensors deliver a high level of waterproofness to allow measurement of heat flows under a variety of environmental conditions. This level of protection means sensors' enclosures are impervious to water projected in powerful jets from any direction, and that they can withstand submersion in water to a depth of 1 m (3.28′) for 30 minutes. In addition to use outdoors, the sensors can be buried in soil or concrete.

8) Operating temperature range: The sensors deliver a broad operating temperature range of −40°C to 150°C (−40°F to 302°F). Consequently, they can withstand use in a variety of settings, from cold to hot.

9) Pressure resistance: Sensors used to measure heat flows between different materials must be able to resist pressure. The Z2012 and its counterparts can resist compressive stress of 4 MPa, and their thin profile makes them ideally suited to measuring heat flows while sandwiched between two materials.

IV. Heat Flow Measurement Applications

A. Measurement of Heat Flows Inside an Engine Compartment

Heat flows inside an automobile's engine compartment can be measured in order to determine whether the measurement target is generating heat or whether heat is coming from an external source. Fig. 7 illustrates actual data from a vehicle as it was driven.

B. Measurement of Heat Flows From Electronic Components

Hioki's smallest flexible heat flow sensor measures approximately 10 mm (0.39″) on each side, making it small enough to be used to measure heat flows from electronic components such as CPUs. Fig. 8 illustrates measurement of heat flows from an electronic component.

C. Diagnosis of the Deterioration of Pipe Insulation

Where the rigidity of past heat sensors made them poorly suited for measurement of curved surfaces, flexible heat flow sensors can be used to measure heat flows from round pipes. By measuring heat flows from insulation, it is possible to assess the deterioration of insulating performance over time. Fig. 9 illustrates measurement of heat flows from a pipe.

V. Conclusion

The LR8432-20 is a logger that provides the functionality needed to measure heat flows. The instrument supports flexible heat flow sensors that can be used in a broader range of settings than conventional designs, and Hioki expects is to be utilized to acquire R&D data in fields such as energy-saving technology and thermal energy.

Eiji Ohnishi[*1]

Reference

[1] E. Ohnishi, "Wireless Heat Flow Logger LR8416," *Hioki Giho (Hioki Technical Notes)*, vol. 36, no. 1, pp. 13-16, 2015. (Japanese, also available in English).

Registered Trademark

- CompactFlash is a registered trademark of SanDisk Corporation (USA).

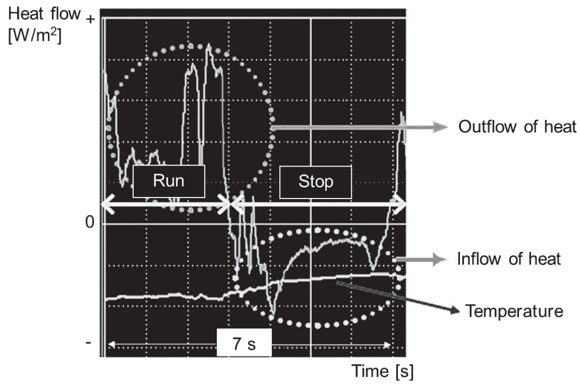


Fig. 7. Waveform data from vehicle operation.

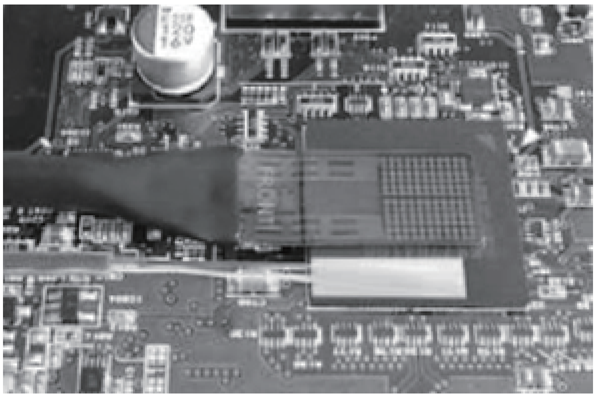


Fig. 8. Heat flow measurement of an electronic component.

Fig. 9. Heat flow measurement of a pipe.

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