PHFS Heat Flux Sensor Instruction Manual

Introduction

Heat flux sensors can be used to measure and quantify the thermal energy per unit area moving through a surface of a system. They are used by engineers to measure and understand the heat transfer in HVAC systems, insulation analysis, refrigeration systems as well as countless other thermal applications.

PHFS Heat Flux Sensor Description

The PHFS heat flux sensors utilize a differential-temperature thermopile design to measure the movement of thermal energy per unit area, or heat flux, through the sensor surface. Using this design, it is possible to measure all three modes of heat transfer; conduction, convection and radiation. Each PHFS sensor includes an integrated thermocouple that can be used for sensor temperature measurements. PHFS-01e & PHFS-09e sensors come standard with a flat black coating with a known emissivity value of 0.94 for radiation heat transfer measurements. PHFS-01 sensors do not come standard with this coating but can be requested at the time of placing your order.

Sensor Mounting/Installation

The manner in which the heat flux sensor is mounted depends on the application that it is being used for. The best results are obtained from mounting the sensor on smooth clean surfaces. The overall goal in mounting the PHFS is to have the sensor strongly adhered, and contacting the measurement surface as uniformly as possible. This will reduce the amount of thermal contact resistance between the surface and the sensor to increase accuracy of measurements. Using either of the following mounting techniques is recommended.

Method #1: Double-stick tape

Commercially available double-stick tape is ideal for temporary mounting to solid surfaces. When using double-stick tape, be sure the measurement surface is clean. Cover the desired area that the sensor to be placed on with the double-stick tape. If using multiple pieces of double stick tape, try to tape the surface as uniformly as possible. Avoid overlapping tape so there is even thermal resistance across the sensor.

Method #2: Thermally conductive glue

Thermally conductive glue can be used for permanent mounting of the PHFS. Before mounting, clean the measurement surface and the surface of the sensor. Spread a thin, uniform layer of the thermally conductive glue across the surface of the sensor. Apply constant, uniform pressure to the sensor until the glue dries.

Method #3: Thermally conductive paste

Another method for temporarily attaching the PHFS is by using thermally conductive paste. This method is only appropriate if the sensor is being held in place with a constant, uniform pressure while the sensor is taking measurements. An example of an appropriate measurement scenario is if the sensor is used for conductive heat transfer measurements while being placed between two surfaces holding it in place. Thermally conductive paste can be placed between the sensor and each of the surfaces to minimize thermal contact resistance and overall thermal resistance. FluxTeq recommends using OmegaTherm conductive paste by Omega or Sarcon SG-26SL by Fuji Polymer Industries Co. Ltd but toothpaste has even been used when nothing else is available.

Another method is to apply a thin layer of thermal conductive paste between the sensor and the measurement surface. Then use an adhesive tape over the entire sensor to keep it pressed down onto the surface.

## Removing Sensor from Measurement Surfaces

Removing the PHFS from the measurement surface is only recommended if a temporary adhesive such as conductive paste or double-stick tape was used for mounting. It is possible that higher strength adhesion methods can comprise the integrity of the sensor if the sensor is removed from them.

IMPORTANT: When removing the sensor, very carefully remove the side with the leads with one hand and peel the opposite side with the other hand to avoid bending as much as possible. Slight bending of the sensor will not affect its performance but ripping it off surfaces and forcing it to bend sharply should be avoided.

Sensor Signal Measurement

The output of the PHFS is a DC voltage that is linearly proportional to the heat flux absorbed by the sensor. Similarly, the type-T thermocouple used for PHFS surface temperature measurements outputs a DC voltage proportional to the temperature difference between the sensor surface and the voltage

measurement location. The output DC voltage signals can be measured with any precision voltmeter or 3rd party voltage data acquisition system with a microVolt µV resolution. FluxTeq also offers low-cost data acquisition systems, the FluxDAQ & FluxDAQ+, with the appropriate capabilities. The construction design of the PHFS allows for measurement of both heat flux and temperature difference using four wires.

(+)   (-)   (+)   (-)
Heat Flux   Thermocouple
Leads   Leads
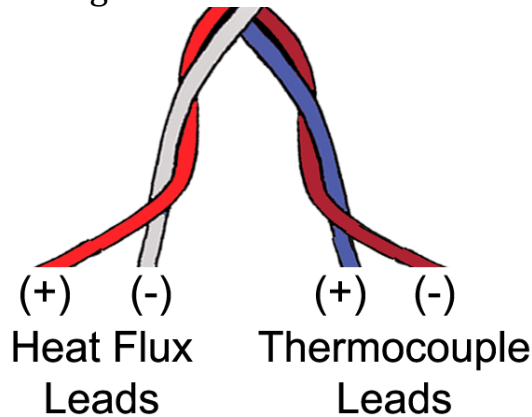
Measuring Heat Flux Voltage
To measure the sensor output voltage that is caused by the sensor absorbing heat flux, $\Delta V_{q''}$, connect the positive (+) terminal of the voltage measurement device to the bright red wire and negative (-) terminal to the white wire.

Temperature Dependence of PHFS Heat Flux Sensor
The output signals from PHFS heat flux sensors have some dependence on the temperature of the sensor itself. This dependence means that sensor's sensitivity changes slightly at different temperatures.

Each sensor is calibrated at a base sensor temperature of 25°C. The sensitivity at this temperature is recorded on the calibration sheet provided with each individual heat flux sensor. An example of the calibration sensitivity, S_{Calib}, is shown below circled in red.
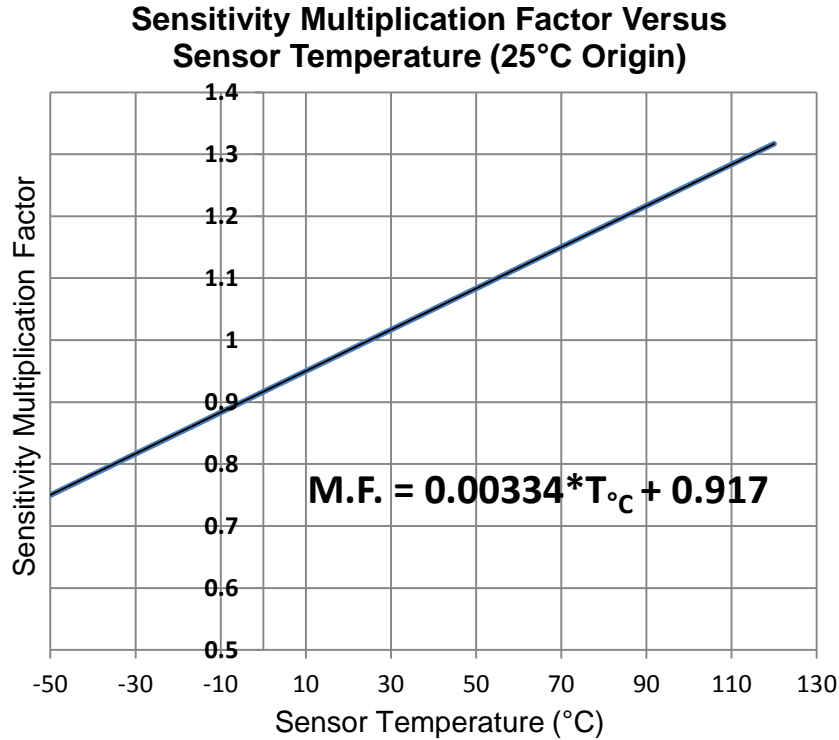
If you are using the heat flux sensor at a temperature that is different from 25°C then it is suggested that you adjust the sensitivity to compensate for the temperature dependence using the following steps.

Calibration Test Results

Heat Flux Sensor Sensitivity, S_{Calib}	1.00	± 0.03 µV/(W/m²)
Sensor Temperature at Time of Calibration, T_{Calib}		25.0 C
Heat Flux at Time of Calibration	3000	W/m²

Take the sensor's temperature measurement, $T_{°C}$, at each measurement in time along with the calibrated sensitivity, S_{Calib}, to determine the heat flux sensitivity at that specific temperature, $S_{@ \, T_{°C}}$.

$$S_{@ \, T_{°C}} = M.F.* S_{Calib} = [\, 0.00334 * T_{°C} + 0.917 \,] \; * \; S_{Calib}$$

Sensitivity Multiplication Factor Versus Sensor Temperature (25°C Origin)

M.F. = 0.00334*T°C + 0.917

Calculating Heat Flux

Using the DC voltage measurements taken from the heat flux wire leads (white & bright red), the heat flux values can be calculated using the adjusted sensitivity for that specific sensor and the following equation.

$$q'' = \frac{\Delta V_{q''}}{S_{@ \, T_{°C}}}$$

where q'' is the heat flux absorbed through the sensor, $\Delta V_{q''}$ is the PHFS sensor output heat flux voltage, and $S_{@ \, T_{°C}}$ is the sensitivity of the sensor that has been adjusted according to the sensor's temperature at that specific time.

> ***For example***: A voltage value of 1.80 mV is measured across the heat flux leads, and the sensor's calibrated sensitivity is specified to equal 0.90 μV/(W/m²), and the sensor's temperature is measured to be equal to 30°C from the thermocouple leads at that point in time. The calculation for heat flux is as follows.
> 1. First, adjust the sensitivity according to the measured sensor temperature from the sensor's integrated Type-T thermocouple.

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$$S_{@\,T°_C} = [0.00334 * T°_C + 0.917\,]\ *\ S_{Calib}$$

$$S_{@\,T°_C} = [0.00334 * (30°C) + 0.917\,]\ *\ 0.90\ \left(\frac{\mu V}{(W/m^2)}\right)$$

$$S_{@\,T°_C} = 0.915\ \left(\frac{\mu V}{(W/m^2)}\right)$$

2. Next, calculate heat flux using the adjusted sensitivity and voltage measurement across the heat flux wire leads.

$$q'' = \frac{\Delta V_{q''}}{S_{@\,T°_C}} = \frac{1800\ \mu V}{0.915\ \mu V/(W/m^2)} = 1967\ W/m^2$$

It should be noted that both positive and negative voltages can be measured by the PHFS sensor. A negative voltage value compared to a positive voltage just means that the heat flux is moving in the opposite direction.

Measuring Thermocouple Voltage to Determine Sensor Temperature:

A thermocouple is integrated in every PHFS heat flux sensor to provide a measurement of the sensor's surface temperature. Measuring the voltage output from the thermocouple will provide an indication of the temperature difference between the temperature measurement location at the top sensor surface and the voltage measurement location. An additional temperature measurement at the voltage measurement location is required to determine absolute temperature of the sensor. This reference temperature is known as cold junction compensation and is commonly built into data acquisition systems.

Connect the darker red constantan wire to a negative (-) terminal of the voltage measurement device. The positive (+) voltage measurement device lead should be connected to the blue copper lead wire.

Calculating Temperature Difference

The voltage output from the thermocouple will provide an indication of the temperature difference between the temperature measurement location of the top sensor surface and the voltage measurement location. An additional thermocouple at the measurement location or known reference temperature is required for absolute temperature measurement. The PHFS sensor's thermocouple is made of type-T thermocouple grade materials copper (blue wire) and constantan (dark red wire).

Rough Temperature Estimation:

For a quick, easy estimation of the temperature difference between the sensor surface and the voltage measurement location the following equation can be used.

$$\Delta T = T_S - T_M = \frac{\Delta V_T}{Se}$$

Where ΔT is the temperature difference from the PHFS sensor top surface temperature, T_S, and the thermocouple output voltage measurement location, T_M. Also, ΔV_T, is the thermocouple output voltage in μV, and Se is the Seebeck coefficient of the type-T thermocouple. For a rough estimation of the temperature difference a Seebeck coefficient value of 40 μV/°C, the value of Seebeck coefficient at 20 °C, can be used.

Precise Temperature Difference Calculation:

For a precise calculation of the temperature difference between the sensor surface and the voltage measurement location an alternate method can be used. Since thermocouple materials are slightly dependent on temperature, precise measurements need to compensate for this. Type-T thermocouples follow the following 7th order polynomial relationship of temperature difference, ΔT, in °C as a function of thermocouple output voltage, ΔV_T, measured in volts using the following equation and coefficients listed in Table 1.

$$\Delta T = a_0 + a_1 \Delta V_T + a_2 \Delta V_T^2 + a_3 \Delta V_T^3 + a_4 \Delta V_T^4 + a_5 \Delta V_T^5 + a_6 \Delta V_T^6$$

Table 1. Coefficients used in relationship of thermocouple temperature as a function of thermocouple output voltage.

Coefficient Symbol	Value
a_0	0.00
a_1	2.5928×10^{-2}
a_2	-7.602961×10^{-7}
a_3	4.637791×10^{-11}
a_4	$-2.165394 \times 10^{-15}$
a_5	6.048144×10^{-20}
a_6	$-7.293422 \times 10^{-25}$

This relation is valid within ±0.5 °C within the temperature range of 0 °C to 400 °C.

Calculating Absolute Sensor Temperature:

In order to determine the absolute temperature of the top sensor surface it is necessary to have an additional reference temperature measurement at the thermocouple voltage measurement location, T_M. This is commonly referred to as cold junction compensation.

$$T_S = \Delta T + T_M$$

Where T_s is the top surface temperature of the PHFS sensor, ΔT is the measured temperature difference between the temperatures of the top sensor surface and the thermocouple voltage measurement location.

Checking the Functionality of PHFS Sensor & Troubleshooting:

There are a couple different simple tests can be performed to ensure that the PHFS is operating correctly. It is good practice to perform these before/after mounting the sensor so that inaccurate measurements are not accidently taken using a faulty sensor.

1. ### *Check electrical resistance of sensor:*
   Connect an ohmmeter to the bright red wire and the white wire leads to check the sensor resistance. It should approximately equal to that value provided on the specification sheet (<2000 ohms for PHFS-01/PHFS-01e sensors and <10 kohms for PHFS-09e sensors). If the resistance is much larger than this then there may be an issue with the PHFS.

2. ### *Check the electrical resistance of the thermocouple:*
   Connect an electrical resistance ohmmeter to the darker red constantan wire and the blue copper wire. The electrical resistance should be approximately 10 ohms for our standard 3 foot lead length. Resistance will be higher for longer lead lengths.

3. ### *Check output voltage with zero heat flux:*
   If possible, while a voltage measurement device is connected across the heat flux wire leads, measure the output heat flux voltage while the sensor is experiencing zero absorbed heat flux. An easy scenario is to let the sensor remain unmounted in ambient conditions such as sitting loose on a tabletop. The DC voltage reading for the heat flux output voltage should be approximately 0.0 μV (+/- 5 μV can be contributed to electrical noise).

4. ### *Check the output voltage for an induced heat flux:*
   A simple method of determining whether the PHFS is roughly operating correctly is by physically inducing a heat flux. This can be done by first

attaching the two heat flux wire leads (white & bright red) to a DC voltmeter. Next place the PHFS sensor on a metallic surface and firmly placing the palm of your hand across the entire sensor surface. The resulting peak output voltage value should be somewhere around 1.0 mV for a PHFS-01/PHFS-01e (this value could vary over 20% from this value depending on the situation). You can also flip the sensor over and a similar output DC voltage signal with an opposite sign (positive (+) versus negative (-)) should be measured.

5. ***Check the output thermocouple voltage:***
If the sensor and voltage measurement location are at equal temperatures, the output voltage from the thermocouple should be approximately zero microvolts (this test scenario is often difficult to achieve easily).

Contact Information for Additional Questions
For additional information about PHFS heat flux sensor specifications, applications, or general inquires use the following contact information or visit the FluxTeq website at www.FluxTeq.com

Direct general inquiries to - info@FluxTeq.com

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