HFS-5 HFS-6 UHFS-09

HFS 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 and can measure heat transfer in HVAC systems, insulation analysis, refrigeration systems as well as countless other thermal applications.

Heat Flux Sensor Description
The HFS-5, HFS-6, & UHFS-09 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. Each HFS sensor includes an integrated type-T thermocouple that can be used for sensor temperature measurements. The sensitivity of each sensor is provided with each unit recorded on their respective calibration certificate. Sensor calibration procedures adhere to ASTM standard C1130 and are described later in this manual.

Instruction Manual Contents

List of Symbols Used in this Manual

Term Represented by Symbol	Symbol	English Units	Metric / SI Units
Heat Flux	q”	BTU/(ft^2-hr)	W/m^2
Electrical Resistance	Ω	Ohms or kOhms	
Voltage Output	ΔV	V or mV or µV	
Heat Flux Sensor Sensitivity	S	µV / BTU/(ft^2-hr)	µV/(W/m^2)
Temperature	T	°F	°C
Temperature Difference	ΔT	°F	°C
Heat Flux Sensor Sensitivity at a Temperature	$S_{@\ T°C}$	µV / BTU/(ft^2-hr)	µV/(W/m^2)
Sensitivity Multiplication Factor	M.F.	No Units	
Temperature Gradient	dT/dx	°F/ft	°C/m
Thickness of Material	δ	ft	m
Thermal Conductivity	λ or k	BTU/(ft^2-hr)/°F	W/(m-K)
Thermal Resistance	R”	°F/BTU/(ft^2-hr)	(m^2-K)/W

Unit Conversion Factors

Term	Conversion Method
Heat Flux	1 W/m^2 = 0.317 BTU/ft^2-hr
Sensor Sensitivity	1 µV/(W/m^2) = 3.155 µV/(BTU/(ft^2-hr)
	1 µV/(W/m^2) = 10 mV/(W/cm^2)

Section 1: How to Use a Heat Flux Sensor

Below are details on how to use a heat flux sensor to take thermal measurements. These directions are for general use and can be somewhat modified depending on the test conditions in order to collect the most accurate measurements for your application.

Brief Overview of Using the Heat Flux Sensor

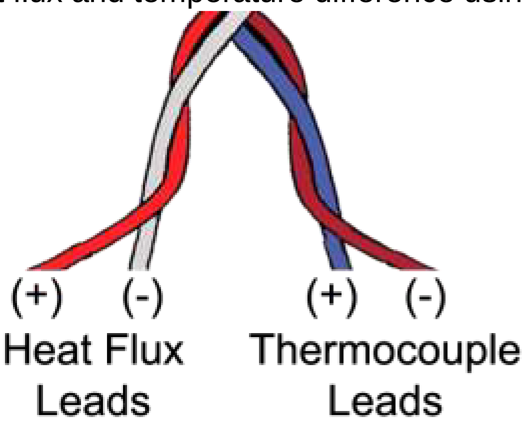
1. Ensure the sensor is operating properly by conducting simple tests of functionality.
2. Mount the sensor to the measurement surface.
3. Connect the heat flux sensor leads and the integrated thermocouple leads to a precision voltmeter or precision data acquisition device.
4. Collect measurements by reading the analog DC voltage signals from the wire leads.
5. Adjust the sensitivity of the heat flux sensor according the sensor's temperature and the temperature dependence function (not necessary for UHFS-09 sensors). The sensitivity of the sensor is provided with each unit on their respective calibration certificate in addition to the temperature dependence function.
6. Calculate heat flux using the adjusted sensitivity.

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

7. Remove the sensor from the measurement surface if necessary while being very careful not to damage it

Sensor Signal Measurement

The output of the HFS is a DC voltage that is linearly proportional to the heat flux absorbed by the sensor. Similarly, the type-T thermocouple used for HFS 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. The construction design of the HFS allows for measurement of both heat flux and temperature difference using four wires.



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. The polarity of these wires does not matter too much since heat flux will be positive or negative depending on the orientation of the sensor.

Measuring Thermocouple Voltage

A thermocouple is integrated in every HFS 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.

Checking the Functionality of HFS Sensor & Troubleshooting

There are a couple different simple tests can be performed to ensure that the HFS 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 that may have been damaged while it was being handled.

1. ***Check Electrical Resistance of the Heat Flux Sensor:***

   Connect an ohmmeter to the bright red wire and the white wire leads to check the heat flux sensor's electrical resistance. It should <1000 Ω for HFS-5 sensors or <5 kΩ for HFS-6 & UHFS-09 sensors. If the resistance is much larger than this then there may be an issue with the sensor. Resistance may be slightly larger for sensors that have lead wire lengths longer than the standard 10 ft / 3 m. Infinite electrical resistance (discontinuity) is an indication that the heat flux sensor is broken.

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 50 Ω for our standard 10 foot / 3 meter lead length. Resistance will be higher for longer lead lengths. Typical resistance of the wire is 5 Ω per foot or 16 Ω per meter. Infinite electrical resistance (discontinuity) is an indication that the thermocouple is broken.

3. ***Check Output Voltage with Zero Heat Flux Through Sensor:***

   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 through the sensor. An easy scenario is to let the sensor remain unmounted in ambient conditions such as sitting loose on a tabletop. The analog 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 Through Sensor:*** A simple method of determining whether the HFS is roughly operating correctly is by physically inducing a heat flux. Place the HFS sensor on a metallic surface and firmly placing the palm of your hand across the entire sensor surface. The resulting peak DC output voltage value should be somewhere around 1.0 mV for a HFS (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). This test is rarely necessary since thermocouple electrical resistance should be sufficient enough of a test.

6. ***Ensure the Sensor's Serial Number Matches the Calibration Certificate*** You will want to double check that the heat flux sensor's serial number matches that indicted on the Calibration Certificate. This will ensure that you use the correct sensor sensitivity appropriate for your sensor. The sensor's serial number should be located on a tag on the wire leads.

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 HFS is to have the sensor strongly adhered and fully contacting the measurement surface as uniformly as possible. This reduces the amount of thermal contact resistance between the measurement surface and the sensor and thus increases accuracy of measurements. Using one of the following mounting techniques is recommended but can be adjusted according to the testing setup.

Mounting Method #1: Double-Stick Adhesive 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 mounting area with double sided tape, then firmly & evenly press the sensor to the tape. If using multiple pieces of double stick tape, avoid overlapping the tape on itself.

Mounting Method #2: Thermally Conductive Glue

Thermally conductive glue can be used for permanent mounting of the HFS. 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. Removing the sensor from the surface after gluing it will likely destroy the sensor.

Mounting Method #3: Thermally Conductive Paste

Thermally conductive paste 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 that are squishing it & holding it in place. Thermally conductive paste can be placed between the sensor and each of the surfaces to minimize thermal contact resistance. One recommended product is using OmegaTherm 201 conductive paste available from Omega. Alternatively toothpaste has even been used when nothing else is available and actually works fairly well.

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 HFS 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

Section 2: Converting Measurements to Heat Flux and Temperature

Type T thermocouple temperature measurement

Thermocouple temperature measurements can be recorded with a thermocouple meter capable of reading T-type thermocouple, with cold junction compensation. (Suggested meter: Omega DP41-TC)

Temperature Dependence of HFS Heat Flux Sensor

The output signals from HFS-5 and HFS-6 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. **UHFS-09 sensors do not experience this dependence so ignore this section if using this sensor model.**

Each sensor is calibrated at a base sensor temperature of 25°C or 77 °F. 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 or 77°F then it is suggested that you adjust the sensitivity to compensate for the temperature dependence using the following steps.

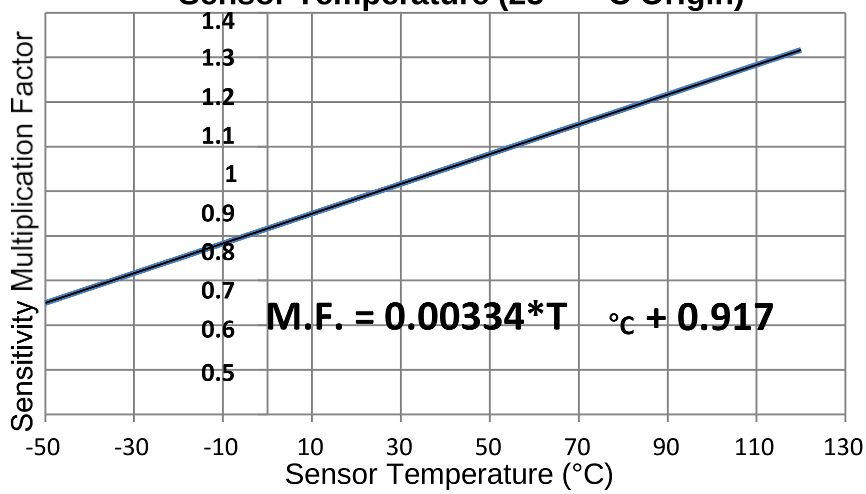
Calibration Test Results

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)



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 HFS 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. (Ignore this step if using the UHFS-09 sensor).

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

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

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

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 HFS sensor. A negative voltage value compared to a positive voltage just means that the heat flux is moving in the opposite direction.

Heat Flux Sensor Sensitivity Determination

The sensor sensitivity is the output voltage induced by the sensor divided by the heat flux conducted through the sensor.

$$Sensitivity = S = \frac{\Delta V}{q"_{absorbed}}$$

Using a custom-made calibration apparatus, Heat flux can be calculated using the measured temperature differential and a Standard Reference material’s known thermal resistance.

The sensor’s sensitivity can be determined by dividing the output voltage from the sensor by the heat flux.

$$q" = \frac{\Delta T}{R"_{SRM}} = \frac{\Delta V_{q"}}{S_{@\,T_{°C}}}$$

$$S_{@\,T_{°C}} \;=\; \frac{\Delta V}{q"}$$

The sensitivity can then be adjusted according to the temperature accordingly.

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

Where $T_{°C}$ is the sensor’s temperature in degrees Celsius & S_{Calib} is the calibrated sensor sensitivity provided in the table above.

Section 4: Directive Compliances

RoHS3 Statement of Compliance Statement

For Directive (EU) 2015/863 of the European Parliament and of the Council of 4 June 2015 on the restriction of use of certain hazardous substances in electrical and electronic equipment.

The directive 2015/863 defines ten (10) substances which are to be restricted. The maximum concentration by weight for each substance is listed below.

Substance	**Maximum Concentration**[1]
Lead (Pb)	0.1%[2]
Mercury (Hg)	0.1%
Cadmium (Cd)	0.01%
HexavalentChromium (Cr VI)	0.1%
Polybrominated biphenyls (PBB)	0.1%
Polybrominated diphenyl ethers (PBDE)	0.1%
Bis(2-ethylhexyl) phthalate (DEHP)	0.1%
Butyl benzyl phthalate (BBP)	0.1%
Dibutyl phthalate (DBP)	0.1%
Diisobutyl phthalate (DIBP)	0.1%

[1]Restricted substances and maximum concentration values tolerated by weight in homogeneous materials

[2]Exemption 6(a) Lead as an alloying element in steel for machining purposes and in galvanized steel containing up to 0.35 % lead by weight; Exemption 6(b) Lead as an alloying element in aluminum containing up to 0.4 % lead by weight; Exemption 6(c) Copper alloy containing up to 4 % lead by weight; and Exemption 7(c)-I Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound.

All HFS-5, HFS-6, & UHFS-09 heat flux sensor products will have the following RoHS3 Compliance:

RoHS3 Status: Compliant

The RoHS Compliance of any product so designated is based upon evidence from the producer (manufacturer) that the part number is in compliance with the RoHS Directive. All reasonable steps have been taken to confirm producers' statements and other evidence regarding the absence of the restricted substances to support the manufacturers' claim of compliance. Based upon a review of the manufacturing records and technical information, this product, to the best of our knowledge, does not contain any of the restricted substances in quantities that exceed the limits, as specified above.

Approved By: Rande Cherry **Date:** 6/1/2019

REACH Compliance Statement

For Directive EC 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

The directive defines substances which are to be restricted. The REACH candidate list of Substances of Very High Concern (SVHC) found at:
http://echa.europa.eu/chem_data/authorisation_process/candidate_list_table_en.asp

All HFS-5, HFS-6, & UHFS-09 heat flux sensor products will have the following REACH Compliance.

REACH Status: Compliant

The REACH Compliance of any product so designated is based upon evidence from the producer (manufacturer) that the part number is in compliance with the REACH Directive. All reasonable steps have been taken to confirm producers' statements and other evidence regarding the absence of the restricted substances to support the manufacturers' claim of compliance. Based upon a review of the manufacturing records and technical information, this product, to the best of our knowledge, does not contain any of the restricted substances in quantities that exceed the limits, as specified above.

Approved By: Rande Cherry **Date:** 7/19/2019

EU DECLARATION OF CONFORMITY

Company Name: Omega Engineering Inc.

Address: 800 Connecticut Ave, Suite 5N01, Norwalk, CT 06854

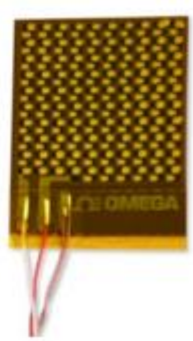
Telephone Number: 1-888-826-6342

Email Address: info@omega.com

We declare that the DoC is issued under the sole responsibility and belongs to the following product:

Objects of the Declaration

Product Model Number: HFS-5 & HFS-6 & UHFS-09



The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

Directive 2014/32/EU

The following harmonized standards and technical specifications have been applied:

RoHS 2015/863	4 June 2015
EN50581:2012	1 November 2012

Signed for and on behalf of:

Rande Cherry

Omega Engineering Inc. 2019-07-18 Rande Cherry CTO