



USER MANUAL **HF01**

High temperature heat flux sensor



Warning statements



Follow the installation instructions of this user manual.



The sensor and sensor-to-cable transition should not be exposed to significant force.



Putting more than 12 Volt across the sensor wiring can lead to permanent damage to the sensor.



Do not use "open circuit detection" when measuring the sensor output.



In aluminium production, use the optional silicone sleeve.



Only for supply with the optional CE type examination (ATEX) certificate: ask the supplier for ATEX rated operating conditions.

Contents

Warning statements	2
Contents	3
List of symbols	4
Introduction	5
1 Ordering and checking at delivery	7
1.1 Ordering HF01	7
1.2 Included items	7
1.3 Quick instrument check	7
2 Instrument principle and theory	9
3 Specifications of HF01	11
3.2 Dimensions of HF01	14
4 Standards and recommended practices for use	15
4.1 Heat flux measurement in industry	15
5 Installation of HF01	16
5.1 Site selection and installation in industry	16
5.2 Electrical connection	18
5.3 Requirements for data acquisition / amplification	19
6 Maintenance and trouble shooting	20
6.1 Recommended maintenance and quality assurance	20
6.2 Trouble shooting	21
6.3 Calibration and checks in the field	22
7 Appendices	24
7.1 Appendix on uncertainty evaluation	24
7.2 Appendix on calibration hierarchy	24
7.3 Appendix on cable extension / replacement	24
7.4 Appendix on magnet replacement	25
7.5 Appendix on recoating/ repainting of sensor surfaces	25
7.6 EU declaration of conformity	26

List of symbols

Quantities

Heat flux
 Voltage output
 Sensitivity
 Temperature
 Temperature difference
 Temperature dependence
 Resistance

Symbol	Unit
Φ	W/m ²
U	V
S	V/(W/m ²)
T	°C
ΔT	°C, K
TD	1/K
R	Ω

Subscripts

property of thermopile sensor
 calibration reference condition
 property of the object on which HF01 is mounted
 property at the (object) surface
 property of the surrounding environment

sensor
 reference
 object
 surface
 environment

Introduction

HF01 measures heat flux and surface temperature at high temperatures, typically in industrial environments. It is particularly suitable for trend-monitoring and comparative testing. HF01 measures heat flux and surface temperature of industrial furnaces, boilers, fluidised beds, distillation columns and ovens. The sensors inside HF01, a thermopile and a thermocouple, are protected by fully sealed stainless steel body. It is suitable for long term use at one location as well as repeated installation when a measuring system is used at multiple locations.

HF01 measures heat flux through the object on which it is mounted, in W/m^2 , as well as its surface temperature in $^{\circ}C$. The sensors in HF01 are a thermopile and a type K thermocouple. The thermopile measures the temperature difference across the body of HF01, creating an output that is representative of the local heat flux. The thermocouple measures the absolute temperature of the surface on which HF01 is mounted, as well as the approximate sensor body temperature. A thermopile and a thermocouple are passive sensors; they do not require power.

The part of the cabling closest to the sensor is a special high-temperature metal sheathed cable with an interlocked spiral stainless steel armour. The sensor as well as the high temperature cable and armour withstand temperatures up to $800^{\circ}C$. The temperature range is reduced to $600^{\circ}C$ in case the black coating is used, to $550^{\circ}C$ in case the frame with magnets is used.

To avoid leakage of current, a risk in aluminium reduction cells, a silicone sleeve is placed over the metal armour. The low-temperature extension cable has wire insulation and a jacket of PTFE type plastic. One face of HF01 is painted black, the other is blank metal.

Using HF01 is easy. It can be connected directly to commonly used data logging systems. The heat flux, Φ , in W/m^2 , is calculated by dividing the HF01 output, a small voltage U , by the sensitivity S , and by applying a linear correction based on the temperature measurement involving the temperature dependence TD .

The measurement function of HF01 is:

$$\Phi = U / (S \cdot (1 + TD \cdot (T - T_{\text{reference}}))) \quad (\text{Formula 0.1})$$

The sensitivity and temperature dependence are provided with HF01 on its product certificate.

Equipped with heavy duty cabling, and having a fully stainless steel casing so that moisture does not penetrate the sensor, HF01 has proven to be very reliable. It survives long-term outdoor installation and repeated installation using the frame with magnets.



Figure 0.1 *HF01 high temperature heat flux sensor*

HF01 is most suitable for relative measurements using one sensor, i.e. monitoring of trends relative to a certain reference point in time or comparing heat flux at one location to the heat flux at another location.

If the user wants to perform accurate absolute measurements with HF01, as opposed to relative measurements, he must make his own uncertainty evaluation and correction for systematic errors. See the appendix on uncertainty evaluation. However the analysis of trends is sufficient in many situations. In those cases a high absolute measurement accuracy is not needed, and a formal uncertainty evaluation is not necessary.

HF01 calibration is traceable to international standards. The factory calibration method follows the recommended practice of ASTM C1130. The recommended calibration interval of heat flux sensors is 2 years.

Suggested use of HF01:

- trend-monitoring and comparative measurement of heat flux and surface temperature in industrial installations

See also:

- our complete product range of heat flux sensors
- ALUSYS measuring system
- HF05 industrial heat flux sensor for lower temperatures up to 170 °C
- needle type heat flux sensors NF01 and NF02

1 Ordering and checking at delivery

1.1 Ordering HF01

The standard configuration of HF01 is with 0.9 m high temperature cable and 3.5 m low temperature extension cable.

Common options are:

- longer cable (specify total cable length for both cable types in m)
- frame with magnets
- frame with 2 mounting holes (no magnets)
- thermocouple type N
- sensor and high temperature cable temperature range -180 to + 800 °C
- EC type examination certificate (ATEX) II 2 G EEx d IIC T6
- connector at HF01 cable end
- low temperature extension cable with 2 connectors, matching cable connector and chassis connector
- chassis connector with internal wiring (colour code of wiring identical to cable colour code)
- silicone protection sleeve around the high temperature cable (specify length in m, standard length 1 m, covering the standard 0.9 m high temperature cable)

1.2 Included items

Arriving at the customer, the delivery should include:

- heat flux sensor HF01
- cable of the lengths as ordered
- product certificate matching the instrument serial number

1.3 Quick instrument check

A quick test of the instrument can be done by connecting it to a multimeter.

1. Check the electrical resistance of the heat flux sensor between the black [-] and red [+] wires and the thermocouple between the green [+] and white [-] wires. Use a multimeter at the 100 Ω range. Measure the sensor resistance first with one polarity, then reverse the polarity. Take the average value. Typical resistance should be the nominal sensor resistance of 10 to 30 Ω for the thermopile sensor at standard cable lengths, plus for additional low temperature extension cable 0.2 Ω /m (resistance per meter cable) for the total resistance of two wires (back and forth added), for high temperature cable 13 Ω /m. For the thermocouple work with 10 to 50 Ω at standard cable lengths, plus additional low temperature extension cable 3 Ω /m resistance per meter cable), for high temperature cable 28 Ω /m. Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit.

2. Check if the heat flux sensor reacts to heat: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100×10^{-3} VDC range or lower. Expose the sensor heat, for instance touching it with your hand. The signal should read $> 2 \times 10^{-3}$ V now. Touching or exposing the black side should generate a positive signal, doing the same at the opposite side, the sign of the output voltage reverses. Also look at the reaction of the thermocouple to heat. The thermocouple is located at the blank metal side of the sensor.
3. Inspect the instrument for any damage.
4. Check the sensor serial number engraved on the transition piece between high temperature cable and low temperature extension cable, against the certificate provided with the sensor.

2 Instrument principle and theory

HF01's scientific name is heat flux sensor. A heat flux sensor measures the heat flux density through the sensor itself. This quantity, expressed in W/m^2 , is usually called "heat flux". HF01 users typically assume that the measured heat flux is representative of the undisturbed heat flux at the location of the sensor. Users may also apply corrections based on scientific judgement.

The heat flux sensor in HF01 is a thermopile. This thermopile measures the temperature difference across the body of HF01. Working completely passive, the thermopile generates a small voltage that is a linear function of this temperature difference. The heat flux is proportional to the same temperature difference divided by the effective thermal conductivity of the heat flux sensor body.

Using HF01 is easy. For readout the user only needs an accurate voltmeter that works in the millivolt range. To convert the measured voltage, U , to a heat flux Φ , the voltage must be divided by the sensitivity S , a constant that is supplied with each individual sensor, and correct for the temperature of the sensor.

The temperature sensor inside HF01 is a type K thermocouple located at the blank metal side of the sensor.

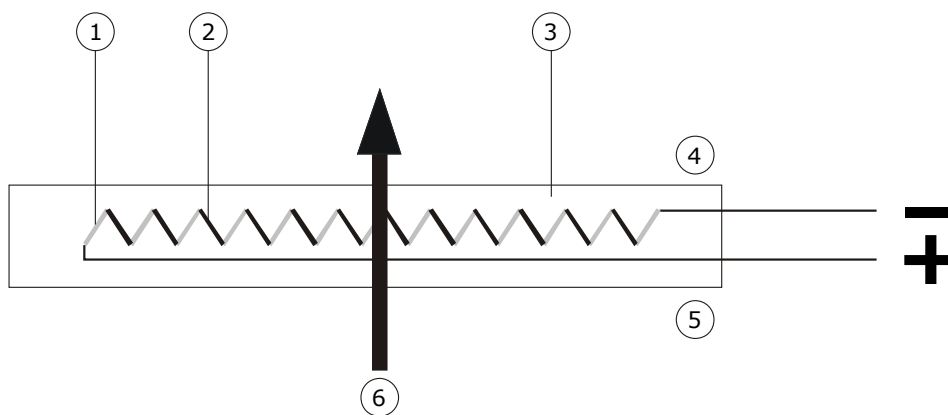


Figure 2.1 *The general working principle of a heat flux sensor. The sensor inside HF01 is a thermopile. A thermopile consists of a number of thermocouples, each consisting of two metal alloys marked 1 and 2, electrically connected in series. A single thermocouple will generate an output voltage that is proportional to the temperature difference between its hot- and cold joints. Putting thermocouples in series amplifies the signal. In a heat flux sensor, the hot- and cold joints are located at the opposite sensor surfaces 4 and 5. In steady state, the heat flux 6 is a linear function of the temperature difference across the sensor and the average thermal conductivity of the sensor body, 3. The thermopile generates a voltage output proportional to the heat flux through the sensor. The exact sensitivity of the sensor is determined at the manufacturer by calibration, and is found on the calibration certificate that is supplied with each sensor.*

Heat flux sensors such as HF01, for use in industry at high heat flux levels, are typically calibrated under the following reference conditions:

- conductive heat flux (as opposed to radiative or convective heat flux)
- homogeneous heat flux across the sensor and guard surface
- room temperature
- heat flux in the order of 1500 W/m^2

Unique features of HF01 are:

- low electrical resistance (low pickup of electrical noise)
- high sensitivity (good signal to noise ratio in low-flux environments such as buildings)
- robustness, including a strong cable
- built-in temperature sensor; type K thermocouple
- IP protection class: IP68 for sensor and high temperature cable

Measuring with heat flux sensors, errors may be caused by differences between calibration reference conditions and the conditions during use. The user should analyse his own experiment and make his own uncertainty evaluation.

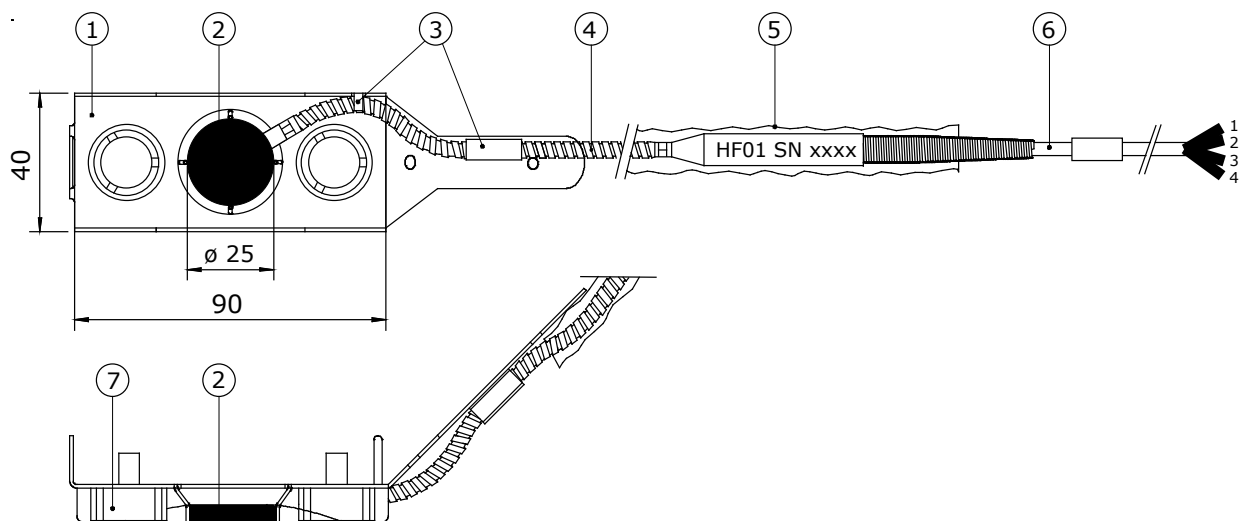


Figure 2.2 Heat flux sensor model HF01 with optional frame with magnets (2), connected to a high-temperature metal sheathed cable with interlocked spiral stainless steel armour (4) and low-temperature extension cable (6). The frame (1) with magnets (7) is an option intended for temporary mounting on carbon steel walls. It is provided with a cable strain relief (3). The armour may be electrically insulated by a silicone sleeve (5). Dimensions are in $\times 10^{-3} \text{ m}$.

3 Specifications of HF01

HF01 measures the heat flux density through the surface of the sensor. This quantity, expressed in W/m^2 , is called heat flux. It also measures the absolute temperature of the surface on which it is mounted. HF01 is passive, using thermopile and thermocouple sensors. The thermopile generates a small output voltage proportional to the heat flux. HF01 can only be used in combination with a suitable measurement system.

Table 3.1 Specifications of HF01 (continued on next page)

HF01 SPECIFICATIONS	
Sensor type	high temperature heat flux sensor
Sensor type according to ASTM	heat flow sensor or heat flux transducer
Heat flux sensor	thermopile
Measurand	heat flux
Measurand in SI units	heat flux density in W/m^2
Measurement range	-50 to $50 \times 10^3 W/m^2$
Temperature sensor	thermocouple type K
Temperature sensor specification	ANSI MC96.1-1982 / EN 60584
Measurand	temperature
Measurand in SI units	temperature in $^{\circ}C$
Measurement function / required programming	$\Phi = U/(S \cdot (1 + TD \cdot (T - T_{reference})))$
Recommended number of sensors	2 per measurement location
Sensitivity (nominal)	$0.5 \times 10^{-6} V/(W/m^2)$
Response time (95 %)	300 s (depends on the thermal contact resistance)
Directional sensitivity	heat flux from black painted side to the opposite blank metal side generates a positive voltage output signal
Expected voltage output	multiply the sensitivity by the maximum expected heat flux
Required readout	heat flux sensor: 1 x differential voltage channel or 1 x single ended voltage channel temperature sensor: 1 x Type K differential thermocouple channel or 1 x Type K single ended thermocouple channel both with input resistance $> 10^6 \Omega$
Rated operating temperature ranges:	
sensor and high temperature cable	-30 to $+800^{\circ}C$
black coating	-30 to $+600^{\circ}C$
optional frame with magnets	-30 to $+550^{\circ}C$
low temperature extension cable	-30 to $+240^{\circ}C$
optional connectors	-50 to $+250^{\circ}C$
optional silicone protection sleeve	-60 to $+250^{\circ}C$
IP protection class	
Sensor and high temperature cable	IP68
Low temperature extension cable	IP67
Rated operating relative humidity range	0 to 100 %
Required sensor power	zero (passive sensors)
Temperature dependence TD	+ 0.0015 1/K
Non-stability	< 1 %/yr (for typical use)
Sensor diameter	$25 \times 10^{-3} m$
Sensor thickness	$6.0 \times 10^{-3} m$
Sensor thermal resistance	$4.2 \times 10^{-3} K/(W/m^2)$
Sensor thermal conductivity	1.4 $W/(m \cdot K)$ (nominal)

Table 3.1 Specifications of HF01 (started on previous page, continued on the next page)

Standard cable lengths	
High temperature cable	0.9 m (see options)
Low temperature extension cable	3.5 m (see options)
Heat flux sensor resistance range	10 to 30 Ω (standard cable length)
Low temperature extension cable: heat flux sensor cable resistance	0.2 Ω /m (nominal)
High temperature cable: heat flux sensor cable resistance	13 Ω /m (nominal)
Temperature sensor resistance range	10 to 50 Ω (standard cable length)
Low temperature extension cable: temperature sensor cable resistance	3 Ω /m (nominal)
High temperature cable: temperature sensor cable resistance	28 Ω /m (nominal)
Black coating emissivity	0.92 (nominal)
High temperature metal interlocked spiral armour diameter	5 x 10 ⁻³ m
Low temperature extension cable diameter	4 x 10 ⁻³ m
Transition piece diameter	10 x 10 ⁻³ m
Marking	1 x engraving on the transition piece, showing serial number 1 x sticker at low temperature extension cable end, showing serial number.
Gross weight including 0.9 and 3.5 m cable	0.75
Net weight including 0.9 and 3.5 m cable	0.60 kg
Packaging	plastic case of 160 x 220 x 50 mm
INSTALLATION AND USE	
Standards governing use of the instrument	N/A
Orientation	the blank metal side usually is in contact with the object. In case the sensor embedded in the object, there is no preferred orientation.
Installation	see recommendations in this user manual avoid mechanical force on the sensor body and sensor-to-cable transition. make user there is good thermal contact between sensor and object. in aluminium production , use the silicone protection sleeve
Cable extension	see options: longer cable, extension cable and connectors
Optional connectors on HF01 cable and extension cable	LEMO brand, 12 x 10 ⁻³ m outer diameter
Recoating	the black surface may be recoated with high temperature black paint, see the appendix on this subject

Table 3.1 Specifications of HF01 (started on previous 2 pages)

CALIBRATION	
Calibration traceability	to SI units
Product certificate	included (showing calibration result and traceability)
Calibration method	method HFC, according to ASTM C1130
Calibration hierarchy	from SI through international standards and through an internal mathematical procedure
Calibration uncertainty	< 20 % (k = 2)
Recommended recalibration interval	2 years
Calibration reference conditions	90 °C, heat flux of 1500 W/m ² , thermal conductivity of the surrounding environment 0.0 W/(m·K)
Validity of calibration	based on experience the instrument sensitivity will not change during storage. During use the instrument "non-stability" specification is applicable.
Field calibration	is possible by comparison to a calibration reference sensor. Usually mounted side by side. Preferably reference and field sensor of the same model and brand. Typical duration of test > 24 h.
Temperature sensor tolerance class	IEC Tolerance class EN60584-2: Type K, class 2
Temperature sensor error limits	ASTM E230-ANSI MC96.1: Type K, standard limits
MEASUREMENT ACCURACY	
Uncertainty of the measurement	statements about the overall measurement uncertainty can only be made on an individual basis. see the chapter on uncertainty evaluation.
VERSIONS / OPTIONS	
Order code	HF01 / high temperature cable length in m / low temperature extension cable length in m
Longer cable	longer cable (specify total cable length for both cable types in m)
Frame with magnets	frame with magnets and silicone sleeve
Frame with 2 mounting holes	frame with 2 mounting holes (no magnets)
Thermocouple type N	thermocouple type N
EC type examination certificate (ATEX)	II 2 G EEx d IIC T6
Extended temperature range	sensor and high temperature cable temperature range -180 to + 800 °C
Connector	connector at HF01 cable end
Extension cable	low temperature extension cable with 2 connectors with 2 connectors matching cable connector and chassis connector (specify cable length in m)
Silicone sleeve	silicone protection sleeve around the high temperature cable (specify length in m, standard length 1 m, covering the standard 0.9 m high temperature cable)
Chassis connector	chassis connector with internal wiring (colour code of wiring identical to cable colour code)
SPARE PARTS	
Magnets	set of 10 magnets for HF01

3.2 Dimensions of HF01

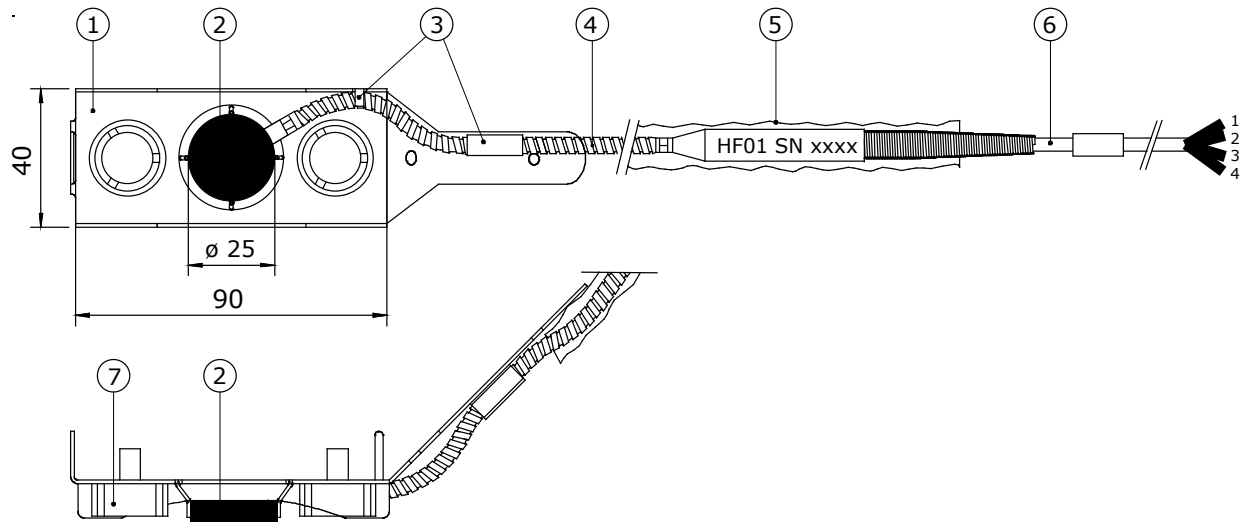


Figure 3.2.1 HF01 heat flux sensor with optional frame with magnets.
 Dimensions in $\times 10^{-3}$ m.

4 Standards and recommended practices for use

Use of HF01 is not subject to standardised operating procedures.

4.1 Heat flux measurement in industry

Many HF01 sensors measure on industrial walls and metal surfaces, estimating the installation's energy balance. Typically the total measuring system consists of multiple heat flux- and temperature sensors. In many cases heat flux sensors are used for trend-monitoring. In such cases reproducibility is more important than absolute measurement accuracy.



Figure 4.1.1 Industrial heat flux sensor mounted on a boiler wall using tack-welded threads and spring-loaded bolts. The sensor is mounted on a well prepared flat surface. Cabling must be provided with strain relief.

5 Installation of HF01

5.1 Site selection and installation in industry

Table 5.1.1 Recommendations for installation of HF01 heat flux sensors

Location	Choose a location that is representative of the process that is analysed if possible, avoid exposure to sun, rain, etc. Do not expose to drafts and lateral heat fluxes Do not mount in the vicinity of thermal bridges, cracks, heating or cooling devices and fans
Performing a representative measurement / recommended number of sensors	We recommend using > 2 sensors per measurement location. This redundancy also improves the assessment of the measurement accuracy
Orientation	Mounted on vertical surfaces, the cable exit from the sensor should point down.
Surface cleaning and levelling	Minimise any thermal contact resistance between sensor and object. Create a clean and smooth surface with a diameter of 0.1 m, so that the air gap between sensor and object surface is less than 0.2×10^{-3} m
Mechanical mounting: avoiding strain on the sensor to cable transition	The sensor-to-cable transition is vulnerable. During installation as well as operation, the user should provide proper strain relief of the cable so that transition is not exposed to significant force. For permanent mooning: first install the cable including strain relief and after that install the sensor.
Mechanical mounting:	The sensor body withstands only limited pressure and strain. Users should not exert significant mechanical force on the sensor or on the sensor to cable transition.
Permanent installation	For permanent mounting using the metal frame with 2 holes: tack-weld or screw M6 thread to the surface on which HF01 is mounted at a hart-to-hart distance of 60×10^{-3} m. Bolts holding the sensor should be used for positioning and for loose fixation only, and should be spring- loaded to guarantee good sensor to surface contact without exerting too much force. If the temperature remains below 240 °C, for long-term installation fill up the space between sensor and object with silicone construction sealant, silicone glue or silicone adhesive, that can be bought in construction depots. Use this in combination with the spring-loaded threads.
Short term installation	In case the object surface is magnetic: use the optional frame with magnets. Consider filling up air gaps with thermal paste.
Signal amplification	See the paragraph on electrical connection.

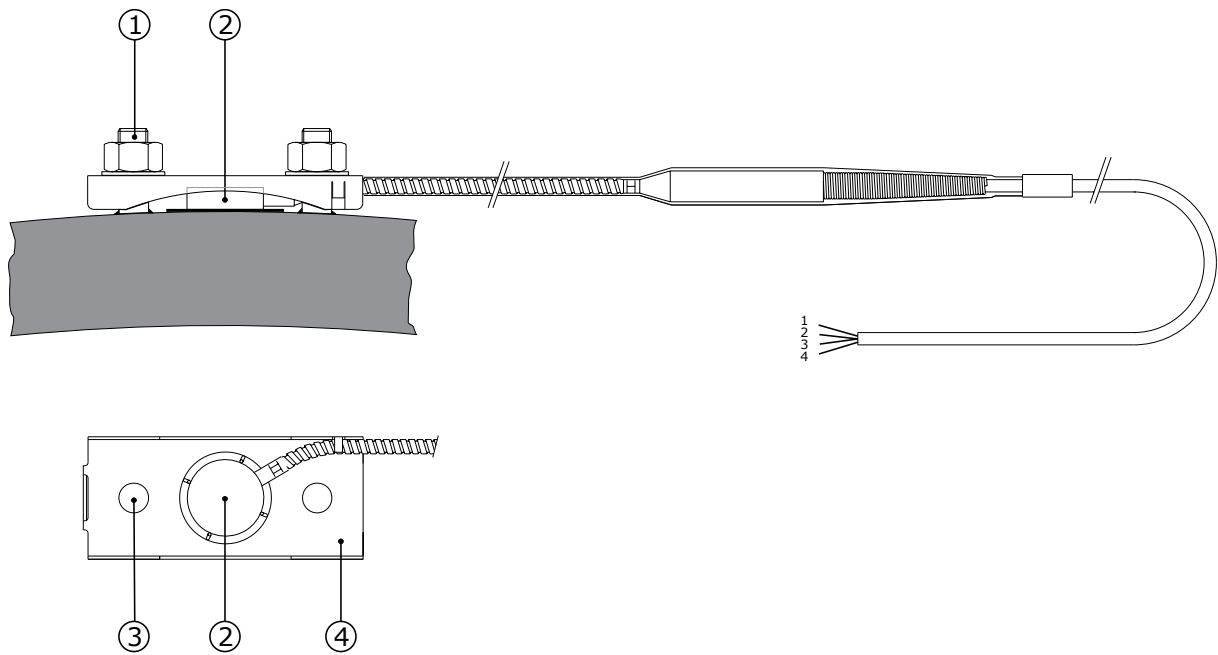


Figure 5.1.1 Permanent installation of HF01 with frame. The HF01 sensor (2) has a frame (4) with 2 holes (3). For permanent mounting, using the metal frame with 2 holes, tack-weld or screw M6 thread to the surface on which HF01 is mounted at a hart-to-hart distance of $60 \times 10^{-3} \text{ m}$. Bolts holding the sensor should be used for positioning and for loose fixation only, and should be spring- loaded to guarantee good sensor to surface contact without exerting too much force.

5.2 Electrical connection

A heat flux sensor should be connected to a measurement system, typically a so-called datalogger. HF01 is a passive sensor that does not need any power, neither for the heat flux sensor, nor for the temperature sensor. Cables may act as a source of distortion, by picking up capacitive noise. We recommend keeping the distance between a datalogger or amplifier and the sensor as short as possible. For cable extension, see the appendix on this subject.

Table 5.2.1 *The electrical connection of HF01. The shield is not connected to the stainless steel sensor body*

WIRE	
Red	heat flux signal [+]
Black	heat flux signal [-]
Green	thermocouple type K [+]
White	thermocouple type K [-]
Blank	shield

5.3 Requirements for data acquisition / amplification

The selection and programming of dataloggers is the responsibility of the user. Please contact the supplier of the data acquisition and amplification equipment to see if directions for use with the HF01 are available.

Table 5.3.1 Requirements for data acquisition and amplification equipment for HF01 in the standard configuration

Capability to measure small voltage signals	preferably: $< 5 \times 10^{-6}$ V uncertainty Minimum requirement: 20×10^{-6} V uncertainty (valid for the entire expected temperature range of the acquisition / amplification equipment)
Capability for the data logger or the software	to store data, and to perform division by the sensitivity to calculate the heat flux. $\Phi = U / (S \cdot (1 + TD \cdot (T - T_{\text{reference}})))$ (Formula 0.1)
Capability to measure thermocouple type K	preferably: measurement uncertainty within ± 3 °C
Data acquisition input resistance	$> 1 \times 10^6 \Omega$
Open circuit detection (WARNING)	open-circuit detection should not be used, unless this is done separately from the normal measurement by more than 5 times the sensor response time and with a small current only. Thermopile and thermocouple sensors are sensitive to the current that is used during open circuit detection. The current will generate heat, which is measured and will appear as a temporary offset.

6 Maintenance and trouble shooting

6.1 Recommended maintenance and quality assurance

HF01 measures reliably at a low level of maintenance. Unreliable measurement results are detected by scientific judgement, for example by looking for unreasonably large or small measured values. The preferred way to obtain a reliable measurement is a regular critical review of the measured data, preferably checking against other measurements.

Table 6.1.1 *Recommended maintenance of HF01. If possible the data analysis is done on a daily basis.*

MINIMUM RECOMMENDED HEAT FLUX SENSOR MAINTENANCE			
	INTERVAL	SUBJECT	ACTION
1	1 week	data analysis	compare measured data to the maximum possible or maximum expected heat flux and to other measurements for example from nearby or redundant instruments. Historical seasonal records can be used as a source for expected values. Look for any patterns and events that deviate from what is normal or expected. Compare to acceptance intervals.
2	6 months	inspection	inspect cable quality, inspect mounting, inspect location of installation look for seasonal patterns in measurement data
3	2 years	recalibration	recalibration by comparison to a calibration standard instrument in the field, see following paragraphs. recalibration by the sensor manufacturer
4		lifetime assessment	judge if the instrument will be reliable for another 2 years, or if it should be replaced

6.2 Trouble shooting

Table 6.2.1 *Trouble shooting for HF01*

General	<p>Inspect the sensor for any damage. Inspect the quality of mounting / installation. Inspect if the wires are properly attached to the data logger. Check the condition of the cable. Inspect the connection of the shield (typically connected at the datalogger side). Check the datalogger program in particular if the right sensitivity is entered. HF01's sensor serial number is engraved on the transition piece between high temperature cable and low temperature extension cable. The sensitivity can be found on the calibration certificate.</p> <p>Check the electrical resistance of the heat flux sensor between the black [-] and red [+] wires and the thermocouple between the green [+] and white [-] wires. Use a multimeter at the 100 Ω range. Measure the sensor resistance first with one polarity, then reverse the polarity. Take the average value. Typical resistance should be the nominal sensor resistance of 10 to 30 Ω for the thermopile sensor at standard cable lengths, plus for additional low temperature extension cable 0.2 Ω/m (resistance per meter cable) for the total resistance of two wires (back and forth added), for high temperature cable 13 Ω/m. For the thermocouple work with 10 to 50 Ω at standard cable lengths, plus additional low temperature extension cable 3 Ω/m resistance per meter cable, for high temperature cable 28 Ω/m. Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit.</p>
The sensor does not give any signal	<p>Check if the heat flux sensor reacts to heat: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100×10^{-3} VDC range or lower. Expose the sensor heat, for instance touching it with your hand. The signal should read $> 2 \times 10^{-3}$ V now. Touching or exposing the red side should generate a positive signal, doing the same at the opposite side, the sign of the output voltage reverses.</p> <p>Also look at the reaction of the thermocouple to heat. Check the reaction of the thermocouple sensor to heat. Check the data acquisition by replacing the sensor with a spare unit.</p>
The sensor signal is unrealistically high or low	<p>Check the cable condition looking for cable breaks. Check the data acquisition by applying a 1×10^{-6} V source to it in the 1×10^{-6} V range. Look at the measurement result. Check if it is as expected. Check the data acquisition by short circuiting the data acquisition input with a 10 Ω resistor. Look at the output. Check if the output is close to 0 W/m².</p>
The sensor signal shows unexpected variations	<p>Check the presence of strong sources of electromagnetic radiation (radar, radio). Check the condition and connection of the shield. Check the condition of the sensor cable. Check if the cable is not moving during the measurement.</p>

6.3 Calibration and checks in the field

The recommended calibration interval of heat flux sensors is 2 years. Recalibration of field heat flux sensors is ideally done by the sensor manufacturer.

On-site field calibration is possible by comparison to a calibration reference sensor, usually mounted side by side.

Hukseflux main recommendations for field calibrations are:

- 1) to compare to a calibration reference of the same brand and type as the field sensor
- 2) to connect both to the same electronics, so that electronics errors (also offsets) are eliminated.
- 3) to mount all sensors on the same platform, so that they have the same body temperature.
- 4) typical duration of test: > 24 h
- 5) typical heat fluxes used for comparison: > 1000 W/m², preferably > 2000 W/m²
- 6) to correct deviations of more than $\pm 10\%$. Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity.

7 Appendices

7.1 Appendix on uncertainty evaluation

If the user wants to perform accurate absolute measurements, as opposed to relative measurements, we recommend that the user calibrates sensors under his own responsibility under "simulated service conditions", and make his own correction for systematic errors and uncertainty evaluation.

The uncertainty of a measurement with HF01 is a function of:

- calibration uncertainty
- differences between reference conditions during calibration and measurement conditions, for example uncertainty caused by temperature dependence of the sensitivity
- the duration of sensor employment (involving the non-stability)
- application errors: the measurement conditions and environment in relation to the sensor properties, the influence of the sensor on the measurand, the representativeness of the measurement location

If you know the total power generated by a process you may calibrate the heat flux measurement by comparison of heat fluxes multiplied by surface area's to the total generated power. Some users apply (temporary) electrical heaters to calibrate the sensors.

7.2 Appendix on calibration hierarchy

HF01 factory calibration is traceable from SI through international standards and through an internal mathematical procedure which corrects for known errors. The formal traceability of the generated heat flux is through voltage and current to electrical power and electric power and through length to surface area.

The Hukseflux HFC method follows the recommended practice of ASTM C1130. It relies on a thin heater apparatus according to principles as described in paragraph 4 of ASTM C1114-06, in the single sided mode of operation described in paragraph 8.2 and in ASTM C1044.

7.3 Appendix on cable extension / replacement

HF01 is equipped with one cable that consists of a high temperature cable and a low temperature extension cable. Keep the distance between data logger or amplifier and sensor as short as possible. Cables may act as a source of distortion by picking up capacitive noise. In an electrically "quiet" environment the HF01 cable may be extended without problem to 50 meters. If done properly, the sensor signal, although small, will not significantly degrade because the sensor resistance is very low (which results in good

immunity to external sources) and because there is no current flowing (so no resistive losses). Cable and connection specifications are summarised below.

Table 7.3.1 Preferred specifications for cable extension of HF01

Cable	Hukseflux HF01 high temperature cable (not extendable) Hukseflux HF01 low temperature extension cable
Extension	use Hukseflux HF01 extension cable with 2 connectors matching cable connector and chassis connector (specify cable length in m) use Hukseflux HF01 cable connector at the end of the HF01 low temperature extension cable to a connector of the extension cable with 2 connectors use Hukseflux HF01 chassis connector
Outer diameter	4×10^{-3} m (low temperature extension cable)
Length	cables should be kept as short as possible, in any case the total cable length should be less than 50 m

7.4 Appendix on magnet replacement

Magnets may be replaced by the user. Order a set of spare magnets. Replacement requires using hex key size 1.

7.5 Appendix on recoating/ repainting of sensor surfaces

Hukseflux recommendations for repainting are:

Verify sensor functionality. This can also be done with a non-coated sensor (see the chapter of the quick sensor test).

Purchase a matt (not glossy) black paint which is temperature resistant up to 600 °C.

Silicone based black paints are a good choice. Typically aerosol spray cans are most easy to use, but such paints can also be used purchased in cans. In case a solvent is needed: typically acetone is a good solvent for these paints.

Surface preparation: In case the existing sensor surface coating has small scratches but is otherwise in good condition, apply new paint directly to the existing paint. In case of heavy damage to sensor surface coatings: remove the existing coating, clean with acetone or ethanol. Lightly sand the metal surface.

Paint application: Spray some paint in a small cup, use a pipette to apply the paint. In case a pipette is not available, use a small paint brush.

7.6 EU declaration of conformity



We, Hukseflux Thermal Sensors B.V.
Delftechpark 31
2628 XJ Delft
The Netherlands

in accordance with the requirements of the following directive:

2014/30/EC The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model: HF01
Product type: High temperature heat flux sensor

has been designed to comply and is in conformity with the relevant sections and applicable requirements of the following standards:

Emission: EN 61326-1 (2006)
Immunity: EN 61326-1 (2006)
Emission: EN 61000-3-2 (2006)
Emission: EN 61000-3-3 (1995) + A1 (2001) + A2 (2005)
Report: 08C01340RPT01, 06 January 2009



Eric HOEKSEMA
Director
Delft
September 08, 2015

