FluxTeq PHFS-01 heat flux sensors

Unreliable heat flux measurement

For an accurate heat flux measurement, users may reasonably assume that:

- *sensitivity does not change over time; stability*
- *sensitivity as specified on the calibration certificate can be relied upon; that it does not depend on the environment of the sensor*

Testing at Hukseflux reveals that FluxTeq heat flux sensors of model PHFS-01 do not perform reliably within their rated operating conditions: they are not stable, and their sensitivity depends on the environment. This leads to a much larger measurement uncertainty than the 5 % stated on the PHFS calibration certificate.

FluxTeq manufacturing technology

FluxTeq manufacturing technology is based on the use of metal-filled electrically conducting inks. See also US patent 10393598.
Hukseflux carried out testing* of model PHFS-01.

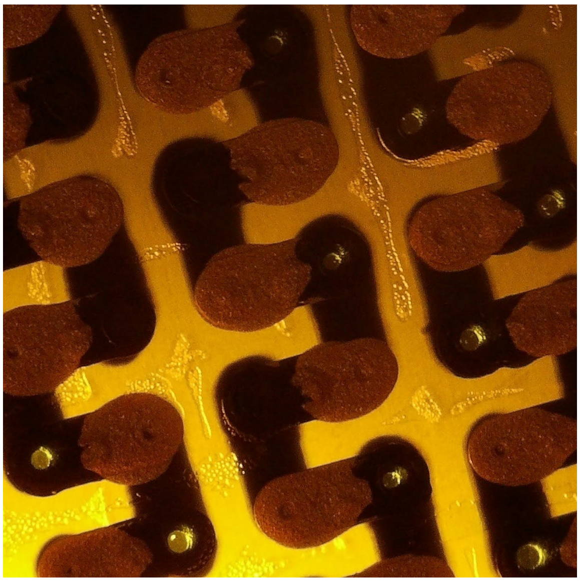

Figure 1 *Close-up of a FluxTeq PHFS-01 heat flux sensor. The thermopile is made using printing technology. Two different metal-filled electrically conducting inks are printed into through-holes.*

* Experiments were carried out on Hukseflux FHF05-series sensors, as well as PHFS-01 sensors purchased from FluxTeq. The test results may not be applicable to sensors produced by other manufacturers or when improving manufacturing technology.

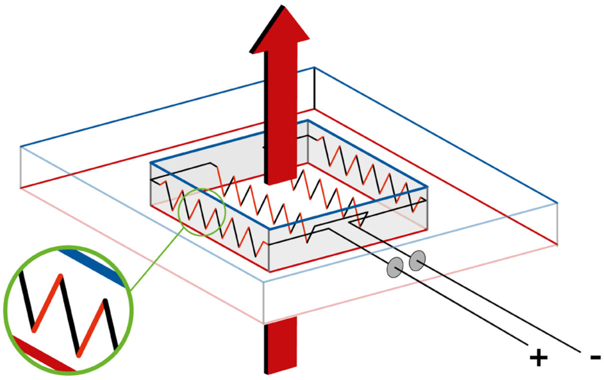

Figure 2 *General heat flux sensor principle: the sensor contains a thermopile consisting of an alternating pattern of two metal alloys.*

Test results: stability

The sensitivities of the sensors were tested for

- stability under bending
- stability at high temperatures

Sensors of FluxTeq and Hukseflux are all rated for long-term use up to 120 °C and sold as “flexible”. FluxTeq confirmed: “suitable for bending up to 1.25 x 10^{-3} m radius”. Changes in sensitivity and electrical resistance are all relative to the sensitivity and resistance at the start of the test; positive values indicate a higher value after testing.

Hukseflux
Thermal Sensors

Testing was performed at 20 °C after bending once around a pipe of 25 x 10^{-3} m radius and after 24 hours of exposure to high temperatures. Sensors were exposed to 120 °C. The changes of sensitivity were all relative to an initial measurement by Hukseflux at 20 °C and were all performed on a flat surface. When determining the sensitivity, the capability to measure changes has a reproducibility in the order of 1 %, asserting that changes of 3 % can meaningfully be detected. In this experiment, the absolute accuracy is not a factor.

sensor technology	test	permanent change of sensitivity	permanent change of resistance
	[name]	[(V/(W/m²)/(V/(W/m²)]	[Ω / Ω]
Hukseflux etched	bending radius 25 x 10^{-3} m	not detectable (< 3 %)	< 2 %
FluxTeq printed	bending radius 25 x 10^{-3} m	-7 %	+11 %
Hukseflux etched	120 °C	not detectable (< 3 %)	< 2 %
FluxTeq printed	120 °C	+ 6 %	+ 250 %

Table 1 *Stability testing: tests were performed before and after 24-hour exposure to high temperature and before and after bending.*

Bending test on YouTube

Interested to see the kind of experiment we perform? See a movie on the bending test on YouTube. At 02:00 min in the video "*Improved technology for heat flux sensors*", you can witness the testing.

Sensitivity as a function of environment

A heat flux sensor is supposed to keep its sensitivity regardless of the environment.
The sensitivity of FluxTeq PHFS-01 sensors, however, depends on the material on which it is mounted. The sensitivity of Hukseflux sensors remains the same in all environments.
Thermal conductivity dependence is an intrinsic property of a heat flux sensor; its sensitivity depends on the thermal conductivity of the surrounding material. This is expressed as a % change of sensitivity, either absolute or per [W/(m·K)] change of thermal conductivity.

Thermal conductivity dependence is reported relative to the sensitivity at the calibration reference condition mounted on a metal heat sink. There are no standardised experiments to perform tests. The results presented are, therefore, "comparative" only.

Test results

The sensitivities of the sensors were tested under various conditions. The reference condition is mounted on aluminium, the other conditions are surrounded by Pyrex (glass) and silicone (plastic) to create an environment with different thermal conductivities.

Conclusions

- heat flux measurements with the FluxTeq PHFS-01 sensors are unreliable. The sensor is not stable under normal rated operating conditions. Depending on the thermal conductivity of the environment, the measurement is also subject to other large systematic errors. The manufacturer does not inform the user about these aspects of the sensor performance.
- the risk that the sensitivity of a PHFS-01 sensor instantly and significantly changes is very high, especially when bending the sensor (at installation) or when using it at high temperatures. Very mild, short-term exposure testing - all within rated conditions of use advertised by FluxTeq – already leads to changes of sensitivity in the order of 7 %. (see Table 1). Hukseflux sensors are perfectly stable under the same conditions.
- the PHFS-01 sensitivity depends on the sensor environment; this dependence is in the ± 10 % range and is significantly larger than the calibration uncertainty of 5 %**. Hukseflux sensors show deviations in the order of only ± 2 % under the same conditions.
- users must take the risk of instability and thermal conductivity dependence into account in their uncertainty evaluations. Hukseflux sensors do not suffer from similar instability or thermal conductivity dependence. Measurements with FluxTeq PHFS-01 sensors, therefore, tend to be less accurate than those with Hukseflux sensors under the same conditions.

*source: text and brochures on FluxTeq website 04 FEB 2023, advertising "*very thin, flexible*" and "*temperature range -50 to 120 °C, Temperature range may be larger than specified. Further testing is currently being conducted.*"
**source: PHFS-01 calibration certificate sn 21340, supplied in 2021

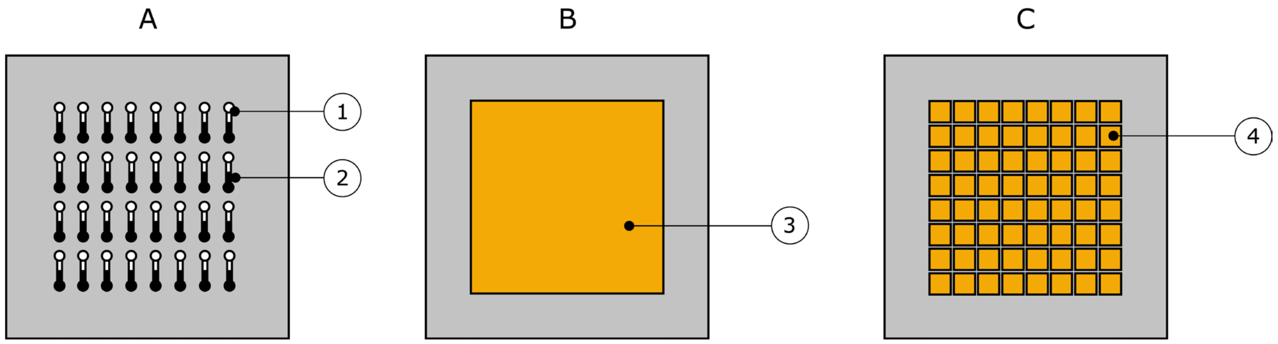

Figure 3 *A: sensor without a spreader such as FluxTeq model PHFS-01. One thermopile alloy (1), other thermopile alloy (2) In B and C, the thermopile is covered by spreaders. B: sensor with a single large spreader (3) C: sensor with multiple small spreaders (4) such as the FHF05-series sensors made by Hukseflux.*

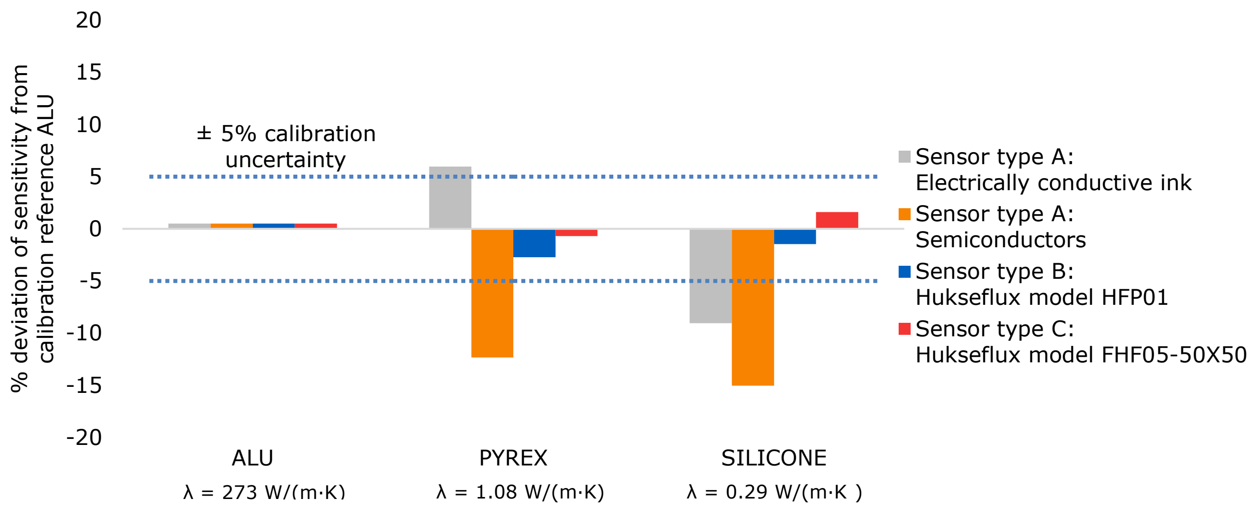

Figure 4 *Thermal conductivity dependence of three sensor types. Two "type A" sensors were tested: one FluxTeq with a thermopile made of electrically conductive inks and the other made of semiconductors. The calibration uncertainty is 5 %. The FluxTeq PHFS-01 makes up to 10 % error when the thermal conductivity of the environment changes. Errors made with type B and C – Hukseflux FHF05-series sensors – are negligible.*

Other FluxTeq models

FluxTeq model PHFS-01e and PHFS-09e are sensors sandwiched between two metal foils. Why is this done? Text from the FluxTeq website page of PHFS-01e on JAN 31, 2023:
"Increased durability is advantageous when the sensor is required to withstand removal and reapplication to measurement surfaces multiple times throughout its lifetime."

This may be beneficial to stability when bending. Metal foils may make it impossible to bend the sensor at all. The foil may also absorb part of the force and also reduce the influence of the environment on sensitivity (thermal conductivity dependence). However, the stability at higher temperatures will not improve.

More details about the tests

Hukseflux has published two detailed notes about the experiments. In these notes, the FluxTeq brand and PHFS model name are not specifically mentioned:

- heat flux sensor technology: why use sensors with spreaders
- heat flux sensor technology: printed thermopile conductors vs. etched-and-plated

Figure 5 *Example of Hukseflux model FHF05-50X50 heat flux sensor. This model is stable under bending and high-temperature exposure.*

About Hukseflux

Hukseflux is the leading expert in measurement of energy transfer. We design and manufacture sensors and measuring systems that support the energy transition. We are market leaders in solar radiation- and heat flux measurement. Customers are served through the main office in the Netherlands, and locally owned representative sales offices in the USA, Brazil, India, China, Southeast Asia and Japan.

Would you like more information?
E-mail us at: info@hukseflux.com