Contents

Scope

This instruction covers the use of Schmidt-Boelter Heat Flux Transducers in FRL custom experiments.

Instrument Description

GENERAL

A heat flux transducer is a device that measures the rate of absorbed incident energy, and expresses it on a per unit area basis. The operating principle of most heat flux transducers is based on one-dimensional heat conduction through a solid. Temperature sensors are placed on a thin, thermally conductive sensor element, and applying heat establishes a temperature gradient across the element. The heat flux is proportional to the temperature difference across the element according to Fourier's Law.

There are many configurations of heat flux transducers, but for fire applications the choice revolves around five decisions: (1) type, (2) range, (3) size, (4) mode and (5) cooling.

Transducer Type: Two primary types of transducers in use are circular foil (Gardon) and thermopile (Schmidt-Boelter). Schmidt-Boelter transducers are recognized as being the most appropriate for fire applications.

In a Schmidt-Boelter transducer, a constantan wire is wrapped around an electrically insulating sensor element and the turns on one side are plated with copper, producing (T-type) thermocouple junctions on both faces of the sensor [1,2]. The number of thermocouple junctions determines the sensitivity, as there is an additive effect of the potential for each junction.

The time constant of a heat flux transducer is the time required for the sensor to reach 62.5 % of a step input. Time constants vary based on sensor range, however for Schmidt-Boelter transducers they are typically less than 250 milliseconds [3].

Range: The range of a heat flux transducer is determined by the sensitivity of the element to an applied heat flux. Transducers are typically designed to provide a signal of nominally 10 mV at the range peak. Heat flux transducers are classified according to the peak flux for which they are calibrated to read. For Schmidt-Boelter transducers, standard ranges vary from 2 kW/m^2 – 50 kW/m^2, however ranges as high as 1100 kW/m^2 are available. In fire applications, a range from 25 kW/m^2 – 150 kW/m^2 will cover most applications. Sensors have an over range capability of up to 150 % of the peak specified heat flux [3].

Size: The size of transducer that is appropriate for use depends on the application. A typical size that is used in fire applications is a 2.5 cm (1 in.) diameter body with a 1 cm (3/8 in.) diameter sensor. When finer spatial resolution is required, 1.3 cm (1/2 in.) or 3 mm (1/8 in.) transducers can be used.

Transducer Mode: Transducers are designed for use as radiometers to measure the radiative flux, or as total flux transducers in which the sum of radiative and convective components are measured. A radiometer isolates the radiative component by placing an IR-transmitting window in front of the sensor element, eliminating the effect of convective heat transfer on the sensor. Some transducers use two sensors, a total heat flux sensor and a radiometer so that the magnitude of the individual components can be determined. Care must be taken, as window materials do not transmit 100% throughout the IR spectrum. The FRL uses Zinc Selenide window material, as it provides a relatively high and consistent transmittance throughout the relevant spectral range.

Transducer cooling: Some transducers come equipped with the capability for water cooling. In this configuration, water flows through the transducer, removing heat from the backside of the sensor. Water-cooling is recommended for conditions in which the temperature of an uncooled transducer will exceed 204ºC (400ºF) [3].

UNCERTAINTY AND ACCURACCY

The uncertainty of the heat flux measurement has two parts: the uncertainty of the instrument and the uncertainty associated with fluctuations over time. The uncertainty in the instrument is a function of the linearity, repeatability and calibration of the instrument. The combined uncertainty of the measurement is estimated by combining the standard uncertainty of each component in quadrature.

Medtherm gives the linearity of the heat flux transducer as ± 2 % full scale [3]. The repeatability is listed as ± 0.5 % and the calibration uncertainty is ± 2 % for ranges up to 3000 kW/m^2. It can be assumed that these errors have a rectangular probability distribution, in which case the standard uncertainty is computed by dividing each component by $\sqrt{3}$ [4]. For a 50 kW/m^2

transducer, the standard uncertainties of these components are then, respectively, 0.58 kW/m^2, 0.14 kW/m^2, and 0.58 kW/m^2.

The uncertainty over time can be calculated using a sample standard deviation. NIST [4] states that for a sample of data, the uncertainty of the samples is:

$$U_s = {}^{\sigma}/_{\sqrt{n}}$$

where:

U_s = Standard uncertainty of the samples
σ = Standard deviation of the samples
n = Number of samples

Using this formula, the uncertainty of the heat flux can be determined. Over a sample of 40 data points, the standard deviation was 0.227 kW/m^2, which yields a standard uncertainty of 0.036 kW/m^2.

The uncertainty components are combined in quadrature to estimate the combined uncertainty of the heat flux measurement. The result is $U_{HF} = \mathrm{u(SG_{NG})} =$ 0.83 kW/m^2. For a 50 kW/m^2 transducer this is equivalent to ± 1.7 %

Operating Instructions

REQUIREMENTS

1. The assigned operator shall be qualified in accordance with laboratory proficiency requirements.
2. The data acquisition equipment shall be calibrated and be marked with the calibration status in accordance with FRL calibration procedures.
3. Heat flux transducers shall be calibrated and be marked with the calibration status in accordance with FRL calibration procedures.
4. Transducers size, range and mode shall be selected to represent the test conditions.

PROCEDURE

1. Set up

1.1. The calibration marking on the transducer shall be checked to confirm that the instrument is calibrated.
1.2. Transducers shall be connected to the data acquisition hardware using the smallest voltage input range that will bound the output range of the transducer. This is usually the 20 mV range.
1.3. All heat flux transducers shall be connected to a constant temperature flowing water source.

1.4. Water lines and wires connected to the heat flux transducer shall be protected if it is anticipated that they will be exposed to excessive heat during the experiment.

2. Pre-Test

2.1. It shall be verified that water is flowing through each transducer.
2.2. The water temperature used to cool the transducer shall be a minimum of 5°C above ambient. This temperature shall be recorded on the data sheet.
2.3. A baseline reading shall be recorded with the transducer prior to conducting experiments. The baseline value shall be the average heat flux measured during a period with a minimum 2-minute duration.
2.4. During the baseline reading, the water temperature will be stable.

3. Test

3.1. Water shall be supplied continuously at the required temperature.
3.2. The output of the heat flux transducer shall be recorded for the duration of the experiment.
3.3. Exception – When the heat flux transducer must be removed prior to the end of the experiment due to experiment design or impending damage to the instrument. The elapsed time at which the transducer was removed and the reason for instrument removal shall be recorded on the data sheet.

4. Post Test

4.1. After the experiment, heat flux transducers in areas where they may have been damaged shall be examined for visible damage or surface dirt.
4.2. If damage or surface dirt is observed the instrument shall be cleaned and/or repaired according to manufacturer's documentation.
4.3. If the heat flux exceeded 150% of the maximum transducer range during any point of a test, the instrument shall be taken out of service until its correct operating condition is confirmed.

Heat Flux Transducer Documentation Requirements

Heat flux transducer usage shall be documented using the FireTOSS experiment design program. The information that the user shall document about the heat flux transducers is shown in **Table 1**. The first column in **Table 1** shows the description of input parameter that will appear in the column heading of the FireTOSS experiment design program. The second column in **Table 1** shows whether the parameter is required in all cases, and column three provides a description of the information to be supplied for the parameter.

Table 1: Data Acquisition Input Parameters

Parameter	Required	Parameter Description
Calibration Factors	True	(m, b) Taken directly from the calibration data sheet or sticker.
Description	True	Description of the location of the heat flux transducer or a description of what it is pointing at.
Location – X	False	X – Location of transducer based on defined coordinate system (m)
Location – Y	False	Y – Location of transducer based on defined coordinate system (m)
Location – Z	False	Z – Location of transducer based on defined coordinate system (m)
Orientation	False	Orientation of transducer based on defined coordinate system

Parameter	Required	Parameter Description
Room Number	False	Identification of transducer location in a compartment
Type	True	Description of transducer type.
Range	True	Peak range (kW/m^2)
OverRange	False	
Mode	True	Total or Radiative
Serial number	True	Manufacturer's serial number
Status	True	
Bar code	True	FRL Equipment identification number (asset number)
Path length	False	Distance in meters from the measuring surface of the flux transducer to the item of interest. A diagram of the test set up typically supports this measurement.
Water temperature	True	Temperature of the cooling water supplied to the heat flux transducer
Chart	False	Allows the user to group instrument data onto different charts. If this parameter is left empty, data for similar instruments will be put on one chart.
Baseline Experiment ID	False	Experiment ID where baseline data is stored for a particular instrument.
Baseline Heat Flux	False	Offset applied to heat flux readings to account for measured background heat flux due to the cooling water. If a value for the 'Baseline Experiment ID' is input in the data sheet this value will be automatically inserted from the calculated 'Average Uncorrected Heat Flux' otherwise the user input value will be used. (kW/m^2)
Out of service time	False	Indicates the elapsed test time that the instrument was removed from the test. All calculations for the data on the instrument cease at this time.
Out of service reason	False	Specifies the reason that the instrument was removed from the experiment. Reasons typically include damage, impending damage, or test design

List of Standards

The following standards apply to the use of heat flux transducers.

ISO/TS 14934-1:2010 "Fire tests -- Calibration and use of heat flux meters -- Part 1: General principles"

ISO/TS 14934-2:2006 "Fire tests -- Calibration and use of heat flux meters – Part 2: Primary calibration methods

ISO/TS 14934-3:2006 "Fire tests -- Calibration and use of heat flux meters – Part 3: Secondary calibration method

ISO/TS 14934-4:2007 "Fire tests -- Calibration and use of heat flux meters – Part 3: Guidance on the use of heat flux meters in fire tests

References

1. Barnes, A., “Heat Flux Sensors Part 1: Theory,” Sensors, January 1999.

2. Technical Data Sheet, “Schmidt-Boelter Heat Flux Sensor,” Vatell Corporation, www.vatell.com/SB.htm

3. Medtherm Corporation, Technical Data Sheet.

4. Taylor, B. N., & Kuyatt, C. E., “NIST Technical Note 1297: Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results,” National Institute of Standards and Technology, Gaithersburg, MD 1993.

5. Bryant, A.R., Ohlemiller, T.J., Johnsson, E.L, Hamins, A., Grove, B.S., Guthrie, W.F., Maranghides, A., Mulholland, G.W., “Special Publication 1007,” National Institute of Standards and Technology, Gaithersburg, MD 2003.

6. Guthrie, W. & Liu, H., “Hands-on Workshop on Estimating and Reporting Measurement Uncertainty,” National Institute of Standards and Technology, Presentation given to CPSC, 2007.