INTERNATIONAL STANDARD

ISO 14934-2

First edition
2006-02-15

Corrected version
2006-04-15

Fire tests — Calibration and use of heat flux meters —

Part 2: Primary calibration methods

Essais au feu — Étalonnage et utilisation des appareils de mesure du flux thermique —

Partie 2: Méthodes d'étalonnage primaire

Reference number
ISO 14934-2:2006(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14934-2 was prepared by Technical Committee ISO/TC 92, *Fire Safety*, Subcommittee SC 1, *Fire initiation and growth*.

ISO 14934 consists of the following parts, under the general title *Fire tests — Calibration and use of heat flux meters*:

— *Part 1: General principles*

— *Part 2: Primary calibration methods*

— *Part 3: Secondary calibration methods*

The following part is under preparation:

— *Part 4: Guidance on the use of heat flux meters in fire tests*

This corrected version of ISO 14934-2 incorporates the following changes:

— 7.1.1: the first item in unnumbered list changed to read as follows:

"...electrically heated [(3), (6)], black-body cavity (4)....";

— 9.1.4: the radiometer range changed to "...0,4 kW/m^2 to 42 kW/m^2, ...";

— 9.2.3: the reference for the procedure for making calibration measurements changed to Annex I;

— Clause 11: in the list in the fourth paragraph, the second bullet changed to read as follows:

"— field of view of the heat flux meter, expressed in degrees. In case of view-limiting apertures, specify field of view from the centre of the sensing surface to the edge of the view-limiting aperture. In case of flat receivers, specify 180°;"

— Clause E.1: the note in Figure E.1 changed to read as follows:

"NOTE If a spacer ring is used, use curve 2. ..."

— Annex G, second paragraph: the radiation range changed to "...2 kW/m^2 and 25 kW/m^2."

— Annex J, Figure J.1: "1" on the right changed to "2".

Introduction

In many fire test methods, the radiation level is specified and, therefore, it is of great importance that the radiant heat flux is well defined and measured with sufficient accuracy. Radiant heat transfer is also the dominant mode of heat transfer in most real fires.

In practice, radiant heat flux is usually measured with so-called total heat flux meters of the Schmidt-Boelter (thermopile) or Gardon[1)] (foil) type. Such meters register the combined heat flux by radiation and convection to a cooled surface. The contribution to the heat transfer by convection depends mainly on the temperature difference between the surrounding gases and the sensing surface and on the velocity of the surrounding gases. It will, however, also depend on size and shape of the heat flux meter, its orientation and on its temperature level, which is near the cooling water temperature. In many practical situations in fire testing, the contribution due to convection to the sensing surface of the instrument can amount to 25 % of the radiant heat flux. Thus it is always necessary to determine and control this part.

To determine the fraction of total heat flux due to radiation, a calibration scheme is developed where primary calibration is performed on two different types of heat flux meters: (1) a total hemispherical radiometer sensitive to radiation only, and (2) a total heat flux meter, (most frequently used) sensitive to both radiant heat transfer and to convective heat transfer. A comparison of measurements between the two types of meters in secondary (or transfer) calibration methods allows a characterization of the influence of convection in the method. Where possible, in all calibrations and measurements of radiative heat flux, the uncertainty calculations should include the uncertainty associated with removing the convective component. For secondary calibration methods, a combined use of hemispherical radiometers and total heat flux meters makes it possible to estimate the convection contribution. The same arrangement can be used in calibration of fire test methods as well.

Primary calibration is performed in a black-body cavity under conditions where the convective part of the heat transfer can be neglected or controlled. One such apparatus is an evacuated black-body facility with the unique characteristic of negligible convection and conduction effects described in this document as the vacuum black-body cavity (VBBC) method (method 1). Other (non-evacuated) black-body facilities can also be suitable as primary heat sources for calibration, providing they are fully characterized, particularly in terms of any convection effects on the sensing surface of the heat flux meter being calibrated. One such facility, described in this document as the spherical black-body cavity method (method 2), is a furnace with an orifice pointing downwards to minimize the convection. Another is the variable temperature black-body method (method 3) in which the effect of the convective component is minimized by the adoption of a substitution procedure in which the heat flux meter to be calibrated is compared with a primary standard radiometer. Under such conditions the convective effect for each measurement can be asumed to be of a similar magnitude.

---

1) Schmidt-Boelter meters and Gardon meters are examples of suitable products available commercially. This information is given for the convenience of users of this part of ISO 14934 and does not constitute an endorsement by ISO of this product.

Fire tests — Calibration and use of heat flux meters —

Part 2: Primary calibration methods

1 Scope

This part of ISO 14934 describes three methods for calibration of total hemispherical radiometers and total heat flux meters that are exposed to a well-defined radiation from a radiant heat source. The equipment is designed to minimize influences due to convective heat transfer during calibration. It is important to note that when the instruments are used in practice they measure a combination of radiant and convective heat transfers. The latter will depend on the design of the heat flux meter, the orientation, local temperature and flow conditions, and on the temperature of the cooling water.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943:2000, *Fire safety — Vocabulary*

IEC 60584-2:1982, *Thermocouples — Part 2: Tolerances*

International vocabulary of basic and general terms in metrology (VIM), BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML, 1993

Guide to the expression of uncertainty in measurement (GUM), BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML, 1993 (Corrected and reprinted, 1995)

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943:2000, GUM, and the following apply.

3.1
radiation
emission or transfer of energy in the form of electromagnetic waves with the associated photons

NOTE See Reference [1].

3.2
convection
movement of fluid

3.3
heat
thermal energy

NOTE Heat is expressed in joules.

3.4
heat transfer
movement of heat between bodies by means of radiation, convection, or conduction

EXAMPLE The bodies can be a gas, a liquid, a solid body or combinations of them.

NOTE Heat transfer is expressed in watts.

3.5
radiant heat transfer
heat transfer by radiation

NOTE Radiant heat transfer is expressed in watts.

3.6
convective heat transfer
heat transfer from a surrounding fluid to a surface by convection depending on the fluid velocity and the temperature difference between fluid and surface

NOTE Convective heat transfer is expressed in watts.

3.7
total heat transfer
sum of the radiant heat transfer and the convective heat transfer

NOTE Total heat transfer is expressed in watts.

3.8
heat flux
heat passing through a surface per unit area and unit time

NOTE Heat flux for fire testing purposes is expressed in watts per square metre. Outside the fire testing field, this definition is given as heat flux density.

3.9
incident heat radiation
incoming radiant heat flux to a surface

NOTE Incident heat radiation is expressed in watts per square metre.

3.10
absorbed heat radiation
radiant heat absorbed by a surface

NOTE Absorbed heat radiation is expressed in watts per square metre.

3.11
emitted heat radiation
radiant heat emitted from a surface

NOTE Emitted heat radiation is expressed in watts per square metre.

3.12
net heat radiation
absorbed heat radiation minus emitted heat radiation

NOTE Net heat radiation is expressed in watts per square metre.

3.13
leaving heat flux
composed of emitted heat radiation and reflected heat radiation

NOTE The term is also called radiosity. Leaving heat flux is expressed in watts per square metre.

3.14
radiant heat flux
heat flux by radiant heat transfer

NOTE Radiant heat flux is expressed in watts per square metre.

3.15
convective heat flux
heat flux by convective heat transfer

NOTE Convective heat flux is expressed in watts per square metre.

3.16
total heat flux
sum of net heat radiation and convective (heat) flux

NOTE Total heat flux is expressed in watts per square metre.

3.17
black-body radiant source
ideal thermal radiating source which absorbs completely all incident heat radiation, whatever wavelength and direction

NOTE This definition is part of the definition given in Reference [1].

3.18
irradiance
incident radiant heat flux arriving from all hemispherical directions

NOTE Irradiance is expressed in watts per square metre.

3.19
emissivity
ratio of the radiant heat flux emitted by a surface to the radiant heat flux emitted by a black-body radiator at the same temperature

NOTE Emissivity is dimensionless.

3.20
absorptivity
ratio of the absorbed radiant heat flux to the incident radiant heat flux

NOTE Absorptivity is dimensionless.

3.21
radiant intensity
radiant heat transfer per unit solid angle leaving a source in a given direction

NOTE Radiant intensity is expressed in watts per steradian.

3.22
heat flux meter
instrument responding to incident radiant heat flux and/or to convective heat transfer to a cooled surface

3.23
radiometer
heat flux meter responding to incident radiant heat flux only

3.24
total hemispherical radiometer
radiometer equally sensitive to radiant intensity arriving from all directions above the sensing surface

3.25
total heat flux meter
heat flux meter responding to both incident radiant heat flux and convective heat transfer to a cooled surface

NOTE The expression “heat flux meter” without the denotation “total” should only be used when it is not defined whether the instrument is a radiometer or a total heat flux meter. When the instrument responds to both radiant and convective heat flux the expression “total heat flux meter” is the proper designation.

3.26
primary standard
standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity

[VIM:1993]

3.27
secondary-standard heat flux meter
heat flux meter with a calibration traceable to a primary standard, used only for calibration of working-standard heat flux meters

3.28
working-standard heat flux meter
heat flux meter to be calibrated by reference to a secondary standard for subsequent use during the course of fire tests

3.29
sensing surface
surface of the heat flux meter which detects the irradiance

3.30
sensitivity
ratio of the output voltage to the measured quantity

3.31
Stefan-Boltzmann constant
σ
constant in the expression for calculating the radiant heat flux from the absolute temperature equal to $5{,}67 \times 10^{-8}$ watt per square metre Kelvin to the fourth power

NOTE See Reference [2].

4 Principles

4.1 General principles

Calibration of heat flux meters (total hemispherical radiometers and total heat flux meters) is performed with a black-body radiant heat source.

4.2 Principle of the vacuum black-body cavity (VBBC) method (method 1)

This method is used to calibrate heat flux meters between 2 kW/m^2 and 70 kW/m^2. It is designed to accept total heat flux meters or total hemispherical radiometers with a housing diameter of up to 50 mm. These may have pipes for water or/and air that are located axially. Calibration of heat flux meters consists of reading the output voltage of total heat flux meters or total hemispherical radiometers when irradiated by a traceable black-body radiant source operating under vacuum. By lowering the absolute pressure in the black-body cavity to between 0,5 Pa and 2 Pa, the convective heat transfer is significantly reduced. Heat flux meters to be calibrated are fixed on a support and form a part of the closed system. The operating procedure is given in Annex A. The relation between the furnace and the irradiance to the heat flux meter is given in Annex B. Examples of computer screens are given in Annex C.

4.3 Principle of the spherical black-body cavity method (method 2)

This method is used to calibrate heat flux meters between 2 kW/m^2 and 70 kW/m^2. A black-body radiant heat source designed as a spherical furnace with an aperture at the bottom is used. The temperature level of the furnace is controlled with high precision and is very uniform inside the furnace assuring a high precision of the radiant heat level.

Heat flux meters to be calibrated are inserted through the aperture at the bottom of the furnace with the sensing surface of the heat flux meter oriented horizontally. The influence of convection is thus reduced to a minimum. The heat flux meter sees nothing but the controlled environment of the black-body emitter. The radiation level of this black-body emitter depends primarily on the measured temperature making it traceable to international thermal calibration standards.

The accuracy of the method depends on the design of the test apparatus. The operating procedure is given in Annex D. The relation between the furnace temperature and the irradiance to the heat flux meter is described in Annex E. The limits of errors assume that the apparatus is constructed according to the figures in Annex F. Guidance notes for operators are given in Annex G.

4.4 Principle of the variable temperature black-body (VTBB) method (method 3)

The technique uses the principle of electrical substitution radiometry to calibrate heat flux sensors up to 50 kW/m^2. The sensors are calibrated with reference to a room-temperature electrical substitution radiometer whose calibration is traceable to a primary standard high accuracy cryogenic radiometer (HACR). This is a standard for optical radiation power and is supported through a chain of independent calibrations.

The calibration uses the 25 mm cavity diameter variable temperature black-body (VTBB) facility as broadband radiant source. The VTBB consists of a dual-cavity, electrically heated graphite tube. The black-body temperature is controlled and is stable within $\pm$ 0,1 K of the set value.

The heat flux sensor to be calibrated and the reference standard radiometer are located at a fixed distance away from the black-body aperture, depending on the heat flux level. The variation in the incident heat flux level at the sensor location is obtained by varying the VTBB temperature. The operating procedure for electrical substitution radiometer is given in Annex H. The calibration procedure is given in Annex I. The data reduction procedure is given in Annex J.

5 Suitability of a gauge for calibration

5.1 Types of heat flux meters

All three methods are intended for calibration of total hemispherical radiometers and of total heat flux meters. The total heat flux meters are usually of so called Schmidt-Boelter and Gardon types. Along with the experimental calibration data, an expression of the sensitivity of the heat flux meter is normally also given. It should be noted that for each given wavelength, λ, the heat flux meter has a specific spectral sensitivity. For heat flux meters used in fire tests, it can, however, be assumed that the sensitivity does not depend on the wavelength over the spectral range of the radiating sources commonly examined. Deviations from the ideal directional response characteristics may be neglected.

The field of view is assumed to be hemispherical (solid angle 180°), and the surface is assumed to behave as a perfect black-body, both regarding the spectral characteristics and the directional response.

The methods can be used for radiometers with a limited field of view, provided that this field of view is characterized, and that corrections made for this field of view are traceable.

5.2 Design of heat flux meters

Radiometers and heat flux meters with a housing diameter of up to 50 mm and a sensing surface diameter up to 10 mm can be accommodated in methods 1 and 2. During the calibration the heat flux meter body temperature must remain constant. This is usually achieved by using water-cooling. In some cases an air supply is used to keep the window free from dust. If possible, water and/or air supply piping are routed parallel to the axis of the meter so as to keep the lines within the housing diameter of 50 mm.

For the NIST open-mode method, there is no restriction on the sensor-housing diameter, and on how the cooling water or purge gas lines are routed. However, it is recommended that the sensing surface of the gauge is limited to less 10 mm in diameter.

5.3 Measuring range

Radiometers are typically designed for use within a certain range. They should be calibrated within this range. For radiometers that will be used beyond the range of the method used extrapolation of the obtained calibration results may not be used unless justified.

5.4 Status of heat flux meter prior to calibration

The coating on the sensor is visually inspected, and if the conditions indicate the need for repainting, the customer is informed accordingly.

6 Relationship between output voltage and total heat flux

The sensitivity of heat flux meters is primarily determined by the physical composition of the sensor itself. The combined properties of the absorber, surrounding geometry (limiting the field of view), window, and thermopile will result in a certain output at a certain level of incident heat radiation.

The total heat flux to the sensor, q_{tot}, may be written as

$$q_{tot} = q_{rad} - q_{emi} + q_{con} \tag{1}$$

where

q_{tot} is the total heat flux to the sensor;

q_{rad} is the heat radiation absorbed by the sensor;

q_{emi} is the emitted heat radiation from the sensor;

q_{con} is the convective heat transfer to the sensor.

The heat radiation that is absorbed by the sensor depends on the absorptivity of the sensor surface as

$$q_{rad} = \varepsilon \cdot I_{rad} \tag{2}$$

where

ε is the absorptivity of the sensor; the absorptivity and the emissivity of the sensor are assumed equal;

I_{rad} is the incident heat radiation as defined by the calibration method (Clauses 7, 8, and 9); the view angle dependence for the method is included in the value.

The emitted heat radiation from the sensor, q_{emi}, is

$$q_{emi} = \varepsilon \cdot \sigma T_w^4 \tag{3}$$

where

T_w is the absolute temperature of the cooling water, which is assumed to represent also the temperature of the sensor

The convective heat transfer, q_{con}, is specific for the calibration method. It depends on calibration configuration and on the temperature of the cooling water and the ambient air.

The total heat flux to the sensor, q_{tot}, is assumed to be a second-degree polynomial of the output voltage signal:

$$q_{tot} = A_0 + A_1 \cdot U_{out} + A_2 \cdot U_{out}^2 \tag{4}$$

where

A_0, A_1, A_2 are constants to be determined by the calibration procedure in a best-fit procedure as described in Clause 10;

U_{out} is the output voltage signal.

7 Vacuum black-body cavity (VBBC) method (method 1)

7.1 Apparatus

7.1.1 General description of apparatus for method 1

The primary calibration apparatus is a closed and insulated system including two essential parts (see a schematic drawing in Figure 1):

— a gun which is a moving cylindrical tube (1) including the electrically heated [(3), (6)], black-body cavity (4), the diaphragms (5), the heat flux meter (10) and its cooling pipes,

— an insulated and cooled chamber (2).