Stationary source emissions — Determination of the volume flowrate of gas streams in ducts — Automated method

ICS 13.040.40; 17.120.10

National foreword

This British Standard reproduces verbatim ISO 14164:1999 and implements it as the UK national standard.

The UK participation in its preparation was entrusted to Technical Committee EH/2, Air quality, to Subcommittee EH/2/1, Stationary source emissions, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the ISO title page, pages ii to iv, pages 1 to 10 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Contents

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Stationary source emissions — Determination of the volume flowrate of gas streams in ducts — Automated method

Émissions de sources fixes — Détermination du débit-volume des courants gazeux dans des conduites — Méthode automatisée

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Contents

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 3.

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.

International Standard ISO 14164 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions*.

Annex A forms a normative part of this International Standard. Annex B is for information only.

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1 Scope

This International Standard describes the operating principles and the most important performance characteristics of automated flow-measuring systems for determining the volume flowrate in the ducts of stationary sources.

Procedures to determine the performance characteristics of automated volume flow-measuring systems are also contained in this International Standard.

The performance characteristics are general and not limited to specific measurement principles or instrument systems.

NOTE Commercial systems which use the operating principles described and meet the requirements of this International Standard are readily available.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 6879:1995, *Air quality — Performance characteristics and related concepts for air quality measuring methods.*

ISO 7935:1992, *Air quality — Stationary source emissions — Determination of mass concentration of sulfur dioxide — Performance characteristics of automated measuring methods.*

ISO 9096:1992, *Stationary source emissions — Determination of concentration and mass flow rate of particulate material in gas-carrying ducts — Manual gravimetric method.*

ISO 9169:1994, *Air quality — Determination of performance characteristics of measurement methods.*

ISO 10155:1995, *Stationary source emissions — Automated monitoring of mass concentrations of particles — Performance characteristics, test methods and specifications.*

ISO 10780:1994, *Air quality — Stationary source emissions — Measurement of velocity and volume rate of flow of gas streams in ducts.*

ISO 10849:1996, *Stationary source emissions — Determination of the mass concentration of nitrogen oxides — Performance characteristics and calibration of automated measuring systems.*

ISO 12039:—, *Stationary source emissions — Determination of the volumetric concentration of CO, CO_2 and O_2 — Performance characteristics and calibration of automated measuring systems*[1].

3 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

3.1
automated flow-measuring system
AMS

system that may be attached to a duct to continuously measure and record the volume flow of a gas

3.2
analyzer

that part of an AMS that measures the parameters used to calculate the volume flow of a gas

3.3
duct

stack, chimney or final exit duct on a stationary process, used for the dispersion of residual process gases

3.4
comparative measurements

measurements of volume gas flow in the duct by the AMS under test (evaluation) and compared to volume flow simultaneously determined in the same duct in accordance with ISO 10780

3.5
comparative method

method for determination of volume gas flow in a duct in accordance with ISO 10780

NOTE Since the purpose of the comparative test is to demonstrate that the AMS under test yields an accurate estimate of the volume flow in the duct, it is necessary for the comparative method to measure the volume flow profile of the entire duct. An AMS cannot be used as the comparative method because all AMS used for measuring volume flow measure the velocity in a small area of the duct and then extrapolate this measurement to obtain the volume flow in the duct.

3.6
standard deviation
s_A

a measure of the working precision of the installed AMS

[1] To be published.

NOTE 1 It is derived using the differences between the pairs of volume flow values obtained by comparative testing of the AMS against ISO 10780 on the basis that a statistically sufficient number of comparative measurements are taken over the period of unattended operation (see Annex A). The value of s_A is expressed as a function of the full-scale range of the AMS and is calculated on the assumption that s_A is an estimate of the precision of a normally distributed set of measurements.

NOTE 2 Whenever possible, the comparative method should measure the same portion of the gas flow as the AMS.

NOTE 3 It is not possible to determine directly the standard deviation of an AMS in a laboratory, because wind tunnels do not normally reproduce all the properties of stack gases and do not replicate all possible measurement conditions. This is the reason the standard deviation is determined after the AMS has been installed in the duct. Applying the comparative method in conjunction with the test for systematic errors (see **A.4.2.3**) ensures that the AMS has a satisfactory accuracy.

NOTE 4 In addition to random error, s_A contains the effect that local site variables such as changes in the gas steams temperature, fluctuations in the electrical power supplied to the AMS and zero and span drift have on the overall precision of the AMS. It also includes the standard deviation of the comparative method. s_A is an estimate of the upper limiting value for the precision of the AMS.

NOTE 5 The procedure in this International Standard is suitable for finding the uncertainty of the data obtained from the AMS, as long as the standard deviation of the measured values of the comparative method, s_C, is significantly smaller than the standard deviation, s_D, of the difference between the pairs of measured values.

3.7
period of unattended operation

period for which given values of the performance characteristics of an instrument can be guaranteed to remain within 95 % probability without servicing or adjustment

[ISO 6879]

NOTE For long-term monitoring installations, a minimum of seven days of unattended operation is required.

3.8
response time

time it takes the AMS to display 90 % of the high-level calibration value on the data acquisition system, starting from the time of initiation of the high-level calibration cycle

NOTE The response time may be determined either in the laboratory or after the AMS is installed.

3.9
stationary source emission

gas emitted by a stationary plant or process and transported to a duct for dispersion into the atmosphere

3.10
calibration

<of an AMS> the setting and checking of the installed AMS before determining its performance characteristics or before beginning any volume flow measurement

3.11
calibration function

correlation over the span range of the AMS between the volume flowrate of the duct as measured by the installed AMS and as measured in accordance with the reference flowrate

NOTE 1 ISO 10780 is an example of a reference flow standard.

NOTE 2 A nonlinear calibration function is acceptable, provided this nonlinearity is compensated for in the output of the AMS.

3.12
linearity

measure of the degree of agreement between the measurements of the comparative method (ISO 10780) and the AMS when the differences between the AMS and the comparative method across a range of volume flows are subjected to a linear regression

3.13
span

difference between the AMS output (reading) for a known flowrate and a zero flowrate

3.14
zero drift

change in the output of the AMS over a stated time interval when exposed to an unchanging zero flowrate

3.15
span drift

change in the output of the AMS over a stated time interval when exposed to an unchanging flowrate near the span value

3.16
AMS location

point in the duct where the AMS is installed

4 Measuring principles of commercially available AMS

4.1 General

Most commercially available AMS operate on one of the following three principles: pressure differential, rate of heat loss, or change in the speed of a sound wave. A brief description of each common type of AMS and the advantages and disadvantages of each are presented below.

Before selecting a specific type of AMS for installation, the characteristics of the flow profile shall be established at the location in the duct where the AMS is to be installed (see clause **A.2** in Annex A). Volume flow-measuring AMS systems should not be used in ducts where non-uniform, asymmetrical, developing, swirling and/or stratified flow is present.

4.2 Differential pressure-sensing systems

4.2.1 *Single Pitot tube methods*

ISO 10780, the manual reference method for measuring velocity and volume flow in ducts, uses Pitot tubes, the traditional means used to determine flow in ducts. A number of Pitot tubes are available, but the Type-S and Type-L Pitot tubes specified in ISO 10780 are those used for the vast majority of flow measurements in ducts. Some Pitot tube-based AMS simply combine devices which continuously record the pressure differential and the stack temperature, an automated data reduction system such as a data-logger or a computer, and a Pitot tube to yield a continuous measurement of flowrate.

Pitot tubes use the temperature of the gas stream and the difference in pressure measured at two or more points on the Pitot's surface to determine the velocity of the gas stream at individual points across a cross-section of the duct. The volume flowrate is then determined by multiplying the average velocity across the cross-section by the area of this cross-section.

These systems are simple and relatively inexpensive to install, operate and maintain, but are subject to the same errors as the Pitot tubes described in clause **6** of ISO 10780:1994. For example, unless special precautions are taken, Pitot tubes can give erroneous results when used to measure gas streams having any of the following conditions:

a) Reynolds numbers less than 1 200;

b) velocities less than 5 m/s or greater than 50 m/s;

c) cyclonic or angular flow;

d) irregular pressure fluctuations; and

e) high concentrations of particles and/or aerosols.

These latter two problem areas frequently can be avoided by ensuring that the Pitot tube does not vibrate and by periodically back-purging through the Pitot tube. Gas stream pressure fluctuations can be compensated for by employing a damping device in the measurement system.

4.2.2 *Multiple-point Pitot tube (MPPT) method*

The MPPT is a modified form of the Pitot tube; it contains three or more openings (ports) in a pipe, located at the traverse points corresponding to the centres of equal areas of the stack cross-section. The openings facing in the direction of flow give the average impact pressure across the stack diameter, while those facing away from the direction of flow give the average wake pressure. A divider in the centre of the tube separates the two pressure legs of the MPPT. The average impact and wake pressures are compared using an electrical pressure transducer or other differential pressure-sensing device. Since the orifice locations are different for each installation, stack dimensions shall be carefully specified before the MPPT is constructed.

AMS systems based on the MPPT approach suffer from the same limitations as the single-Pitot AMS systems. They can also yield erroneous measurements where the velocity varies substantially across the duct. This latter error results because secondary flows in the MPPT affect the average pressure differentials measured.

4.3 Temperature-sensing systems

These systems, which are frequently referred to as thermal anemometers, operate on the phenomenon that a flowing gas can cool a heated body. The most widely used systems employ two thermal convection mass flow sensors; one of which is heated and the other maintained at ambient temperature. Both sensors are inserted into the gas stream. The temperature differential (measured in terms of voltage or current) between the two sensors is used to determine the flowrate of the gas stream.

Two basic types of thermal convection mass flow sensors are in general use today: the constant-power sensor (CP) and the constant-temperature sensor (CT). The CP-based systems are not widely used because they:

a) are slow to respond to changes in velocity and temperature;

b) do not have a stable “zero”; and

c) have a limited range of temperature compensation.

Because of the above limitations, most thermal-differential AMS systems use the CT approach. In this system, a solid-state feedback control circuit is used to maintain the heated sensor at a constant temperature. The current required to maintain this temperature is measured and converted to mass flow units based on calculations which employ the transport properties of the gas stream. CT-based systems have a much faster response to velocity changes than CP systems, because in the CT-based system only the outer surface of the heated sensor is dependent on its thermal inertia, that is, the centre is already at constant temperature. CT-based systems usually have response times of 5 s or less.

Temperature-differential-based AMS have the following advantages: high-level electronic signal output; accurate at very low gas-stream velocities; no moving parts; and good repeatability from 0 °C to 450 °C. However, the output of the sensor is not linear, and it is necessary to fine-tune the factory-calibrated AMS after it is installed to compensate for differences between the properties of the actual gas stream and the gas stream generated in the manufacturer's wind tunnel at the factory. This fine-tuning is generally done using one of the Pitot tubes described in ISO 10780.

Thermal sensor-based AMS cannot be used in ducts where condensing liquid droplets are present in the gas stream, nor can they be used in cases where the velocity vector of the gas stream differs by more than 10° from the duct's primary axis. Buildup of particulate coating on the sensor or corrosion can also cause significant measurement error.

Suppliers of thermal sensor-based AMS generally recommend installing and operating the AMS for a minimum of seven days before attempting to fine-tune the AMS. This allows the AMS sensors and electronics to come to equilibration with conditions in the duct.

Most of these AMS use multiple sensors located at predetermined points in the duct to yield an average velocity for the gas stream. This average velocity is multiplied by the stack cross-section to yield the volume flowrate of the gas in the duct. Since each sensor makes an independent measurement, multi-sensor systems can be used to monitor the distribution of the gas flow across the cross-section of the duct.

4.4 Sound-based systems

These systems determine flowrate by comparing the time it takes for a sound pulse to travel in the general direction of gas flow to the time it takes for an identical sound pulse to travel along the same path in the opposite direction. In this type of AMS, two transceivers are located opposite each other on the stack and offset at a known angle. In each transceiver, a piezoelectric transducer transmits ultrasonic pulses to the opposite transceiver. Each transducer converts electrical signals to acoustic signals and acoustic signals to electrical signals. The speed at which the pulse crosses the stack is dependent upon whether it travels with or against the flow.

Since this type of AMS transmits the sound pulse across the stack, it is extremely important to confirm that there are no obstructions present that will interfere with the passage of the pulses across the duct. For highest accuracy, it is also important to locate the AMS at a point where vibration in the duct walls is not present and to ensure that the optical windows remain clean. However, if an air purge is used to keep the transceivers clean, care shall be taken to correct the AMS response for any effect the purge air has on the gas velocity near the transceivers.

These systems have the following advantages: non-intrusive measurement, no moving parts, easily accessible components and stable precision over a wide range of flowrates.

5 Numerical performance characteristics and their applicability

Table 1 gives the performance characteristics for automated flow-measuring systems. These performance characteristics were derived from tests done on commercially-available AMS which utilize one of the three operating principles described above.

When measured in accordance with the methods given in Annex A, the AMS being evaluated shall yield results which meet the criteria shown in Table 1.

Table 1 — Main performance characteristics of continuous flow measuring systems

Performance characteristic	Numerical value	Test methods see Annex A
Standard deviation, s_A	≤ 5 %[a]	**A.4**
Systematic error	≤ 3 %[b]	**A.5**

NOTE 1 Table B.1 in Annex B gives additional performance characteristics which can serve as a guideline to facilitate meeting the performance specifications given in Table 1.

NOTE 2 When corrected for known systematic errors, the output of the AMS is presumed to lie in the centre of an interval which contains the true value of the volume flow at the 95 % statistical uncertainty level. The difference between either the upper or the lower limit of this interval and the corrected AMS value is termed the uncertainty in the measurement.

[a] Expressed as the absolute value (100 %)(s_A) divided by the full-scale range of the AMS.

[b] Expressed as the absolute value (100 %)(mean difference) divided by the full scale range of the AMS.

6 Test report

The test report shall include the following information:

a) reference to this International Standard;

b) full identification of all sampling and measurement conditions;

c) details of which tests were carried out in a laboratory and which were carried out on-site, and pertinent details of the site testing location and conditions, such as gas temperature, flowrate and gas composition;

d) any modifications to procedures specified in this International Standard;

e) any additional or optional procedures incorporated in the test;

f) all of the test results required in Annex A and Annex B (as applicable), and a statement as to whether the results comply with the requirements in Table 1;

g) final operating parameters of the AMS and any adjustments made to the installed AMS during determination of performance characteristics;

h) date and time of sampling.

Annex A (normative) Determination of the main performance characteristics

A.1 Scope

Annex A describes methods for determining the main performance characteristics of the AMS. Response time can be determined in the laboratory. The standard deviation, however, is determined as a function of process conditions after the AMS has been installed in the duct at the plant. It is determined by comparing the volume flow calculated (predicted) by the AMS with that actually measured in the duct for the same time interval by the comparative method. The data obtained are used to determine performance characteristics identified in Table 1.

The performance characteristics established after installation of the AMS require revalidation in the event of a change in plant operation which could effect the performance of the AMS.

Unless otherwise indicated in this annex, the numerical values of the performance characteristics for automated flow-measuring systems shall be determined for the complete AMS, which includes the equipment required to sample, analyze, measure and provide, on a continuous basis, a permanent record of the volume flowrate.

The AMS shall provide a procedure (a manual one is acceptable) for setting and checking the accuracy of the calibration of the installed AMS over its full span range. As far as possible, this procedure should extend from the flow sensor up to and including the data acquisition system. The procedure shall allow a check of the AMS once every 24 h at two levels: 1) between 0 % and 20 % of the span value; and 2) between 60 % and 80 % of the span value. The manufacturer of the AMS shall also provide a written list of components of the AMS which are not checked by the calibration procedures.

A.2 Selecting and installing the AMS

A.2.1 *Overview*

The selection of the AMS, the location where the AMS will be installed and the location where the comparative test samples will be determined are interrelated activities. Before deciding on which AMS to buy, one must conduct a thorough characterization of the flow profiles in the duct at the candidate locations. All continuous flow measuring systems measure the velocity in only a small segment of the duct and use this value and the dimensions of the duct to obtain an estimate of the total volume flow in the duct. Thus, it is important to select an AMS which will be accurate under the flow conditions in the duct and to locate the sensor(s) of the AMS at a point(s) which will provide velocity measurements representative of the duct's total volume flow. It is also important to select a sampling position in the duct at which the comparative method will accurately determine the flow profile and total flowrate for the duct.

The AMS should be located at a place in the duct which is both easily accessible and which minimizes the effects of condensation, coating, corrosion, plugging and other conditions that could adversely affect the performance of the AMS. As discussed in clause **4** of this International Standard, the principle of operation and the components of an AMS affect the degree to which the AMS remains accurate under non-ideal and low flow conditions and when it encounters a gas stream containing water droplets, high particle concentrations, stratification in temperature or flow, corrosive gases, air infiltration, etc.

Stratification can exist in a duct even when swirling flow is not present. Flow stratification may be caused by air leaking into a duct due to improper seals, the combining of two or more process gas streams, temperature differentials, etc. Stratification patterns may vary as a function of process conditions. As process load or other conditions change, the gas velocity profile may vary dynamically and dramatically.

To avoid problems of stratification, a measurement location should be chosen far enough away from any point of air leakage or combining gas streams so that the dissimilar streams are well mixed. In circular and rectangular ducts, the AMS should be located at least five hydraulic diameters downstream and five hydraulic diameters upstream of any flow disturbance. The hydraulic diameter is calculated by multiplying the duct cross-sectional area by four and dividing the resulting quantity by the duct perimeter.

A.2.2 ***Determining acceptability of candidate installation and comparative testing locations***

A.2.2.1 *Determining the flowrates and flow profiles*

Determine the volume flowrate at each duct location using either ISO 10780 or ISO 9096. ISO 9096 is more accurate than ISO 10780, because it includes procedures to determine the effects of molecular composition, density, temperature and moisture content of the gas stream. These procedures are contained in clauses **5**, **8** and **10** of ISO 9096. However, if the gas stream composition closely approximates that of ambient air or if these parameters are known from previous tests, the simplified procedure described in ISO 10780 is sufficiently accurate for determining the flowrate, and flow profiles may be used. This characterization should cover the full range of flowrates the AMS will encounter in routine operation.

A.2.2.2 *Checking for the presence of swirling flow*

Check for the presence of swirling flow as described in Annex C of ISO 10780:1994.

Swirling flow exists if the swirl angle deviates by more than ± 10° from the local direction of flow parallel to the duct axis at any point in the plane of measurement. If swirling flow conditions or other non-desirable gas or flow conditions are present, either an alternative location shall be chosen or the flow pattern shall be straightened by installing baffles or other flow-straightening devices. Annex D of ISO 10780:1994 describes a method to straighten swirling flow.

A.2.2.3 *Checking for the presence of stratified flow*

Check for the presence of stratified flow as follows.

Traverse the duct using a Pitot tube or other suitable flow-measuring device so as to obtain velocity measurements at the sampling points specified by ISO 10780. When performing this stratification test, one should sample continuously at a single point over the entire sampling period. The data obtained can be used to determine if the velocity changes as a function of time as well as spatially. If it is seen that the velocity varies at this point over the sampling period, the traverse data will be difficult to interpret.

Calculate the percent of stratification at each sampling point as follows:

$$\%\ \text{Stratification at point } i = \frac{(v_i - v_{\text{av}}) \times 100}{v_{\text{av}}}$$

where

v_i is the velocity at point i;

v_{av} is the average of all velocity measurements.

The flow in the sampling plane is stratified if the percent stratification at any one point is greater than 10 %, as calculated above.

A.2.3 ***Selecting installation and comparative test sampling locations***

Based on the above flowrate testing and the information given in **A.2.1** of this International Standard, select the most appropriate AMS, the duct location in which it will be installed and the duct location in which the comparative test samples will be taken.

A.3 Installation and calibration of the AMS

Install and calibrate the AMS in accordance with the manufacturer's instructions. Set the span range of the AMS at 120 % of the highest flow value that it will encounter in the duct. (For most applications, the average flowrate in the duct should lie between 40,0 % and 75,0 % of the span value of the AMS.)

A.4 Determination of the standard deviation, s_{A}

After the installed AMS has been calibrated, determine the standard deviation, s_{A}, as a function of the plant's customary operating conditions. A minimum of three gas flowrates (or unit operating levels) shall be used. For example, these operating levels could be: a) the minimum safe and stable operating level, b) 90 % or greater of the maximum customary operating level, and c) at the normal operating level or at an evenly spaced intermediate level if the normal operating level is within 10 % of a) or b) above.

The standard deviation shall represent at least ten comparative measurements at each operating level. They can be made at any time interval at least one hour apart during the seven day period of unattended operation. Ideally, these measurements should be spread over the seven day period and that each measurement comprise at least a 30-min interval.

Compare the results of the AMS with those obtained using the comparative method. The volume flow reading of the AMS corresponding to the period of time during which each comparative (reference method) measurement was made, may be obtained by continuous integration of the measurement system signal over the test interval.

Use the formula below to calculate the standard deviation, s_{A}, of the AMS at each operating level:

$$s_{\text{A}} = \sqrt{s_{\text{D}}^2 - s_{\text{C}}^2}$$

The value of s_D, in cubic metres per second, is given by the formula:

$$s_D = \sqrt{\frac{1}{n-1}\left[\sum_{i=1}^{n} z_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} z_i\right)^2\right]}$$

where

- s_A is the standard deviation of the AMS under test (defined in **3.6**), in cubic metres per second;
- s_C is the standard deviation of the comparative method, in cubic metres per second (see **A.5**);
- s_D is calculated from the differences in the pairs of measured values according to the equation for standard deviation, in cubic metres per second;
- $z_i = x_i - y_i$ is the difference in the pairs of measured values, in cubic metres per second;
- x_i is the volume flowrate of the gas determined by the comparative reference method, in cubic metres per second;
- y_i is the volume flowrate of the gas determined by the AMS under test, in cubic metres per second;
- n is the number of determinations at each plant operating level.

If the AMS is installed in a location that does not satisfy these physical criteria, but nevertheless the AMS achieves the performance specifications of this International Standard, the location may be accepted, but the permanent record shall note that the AMS is installed in a location which does not meet all the specifications of this International Standard.

A.5 Determining the standard deviation of the comparative method

If ISO 10780 or ISO 9096 was used as the comparative method, the standard deviation s_A for a complete volume flowrate determination can be assumed to be 3 %. However, for highest accuracy in the determination of s_A, one should determine the standard deviation of the comparative method at the location where the comparative testing was done, by using two identical Pitot tubes and simultaneously measuring the velocity at the same points in the duct. This comparison can be made either when the preliminary flow measurements are made or when s_A is being determined.

These measurements should cover the range of velocities encountered in the determination of s_A. At least nine comparative measurements should be made at each velocity sampling point. The Pitot tubes will not interfere with each other, if they lie in the same sampling plane and the distance between their nearest sides is at least 3 cm for a type S Pitot tube and 5 cm for a type L Pitot tube.

An alternative approach is to take a velocity measurement at the sampling point first with one Pitot tube and then with the other, and continue this process until at least nine velocity measurements have been obtained at that sampling point for each Pitot tube.

The standard deviation s_c of the comparative method can then be calculated according to the following formula:

$$s_C = \sqrt{\sum_{i=1}^{m} (v_{1i} - v_{2i})^2 / n}$$

where

- v_{1i}, v_{2i} are the velocities determined at the same sampling point by the two identical Pitot tubes;
- n is the number of comparative measurements at that sampling point and at that velocity.

A.6 Determination of systematic error

To check if a significant systematic error is present, calculate the mean difference, z, for each operating level as follows:

$$z = \frac{1}{n}\sum_{i=1}^{n} (x_i - y_i)$$

A systematic error is present if:

$$|z| \geq 2\frac{s_D}{\sqrt{n}}$$

If a systematic error is present, and if it exceeds 3 % of the range of the AMS, the cause of the error shall be determined and eliminated, and the standard deviation test repeated to determine if the systematic error has been eliminated.

NOTE The procedure in this International Standard is suitable for finding the uncertainty of the data obtained from the AMS, as long as the standard deviation of the measured values of the comparative method, s_c, is significantly smaller than the standard deviation of the difference between the pairs of test measurements.

Annex B (informative) Additional performance characteristics

B.1 Scope

The performance characteristics and the numerical values in Table B.1 are given as a guideline to facilitate meeting the performance characteristics given in Table 1. The performance characteristics described in Table B.1 should be determined by the manufacturer of the AMS through laboratory tests, and the results of these tests documented in a certificate of conformance which should accompany the AMS when it is delivered to the user.

Table B.1 — Additional performance characteristics

Performance characteristic	Numerical value	Test method (Annex B)
Linearity	≤ ± 3 %[a]	**B.2.1**
Zero drift	≤ ± 3 %[a, b]	**B.2.2**
Span drift	≤ ± 3 %[a, b]	**B.2.2**
Response time	≤ 10 s	**B.2.3**

[a] As a percentage of full scale.
[b] Should be done during a period of unattended operation (a period of unattended operation of 7 days is recommended as a minimum).

B.2 Determination of additional performance characteristics

B.2.1 *Linearity check*

If the AMS exhibits or is expected to exhibit a nonlinear calibration response, determine a calibration curve in a wind tunnel, at a minimum of ten velocity test points over the measuring range of the AMS. For comparative analysis, the actual velocity in the wind tunnel should be measured as specified in ISO 10780.

The results from the comparative method are compared to those recorded concurrently by the AMS, and a linear regression is done on the differences.

B.2.2 *Evaluation of zero drift and span drift*

Install the AMS in the duct and set the zero and span points as directed by the manufacturer. Allow the AMS to operate in the routine mode for at least the minimum time specified by the manufacturer before making any adjustments to the span and zero settings.

After the zero- and span-setting operations are completed, measure the change in the zero and span set points over at least seven, non-overlapping 24-h intervals in accordance with the manufacturer's instructions. If necessary, the zero and span set points can be adjusted before the beginning of each 24-h drift test. To the extent possible, these zero and span checks shall cover the complete AMS (i.e. from the sensor to the data acquisition system).

Determine the change in the zero and span set points for each 24-h interval and record the individual differences. Express each difference in terms of the span of the AMS by dividing each difference by the span setting and multiplying the resulting value by 100 %. The AMS meets the zero- and span-drift performance characteristics specifications of this International Standard if the change in the zero setting and the change in the span setting are less than or equal to 3 % of the span setting for each 24-h interval.

If the performance of the AMS fails to meet either or both of these drift tests, the cause for this failure should be determined and corrective action taken before the zero- and span-drift testing is repeated.

It is not acceptable to simply continue to conduct 24-h zero and span checks until seven consecutive zero- and span-drift measurements meet the performance specifications of this International Standard.

B.2.3 *Determination of response time*

Place the velocity sensor(s) of the AMS in the test section of the wind tunnel. Establish a flowrate between 30 m/s and 45 m/s in the wind tunnel and record the start time. Record the time required for the AMS to respond to 90 % of the final velocity measured in the wind tunnel, as determined from a previously calibrated reference flow device such as a Pitot tube. Repeat the test more four times and average the results. The response time is the average of the five test runs.

B.2.4 *Determination of lower detection limit*

The detection limit for an AMS can be affected by the characteristics of the gas stream in the duct. In addition the lower detection limit for most AMS is lower than that for ISO 10780 (5 m/s). For these reasons this International Standard does not specify a lower detection limit for the AMS. The manufacturer of the AMS is expected to specify a lower detection limit for the AMS. This limit, and the procedure used to determine it, shall be contained in the permanent file associated with the AMS.

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