



BSI Standards Publication

Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts

Part 2: Automated measuring systems

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National foreword

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Automated measuring systems (ISO 16911-2:2013)

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Foreword

This document (EN ISO 16911-2:2013) has been prepared by Technical Committee CEN/TC 264 "Air quality", the secretariat of which is held by DIN, in collaboration with Technical Committee ISO/TC 146 "Air quality".

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2013, and conflicting national standards shall be withdrawn at the latest by September 2013.

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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 16911-2 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions*.

ISO 16911 consists of the following parts, under the general title *Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts*:

- *Part 1: Manual reference method*
- *Part 2: Automated measuring systems*

Introduction

EN ISO 16911-2 describes the quality assurance (QA) procedures related to automated measuring systems (AMSs) for the determination of the volume flow rate of flue gas with a total uncertainty that accords with the requirements of Commission Decision of 2007-07-18.^[4]

The calibration and validation of flow AMSs are performed by parallel measurements with the reference manual method described in EN ISO 16911-1.

The purpose of EN ISO 16911-2 is to secure flow monitoring with a minimized uncertainty for use according to EU Directive 2000/76/EC,^[1] EU Directive 2001/80/EC,^[2] and EU Directive 2010/75/EU.^[5]

The purpose of EN ISO 16911-2 is also to secure flow monitoring with an overall uncertainty equal to or less than stipulated in Commission Decision of 2007-07-18^[4] and establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC.^[3]

Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts —

Part 2: Automated measuring systems

1 Scope

EN ISO 16911-2 describes specific requirements for automated measuring system (AMS) flow monitoring. It is partly derived from EN 14181 which is the general document on the quality assurance of AMSs and is applicable in conjunction with that document.

EN ISO 16911-2 specifies conditions and criteria for the choice, mounting, commissioning and calibration of AMSs used for determining the volume flow rate from a source in ducted gaseous streams. EN ISO 16911-2 is applicable by correlation with the manual reference methods described in EN ISO 16911-1.

EN ISO 16911-2 is primarily developed for monitoring emissions from waste incinerators and large combustion plants. From a technical point of view, it can be applied to other processes for which flow rate measurement is required with a defined and minimized uncertainty.

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 14956, *Air quality — Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty*

EN ISO 16911-1:2013, *Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts — Part 1 Manual reference method*

EN 14181:2004, *Stationary source emissions — Quality assurance of automated measuring systems*

EN 15267-3:2007, *Air quality — Certification of automated measuring systems — Part 3: Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources*

EN 15259, *Air quality — Measurement of stationary source emissions — Requirements for measurement sections and sites and for the measurement objective, plan and report*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 14181 and the following apply.

3.1

automated measuring system

AMS

measuring system permanently installed on site for continuous monitoring of flow

Note 1 to entry: An AMS is a monitoring technology which is traceable to a reference method.

Note 2 to entry: The AMS is a complete system for measuring flow rate, and includes the features required for conducting regular functional checks.

3.2 cross-sensitivity

response of the AMS to determinants other than flow rate, e.g. caused by the presence of particulate matter, changes in gas composition, duct temperature

3.3 linearity lack of fit

systematic deviation, within the range of application, between the accepted value of a flow reference material applied to the measuring system and the corresponding measurement result produced by the AMS

Note 1 to entry: The linearity test is described in EN 15267-3:2007, [Annex B](#).

3.4 limit of detection

minimum value of the measurand for which the measuring system is not in the basic state, with a stated probability

Note 1 to entry: Basic state is normally the zero reading or the minimum measured by the instrument.

3.5 period of unattended operation maintenance interval

maximum interval of time for which the performance characteristics remain within a predefined range without external servicing, e.g. calibration or adjustment

3.6 reproducibility under field conditions

measure of the agreement between two measurements in field tests at a level of confidence of 95 % expressed as the standard deviation of the difference of paired measurements:

$$s_D = \sqrt{\frac{\sum_{i=1}^n (x_{1i} - x_{2i})^2}{2n}} \quad (1)$$

where

x_{1i} is the i th measurement result of AMS 1;

x_{2i} is the i th measurement result of AMS 2;

n is the number of parallel measurements.

Note 1 to entry: The absolute reproducibility in the field, $R_{f,abs}$, is calculated according to:

$$R_{f,abs} = t_{0,05(N-1)} \times s_D \quad (2)$$

where

$t_{0,05(N-1)}$ is the two-sided Student t -factor at a confidence level of 0,05, with $N - 1$ degrees of freedom.

Note 2 to entry: Adapted from EN 15267-3:2007.

3.7 **standard reference method** **SRM**

method described and standardized to define an air quality characteristic, temporarily installed on site for verification purposes

Note 1 to entry: For the purposes of EN ISO 16911-2, the manual reference methods are described in EN ISO 16911-1.

3.8 **flow reference material** surrogate for flow for testing the AMS performance

Note 1 to entry: A surrogate for flow is normally the parameter measured directly by the instrument, e.g. pressure, time delay, temperature, heat dissipation or frequency.

3.9 **lower reference point** output of the instrument in response to an internally generated function, intended to represent a defined amount of the measured flow at or close to the lowest flow rate that the system can measure with a given uncertainty

3.10 **upper reference point** output of the instrument in response to an internally generated function, intended to represent a defined amount of the measured flow at or close to the highest flow rate the system is intended to measure in a given installation

3.11 **flow profile** represented by two diagrams showing the gas velocity in the axial direction along a line across the duct passing through the centre of gravity of the duct, and a line perpendicular to the first

Note 1 to entry: The gas velocity is expressed in m/s.

3.12 **crest factor** **peak-to-average ratio** characteristic of a flow profile, calculated from the measured peak value of each flow profile divided by the average value of each flow profile in the primary and secondary monitoring paths

Note 1 to entry: If the measurement is made according to EN ISO 16911-1 and EN 15259, each measurement represents the same area of flow in the duct, and the crest factor divisor can be calculated from a simple average of the individual measurements.

Note 2 to entry: Crest factor shall be calculated for both flow profiles, the primary and secondary monitoring paths, which are perpendicular to each other.

3.13 **skewness** measure of asymmetry defined as the total flow to the left of the centre of the duct divided by the total flow to the right of the centre of the duct, or the inverse thereof, whichever is larger than 1,00

Note 1 to entry: If the measurement is made according to EN ISO 16911-1 and EN 15259, each measurement represents the same area of flow in the duct, and the skewness can be calculated from a simple average of the individual measurements, not including a possible measurement in the centre of the duct.

Note 2 to entry: Skewness shall be calculated for both flow profiles, perpendicular to each other.

3.14 **swirl** also referred to as cyclonic flow, is the tangential component of the gas velocity vector

3.15

certification range

range over which the flow monitor has been tested

Note 1 to entry: The certification range is normally from zero, if the instrument reads zero, or from the lower reference point, if the instrument does not read zero.

Note 2 to entry: The flow monitor is tested according to EN 15267-3 and EN ISO 16911-2.

3.16

primary monitoring path

P

line across the duct through the centre and where the maximum velocity is expected to be found

3.17

secondary monitoring path

S

line across the duct through the centre perpendicular to the primary monitoring path

3.18

Reynolds number

Re

$$Re = \rho v_m \frac{d}{\eta_{\text{dyn}}} \quad (3)$$

where

ρ is the gas density, in kg/m³;

v_m is the gas velocity, in m/s;

d is the duct diameter, in m;

η_{dyn} is the dynamic viscosity, in Pa s

4 Symbols and abbreviations

4.1 Symbols

a intercept of the calibration function

b slope of the calibration function

D_i difference between measured SRM value y_i and calibrated AMS value $\hat{y}_i$

D_{AVG} average of D_i

D amount by which the AMS has to be adjusted when drift is detected

d duct diameter

$k_v, k_v(N)$ test value for variability (based on a χ^2 -test, with a β -value of 50 %, for N numbers of paired measurements)

n number of paired samples in parallel measurements

q_v volume flow rate

R^2	coefficient of determination from a linear regression
Re	Reynolds number
$R_{f,abs}$	absolute reproducibility in the field
s_D	standard deviation of the differences D_i in parallel measurements
$t_{0,95(N-1)}$	two-sided Student t -factor at a confidence level of 95 % with $N - 1$ degrees of freedom
$t_{0,05(N-1)}$	two-sided Student t -factor at a confidence level of 5 %, with $N - 1$ degrees of freedom
v_{AVG}	weighted average of velocity across a monitoring path
$v_{L,AVG}$	weighted average of velocity to the left of the centreline
$v_{L,12\%}$	velocity measured at a point 12 % of the diameter from the duct wall to the left of the centreline, $L_{12\%}$
v_{PEAK}	peak velocity value on the monitoring path
v_m	gas velocity, in m/s
$v_{R,AVG}$	weighted average of velocity to the right of the centreline
$v_{R,12\%}$	velocity measured at a point 12 % of the diameter from the duct wall to the right of the centreline, $R_{12\%}$
x	measured signal obtained with the AMS at AMS measuring conditions
x_i	i th measured signal obtained with the AMS at AMS measuring conditions
x_{AVG}	average of AMS measured signals x_i
x_{1i}	i th measurement result of AMS 1
x_{2i}	i th measurement result of AMS 2
y	result obtained with the SRM
y_{AVG}	average of the SRM results y_i
y_{cal}	best estimate for the “true value”, calculated from the AMS measured signal x by means of the calibration function
η_{dyn}	dynamic viscosity, in Pa s
ρ	gas density, in kg/m ³
σ_0	uncertainty derived from requirements of legislation

4.2 Abbreviations

AMS	automated measuring system
AST	annual surveillance test according to EN 14181
CFD	computational fluid dynamics
ELV	emission limit value

SRM	standard reference method
QA	quality assurance
QAL1	quality assurance level 1 according to EN 14181
QAL2	quality assurance level 2 according to EN 14181
QAL3	quality assurance level 3 according to EN 14181

5 Principle

5.1 General

To achieve the uncertainty required by the relevant EU Directives^{[1]-[3][5]} and the EU Commission Decision,^[4] the focus of EN ISO 16911-2 is the systematic error.

EN ISO 16911-2 allows three different ways of achieving high accuracy:

- assuring correct installation by means of a pre-investigation, see [7.2](#);
- establishing that a fully developed flow profile is present, see [7.3](#);
- assuring correct measurement by a quality assurance level 2 (QAL2), see [7.4](#).

Noting that, if a pre-investigation has been performed, the subsequent QAL2 and annual surveillance test (AST) may be reduced in scope, see 9.1 b).

EN ISO 16911-2 also introduces some extra requirements to type testing according to EN 15267-3, see [Clause 6](#).

5.2 Importance of minimizing systematic errors

The uncertainties required in Commission Decision of 2007-07-18,^[4] 2.1.3, are dependent on the “tier” of the plant and shall be:

- 10 % for tier 1;
- 7,5 % for tier 2;
- 5 % for tier 3;
- 2,5 % for tier 4.

These uncertainties include the uncertainty for both concentration monitoring and volume flow rate monitoring, and are uncertainties for the yearly mass emission.

The uncertainty of any measurement is combined from the uncertainties originating from random errors and systematic errors.

Since the random error component can be reduced by repeated measurements, and the factor it is reduced by, according to the general theory of propagation of errors, is the square root of the numbers of measurements, the random error component of the yearly average is negligible. For example, the yearly average is combined of (ideally) up to 17 520 half-hourly averages, in which case the uncertainty originating from the random error component carried from the individual half-hourly average is reduced by a factor of around 132.

However, the systematic error is not reduced by repeated measurements.

In flow monitoring, systematic errors originate from a series of sources, e.g. changing flow profiles under plant operating conditions not covered by the calibration function or changes in the monitoring system, caused by contamination, blocking of holes, drift in electronics, and general wear and tear.

EN ISO 16911-2 therefore focuses on reducing the systematic error of each individual measurement.

Specifically, a pre-investigation test is recommended in order to assess whether the flow profile changes under different plant operating conditions and this test is used for the selection and configuration of the AMS.

5.3 Relationship to EN 14181

EN ISO 16911-2 is applicable in conjunction with the general document, EN 14181, on quality assurance (QA) of AMSs and provides indications which are specific to flow measurements.

EN ISO 16911-2 follows, as far as possible, the structure of EN 14181, with the caveat that the emission limit value (ELV) and the uncertainty limit specified as a 95 % confidence interval for flow monitoring are not stated in any EU Directive. Since these data are required by the procedure prescribed in EN 14181, suggestions for surrogate values are given in EN ISO 16911-2.

If a pre-investigation has been performed, the number of paired measurement points required for a calibration is reduced.

An alternative calibration method has been added (method D) using linear regression and forcing the regression line through the zero point.

6 Type testing, quality assurance level 1 data

6.1 Introduction

6.1.1 General

According to EN 14181 and EN 15267,^[6] the flow monitoring system shall consist of all necessary parts to keep the flow monitor operating within a specified uncertainty. These components shall include, but are not limited to, necessary air-purging systems and auxiliary equipment to control continued operation within the stipulated uncertainty.

Either [6.1.2](#) or [6.1.3](#) applies as appropriate.

6.1.2 Requirements within the European Economic Area

The relevant performance characteristics of the AMS shall be documented by the manufacturer and/or his European representative by suitability tests performed according to the relevant European Standards.

6.1.3 Requirements outside the European Economic Area

The relevant performance characteristics of the AMS shall be documented by the manufacturer by suitability tests performed according to the relevant standards.

6.1.4 Conclusion

These tests are usually carried out in the framework of certification or type approval procedures according to EN 15267,^[6] and the AMS delivered to the plant shall have the same characteristics as the tested devices. The tests comprise of a separate laboratory test and a 3 month field test in a typical application.

The test report shall include the total AMS uncertainty calculated according to EN 14181 and ISO 14956.

6.2 Performance criteria

The requirements for the test results are developed from EN 15267-3 and stated in [Table 1](#) and [Table 2](#).

EN 15267-3 requires the manufacturer to describe, and the test laboratory to assess, the quality assurance level 3 (QAL3) functionality.

EN ISO 16911-2 also requires the manufacturer to describe and the test laboratory to assess the capability of the AMS to be linearity tested as a part of the functional test. If another test, other than the linearity test, is assessed and certified by a test laboratory, that test is sufficient as part of the functional test.

The manufacturer shall declare and quantify any influencing parameters known to affect instrument uncertainty, e.g. gas temperature, change in specific mass and/or specific heat capacity, gas composition, gas pressure, as well as any method of compensation.

Interference tests shall be performed and the sensitivity coefficients shall be calculated and reported according to EN 15267-3.

Using test results from the type approval certificate according to EN 15267-3 and ISO 14956, the total uncertainty, systematic and random, of the results obtained for the flow AMS shall be calculated and reported.

6.3 Flow reference material or procedure

Most volume flow rate monitors measure flow indirectly using an associated parameter, e.g. differential pressure, heat loss or transit time, in which case a flow reference material or procedure is used to test these parameters.

The part of the monitor not tested by the reference material or procedure shall be tested by a procedure described by the manufacturer and assessed and documented during the type approval.

The test laboratory shall assess whether the flow reference procedure provided for testing the AMS functionality challenges all or as much of the AMS as possible with a repeatable reference value and a specified uncertainty, see [Table 1](#) and [2](#).

Table 1 — Automated measuring system performance criteria in laboratory tests

Performance characteristic	Performance criteria
Response time	≤60 s
Repeatability standard deviation at lower reference point	≤2,0 % ^a
Repeatability standard deviation at upper reference point	≤2,0 % ^a
Lack of fit	≤3,0 % ^a
Lower reference point shift due to ambient temperature change from 20 °C within specified range	≤5,0 % ^a
Upper reference point shift due to ambient temperature change from 20 °C within specified range	≤5,0 % ^a
Influence of voltage at +15 % and at -10 % from nominal supply voltage	≤2,0 % ^a
Influence of vibration	≤2,0 % ^a
Assessment of QAL3 check capability	Pass ^b
Assessment of linearity check capability	Pass ^b
^a Percentage value as percentage of the upper limit of the certification range.	
^b The test house shall assess the possibility for the test procedure as described in 6.2 .	

Table 2 — Automated measuring system performance criteria in field tests

Performance characteristic	Performance criteria
Coefficient of determination of calibration function, R^2	$\geq 0,90$
Response time	≤ 60 s
Period of unattended operation (maintenance interval)	≥ 8 days
Lower reference point drift within maintenance interval	≤ 2 % ^a
Upper reference point drift within maintenance interval	≤ 4 % ^a
Availability	≥ 95 %
Reproducibility, R_f	$\leq 3,3$ %
^a Percentage value as percentage of the upper limit of the certification range.	

6.4 Quality assurance level 1 calculation

6.4.1 General

Either [6.4.2](#) or [6.4.3](#) applies as appropriate.

6.4.2 Requirements within the European Economic Area

The AMS shall be approved and certified according to EN 15267-3 and the additional requirements in EN ISO 16911-2.

6.4.3 Requirements outside the European Economic Area

The AMS shall meet the requirements specified in EN 15267-3 and the additional requirements in EN ISO 16911-2.

6.4.4 Conclusion

The instrument configuration shall be audited by the test laboratory during type testing, and this auditing shall include the geometrical configuration, including measurement of the duct cross-sectional area and any reference quantity with an influence on the flow monitoring result, e.g. changes in flow profile, changes in temperature, changes in pressure, changes in gas composition, and contamination.

All of these influences shall be estimated within a combined expanded uncertainty, calculated as described in ISO 14956.

The test laboratory shall assess the influence of the change in flow profile on the flow monitor reading.

NOTE This facilitates the end user to estimate the expected flow profile influence, when the result of the pre-investigation is known.

6.5 Velocity check points and quality assurance level 3

EN 15267-3 requires the manufacturer to provide a description of the methodology used by the AMS to determine whether it is operating according to its product specification. This is made up of AMS checks (automatic or manual internal zero point or lower reference point and upper reference point), combined with an additional procedure, if the instrument checks do not challenge the whole measurement chain.

The test laboratory shall assess whether the mechanism for determining the internal reference points, being at zero or defined lower reference velocity and upper reference velocity points, is as comprehensive as is practical for the measurement technique used. The internal control combined with a procedure shall be capable of detecting instrument malfunction, including problems caused by contamination and internal drift.

The manufacturer shall provide details of this procedure in the instruction manual describing how to ensure the correct operation of the parts of the measurement not tested by the internal reference point checks.

The QAL3 test shall be made up of the reference point checks and, if required, the results of the inspection procedure.

7 Selection of automated measuring system location

7.1 General

The axial position of the AMS on the duct (normally vertical) as well as its circumferential position on the duct perimeter may have a significant influence on the AMS performance.

It is strongly recommended that a pre-investigation be performed as described in [Clause 8](#) in order to characterize the flow so that the AMS can be located in a position where changes in the flow profile do not adversely affect AMS performance.

NOTE To reduce costs, the pre-investigation can be done together with the investigation of the homogeneity test required by EN 15259.

The pre-investigation also enables the operator to determine whether a point AMS, probe AMS or cross-duct AMS measurement satisfies the uncertainty requirements of EN ISO 16911-2, see [Table 2](#).

NOTE The EU Directive 2010/75/EU^[5] states in Article 38, Section 3, and in Article 48, Section 3, that “The competent authority shall determine the location of the sampling or measurement points to be used for the monitoring of emissions”.

This section is intended to be a guideline for operators to enable them to make a good engineering decision.

If more than one AMS is being used, the AMSs shall be mounted so that they do not interfere with one another.

7.2 Selection based upon pre-investigation

A pre-investigation shall be performed according to [Clause 8](#).

The location shall be chosen to give a representative measurement that also minimizes influence of changes in the flow profile on the flow measurement uncertainty.

The proposed location and monitoring path(s) shall be determined based upon the recorded change in flow profile, quantified using the crest factor and skewness of the flow profile as described in [Annex F](#).

The installer shall select the AMS measurement location in accordance with the instructions given by the manufacturer or in consultation with the manufacturer's representative. The operator is advised to liaise with the competent authority to ensure this location meets with their approval.

7.3 Selection based upon a predictable flow profile

The position of an AMS may be decided without a pre-investigation if it can be positioned in a place where the flow profile is fully developed and cannot change, and if it is accepted by the competent authority.

This is normally achieved if all of the following criteria are fulfilled:

- the monitoring point is at least 25 times the hydraulic diameter, away from any upstream disturbance, and at least five times the hydraulic diameter from any downstream disturbance;
- the flow has a Reynolds number larger than 10 000;
- the duct has no movable dampers or guide vanes;
- the duct does not have multiple feeds;

— the duct does not have off centre feeds.

If the above conditions are all met, any AMS should be suitable, including measurement at a single point.

NOTE For a fully developed turbulent flow, in a duct with a circular cross-section, the average flow is expected to be identical to the flow at a point 12 % of the diameter from the wall.

In this case the QAL2 procedure may be performed according to [Clause 9](#) with a reduced number of data points.

If this installation does not pass the QAL2 procedure, as specified in [Clause 9](#), even though the above conditions are fulfilled, the procedure described in [7.4](#) shall be used, or a pre-investigation shall be carried out as described in [Clause 8](#).

7.4 Qualifying the automated measuring system calibration through a type 2 quality assurance level 2 procedure

An operator may opt not to perform a pre-investigation, e.g. where there is pre-existing equipment installed, provided that a type 2 QAL2 procedure is performed and passed.

The installation can be approved according to EN ISO 16911-2 without having made a pre-investigation, if the QAL2 calibration is performed with measurement points spread from the highest flow rate the plant is designed to operate at continuously, down to the lowest flow rate the plant is designed to operate at continuously (at least the flow rate so low, that is occurring lower no more than 10 % of the plant's normal operation time or the point of minimum stable load), and the calibration passes the criteria described in [Clause 9](#).

NOTE This subclause does not remove the requirement of the operator to perform the duct investigation tests as described in EN 15259.

7.5 Ports and working platforms

The measurement ports and platforms for the parallel measurements shall be located to ensure that there is no measurable interference between the SRM and the AMS.

Working platform(s) shall provide an easy and safe access to the AMS, to allow inspection and the implementation of QA procedures (QAL2, AST and QAL3).

The working platform for the SRM shall comply with EN 15259 requirements related to the manual method.

8 Pre-investigation of flow profile

8.1 General

The stability of the flow profiles, as the plant operating conditions change, is a major concern with regards to flow monitor calibration. If the flow profile changes as the plant load condition changes, or as dampers are operated, or as different duct inlets are brought into operation, this shall be taken into account when deciding on the type of flow AMS to install, and when performing the calibration.

In order to minimize any systematic error associated with a non-representative measurement, it is recommended that the plant operator measure or calculate any change in the cross-duct flow profile at the AMS location as the plant operating conditions are changed. Therefore, either a CFD calculation or pre-investigation by measurement of the change in flow profile under different flow conditions at the AMS location shall be undertaken enabling the plant operator to make an informed engineering decision on whether a single point AMS, an AMS with a limited path length, cross-duct single path AMS or cross-duct

double path AMS measurement principle is sufficient for minimizing systematic error under the likely conditions of the plant at the intended location, i.e. at different plant operating conditions and flow levels.

NOTE 1 The predominant source of systematic error is the change in the flow profile. The major sources of changes in flow profile are changes to the disturbances in the duct, or large changes in flow rate. At high gas velocities, the flow profile is expected to be fully developed, and not to change profile even at higher gas velocities, see [Annex B](#) for details of flow profile characterization. At lower gas velocities, the flow profile might develop asymmetry and/or a higher crest factor, and consequently the relation between a point or line measurement and the volume flow rate changes, which is identical to a change in calibration function.

The pre-investigation shall establish the main characteristics of the flow profile at the planned AMS installation position and establish if changes in profile are likely to occur and the severity of their influence on the calibration function.

The pre-investigation shall always be undertaken as a part of the design phase before an AMS flow monitor is acquired and mounted.

NOTE 2 Part of the pre-investigation process is identical to the EN 15259 investigation, and can be combined with that to minimize costs.

A pre-investigation may be omitted as described in [7.2](#), in which case a type 2 calibration procedure as described in [Clause 9](#) shall be used for any subsequent QAL2 and AST calibration.

A type 1 QAL2 and AST calibration procedure as described in [Clause 9](#) may only be used if a pre-investigation according to [Clause 8](#) has been performed.

NOTE 3 The choice of not performing a pre-investigation according to [Clause 8](#) does not in any way influence the obligation to test the duct condition according to EN 15259.

8.2 Pre-investigation by measurement

8.2.1 General

The pre-investigation shall consist of at least two measurements performed according to EN ISO 16911-1, each establishing the flow profile in the primary monitoring axis, and an axis perpendicular to this.

The two measurements shall be performed at two different plant operating conditions:

- a) one where the flow profile is expected to be the most uniform, i.e. close to the highest possible flow rate and with the least possible obstruction to the flow path;
- b) one where the flow rate is so low, that it is not occurring lower more than 10 % of the plant's normal operation time or the point of minimum stable operation, combined with the maximum obstruction to the flow path, e.g. closure of dampers or regulation of the fan blowers.

NOTE 1 Least possible obstruction means that the effects of any non-permanent obstructions are minimized or removed.

If a plant has not yet been commissioned, the lowest flow level shall be estimated from plant design data.

NOTE 2 If an AMS is installed in a multi-inlet duct, it may be necessary to calibrate the AMS at different production configurations since changes to the relative contributions of the individual inlets can produce different calibration functions.

From the two measurements at high and low flow rates, the reproducibility of the normalized flow calculated for each of the measuring planes shall be calculated, and crest factor and skewness shall be calculated for each of the four profiles.

From these data the AMS selection is evaluated as described in [8.4](#).

At complicated installations, or those with the potential for the flow profiles to change with the operating conditions (e.g. flow splitting immediately upstream of the duct), further investigations may be required to fully describe the flow profile complexity.

8.2.2 Measuring flow profiles in a duct

The flow profile shall be measured in accordance with EN ISO 16911-1 which specifies that the measurement points are selected in accordance with EN 15259 along the primary and secondary measurement paths. EN 15259 also requires that the velocity is measured simultaneously at a fixed reference point. The flow profile is calculated by correcting the individual measurements with the reference point flow.

8.2.3 Measurement method

The flow profiles shall be measured with an SRM as described in EN ISO 16911-1 and the measurement plan shall be in accordance with EN 15259.

After completion of the two profile measurements along the primary and secondary measurement paths, all of the measurement results shall be corrected to account for changes in the fixed point reference velocity.

This procedure shall be performed at a high flow rate and a low flow rate, as described in [8.2.1](#).

An example is shown in [Annex F](#).

8.3 Pre-investigation by computational fluid dynamics (CFD)

A physical pre-investigation as described in [8.2.1](#) may be replaced by a CFD assessment to establish the flow profiles, which are assessed as described in [Annex G](#), if a physical pre-investigation is not possible or is likely not to yield a sufficient result.

NOTE A CFD pre-investigation is acceptable e.g. if the plant is not yet built, or if the duct configuration is so complicated, that conditions for SRM-measurements cannot be fulfilled.

CFD is an established method for pre-investigation of the flow conditions in a duct or a pipeline.

The CFD requires accurate information about the route and the geometrical dimensions of the ductwork including the upstream section. Furthermore, important basic design parameters have to be considered (e.g. the number and position of the duct inlets, the plant load and the gas velocity range).

Based on this information, the flow is modelled using specialized software. The results of the computer simulation are processed and evaluated using two- or three-dimensional graphics from which the flow profiles can be created.

This can be used:

- to determine the expected flow profile changes as the plant operation conditions are changed;
- to assist the selection of the AMS type (single point AMS, a single probe AMS with limited path length, one path cross-duct AMS, two path cross-duct AMS etc.);
- to determine the optimal position of the AMS.

The accuracy of the CFD depends strongly on the quality and quantity of the input data (geometry and process conditions) and the use of a suitable model for the calculation.

The CFD shall be used to characterize the flow as described in [8.1](#).

The input data and the results of the pre-investigation by CFD shall be retained by the operator for inspection by the competent authority.