INTERNATIONAL STANDARD

ISO 16911-2

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

Part 2:
Automated measuring systems

Émissions de sources fixes — Détermination manuelle et automatique de la vitesse et du débit-volume d'écoulement dans les conduits —

Partie 2: Systèmes de mesure automatiques

Reference number
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Foreword

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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.

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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:

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

where

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

x_{2i} is the ith 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:

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

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/m^3;

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}, $k_{\text{v}}(N)$ 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

$R_{\mathrm{f.abs}}$ 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

$v_{\mathrm{L,\,AVG}}$ weighted average of velocity to the left of the centreline

$v_{\mathrm{L,\,12\,\%}}$ velocity measured at a point 12 % of the diameter from the duct wall to the left of the centreline, $\mathrm{L}_{12\,\%}$

v_{PEAK} peak velocity value on the monitoring path

v_m gas velocity, in m/s

$v_{\mathrm{R,\,AVG}}$ weighted average of velocity to the right of the centreline

$v_{\mathrm{R,\,12\,\%}}$ velocity measured at a point 12 % of the diameter from the duct wall to the right of the centreline, $\mathrm{R}_{12\,\%}$

x measured signal obtained with the AMS at AMS measuring conditions

x_i ith measured signal obtained with the AMS at AMS measuring conditions

x_{AVG} average of AMS measured signals x_i

x_{1i} ith measurement result of AMS 1

x_{2i} ith 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	≥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	≤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.