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Measurement of road tunnel air quality

Mesurage de la qualité de l'air du tunnel routier

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Foreword

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This document was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 3, *Ambient atmospheres*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC216, *Gas detectors*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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Introduction

The objective of this document is to provide road tunnel owners and operators with standard methods for checking and calibrating instruments used in road tunnels to continuously monitor air speed, carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO_2) concentrations and visibility.

Data from these instruments enables tunnel operators to manage the ventilation system in real time or to take emergency measures (e.g. closure to traffic).

This document has been developed as a performance-based standard that allows for use of a number of direct-reading instruments. Statements expressed in mandatory terms in notes to tables and figures are deemed to be requirements of this document.

In order to improve traffic flow in central business districts and through sensitive environments, road tunnels are increasingly used throughout the world to achieve the desired outcomes. There are a large number of tunnels in operation, with a number of others in the planning stages.

Road tunnel projects are subject to environmental and/or planning approval conditions by regulatory authorities that specify the parameters to be monitored in-tunnel, typically including air speed, CO, NO, NO_2 and visibility, with NO measured as a surrogate for NO_2, with, historically, 10 % of total nitrogen oxides assumed to be NO_2. However, this assumption is no longer considered appropriate, given the increased proportion of diesel fuelled vehicles in vehicle fleets. It can also be a requirement that the tunnel ventilation system is controlled to:

a) reduce CO and NO_2 concentrations within the tunnel environment to enable conformance with in-tunnel air quality criteria for various averaging periods;

b) prevent or reduce portal emissions and resultant environmental impacts;

c) ensure appropriate visibility for different tunnel operating conditions; and

d) control smoke and improve the self-rescue time and security of tunnel users in emergency situations such as fires.

Conformance with in-tunnel air quality criteria is typically determined by averaging measured CO and measured or estimated NO_2 concentrations from a number of instruments located on possible travel paths throughout the tunnel system.

The number of instruments required to adequately characterise the tunnel environment is dependent on a number of factors, including:

a) tunnel length and number of gradient changes and entry and exit ramps;

b) volume of traffic and types of vehicles;

c) exhaust ventilation system flowrate and control regime; and

d) regulatory requirements.

Consequently, this aspect is not addressed in this document. It is noted, however, that computational fluid dynamics modelling can be used as a design tool to assist in the placement of instruments, ensuring that indicative maximum and average concentrations are measured.

Measurement of road tunnel air quality

1 Scope

This document describes methods for determining air speed and flow direction, CO, NO and NO_2 concentrations and visibility in road tunnels using direct-reading instruments. This document specifically excludes requirements relating to instrument conformance testing.

2 Normative references

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

ISO 5802, *Industrial fans — Performance testing in situ*

ISO 6145, *Gas analysis — Preparation of calibration gas mixtures using dynamic methods*

ISO 10780, *Stationary source emissions — Measurement of velocity and volume flowrate of gas streams in ducts*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Guide 98-3: 2008 Part 3: Guide to the expression of uncertainty in measurement*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
calibration
set of operations that establish, under specified conditions, the relationship between the value indicated by a measuring instrument and the corresponding known value of a reference standard

3.2
certified reference material
reference material, characterized by a metrologically valid procedure for one or more specified properties, accompanied by a reference material certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability

3.3
check
confirmation of acceptable instrument response, without adjustment

3.4
fall time
time interval, after a step decrease in input concentration, between initial instrument response and 10 % of initial instrument response

3.5
full scale
FS
nominated maximum concentration for which an instrument has been calibrated

Note 1 to entry: The full scale (FS) is selected to cover the normal range of values expected in the sampling environment.

3.6
interference equivalent
positive or negative instrument response caused by a substance other than the one being measured

3.7
linearity
deviation of an instrument's output from a linear best fit line when subjected to varying reference test atmospheres

3.8
lower detectable limit
minimum pollutant concentration that produces a signal of exactly three times the repeatability standard deviation

Note 1 to entry: See ISO 5725-1.

3.9
parameter
one of the characteristics related to an air sample

EXAMPLE Concentration of pollutant or other quantifiable property (e.g. air speed).

3.10
ppm
parts per million
ratio expressing the volume of gaseous pollutant contained in 1 000 000 volumes of atmosphere

Note 1 to entry: It may be expressed in terms of millilitres per cubic metre as the values are identical. Alternatively, it is one million times the ratio of the partial pressure of gaseous pollutant to the pressure of the atmosphere in which it is contained.

3.11
precision
variation about the mean of repeated measurements of the same pollutant concentration on the same instrument, expressed as one standard deviation about the mean

3.12
range
nominal minimum and maximum concentrations that a method is capable of measuring

Note 1 to entry: The nominal range is specified by the lower and upper range limits in concentration units, e.g. 0 to 250 ppm.

3.13
reference test atmosphere
test atmosphere containing a known concentration of pollutant, typically generated by diluting the contents of a cylinder containing a gaseous *certified reference material* (3.2)

3.14
rise time
time interval, after a step increase in input concentration, between the instrument initial response and 90 % of the final instrument response

3.15
road tunnel
any fully enclosed length of roadway with a minimum length ranging between 90 m and 150 m

EXAMPLE National Fire Protection Association and UK Design Manual for Roads and Bridges.

3.16
span drift
percentage change in the instrument response to an on-scale pollutant concentration over a period of continuous unadjusted operation

3.17
$\mathbf{U_{95}}$
measurement of expanded uncertainty at a confidence interval of 95 % according to ISO/IEC Guide 98-3

3.18
zero air
air free from contaminants likely to cause a detectable response on the test instrument

3.19
zero drift
change in the instrument response to a zero-pollutant concentration over a period of continuous unadjusted operation

4 Test parameter — Air speed and flow direction

4.1 General

Clause 4 describes continuous, direct-reading instruments for determining air speed and flow direction in road tunnels. Providing the instrument performance is within the specifications given in Table 1, alternate methods may be used within the context of this document.

4.2 Principle

Air speed and flow direction in modern road tunnels are typically measured using ultrasonic flow sensors.

Ultrasonic sensor systems are based on the principle that the speed of air movement changes the transit time of a sound pulse across a fixed distance, allowing calculation of the air speed and determination of flow direction.

Instrument outputs may be used to control mechanical ventilation in a tunnel during both routine and emergency operation.

The measurement of flow in road tunnels is important for emergency operation (e.g. vehicle fire), enabling the control of air flow such that fumes are not dispersed in the tunnel tube. The choice of cross section or single point air flow measurements for this purpose is dependent on local technical practices.

Air flow measurement can also be important for the management of mechanical ventilation, either to dilute pollutants, or to control the atmospheric discharges at the portals.

Ultrasonic sensors are either open path or single point instruments, installed at various locations along the tunnel length, including portals and exit ramps.

Open path ultrasonic flow sensors measure the average value over the tunnel width, with transceiver pairs installed on opposing walls at an angle of 45° to 60° to the tunnel axis. In order to eliminate potential measurement errors caused by variations in ultrasonic sound speed due to temperature and pressure, the transceiver units shall be installed on each side of the tunnel wall, with the transit time measured in both directions.

Single point ultrasonic flow sensors use the same measurement principle as open path sensors, measuring changes in the transit time of a sound pulse across a fixed distance, but in this case the distance evaluated is within the instrument casing.

NOTE 1 Open path ultrasonic flow sensors are typically located high on tunnel walls; consequently, it is possible that the measured air speed is not representative of the average speed for the overall tunnel cross-section. Similarly, single point ultrasonic flow sensors measure air speed close to the tunnel wall (or ceiling) and nearer the pavement, consequently it is possible that the measured air speed is not representative of the average speed for the tunnel cross-section, with the added potential, under normal operating conditions, for increased error due to turbulence created by vehicular traffic.

4.3 Apparatus

4.3.1 Instrument

A continuous direct-reading instrument that meets or exceeds the specifications given in Table 1. The manufacturer's published performance specifications shall be deemed as acceptable evidence of conformance to the given requirements, if accompanied by a statement of measurement uncertainty issued by an organization that meets the requirements of ISO/IEC 17025.

Table 1 — Instrument performance specifications for tunnel air speed systems

Parameter	Minimum requirements
Range	(−20 to 20) m/s
Expanded measurement uncertainty	2 % of reading or 0,2 m/s[a]
Resolution	≤ 0,1 m/s
[a] Whichever is the greater.	

4.3.2 Reference path length measurement device (open path instruments only)

A metrologically traceable reference path length measurement device with an uncertainty of 0,5 % U_{95} is required to make an accurate determination of the path length. The reference path length measurement device shall be checked over a path length of at least the instrument measurement path length.

Organizations performing the tests outlined in this clause shall meet the requirements of ISO/IEC 17025.

4.3.3 Transfer standard flow sensor

A metrologically traceable hand-held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the air speed sensor, with an uncertainty of 2 % U_{95} is required to check the operation of air speed sensors. The transfer standard flow sensor shall be calibrated over a range exceeding the maximum air flow experienced in the tunnel.

Organizations performing the tests outlined in this clause shall meet the requirements of ISO/IEC 17025.

4.4 Procedure

The procedure shall be as follows:

a) For open path ultrasonic flow sensors, ensure that the transceivers are installed such that the path for the sonic pulse is unimpeded by tunnel equipment or other obstructions, including vehicular traffic, whilst allowing ease of access for instrument maintenance and calibration.

b) For open path ultrasonic flow sensors check instrument horizontal and vertical alignment and beam angle, in accordance with the manufacturer's instructions.

c) For open path ultrasonic flow sensors, accurately measure and record the distance between the transceivers using a reference path length measurement device (4.3.2).

d) Set up the instrument and carry out initial checks in accordance with the manufacturer's instructions (e.g. setting the path length, configuring and scaling of analogue outputs, setting of alarm values and level of damping) and the requirements of 4.5.

e) Take measurements in accordance with the manufacturer's instructions and ensure that the values obtained relate to the correct date and time.

4.5 Instrument checks and calibrations

4.5.1 General

Calibration of an instrument establishes the quantitative relationship between the air speed and the instrument's response.

Instrument checks and calibrations shall be carried out in accordance with the frequencies specified by the equipment manufacturer and in accordance with Table 2.

In addition, operational precision checks shall be carried out as follows:

a) Prior to decommissioning or physical relocation of the instrument, if operational.

b) Following physical relocation of the instrument.

c) After any repairs that might affect the instrument's response.

d) Upon any indication of an instrument malfunction or change in response that may cause the instrument to drift by more than the values given in Table 2.

NOTE 1 The air flow and direction monitor can incorporate an automatic daily zero and span check function for daily quality control and assurance purposes.

NOTE 2 Checks and calibrations specified in this section can be omitted if the air flow measuring instrument provides proven equivalent self-test functions (e.g. read back of analogue or digital outputs).

4.5.2 Measurement path length (open path instruments only)

The measurement path length for open path ultrasonic flow sensors is normally defined as the distance between the faces of opposing transceiver units, however, this should be confirmed with the manufacturer. The measurement path length shall be determined upon installation (see Table 2) using a reference distance measurement device as described in 4.3.2.

A check of the measurement path length shall also be conducted whenever an open path instrument is reinstalled following maintenance or repair, if the maintenance or repair could result in a change of measurement path length.

4.5.3 Initial check

Conduct an initial check on the ultrasonic flow sensor prior to road tunnel opening using a collocated transfer standard (CTS) method at a minimum of three air velocities (if technically feasible) evenly spread over the tunnel design operational range.

For open path ultrasonic flow sensors, measurements shall be taken at a minimum of two points per trafficable lane over the measurement path. For a single point ultrasonic flow sensor, the CTS needs to be within 1 m of the subject sensor in the horizontal and 0,5 m in the vertical, but the same distance from the tunnel wall.

The CTS method requires a calibrated hand-held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the ultrasonic flow sensor, located in the vicinity of the measurement path for the sensor being assessed.

For both single point and open path ultrasonic flow sensors it is important to site the CTS to be representative of the air flow at the subject sensor, without interfering with either instrument's response.

The procedure shall be as follows:

a) Ensure that the CTS is oriented such that the reading is obtained in the direction of air flow.

b) Connect the CTS to an independent data logger. Once the air speed has stabilised, record check data for a period of not less than 5 min. Simultaneously record the response from the in-situ sensor over the same period.

c) Average the recorded data over the selected period, and, if applicable, across all CTS measurement points. Calculate the difference between the in-situ sensor and CTS average readings.

d) Check that the difference conforms to the tolerance given in Table 2. If the result is not within the prescribed tolerance, review siting and site-specific issues, conduct repairs and/or instrument calibrations as required and repeat the above procedure until compliance with the specified tolerance is indicated.

4.5.4 Cross-section calibration

A correlation may also be required between the ultrasonic flow sensor output and the total ventilation system flowrate, in order to obtain a factor or algorithm for use in the tunnel ventilation control system.

If required, the cross-section calibration shall be performed following instrument commissioning and after the initial check (4.5.3) has been conducted.

The total ventilation system flowrate may be determined by measuring air speeds across the tunnel cross-section, at approximately the same tunnel longitudinal position as the ultrasonic flow sensor, using a calibrated hand-held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the ultrasonic flow sensor.

In this instance, the number and location of measurement points across the tunnel cross-section will be dependent on the hydraulic diameter and shape of the tunnel cross-section. Methods typically used are the tracer gas method, the equal area method described in ISO 10780 and the Log-Tchebycheff method described in ANSI/ASHRAE Standard 41.2 and ISO 5802. The average measured speed is multiplied by the cross-sectional area in order to calculate the total ventilation system flowrate.

Measurement of the total ventilation system flowrate does not preclude the need to check the actual instrument response in accordance with the procedure described above. It should also be recognised that the correlation determined between total ventilation system flowrate and ultrasonic flow sensor output in an empty tunnel may not reflect what occurs in an operational tunnel.

4.5.5 Zero check

If a zero-air flow environment can be attained, the zero response of the ultrasonic flow sensor shall be checked on a yearly basis, in accordance with the manufacturer's instructions.

For single point sensors this can be readily achieved by enclosing the sensor in a box which isolates it from any draughts.

Check that the zero response is within the tolerance given in Table 2. If the result is not within the tolerance, conduct repairs and/or instrument calibrations as required and repeat the procedure until the zero response is within the tolerance.

4.5.6 System component check

Cables, recorders, signal conditioning and data processing devices can corrupt the sensor's output.

