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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 2: Measurement of gaseous and particulate exhaust emissions under field conditions

Moteurs alternatifs à combustion interne — Mesurage des émissions de gaz d'échappement —

Partie 2: Mesurage des émissions de gaz et de particules sur site

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

This third edition cancels and replaces the second edition (ISO 8178-2:2008), which has been technically revised.

The main changes are as follows:

— Clause 4 has been amended to update requirements applicable for discrete-mode steady-state tests in the field when it is intended to either conduct measurements at a single operating point or conduct a weighted cycle-based test, reflecting changes in other parts of the ISO 8178 series;

— Clause 5 has been expanded to set out requirements for measurement of gaseous emissions performance of engines during typical in-service operation under field conditions using portable emission measurement systems (PEMS) and moving average window data evaluation.

A list of all parts in the ISO 8178 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Evaluating emissions from non-road engines is more complicated than the same task for on-road engines due to the diversity of non-road applications. For example, on-road applications primarily consist of moving a load from one point to another on a paved roadway. The constraints of the paved roadways, maximum acceptable pavement loads and maximum allowable grades of fuel, narrow the scope of on-road vehicle and engine sizes.

Non-road engines and vehicles include a wider range of size, including size of the engines that power the equipment. Many of the engines are large enough to preclude the application of test equipment and methods that were acceptable for on-road purposes. In cases where a laboratory test using a dynamometer is not possible, testing at site or under appropriate conditions can be a viable alternative.

Where it is not possible to use a test bed or where information is required on the actual emissions produced by an in-service engine, the site test procedures and calculation methods specified in this document are appropriate. It should be recognized that data obtained under these circumstances may not agree completely with previous or future data, obtained in a laboratory or in the field, due to the variability and uncontrolled nature of testing in the field.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 2: Measurement of gaseous and particulate exhaust emissions under field conditions

1 Scope

This document specifies the measurement and evaluation methods for gaseous and particulate exhaust emissions from reciprocating internal combustion engines (RIC engines) in the field.

This document is applicable when the emissions from RIC engines used in non-road machinery, industrial equipment, marine installations, generating sets, diesel rail traction or similar machinery applications need to be measured in the field. Clause 4 applies for the conduct of discrete-mode steady-state gaseous or particulate emission measurements at a single operating point or conduct a weighted cycle-based test in the field. Clause 5 applies where it is necessary to assess gaseous emissions performance of engines during typical in-service operation under field conditions using portable emission measurement systems (PEMS).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 8178-1:2020, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement systems of gaseous and particulate emissions*

ISO 8178-4:2020, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Steady-state and transient test cycles for different engine applications*

ISO 8178-5, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels*

ISO 8178-6, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 6: Report of measuring results and test*

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

ISO 27145-4, *Road vehicles — Implementation of World-Wide Harmonized On-Board Diagnostics (WWH-OBD) communication requirements — Part 4: Connection between vehicle and test equipment*

ISO 15765-4, *Road vehicles — Diagnostic communication over Controller Area Network (DoCAN) — Part 4: Requirements for emissions-related systems*

ISO 13400, *Road vehicles — Diagnostic communication over Internet Protocol (DoIP)*

ISO 15031-3, *Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 3: Diagnostic connector and related electrical circuits: Specification and use*

SAE J1939-73, *Application layer – diagnostics*

ASTM E 29-06b, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8178-1, ISO 8178-4 and the following apply.

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

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

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

3.1.1
event
data measured in an in-service test for the gaseous pollutant emissions calculations obtained in a time increment Δt equal to the data sampling period

3.1.2
field conditions
conditions under which the engine under test is installed in, and coupled with, the actual equipment or vehicle, which is driven by the engine, and conditions under which the equipment or vehicle is allowed to function in normal use

3.1.3
moving average window
period, measured in cumulative amount of work or CO_2, over which each integration of gaseous pollutant emissions is performed

3.1.4
operating sequence
elapsed time of uninterrupted machinery operation and continuous data sampling during an in-service test

3.1.5
portable emission measurement system
PEMS
emission measurement system that is transportable and suitable for conducting in-service measurements

3.1.6
proxy power
value obtained by simple linear interpolation based on certain assumptions for the sole purpose of identifying non-working events when there is no torque signal from an Electronic Control Unit (ECU)

3.1.7
reference mass of CO_2
amount of cumulative CO_2 measured during a prior bench-test of the engine type or, where applicable, engine family, which is used to determine the size of the moving average CO_2 window

3.1.8
reference work
amount of cumulative work measured during a prior bench-test of the engine type or, where applicable, engine family, which is used to determine the size of the moving average work window

3.2 Symbols

3.2.1 General symbols

Symbol	Term	Unit
D_{max}	Maximum averaging window duration	s
e_{gas}	Brake specific gaseous pollutant emissions	g/kWh
f_a	Laboratory atmospheric factor	—
f_{CF}	Conformity factor	—
f_{CFC}	Certification ratio	—
f_{CFI}	In-service ratio	—
f_{WF}	Weighting factor	—
K_{veline}	Simplified engine-family-specific CO_2 constant	—
L	Limit value	g/kWh
m	Mass emission of gaseous pollutant	g
m_{CO2}	Mass of CO_2 for the test cycle	g
m_{CO2ref}	Reference mass of CO_2	g
N_{mode}	Number of mode in test cycle	—
p_b	Total barometric pressure	kPa
p_S	Dry atmospheric pressure	kPa
P	Uncorrected brake power	kW
P_{aux}	Declared total power absorbed by auxiliaries fitted for the test and not required by Annex B of ISO 8178-4:2020	kW
P_{max}	Maximum measured or declared power	kW
$P_{proxy,i}$	Instantaneous proxy power (see Annex F)	kW
P_m	Measured power	kW
q_{mCO2}	Mean CO_2 mass flow rate	g/h
r_{NOx}	NO_x response factor of zirconium dioxide analyser	—
r_{NO2}	NO_2 response factor of zirconium dioxide analyser	—
$r_{NO2,max}$	Maximum NO_2/NO_x concentration ratio	—
t	Time	s
t_{ref}	Reference time	s
T	Temperature	°C
T_a	Absolute temperature	K
W	Work	kWh
W_{act}	Actual work	kWh
W_{ref}	Reference work	kWh

3.2.2 Symbols for measured chemical components

Symbol	Component
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbons
NH_3	Ammonia
NMHC	Non-methane hydrocarbons
NO_2	Nitrogen Dioxide

Symbol	Component
NO_x	Oxides of nitrogen
PM	Particulate matter
PN	Particulate number
THC	Total hydrocarbons

3.3 Abbreviated terms

ECU	Electronic Control Unit
EFM	Exhaust Flow Meter
LSI-NRTC	Large Spark-Ignition Non-Road Transient Cycle
NRMM	Non-Road Mobile Machinery
NRSC	Non-Road Steady-State Cycle
NRTC	Non-Road Transient Cycle
RMC NRSC	Ramped Modal Non-Road Steady-State Cycle
ZRDO	Zirconium dioxide (analyser)

4 Discrete-mode steady-state tests in the field when it is intended to either conduct measurements at a single operating point or conduct a weighted cycle-based test

4.1 General

Testing conducted according to Clause 4 shall in general follow the requirements set out in ISO 8178-1:2020 and ISO 8178-4 for discrete-mode steady-state testing. Deviations from the requirements of those parts are limited to those set-out in Clause 4. This clause shall not be used for transient testing.

4.2 Test conditions

4.2.1 General requirements

Field measurements according to Clause 4 shall be conducted only when test-bed measurement is not appropriate because the required measurement cannot be performed on the test-bed.

NOTE When testing under field conditions the test cycles specified in ISO 8178-4:2020 might not be fully reproduceable, there might be differences in engine operating parameters from laboratory conditions and there might be differences in the accuracy of emission measurement equipment. Consequently, it is not expected that the emission results obtained when testing according to Clause 5 will be directly comparable to the values obtained on the test bed.

4.2.2 Engine test conditions

4.2.2.1 Ambient conditions

The temperature of the engine intake air, expressed in °C and the dry atmospheric pressure, p_s, expressed in kilopascal (kPa), shall be measured and recorded, and the parameter, f_a, shall be determined according to ISO 8178-4:2020, 5.1.1 and recorded. The calculation of f_a requires the absolute temperature, T_a, of the intake air to be expressed in Kelvin (K).

With the agreement of the parties concerned, taking into consideration the purpose for which the test is being conducted, the range of f_a and intake air temperature may be outside of the range given in ISO 8178-4:2020, 5.1.2.

NOTE f_a is calculated using intake air temperature, not ambient air temperature.

The humidity of the engine intake air shall be measured and the absolute humidity determined.

4.2.2.2 Engines with charge air cooling

The temperature of the cooling medium and the temperature of the charge air shall be recorded.

4.2.2.3 Engine parameters

The engine parameters necessary to complete the emission calculations and ensure the validity of the test in accordance with this document shall be determined from measured values and recorded in appropriate units.

Where it is not practicable to measure a parameter using instrumentation in conformance with the requirements of ISO 8178-1, alternative methods of measurement may be utilized with the agreement of the parties concerned. This may include using signals from an engine control unit or the machinery in which the engine is installed.

Other parameters may be measured and recorded according to the agreement of the parties concerned.

4.2.3 Power

Terms of power are defined in ISO 14396, as applied in ISO 8178-4:2020. The basis of specific emission measurement, expressed in g/kWh, is uncorrected brake power. Power, engine speed and torque values may differ at field compared to the test-bed conditions. Therefore, the emission values expressed in g/kWh differ at field compared to those under test-bed conditions. If the 100 % load of the test-bed measurement cannot be reached, the maximum power output to be measured is limited by maximum allowed engine speed and maximum allowed torque.

In cases where a direct measurement of torque is not possible, the power output shall be calculated based on other available data including signals from the engine ECU or fuel rack position. The method of calculation and estimation shall be agreed between parties involved.

Subclause 5.2 of ISO 8178-4:2020 shall be used to account for auxiliaries, to the extent possible, taking into consideration that it might not be practical to remove auxiliaries from an installed engine, nor disconnect the engine from the driven machinery. Where there is a risk that the auxiliaries that would normally be removed for testing according to ISO 8178-4 might absorb more than 5 % of the maximum observed power, agreement between the parties concerned shall be sought prior to the test.

4.2.4 Engine air intake system

The engine shall be equipped with an air intake system presenting an air inlet restriction within the limit specified by the manufacturer.

4.2.5 Charge air cooler

Where applicable, the engine shall be equipped with a charge air cooling system with sufficient capacity to maintain the engine at the normal operating temperatures prescribed by the manufacturer.

4.2.6 Engine exhaust system

The engine shall be equipped with an exhaust system presenting an exhaust back pressure within the limit specified by the manufacturer.

4.2.7 Engines with exhaust after-treatment systems

4.2.7.1 Use of reagent

In the case of an engine equipped with an exhaust after-treatment system that requires the consumption of a reagent, the reagent used for all tests shall be within the specification prescribed by the manufacturer, be recorded and presented with the results of the tests.

4.2.7.2 Regeneration

In the case of an engine equipped with an exhaust after-treatment system that regenerates on an infrequent (periodic) basis, as described in ISO 8178-4:2020, 5.5.1.2.2, emission results shall be adjusted to account for regeneration events. In this case, the average emission depends on the frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs, and the extent to which the emissions increase during regeneration. The method for determination of emissions during regeneration and the corresponding adjustment shall be agreed by the parties concerned.

4.2.8 Crankcase emissions

Where the parties involved require crankcase emissions that are normally discharged to ambient atmosphere to be included, the emissions shall be added to the exhaust emissions during all emission testing either physically or mathematically. Methods to achieve this are set out in ISO 8178-4:2020, 5.5.2.

4.2.9 Cooling system

The engine shall be equipped with a cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer.

4.2.10 Lubricating oil

Specifications of the lubricating oil used for the test shall conform with the requirements of the manufacturer, be recorded and presented with the results of the test.

4.2.11 Test fuels

Fuel characteristics influence the engine exhaust gas emission. Therefore, in all cases, the characteristics of the fuel used for the test shall be verified as required, recorded and declared with the results of the test. The characteristics to be recorded shall be those listed in the appropriate universal data sheet in ISO 8178-5. A certificate of analysis of the fuel that includes these characteristics shall satisfy this requirement.

Unless otherwise agreed, the test fuel shall be either the appropriate reference fuel given in ISO 8178-5 or the typical fuel for the engine in its field application.

The fuel temperature shall be in accordance with the manufacturer's recommendations.

4.3 Installation of sampling probes and equipment

Provisions that shall be taken for the proper installation of the sampling probes and measuring equipment are described in ISO 8178-1:2020, 5.2 and 8.1.1. Modifications to suit field installation conditions are permitted under the following conditions:

a) The space available for the necessary instrumentation shall be large enough to meet the requirements for safety and working ambient conditions.

b) The engine exhaust shall be routed using short connectors, preferably flexible, at the end of the engine's exhaust pipe downstream of any aftertreatment device, if used.

c) Flexible connectors that do not exceed a length of three times their largest inside diameter may be used to enlarge or reduce the exhaust-pipe diameter to match that of the test equipment.

d) Rigid stainless steel raw exhaust tubing shall be used to connect between flexible connectors. The tubing may be straight or bent to accommodate equipment geometry. “T” or “Y” stainless steel fittings may be used to join exhaust from multiple tailpipes.

e) Connectors and tubing shall not increase back pressure so much that it exceeds the manufacturer's maximum specified exhaust restriction.

f) Where there is a risk that the measurement might be distorted by condensation, action shall be taken to avoid this. This may include additional heating or insulation.

4.4 Measurement equipment and data to be measured

4.4.1 General

The emission of gaseous and particulate pollutants by the engine submitted for testing shall be measured using methods set out in ISO 8178-1:2020, Clause 5.

That clause describes the analytical systems for the gaseous pollutants and the particulate dilution and sampling systems used in the test cell. The same principles shall also be applied to field measurement systems. Field analytical systems shall be installed in a manner to minimize the impact of field ambient conditions such as temperature, pressure, humidity, physical orientation, mechanical shock and vibration, electromagnetic radiation, and background emissions.

The types of systems to be used for testing shall be declared prior to the test and shall be agreed upon by the parties involved.

4.4.2 Zirconium dioxide (ZRDO) NO_x analyser

A zirconium dioxide (ZRDO) NO_x analyser used under conditions that provide a NO_x response factor not less than 0,9 may be used to perform measurements in the field for the purposes, and under the conditions, set out in this clause:

a) As a monitoring device to confirm activation of a NO_x emission control system;

b) To perform a spot-check verification measurement at site where the parties concerned have agreed that the use of an instrument set out in ISO 8178-1:2020, 7.3.6 is not necessary;

c) Where the analyser has been demonstrated to meet the requirements of 4.4.3 under operating conditions similar to those of the intended test and the parties concerned have also agreed to use of that analyser.

Prior to performing any measurement with a ZRDO NO_x analyser, the parties concerned shall evaluate the uncertainties associated with the use of that analyser for the intended measurement. The following points shall be included in that evaluation:

a) Location of sensor(s) within exhaust system;

b) Potential interference by NH_3 that may increase measured result, and which may be dependent upon various factors including, but not limited to:

   1. Design of engine including after-treatment system, where installed;

   2. Age and deterioration of after-treatment system, where installed;

   3. Design characteristics of ZRDO NO_x analyser;

   4. Exhaust gas temperature.

NOTE A ZRDO NO_x analyser generally has a positive response to NH_3. Consequently, where NH_3 is present in the exhaust (for example downstream of a selective catalytic reduction (SCR) NO_x after-treatment system), it will create interference and the value measured by the ZRDO NO_x analyser will be a function of both NO_x and NH_3 concentration in the exhaust gas.

When using a ZRDO NO_x analyser, the following requirements shall be met:

a) The sensor of the analyser shall be mounted directly in the exhaust gas flow for making measurements on a wet basis;

b) Prior to conducting an emission test, the analyser shall be warmed-up and stabilized in accordance with the specifications of the instrument manufacturer and a zero and span check performed as specified in Clause K.1;

c) At the conclusion of the emission test, a post-test zero and span check shall be performed and drift verified according to ISO 8178-4:2020, 8.7.4.

d) The NO_x response factor shall be calculated as specified in Clause K.2.

4.4.3 Alternative measurement procedures

Other systems or analysers may be accepted, if it is found that they yield equivalent results using the general measurement principles and system equivalency set out in ISO 8178-1:2020, Clause 5, or if parties involved agree to the use of such a system or analyser.

4.4.4 Torque and speed

When performing measurements at a single steady-state operating point, each combination of torque and speed shall be agreed by the parties concerned and measurements reported on a point-by-point basis.

When performing a steady-state discrete-mode weighted cycle-based test, the engine shall be operated with the torque and speed sequence applied according to the relevant test cycles described in ISO 8178-1:2020. In cases where the relevant test cycle is not possible, e.g. due to the characteristic of the load or because of the torsional vibration of the plant, the required test point shall be replaced by a point as close as possible, by agreement with all parties involved.

The instrumentation for torque and speed measurement shall enable the determination of the shaft power to be within the given limits. Additional calculations and comparison with test-bed measurement results might be necessary.

Signals from the engine's ECU may be used in place of values measured by individual instruments, provided the signals are correctly filtered and in case of a signal that changes with time, time-aligned with the emissions signals from the instruments in accordance with the principles set out in Clause D.3. Any combination of ECU signals, with or without other measurements, may be used to estimate engine speed and torque for use in brake-specific emission calculations, provided the overall performance of any speed or torque estimator meets the performance specifications in ISO 8178-1:2020, Table 4.

Other available data including fuel rack position may be used for this purpose. In this case the method of calculation and estimation shall be agreed between parties involved.

4.4.5 Exhaust gas flow

The principal methods applicable for determining the exhaust gas flow and the required accuracy and linearity requirements are described in ISO 8178-1:2020, 6.4.3 and 6.4.4.

4.4.6 Accuracy of the data to be measured

4.4.6.1 Exhaust gas analyser

Measurement instruments shall meet the specifications set out in ISO 8178-1:2020, 5.3 and the requirements on calibration and performance checks set out in ISO 8178-1:2020, 9.1.

Special attention shall be given to perform the following actions:

a) the vacuum-side leak verification as set out in ISO 8178-1:2020, 9.3;

b) the response and updating-recording verification of the gas analyser as set out in ISO 8178-1:2020, 9.1.5.

The minimum frequency for gas analyser linearity verification and NO_2-to-NO converter conversion verification set out in ISO-8178-1:2020, Tables 6 and 7 may be increased to 3 months.

4.4.6.2 Other measuring equipment

The requirements set out in ISO 8178-1:2020, Clauses 6 and 9 shall be met. The calibration of all measuring instruments shall be traceable to national (international) standards. The instruments shall be calibrated as required by internal audit procedures, by the instrument manufacturer, according to ISO/IEC 17025.

In practical cases it is often impossible to measure the fuel consumption at site. In such cases, especially those concerning gas or heavy fuel, an estimation using a method other than chemical balance, with a corresponding estimated error shall be made.

The consequences of such an error on the final emissions shall be calculated and reported with the results of the emission measurement. The acceptance of test results established using such estimation shall be determined by the parties concerned.

4.4.7 Determination of the gaseous components

The analytical measuring equipment and the methods are described in ISO 8178-1:2020, Clauses 5 and 7. For field measurements, the non-methane hydrocarbon analysis according to ISO 8178-1:2020, 7.3.5.2 (gas chromatography) is not applicable in most cases, as this method needs laboratory equipment.

For the measurement of non-methane hydrocarbons (NMHC), the hydrocarbon cutter method of ISO 8178-1:2020, 7.3.5.3, should preferably be applied. Alternatively, a factor of 0,98 THC may be used for diesel engines.

4.4.8 Determination of the particulates

The determination of particulate matter (PM) or number (PN) and the equipment needed shall be as specified in ISO 8178-1:2020, Clauses 5 and 8. However, the reference filter weighing time may be exceeded.

The weighing chamber and analytical balance specifications according to ISO 8178-1:2020, 8.1.5 also apply to the measurement at site and under field conditions. In cases where the weighing chamber is not located near the measurement site, it shall be ensured that the loading of the filter does not change during the transport from or to the weighing chamber [e.g. caused by mechanical vibrations, evaporation at temperatures above 52 °C (325 K)]. It is permissible to collect and store particulate samples from several tests before transporting them to the weighing chamber, but this storage time should be minimized.

PM measurement might prove difficult under field conditions, especially on-board ships, locomotives and non-road mobile machinery. It is therefore acceptable to use alternative particulate sample media or measurement procedures, if their equivalency is proven in accordance with 4.4.3, including non-filtering techniques. This includes particulate deposition on an inert substrate using electrostatic, thermophoresis, inertia, diffusion, or some other deposition mechanism. If alternative particulate measurement methods are used, preparation shall be conducted in accordance with the instrument manufacturers specifications and by agreement of the parties concerned.

When PN measurement is required it shall be performed as set out in this clause unless the use of alternative equipment is agreed between the parties involved.

4.5 Running conditions

4.5.1 Test cycles

When performing measurements at independent steady-state torque and speed points, those points shall be agreed by the parties concerned and measurements reported on a point-by-point basis.

When performing a weighted cycle-based test in the field the discrete-mode, test-cycles and corresponding requirements set out in ISO 8178-4:2020, Clause 7 and Annex A should be utilized where possible. However, it may not be possible to use the same measuring points as in ISO 8178-4:2020 in the field. Furthermore, the number of measuring points might be limited under field conditions. If the number of measuring points for field measurement is different from that of the test cycles as defined in ISO 8178-4:2020, the weighting factors in ISO 8178-4:2020 cannot be used, and the emission values can be different from the values obtained under the test-bed conditions.

Where engine mapping according to ISO 8178-4:2020, 7.4 is not practical, the maximum power values at the specified test speeds or nominal torque curve shall be declared by the manufacturer in order to calculate the torque or power values for the specified test modes. The engine setting for each test mode shall be determined, to the extent possible, using ISO 8178-4:2020, 7.7.

Measuring points and weighting factors shall be agreed between parties involved, prior to the test, when it is not possible to use the points set out in ISO 8178-4:2020.

4.5.2 Preparation of the engine

Prior to testing, the engine, including auxiliary equipment and the exhaust system, shall be conditioned according to the engine manufacturer's and/or user's recommendations in order to achieve reliable test results. This preconditioning is important for engines with long exhaust stacks and engines with silencers and exhaust aftertreatment systems in place, as well as infrequently operated engines.

4.6 Test run

4.6.1 General

The test run shall follow all requirements set out in ISO 8178-4:2020, Clause 8, as applicable for discrete-mode steady-state testing, except as permitted by this section.

4.6.2 PM measurement

For measurements conducted at independent torque and speed points. a separate PM sample filter shall be used for each test point. For cycle-weighted tests, either the multiple filter or single filter method may be used according to ISO 8178-1:2020, 5.2.6. Since the results of the methods might differ slightly, the method used shall be declared with the results.

4.6.3 Dilution air for particulate measurement

Where possible, the dilution air temperature requirements set out in ISO 8178-1:2020, 8.3 shall be followed. A dilution air temperature of less than 15 °C is permitted if the ambient air temperature is below 15 °C and the parties involved agree.

4.6.4 Test sequence

For measurements conducted at independent torque and speed points, the sequence shall be agreed by the parties concerned. For cycle-weighted tests, if steady-state test mode points different from those given in ISO 8178-4:2020, Annex A are used, the test sequence shall be conducted in the manner that most closely represents the applicable test cycle, in the order of decreasing power or torque, agreed by the parties concerned.

4.6.5 Gas analyser drift validation and correction

If the drift is within ±2 %, the data can be either accepted without any correction or accepted after correction. If the drift is greater than ±2 %, the correction set out in ISO 8178-4:2020, 8.2.2.2. shall apply.

The drift validation and correction may be applied at the end of each individual steady state mode test point.

4.6.6 Emissions evaluation and calculation

The steady-state emissions data evaluation and calculation shall be performed in accordance with ISO 8178-4:2020, Clause 9 or Annex H. In the case of measurements conducted and reported for independent torque and speed points, the results shall be calculated for each independent point and a weighting factor of 1 shall apply.

4.6.7 Test report

4.6.7.1 General

The test report shall be in accordance with ISO 8178-6, supplemented by any additional pertinent information. This shall include details of any deviations from the respective requirements set out in ISO 8178-1:2020 or ISO 8178-4 as permitted by this document.

4.6.7.2 General guidelines

The report shall be clear concerning what has been measured and how, and what has been calculated and/or corrected and how. An assessment of accuracy and reasons for choice of test options shall be included where applicable.

4.6.7.3 Measuring equipment

A record shall be made of the measuring equipment which has been used, including span gases indications, the ambient conditions at air inlet including humidity and the engine performance data and fuel characteristics, which indicate how the values of those characteristics have been obtained.

5 Measurement of gaseous emissions performance of engines during typical in-service operation under field conditions using portable emission measurement systems (PEMS)

5.1 Test conditions

5.1.1 General requirements

Testing according to Clause 5 is not based upon a specified test cycle, but on running the non-road machinery, industrial equipment, marine installations, generating sets, diesel rail traction or similar machinery application in typical in-service operation under field conditions.

With the agreement of the parties concerned the measurement and calculation method set out in Clause 5 may also be used where in-service operation is being replicated, or where emissions data is being obtained without the use of PEMS but instead using alternative types of sensors.

Although Clause 5 covers in-use testing in the field it relies upon measurement of reference work (kWh) or CO_2 reference mass (g/cycle) obtained from a prior bench-test of the engine type or, where applicable, engine family. Where such data is not available reference work may be determined according to Clause C.4 by agreement of the parties concerned.

5.1.2 Selection of engine for assessment of design performance

5.1.2.1 Selection criteria

Where the purpose of testing is to assess the design performance of an engine type or, where applicable, engine family or group, the engine subject to testing inclusive of the emission control system shall:

a) be installed in one of the most representative applications for the selected engine type or, where applicable, engine family;

b) have a maintenance record to show that the engine has been properly maintained and serviced in accordance with the manufacturer's recommendations;

c) exhibit no indications of misuse (e.g. overloading or misfuelling), or other factors (such as tampering) that could affect the gaseous pollutant emissions performance;

d) be constructed and installed in conformity with the specifications of the manufacturer.

5.1.2.2 Non-eligible engines

The following engines shall be considered as non-eligible for testing, and an alternative engine shall be selected:

a) engines with an Electronic Control Unit (ECU), produced with a communication interface intended to permit the collection of the necessary ECU data as specified in Annex I but where that interface is missing;

b) engines with an ECU and a communication interface intended to provide the necessary data as specified in Annex I but with missing data or where it is not possible to achieve clear identification and validation of the necessary signals.

5.1.3 Machinery operation

The test shall be performed during the actual (complete or partial) operation of the machinery.

When it is not possible to test during actual operation, a representative test duty cycle shall be determined by the parties concerned. That test duty cycle shall represent, as far as possible, the actual operation of the machinery.

Regardless of whether the test is conducted during the actual operation of the non-road mobile machinery or under a representative test duty cycle, it shall:

a) assess the actual operation of the majority of in-service population of the selected category(ies) of machinery;

b) not include a disproportionate amount of activity at idle speed;

c) comprise of sufficient loaded operation activity to achieve the minimum test duration set out in Clause B.2;

The operator of the machinery shall have the skills and training to operate that machinery in the manner of a professional operator.

5.1.4 Ambient conditions

The test shall be conducted under ambient conditions meeting the following requirements:

a) Atmospheric pressure shall be equal or greater than 82,5 kPa;

b) Ambient temperature shall be equal or greater than –7 °C and equal or less than the temperature determined by the following formula at the specified atmospheric pressure:

$$T = -0{,}4514 \cdot (101{,}3 - p_b) + 38$$

where:

T is the maximum ambient air temperature under which the test shall be conducted, °C;

p_b is the atmospheric pressure, kPa.

Testing may be conducted under different ambient conditions with the agreement of the parties concerned, taking into consideration the range of ambient conditions for which the emission control strategy of the engine concerned was designed.

5.1.5 Lubricating oil, fuel and reagent

The lubricating oil, fuel and reagent (for exhaust after-treatment systems that use a reagent to reduce gaseous pollutant emissions) shall conform with the specifications issued by the manufacturer.

The fuel shall be market fuel for which the engine has been designed, as specified by the manufacturer and agreed by the parties concerned, or reference fuel as specified in ISO 8178-5.

Samples of the lubricating oil, fuel, and where applicable, reagent, shall be taken and stored for a minimum of 12 months, unless this is not required by the parties concerned. Reagent samples shall not be frozen.

5.1.6 Operating sequence

The in-service test shall be conducted in one single operating sequence (continuous data sampling), except under the combined data sampling method set out in 5.2.2, where several operating sequences are combined in a single in-service test.

The duration of the test comprising all operating sequences is set out in Clause B.2.

5.2 Data sampling methods

5.2.1 Continuous data sampling

Continuous data sampling shall be used when one single operating sequence is equal to or more than the minimum test duration set out in Clause B.2.

5.2.2 Combined data sampling

5.2.2.1 General

As alternative to continuous data sampling, the data sampling may be obtained from combining the results of more than one operating sequence.

Combined data sampling shall be used only when the test conditions do not enable reaching the minimum test duration set out in Clause B.2 with one single operating sequence despite attempting to achieve this, or when the category(ies) of non-road mobile machinery selected for testing is employed in multiple working activities with different relevant duty cycle(s).

5.2.2.2 Additional requirements

The following additional requirements shall be fulfilled when applying combined data sampling:

a) the different operating sequences shall be obtained using the same non-road mobile machinery and engine;

b) the combined data sampling shall contain a maximum of three operating sequences;

c) the maximum period elapsed between the start of the first and start of the last operating sequence shall be 72 hours;

d) combined data sampling shall not be used if an engine or machine malfunction occurs, as set out in Clause B.8;

e) to be eligible for combination each operating sequence of an in-service test shall contain the following minimum amount of work (kWh) or CO_2 mass (g/cycle) after completion of pre-processing in accordance with Annex D;

   1. where the engine type or, where applicable, engine family, has been bench tested using the NRTC, a minimum of one hot-start NRTC reference work or CO_2 reference mass;

   2. where the engine type or, where applicable, engine family, has been bench tested using the LSI-NRTC, a minimum of one LSI-NRTC reference work or CO_2 reference mass;

   3. where the engine type or, where applicable, engine family, has been bench tested using only a steady-state test cycle, a minimum of one steady-state cycle reference work or CO_2 reference mass determined using the method set out in Annex C.

   In case of an in-service test of an engine type within an engine family the value shall be that for the parent engine type.

f) prior to joining the sequences all necessary pre-processing shall be completed according to the requirements set out in 5.5;

g) the operating sequences in the combined data sampling shall be joined in a chronological order including all data not excluded by list item f);

h) the combined data shall be considered one test;

i) the determination of working events set out in 5.6 and calculations set out in 5.8 shall be applied to the complete combined data sampling.

5.2.3 Temporary signal loss

Parameter recording shall reach a data completeness of not less than 98 %. A maximum of 2 % of data with no consecutive period more than 30 s duration may be excluded from each operating sequence due to one or several episodes of unintended temporary signal loss in the original data recording. No signal loss shall be created during pre-processing, combination or post-processing of any operating sequence.

5.3 ECU data stream

5.3.1 General

Where the engine to be tested was designed with an ECU and a communication interface intended to provide the data specified in Annex I, that data stream information shall be provided to the measurement instruments or data logger of the PEMS.

5.3.2 Verification of availability and conformity of information

The availability of the data stream information according to Annex I shall be verified prior to the in-service test.

Where the engine was designed with an ECU and a communication interface intended to provide data stream information, but that data is not available, 5.1.2.2 b) applies.

The conformity of the ECU torque signal shall be verified in accordance with the method set out in Annex H.

5.4 Test procedures

Each operating sequence shall be conducted according to the test procedure set out in Annex B using a Portable Emissions Measurement System (PEMS) conforming with the requirements set out in Annex A.

With the agreement of the parties concerned tests may be conducted using alternative types of sensors to measure emissions. In this case the requirements applying to those alternative types of sensors shall be agreed by those parties concerned.

5.5 Data pre-processing

Pre-processing of the test data of each operating sequence shall be performed according to the procedures set out in Annex D.

5.6 Determination of working events

5.6.1 General

Working events shall be determined for each in-service test according to the procedures set out in Annex E.

5.6.2 Combining operating sequences

Where combined data sampling according to 5.2.2 is used, the requirements of 5.3 to 5.5 shall apply individually to each operating sequence prior to joining sequences according to 5.2.2.2. The determination of working events set out in 5.6 and calculations set out in 5.8 shall be applied to the complete combined data sampling.

5.7 Test data availability

No data shall be modified or removed from the raw test data file(s) used for the completion of 5.5, 5.6 and 5.8. Those raw test data file(s) shall be retained for a period agreed by the parties concerned.

5.8 Calculations

5.8.1 General

Gaseous emission calculations shall be performed, following the pre-processing of 5.5, where applicable, combination of operating sequences of 5.2.2.2 g) and finally determination of working events of 5.6, according to the procedures set out in Annex G.

5.8.2 Engines without communication interface

For engines that were not designed with a communication interface intended to permit the collection of the engine torque and speed data as specified in Annex I the calculations shall be performed, and results reported, using only the CO_2 mass based method.

5.9 Test report

A possible format for a test report is provided in Annex J. Other formats may be used by agreement of the parties concerned.

5.10 Instantaneous measured data file and instantaneous calculated data file

Instantaneous measured data and instantaneous calculated data shall not be included in the test report but shall be retained for a period agreed by the parties concerned.

Instantaneous measured data and instantaneous calculated data shall include at least the information required by Clauses J.11 and J.12. Other formats may be used by agreement of the parties concerned.

5.11 Overview of measurement and evaluation sequence

An overview of the sequence set out in Clause 5 is provided in Figure 1.

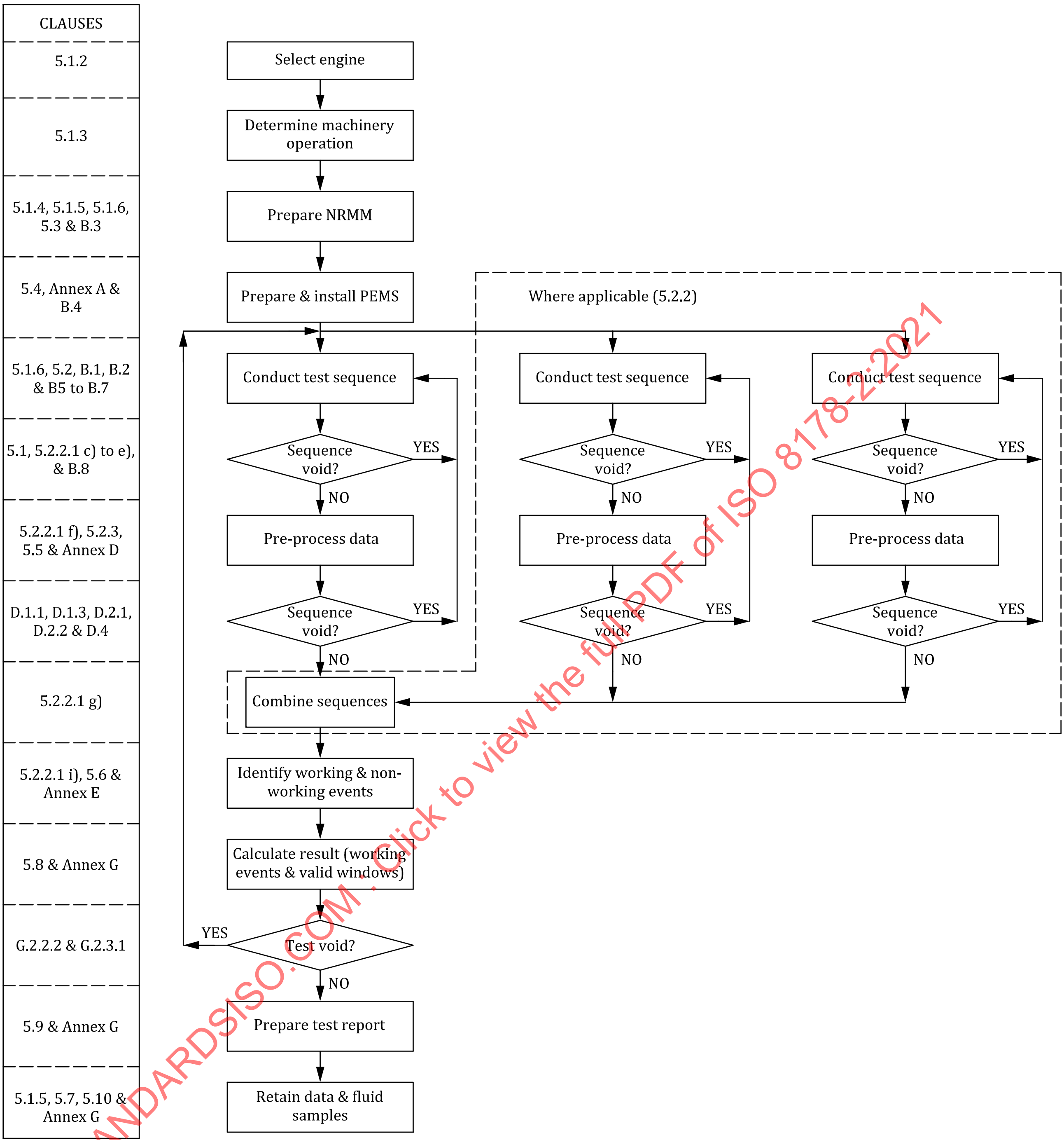


Figure 1 — Overview of measurement and evaluation sequence according to Clause 6

Annex A
(normative)

Portable Emissions Measurement System (PEMS)

A.1 General

The PEMS shall include the following measurement instruments:

a) gas analysers to measure the concentrations of the gaseous pollutant emissions set out in Annex B;

b) an Exhaust Flow Meter (EFM) based on the averaging Pitot or equivalent principle, except where an alternative approach is permitted by footnote c to Table B.1;

c) sensors to measure the ambient temperature and pressure;

d) other measurement instruments required for the in-service test.

PEMS shall also include:

e) a transfer tube to transport the extracted samples from the sampling probe to the gas analysers, including a sampling probe;

f) a data logger to store the data collected from the ECU;

g) PEMS may include a Global Positioning System (GPS).

A.2 Measurement instruments requirements

A.2.1 Calibration

A.2.1.1 General

Measurement instruments shall meet the requirements on calibration and performance checks set out in ISO 8178-1:2020, 9.1. Special attention shall be given when performing the following actions:

a) the vacuum-side leak verification of the PEMS as set out in ISO 8178-1:2020, 9.3;

b) the response and updating-recording verification of the gas analyser as set out in ISO 8178-1:2020, 9.1.5.

A summary of pre-test system checks is provided in Figure A.1.

A.2.1.2 Minimum frequency for gas analyzer linearity verification and NO_2-to-NO converter conversion verification

The minimum frequency set out in ISO-8178-1:2020, Tables 6 and 7 may be increased to 3 months.

A.2.1.3 Raw exhaust gas flow rate (EFM) performance and calibration checks

The minimum frequency of EFM performance and calibration checks, and the details of those checks, shall be those specified by the instrument manufacturer.

A.2.2 Specification

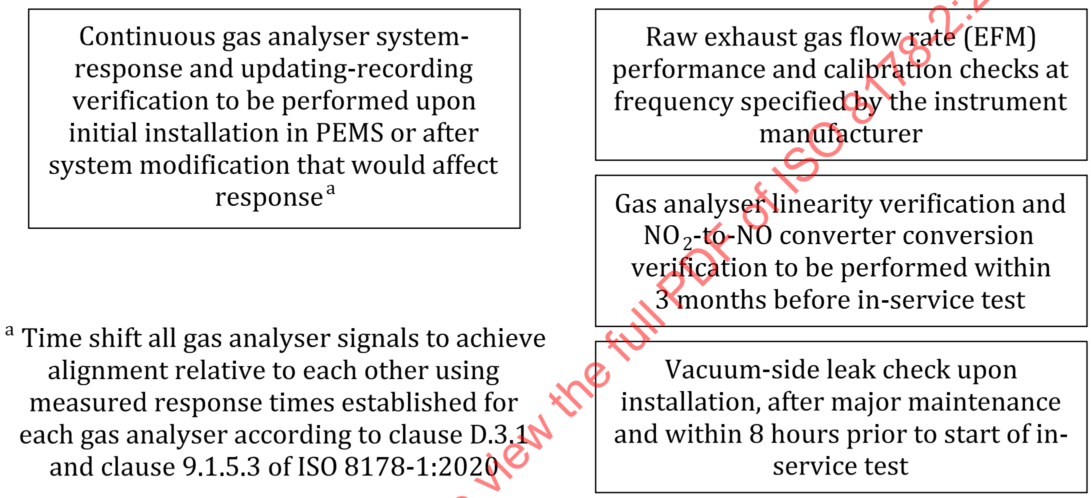
Measurement instruments shall meet the specifications set out in ISO 8178-1:2020, 5.3.

A.2.3 Calibration gases

The analytical gases used for calibrating the measurement instruments shall meet the requirements set out in ISO 8178-1:2020, 9.2.

A.3 Transfer tubes and sampling probe requirements

The transfer tubes and sampling probe shall meet the requirements set out in 5.2.1.2 and 5.2.1.1 of ISO 8178-1:2020, respectively.



NOTE Pre-test system-response, linearity verification and vacuum-side leak verification requirements are performed according to A.2.1 and ISO 8178-1:2020, Table 6; 9.1.5, 9.1.6 and 9.3.

Figure A.1 — Summary of pre-test system checks

Annex B
(normative)

Test procedure for gaseous emission measurement with a PEMS

B.1 Test parameters

B.1.1 General

The gaseous pollutant emissions that may be measured and recorded during the in-service test are: carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x). Additionally, carbon dioxide (CO_2) shall be measured to enable the calculation procedures described in Annex G.

The selected gaseous pollutant emissions and the other parameters set out in the Table B.1 shall be measured and recorded during the test.

B.1.2 Multiple exhaust stacks

Where it is agreed by the parties concerned that it is not practical to combine the flow from multiple exhaust stacks, and there is similarity in the technical configuration and operation of the part of the engine exhausting into each stack, it shall be sufficient to measure the emissions and exhaust mass flow from one exhaust stack. In this case, when performing the calculations set out in Annex G, the instantaneous mass flow rate of emissions from the measured stack shall be multiplied by the total number of stacks to obtain the total instantaneous mass flow rate of emissions for the engine.

B.1.3 Sampling period

The parameters set out in Table B.1 shall be measured at a data sampling period of 1 s or less during the in-service test.

Table B.1 — Test parameters

Parameter	Unit [a]	Source
HC concentration [b]	µmol/mol	Gas analyser
CO concentration [b]	µmol/mol	Gas analyser
NO_x concentration [b]	µmol/mol	Gas analyser
CO_2 concentration [b]	% vol	Gas analyser
Exhaust mass flow [c]	kg/h	EFM
Exhaust temperature [d]	°C	EFM or ECU or Sensor
Ambient air temperature [e]	°C	Sensor
Ambient air pressure	kPa	Sensor
Ambient air relative humidity	%	Sensor
Engine torque [f,g]	Nm	ECU or Sensor
Engine speed [g]	r/min	ECU or Sensor
Engine fuel flow [g]	g/s	ECU or Sensor
Engine coolant temperature [h]	°C	ECU or Sensor
Engine intake air temperature [e]	°C	ECU or Sensor
Non-road mobile machinery latitude	degree	GPS (optional)
Non-road mobile machinery longitude	degree	GPS (optional)

[a] Where the available data stream uses different units to those required by the table, that data stream shall be transformed into the required units during the data pre-processing set out in Annex D.

[b] Measured or corrected to a wet basis.

[c] Direct measurement of exhaust mass flow shall be used unless one of the following is applicable:

1 the exhaust system installed in the non-road mobile machinery results in dilution of the exhaust by air upstream of the location where an EFM could be installed. In this case the exhaust sample shall be taken upstream of the point of dilution; or,

2 the exhaust system installed in the non-road mobile machinery diverts a portion of the exhaust to another part of the non-road mobile machinery (e.g. for heating) upstream of the location where an EFM could be installed.

3 the engine to be tested is of a reference power greater than 560 kW or is installed in an inland waterway vessel or a railway vehicle, or installed in non-road mobile machinery where the parties concerned agree that installation of an EFM is impractical due to either the size or location of the exhaust on the non-road mobile machinery.

In these cases, where there is robust evidence of the correlation between the fuel mass flow estimated by the ECU and the fuel mass flow measured on the engine dynamometer test bench, the EFM may be omitted and indirect exhaust flow measurements (from fuel and intake air flows or fuel flow and carbon balance) may be applied.

[d] In order to determine the duration of the take-off phase after a long non- working event for an engine equipped with an after-treatment device used for NO_x reduction, as set out in E.2.2 b), the exhaust gas temperature shall be measured during the operating sequence within 0,30 m of the outlet of the after-treatment device used for NO_x reduction. Where installing a sensor within 0,30 m would result in damage to the after-treatment the sensor shall be installed as close to this location as can be practically achieved.

[e] Use the ambient temperature sensor or an intake air temperature sensor. Use of an intake air temperature sensor shall conform with the requirements set out in the second paragraph of B.5.1.

[f] The recorded value shall be either (a) the net torque; or (b) the net torque calculated from the actual engine percent torque, the friction torque and the reference torque, according to standards set out in I.2.81. The basis for the net torque shall be uncorrected net torque delivered by the engine inclusive of the equipment and auxiliaries to be included for an emissions test in accordance with ISO 8178-4:2020, Annex G.

[g] Not required for engines that are not designed to have a communication interface capable to provide these data streams.

[h] In the case of air-cooled engines, the temperature at the reference point location identified by the manufacturer.

B.2 Minimum test duration

The test duration, comprising all operating sequences, shall be long enough to obtain the following amount of working events:

a) For engines where the engine type or, where applicable, engine family, has been bench tested using the NRTC, between five and seven times the reference work in kWh performed on the hot-start NRTC run or to produce between five and seven times the CO_2 reference mass in g/cycle from the hot-start NRTC run;

b) For engines where the engine type or, where applicable, engine family, has been bench tested using the LSI-NRTC during the type-approval test or to produce between five and seven times the CO_2 reference mass in g/cycle of the LSI-NRTC;

c) For engines of power <19 kW, SI engines with both power <30 kW and swept volume ≤1 000 cm^3 and SI engines which are installed in all-terrain vehicles, side-by-side vehicles or snowmobiles, between three and five times the applicable reference work in kWh or CO_2 reference mass in g/cycle determined using the method set out in Annex C.

d) For engines not listed in sub-clauses a), b) or c), between five and seven times the applicable reference work in kWh or CO_2 reference mass in g/cycle determined from the applicable laboratory bench test result using the method set out in Annex C.

In case of an in-service test of an engine type within an engine family the values in list items a) to d) shall be those for the parent engine type.

All data remaining after the completion of pre-processing according to Annex D, collected during all operating sequences, shall be assembled chronologically even if the maximum amount of work or CO_2 mass specified in list items a) to d) is exceeded. In that case during the calculation set-out in Annex G;

— when the amount of work or CO_2 reference mass in the working events exceeds that maximum, the calculation shall be truncated at the end of the time increment in which that occurs, and,

— the results listed in the test report for the in-service test shall be those for that truncated calculation.

B.3 Preparation of the non-road mobile machinery

The preparation of the non-road mobile machinery whose engine has been selected for testing in accordance with 5.1.2 shall comprise at least the following:

a) the check of the engine; any identified problems, once solved, shall be recorded and presented to the parties concerned;

b) the replacement of the oil, fuel and reagent, if any, where no documented evidence is available that the fluid in question conforms with the engine manufacturer's specification applicable to the engine type, and it is practically and economically feasible to do so;

c) where applicable, verification of the availability of the ECU data stream information, according to the requirements set out in Clause I.2.

B.4 Installation of the PEMS

B.4.1 Installation constraints

The installation of the PEMS shall not influence the non-road mobile machinery gaseous pollutant emissions or performance.

The installation shall follow the instructions issued by the PEMS, measurement instruments, transfer tube and sampling probe manufacturer (locally applicable safety regulations and insurance requirements might exist).

Where it is not possible to install a PEMS without exceeding the maximum dimensions for safe operation of the non-road mobile machinery, and it is feasible to apply load to the engine whilst that machinery is stationary, the use of 5.1.3 shall include testing whilst stationary using a representative test cycle agreed by the parties concerned.

For engines of power <19 kW and SI engines with both power <30 kW and swept volume ≤1 000 cm^3 the engine may be removed from the non-road mobile machinery and the test conducted on a dynamometer test bench. In that case the following shall apply:

a) The engine inclusive of the entire emission control system shall be removed from the non-road mobile machinery and installed on the dynamometer test bench without adjustment to the emission control system;

b) Notwithstanding sub-clause a) the test shall be conducted in accordance with Clause 5;

c) The procedure for removing engine from non-road mobile machinery and installing in test cell to replicate operation in the non-road mobile machinery shall be agreed by the parties concerned prior to conducting the test;

d) A representative test duty cycle shall be used as determined by the parties concerned in accordance with 5.1.3;

e) The test duty cycle of sub-clause d) shall span a range of speed and load that represents the operation of the selected machine when used in the field. Methods to establish that range shall include, but are not limited to, logging operational data for one or more comparable machines operated in the field.

B.4.2 Electrical power supply

The electrical power supply of the PEMS shall be provided by an external power supply unit.

When the parties concerned agree that it is not possible to use an external power supply unit, a source drawing its energy (directly or indirectly) from the engine during the test may be used. In this case, the peak power consumption of the PEMS shall not exceed 1 % of the engine maximum power, and additional measures shall be taken to prevent the excessive discharge of the battery when the engine is not running or idling.

B.4.3 Measurement instruments other than the EFM

As far as possible, the measurement instruments other than the EFM shall be installed in a location subject to minimal:

a) ambient temperature changes;

b) ambient pressure changes;

c) electromagnetic radiation;

d) mechanical shock and vibration;

e) ambient hydrocarbons — if using a FID analyser that uses ambient air as FID burner air.

B.4.4 EFM

The installation of the EFM shall:

a) not increase the engine exhaust backpressure beyond the value recommended by the manufacturer;

b) be attached to the non-road mobile machinery's tailpipe. The EFM's sensors should be placed between two pieces of straight tube whose length should be at least 2 times the EFM diameter (upstream and downstream);

c) be placed after the non-road mobile machinery silencer, and, if applicable, after an additional damping chamber, to limit the effect of exhaust gas pulsations upon the measurement signals;

d) be in accordance with the instrument manufacturer's specifications.

B.4.5 Transfer tube and sampling probe

The transfer tube shall be properly insulated at the connection points (sampling probe and back of the measurement instruments).

If the length of the transfer tube is changed, the transport times shall be verified and, if necessary, corrected.

The transfer tube and the sampling probe shall be installed in accordance with the requirements set out in ISO 8178-1:2020, 5.2.2.

B.4.6 Data logger

Where ECU data is to be used, a data logger shall be connected with the engine ECU to record the engine parameters listed in Table I.1, and, where applicable, the engine parameters listed in Table I.2 with a data sampling period of 1 s or less.

B.4.7 GPS (where applicable)

The antenna should be mounted at the highest possible location, without risking interference with any obstructions encountered during in-use operation.

B.5 Pre-in-service test procedures

B.5.1 Ambient temperature measurement

The ambient temperature shall at a minimum be measured at the beginning of the test and also at the end of the operating sequence. The measurement shall be made within a reasonable distance from the non-road mobile machinery. A sensor or ECU signal for intake air temperature (temperature experienced by the engine) may be used.

If an intake air temperature sensor is used to estimate the ambient temperature, the recorded ambient temperature shall be the intake air temperature adjusted by the applicable nominal offset between ambient and intake air temperature as specified by the manufacturer.

B.5.2 Starting and stabilising the measurement instruments

The measurement instruments shall be warmed up and stabilized until pressures, temperatures and flows have reached their operating set points, according to the instructions issued by the measurement instrument/PEMS manufacturer.

B.5.3 Cleaning and heating the transfer line

To prevent system contamination, the transfer line shall be purged until sampling begins, according to the instructions issued by the transfer line/PEMS manufacturer. The transfer line shall be heated to 190 °C (+/− 10 °C) before starting the test to avoid the presence of cold spots that could lead to a contamination of the sample by condensed hydrocarbons.

B.5.4 Checking and calibrating the gas analysers

The zero and span calibration and the linearity checks of the gas analysers shall be performed using the analytical gases set out in A.2.3.

B.5.5 Cleaning the EFM

The EFM shall be purged at the pressure transducer connections in accordance with the instructions issued by the PEMS or EFM manufacturer. This procedure shall remove condensation and diesel particulate matter from the pressure lines and the associated flow tube pressure measurement ports.

B.6 In-service test data logging

B.6.1 Before the operating sequence

Gaseous pollutant emissions data sampling, measurement of the exhaust parameters and recording of the engine and ambient data shall start prior to starting the engine.

B.6.2 During the operating sequence

Gaseous pollutant emissions data sampling, measurement of the exhaust parameters and recording of the engine and ambient data shall continue throughout the normal in-use operation of the engine.

The engine may be stopped and started, but the gaseous pollutant emissions data sampling, measurement of the exhaust parameters and recording of the engine and ambient data shall continue throughout the entire in-service test.

B.6.3 After the operating sequence

At the end of the operating sequence, sufficient time shall be given to the measurement instruments and data logger to allow their response times to elapse. The engine may be shut down before or after data logging is stopped.

B.7 Checking of gas analysers

B.7.1 Periodic zero verification during the operating sequence

Where practical and safe to perform, zero verification of the gas analysers shall be conducted at least every 2 hours during an operating sequence.

B.7.2 Periodic zero correction during the operating sequence

The results obtained with the checks performed in accordance with B.7.1 may be used to perform a zero drift correction during that operating sequence.

B.7.3 Drift verification after the operating sequence

The drift verification shall be performed only if no zero drift correction was made during the operating sequence in accordance with B.7.2.

No later than 30 minutes after the operating sequence is completed, the gas analysers shall be zeroed and spanned in order to verify their drift compared to the pre-test results.

The zero, span and linearity checks of the gas analysers shall be performed as set out in B.5.4.

B.7.4 Summary of zero, span and drift checks

A summary is provided in Figure B.1.

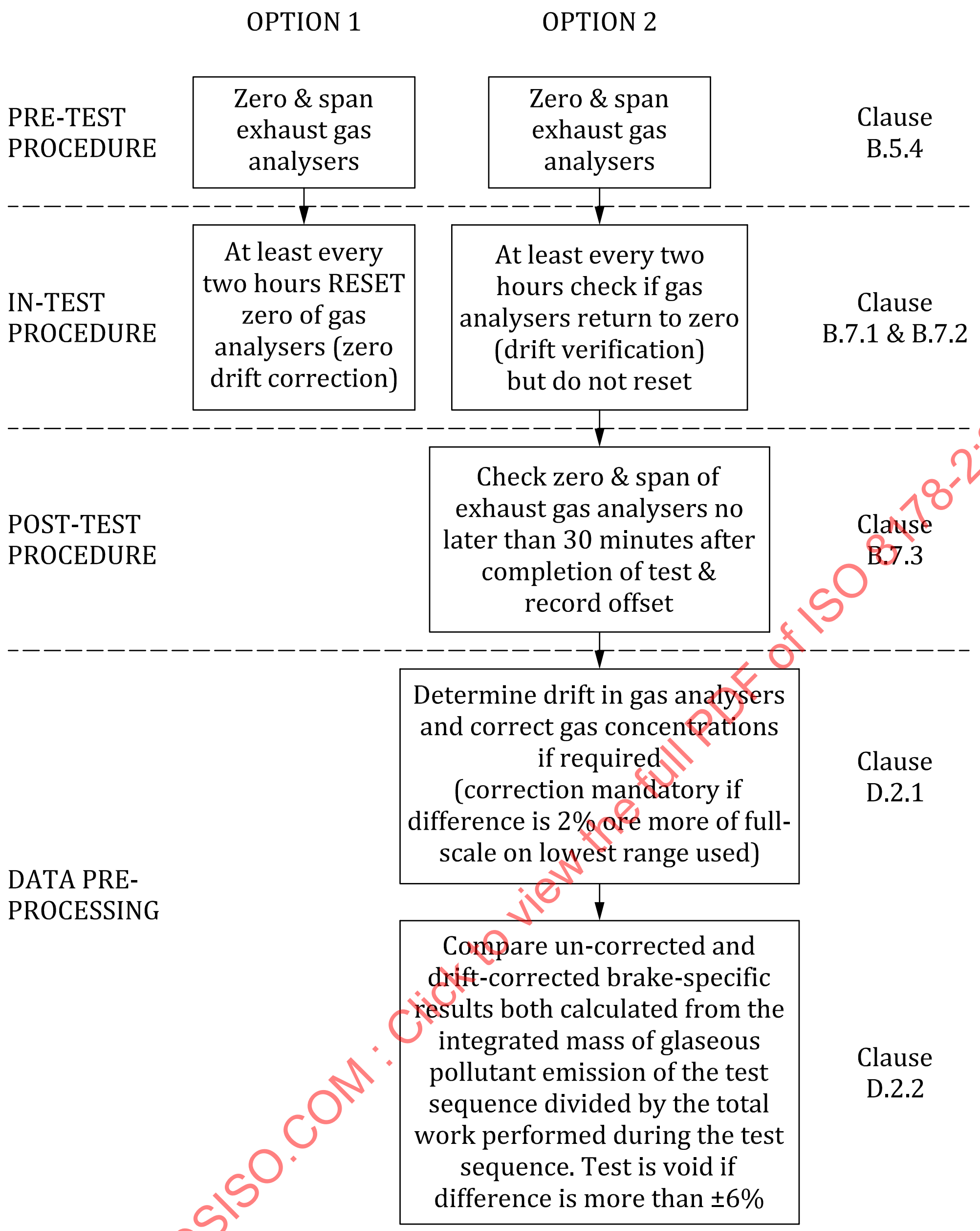


Figure B.1 — Summary of zero, span and drift checks set out in Annexes B and D

B.8 Engine or machine malfunction

In the case that a malfunction occurs during an operating sequence that affects engine operation and either:

a) the non-road mobile machinery operator is clearly notified of that malfunction by the on-board diagnostics system via a malfunction visual warning, text message or other indicator; or,

b) the non-road mobile machinery is not fitted with a malfunction diagnostic or warning system, but the malfunction is clearly detected by aural or visual means;

the operating sequence shall be considered void.

Any malfunction shall be corrected before any further operating sequence is conducted on the engine.

Annex C
(normative)

Determination of reference work and CO_2 for engines for which the applicable bench test cycle is solely NRSC

C.1 Reference laboratory bench test cycles for determination of reference work and CO_2

The reference laboratory bench test cycle shall be the Non-Road Transient Cycle (NRTC) or the Large Spark Ignition Non-Road Transient Cycle (LSI-NRTC) where these are used for the laboratory bench tests of the engine type or engine family.

This annex defines how to determine the reference work and reference mass of CO_2 for engines for which neither the Non-Road Transient Cycle (NRTC) nor the Large Spark Ignition Non-Road Transient Cycle (LSI-NRTC) are applicable for laboratory bench tests. In that case the reference laboratory bench test cycle shall be the discrete-mode or RMC NRSC applicable to the engine to be tested in-service as set out in ISO 8178-4:2020, Annexes A and B.

C.2 Determination of W_{ref} and $m_{CO_2,ref}$ from RMC Non-Road Steady-State Cycle (NRSC)

The reference work W_{ref} [kWh] is equal to the actual work W_{act} [kWh] as given by ISO 8178-4:2020, 9.1.7.1.

The reference mass of CO_2 $m_{CO_2,ref}$ [g] is equal to the mass of CO_2 for the test cycle m_{CO_2} [g], calculated according to 9.1.4.2.2, 9.1.4.2.3, H.5.1 or H.6.1 of ISO 8178-4:2020 according to whether raw or dilute gaseous sampling is used and whether mass-based or molar-based calculation is applied.

C.3 Determination of W_{ref} and $m_{CO_2,ref}$ from discrete-mode Non-Road Steady-State Cycle (NRSC)

C.3.1 Reference work

The reference work W_{ref} (kWh) shall be calculated using Formula (C.1).

$$W_{ref} = \sum_{i=1}^{N_{mode}} \left(P_i \cdot f_{WF,i}\right) \cdot \frac{t_{ref}}{3600} \tag{C.1}$$

where:

P_i is the engine power for mode i [kW] with $P_i = P_{m,i} + P_{AUX}$ (see ISO 8178-4:2020, 5.2 and 7.7.1.3);

$f_{WF,i}$ is the weighting factor for the mode i [-];

t_{ref} is the reference time [s] (see Table C.1);

i is the mode number;

N_{mode} is the total number of modes in the test cycle.

C.3.2 Reference mass of CO_2

The reference mass of CO_2 $m_{CO_2,ref}$ [g] shall be determined from the mean CO_2 mass flow rate $q_{mCO_2,i}$ [g/h] for each mode i calculated in accordance with Clause 9 or Annex H of ISO 8178-4:2020 using Formula (C.2).

$$m_{CO_2,ref} = \sum_{i=1}^{N_{mode}} \left(q_{mCO_2,i} \cdot f_{WF,i} \right) \cdot \frac{t_{ref}}{3600} \qquad (C.2)$$

where

$q_{mCO_2,i}$ is the mean CO_2 mass flow rate for mode i [g/h];

$f_{WF,i}$ is the weighting factor for the mode i [-];

t_{ref} is the reference time [s] (see Table C.1);

i is the mode number;

N_{mode} is the total number of modes in the test cycle.

C.3.3 Reference time

Reference time t_{ref} is the total duration of the equivalent Ramped Modal Cycle (RMC) set out in ISO 8178-4:2020, Annex B. These values are set out in Table C.1.

Table C.1 — Reference time t_{ref} for each discrete-mode NRSC

NRSC	t_{ref} [s]
C1	1 800
C2	1 800
D2	1 200
E2	1 200
E3	1 200
F	1 200
G1	1 800
G2	1 800
H	1 200

C.4 Determination of W_{ref} in the case that Non-Road Steady-State Cycle (NRSC) bench test data is unavailable

In the case that test-bed measurements are not available, the reference work may be calculated from Formula (C.1) using the applicable test cycle engine speed and torque set-points based upon the nominal full-load torque curve representative of the engine type.

Annex D
(normative)

Data pre-processing for gaseous pollutant emissions calculations

D.1 Exclusion of data

D.1.1 Temporary signal loss

Any episodes of temporary signal loss shall be identified.

A maximum of 2 % of data with no consecutive period of more than 30 s duration may be excluded from each operating sequence due to one or several episodes of unintended temporary signal loss in the original data recording, in accordance with 5.2.3.

In case the test sequence contains episodes of signal loss either greater than 2 % of data or for a consecutive period greater than 30 s, that entire sequence shall be considered void and a further test shall be run.

D.1.2 Periodic checks of measurement instruments

Any data points corresponding with checking of gas analysers according to Clause B.7 shall be identified and excluded from further processing of an operating sequence except as required to perform the drift correction in Clause D.2.

D.1.3 Ambient conditions

Any data points in an operating sequence corresponding with ambient conditions that do not conform with the requirements in 5.1.4 shall be identified. If the proportion of data points not conforming with that clause exceeds 1 % that entire sequence shall be considered void and a further test shall be run.

In the case that ambient conditions are only measured at the start and the end of the test, the entire test sequence shall be considered void if either measurement does not conform with the requirements set out in 5.1.4.

D.1.4 Cold start data

D.1.4.1 General

Cold start gaseous pollutant emissions measured data shall be excluded prior to the gaseous pollutant emissions calculations.

D.1.4.2 Liquid cooled engines

Valid measured data for gaseous pollutant emissions calculations shall start after the engine coolant temperature has reached 70 °C for the first time or after the engine coolant temperature is stabilized within +/– 2 °C over a period of 5 minutes, whichever comes first; in any case it shall start no later than 20 minutes after starting the engine.

D.1.4.3 Air cooled engines

Valid measured data for gaseous pollutant emissions calculations shall start after the temperature measured at the reference point identified by the manufacturer is stabilized within +/– 5 % over a period of 5 minutes; in any case it shall start no later than 20 minutes after starting the engine.

D.2 Drift correction

D.2.1 Maximum drift allowed

Drifts of the zero response and the span response shall be less than 2% of full scale on the lowest range used:

a) if the difference between the pre-test and post-test results is less than 2%, the measured concentrations may be used uncorrected or may be corrected for drift according to D2.2;

b) if the difference between the pre-test and post-test results is equal to or greater than 2%, the measured concentrations shall be drift corrected according to D2.2. If no correction is made, the test shall be considered void.

D.2.2 Drift correction

The drift corrected concentration value shall be calculated in accordance with the requirements set out in ISO 8178-4:2020, 9.1.4 or H.5.

The difference between the uncorrected and the corrected brake-specific gaseous pollutant emission values shall be within ±6% of the uncorrected brake-specific gaseous pollutant emission values. If the drift is greater than 6%, the test shall be considered void.

Each brake-specific gaseous pollutant emission value shall be calculated from the integrated mass of gaseous pollutant emission of the test sequence divided by the total work performed during the test sequence. This calculation shall be performed prior to determination of working events according to Annex E or calculation of gaseous pollutant emissions according to Annex G.

If drift correction is applied, only the drift-corrected gaseous pollutant emission results shall be used when reporting gaseous pollutant emissions.

D.3 Time alignment

D.3.1 General

To minimize the biasing effect of the time lag between the different signals on the calculations of the mass of the gaseous pollutant emissions, the data relevant for gaseous pollutant emissions calculations shall be time aligned, in accordance with the requirements set out in D.3.1 to D.3.4. A summary is provided in Figure D.1.

D.3.2 Gas analysers data

The data from the gas analysers shall be properly aligned in accordance with the requirements set out in ISO 8178-1:2020, 9.1.5.3.

D.3.3 Gas analysers and EFM data

The data from the gas analysers shall be properly aligned with the data of the EFM using the procedure set out in D.3.5.

D.3.4 PEMS and engine data

The data from the PEMS (gas analysers and EFM) shall be properly aligned with the data from the engine ECU using the procedure in D.3.5.

D.3.5 Procedure for improved time alignment of the PEMS data

D.3.5.1 General

The test parameters listed in Table B.1 are split into three different categories:

— Category 1: Gas analysers (HC, CO, CO_2, NO_x concentrations);

— Category 2: EFM (Exhaust mass flow and exhaust temperature);

— Category 3: Engine (Torque, speed, temperatures, fuel rate from ECU).

The time alignment of each category with the other two categories shall be verified by finding the highest correlation coefficient between two series of test parameters. All the test parameters in a category shall be shifted to maximize the correlation factor. The following test parameters shall be used to calculate the correlation coefficients:

a) Categories 1 and 2 (Gas analysers and EFM data) with Category 3 (Engine data): the exhaust mass flow from the EFM with torque from the ECU;

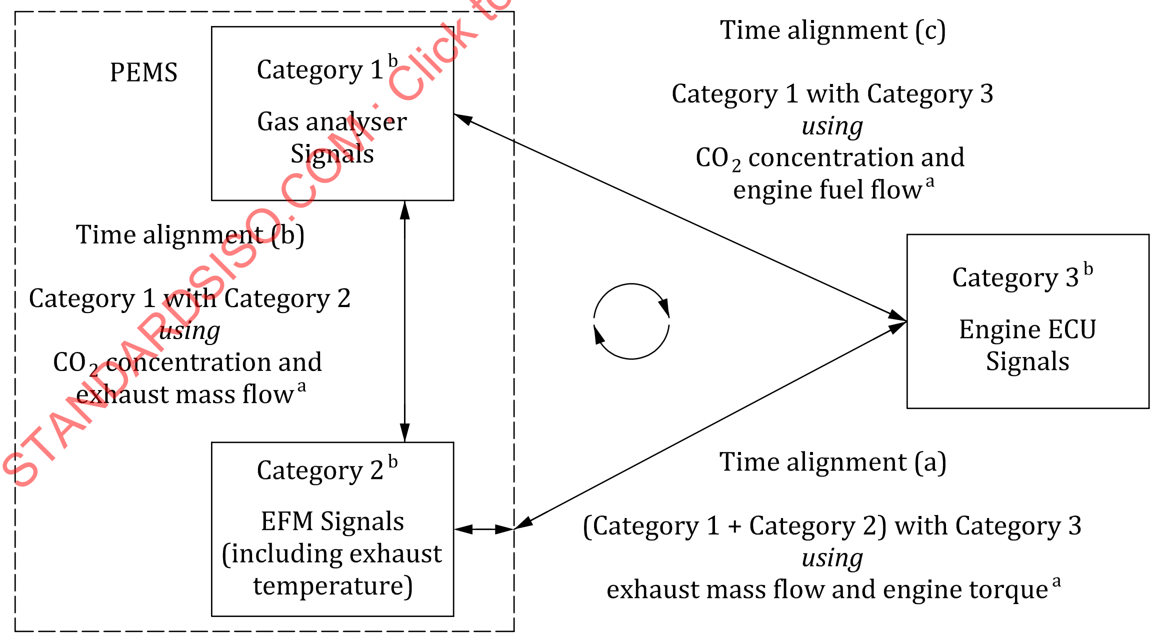
b) Category 1 with Category 2: the CO_2 concentration and the exhaust mass flow;

c) Category 1 with Category 3: the CO_2 concentration and the engine fuel flow.

D.3.5.2 Special cases

In the case of engines not designed to have a communication interface to permit the collection of the ECU data as specified in Annex I the correlation at list items a) and c) of D.3.5.1 shall be omitted.

In the case of engines for which direct measurement of exhaust mass flow was omitted according to footnote c to Table B.1 the correlation at list item a) of D.3.5.1 shall be omitted.



[a] Conduct time-alignment by finding highest correlation coefficient between the two series of test parameters.

[b] Time-shift all signals within a category by same amount.

Figure D.1 — Summary of post-test signal time-alignment requirements according to Clause D.3

D.4 Data consistency check

D.4.1 General

The parties concerned may consider the test void if they are not satisfied with the results of the data consistency check.

D.4.2 Gas analysers and EFM data

For engines designed to have a communication interface capable to provide fuel flow according to Table I.2 and where an EFM was installed for the test, the consistency of the data (exhaust mass flow measured by the EFM and gas concentrations) shall be verified using a correlation between the measured engine fuel flow from the ECU and the engine fuel flow calculated in accordance with the procedure set out in ISO 8178-1:2020, D.3.2.

A linear regression shall be performed for the measured and calculated fuel rate values. The method of least squares shall be used, with the best fit equation having the form given in Formula (D.1):

$$y = mx + b \tag{D.1}$$

where

y is the calculated fuel flow [g/s];

m is the slope of the regression line;

x is the measured fuel flow [g/s];

b is the y intercept of the regression line.

The slope (m) and the coefficient of determination (r^2) shall be calculated for each regression line. To the extent possible this analysis shall be performed in the range from 15 % of the maximum value to the maximum value and at a frequency greater or equal to 1 Hz. The test shall be considered valid if the tolerances set out in Table D.1 are met.

Table D.1 — Tolerances

Slope of the regression line, m	0,9 to 1,1
Coefficient of determination, r^2	min. 0,90

When the result of the correlation is outside of the range of tolerance given in Table D.1 the test may be considered valid by agreement of the parties concerned.

NOTE The correlation can be adversely affected by exhaust flow leakage between the engine and the EFM, or by deficiencies in time-alignment between the signals. Consequently, this correlation is used as a quality control check of the test performed. It can also be affected by the precision of the measured engine fuel flow signal available from the ECU.

D.4.3 ECU torque data

Where ECU torque data is to be used in the calculations the consistency of the ECU torque data shall be verified by comparing the maximum ECU torque values at different (if appropriate) engine speeds with the corresponding values on the official engine full load torque curve and in accordance with Annex H.

D.4.4 Brake-Specific Fuel Consumption (BSFC)

Where ECU data is available, the BSFC shall be checked using:

a) the fuel consumption calculated from the gaseous pollutant emissions data (gas analysers concentrations and exhaust mass flow data), in accordance with the procedure set out in ISO 8178-1:2020, D.3.2;

b) the work calculated using the data from the ECU (Engine torque and engine speed).

D.4.5 Ambient pressure

The ambient pressure value shall be checked against the altitude indicated by the GPS data, if available.

D.5 Dry-wet correction

If the concentration is measured on a dry basis, it shall be converted to a wet basis in accordance with the procedure set out in 9.1.5 or H.5.2 of ISO 8178-4:2020.

D.6 NO_x correction for humidity and temperature

The NO_x concentrations measured by the gas analysers shall not be corrected for ambient air temperature and humidity.

Annex E
(normative)

Algorithm for the determination of working events during in-service testing

E.1 General provisions

The methodology set out in this annex is based on the concept of working and non-working events.

Any event considered as a non-working event in accordance with this annex shall not be considered as valid for the calculations of the work or CO_2 mass and the gaseous pollutant emissions and conformity factors of the averaging windows set out in Annex G. Only working events shall be used for the purpose of calculations.

Non-working events shall be categorized as short non-working events (≤D2) and long non-working events (>D2) (see the Table E.1 for the value of D2).

E.2 Procedure to determine non-working events

E.2.1 Non-working events

E.2.1.1 General

Non-working events are those where either:

a) for engines not designed to have a communication interface capable to provide torque and speed data according to Table I.1, the instantaneous proxy power determined according to the procedure set-out in Annex F; or

b) in all other cases, the instantaneous engine power

is below 10 % of the engine rated power for engine types, or where applicable engine families, for which the reference bench test cycle is D1, D2, E2 or E4, or below 10 % of maximum power in all other cases.

E.2.1.2 Proxy power

For engines tested under Clause 5 that are not designed to have a communication interface capable to provide torque and speed data according to Table I.1 the instantaneous proxy power shall be calculated using the procedure described in Annex F prior to applying the procedure in this Annex.

E.2.2 Additional steps

The following additional steps shall be conducted:

a) Non-working events shorter than D0 shall be considered as working events and merged with the surrounding working events (see the Table E.1 for the values of D0).

b) The take-off phase following long non-working events (>D2) for engines equipped with an after-treatment device used for NO_x reduction and exhaust gas temperature measurement according to footnote d to Table B.1 shall also be considered as a non-working event until the exhaust gas temperature reaches 250 °C. If the exhaust gas temperature does not reach 250 °C within D3 minutes, all events after D3 shall be considered as working events (see the Table E.1 for the value of D3).

c) For all non-working events, the first D1 minutes of the event shall be considered as working event (see the Table E.1 for the values of D1).

E.3 'Machine work' marking algorithm to implement requirements of Clause E.2

E.3.1 Step 1: Detect and split into working events and non-working events

a) Identify and mark the working events and non-working events in accordance with Clause E.2;

b) Calculate the duration of non-working events;

c) Mark the non-working events shorter than D0 as working events;

d) Calculate the duration of the working events.

E.3.2 Step 2: Merge short working events (≤D0) into non-working events

Merge working events shorter than D0 with the surrounding non-working events of duration longer than D1 and re-mark as part of those non-working events.

E.3.3 Step 3: Exclude working events after long non-working events (take off phase)

Where applicable, re-mark as non-working events those events after long (>D2) non-working events until the exhaust gas temperature reaches 250 °C or until D3 minutes have elapsed, whatever happens first.

E.3.4 Step 4: Include non-working events after working events

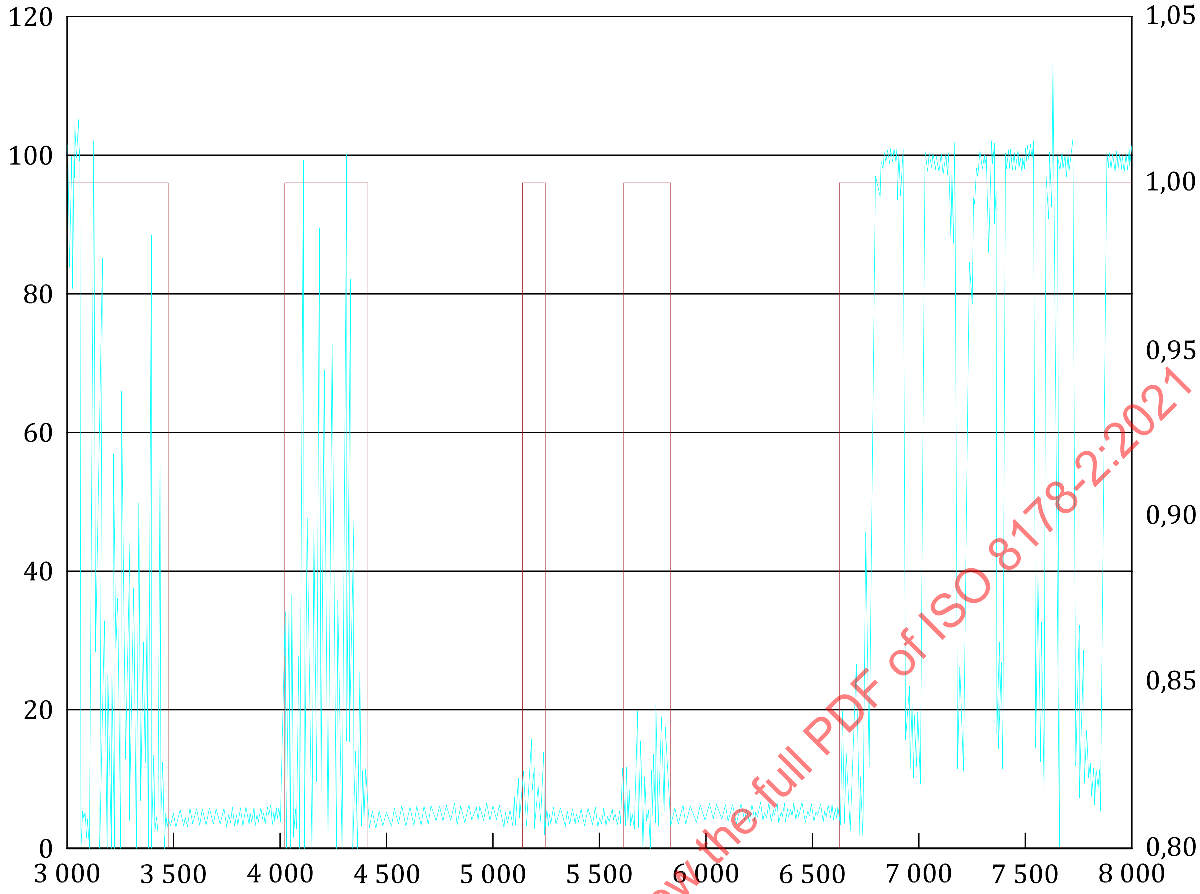
Include D1 minutes of non-working event following any working event as part of that working event.

Table E.1 — Values for the parameters D0, D1, D2 and D3

Parameters	Value
D0	2 minutes
D1	2 minutes
D2	10 minutes
D3	4 minutes

E.4 Examples

Figures E.1 to E.4 provide an example of data processed according to this annex.



Key

% of Max. Power

Working[1]/non-working[0]

Figure E.1 — Exclusions of non-working data at the end of Step 1

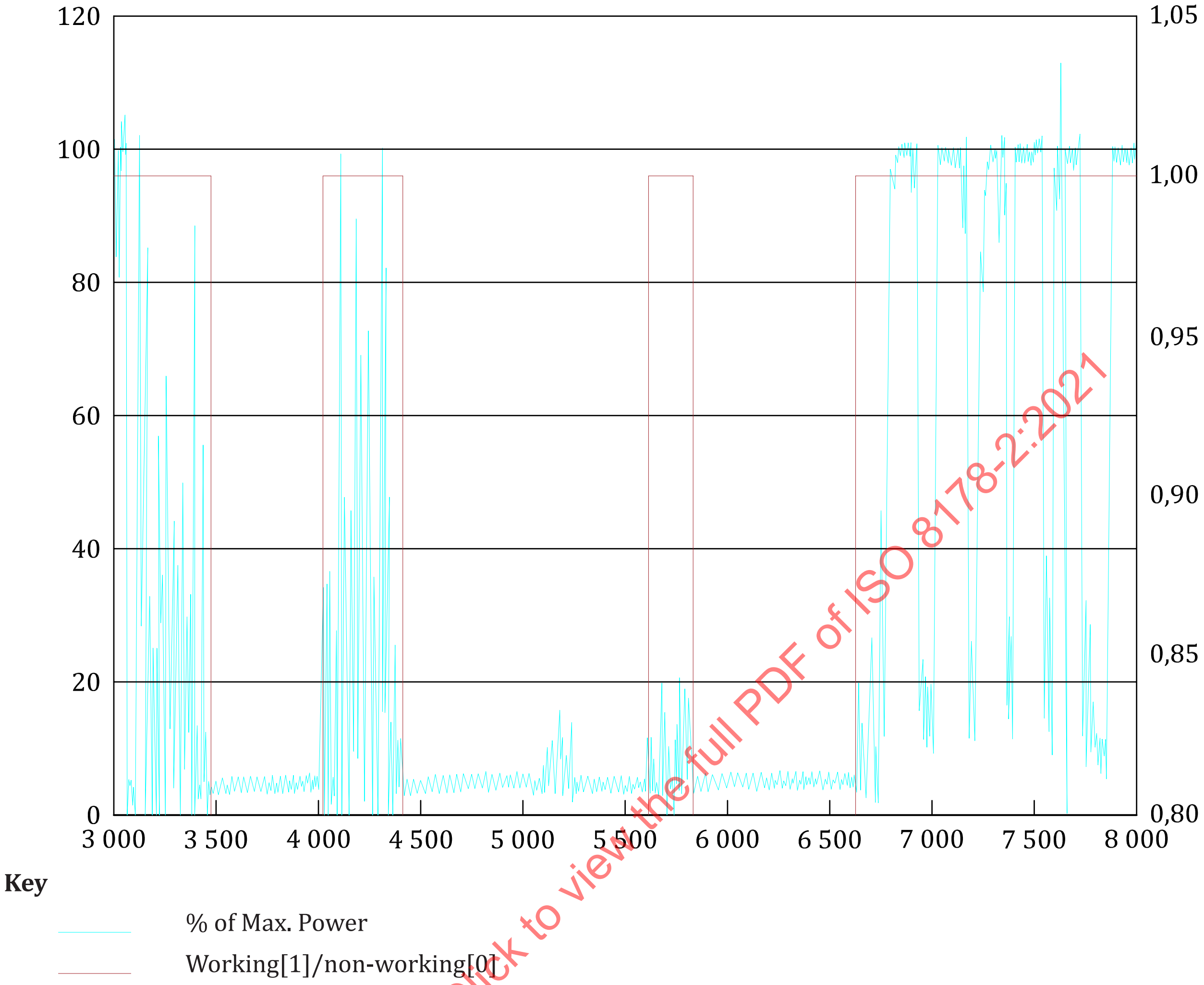
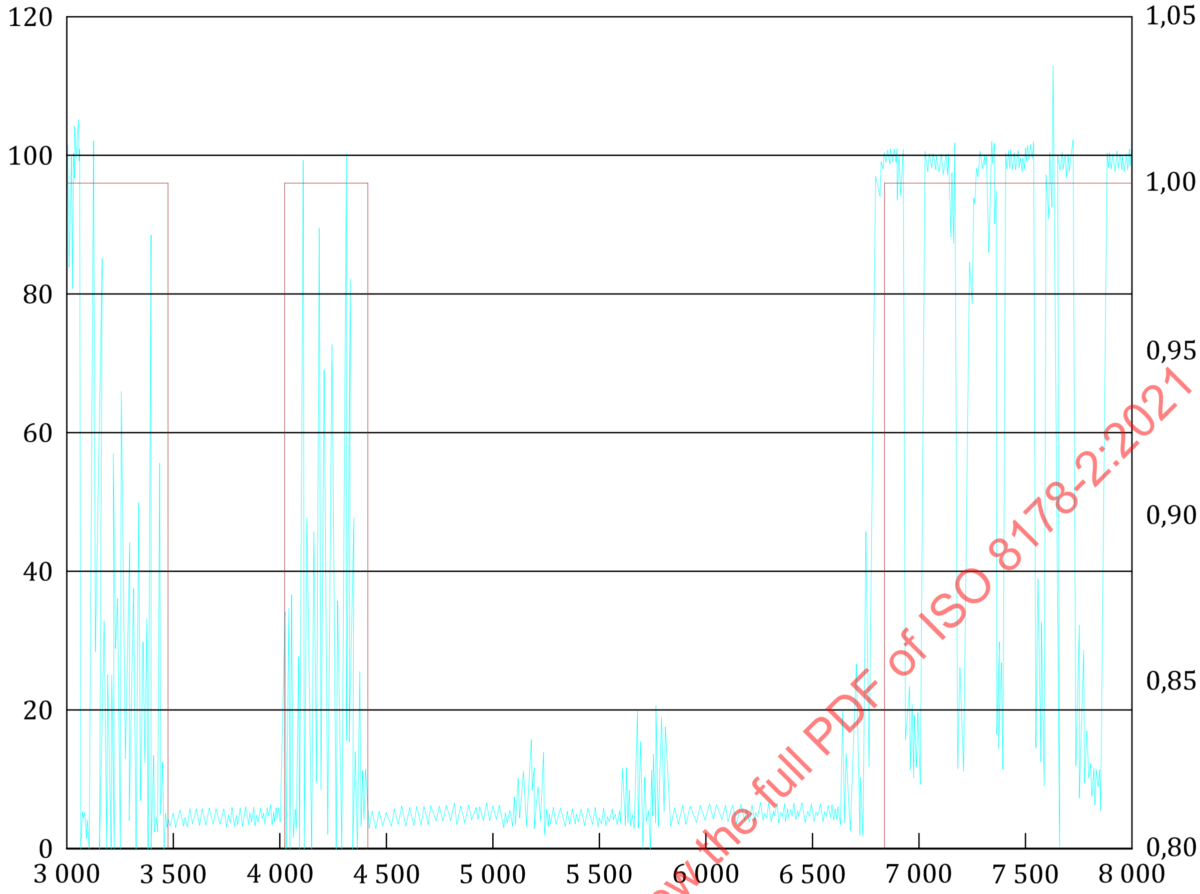


Figure E.2 — Exclusions of non-working data at the end of Step 2

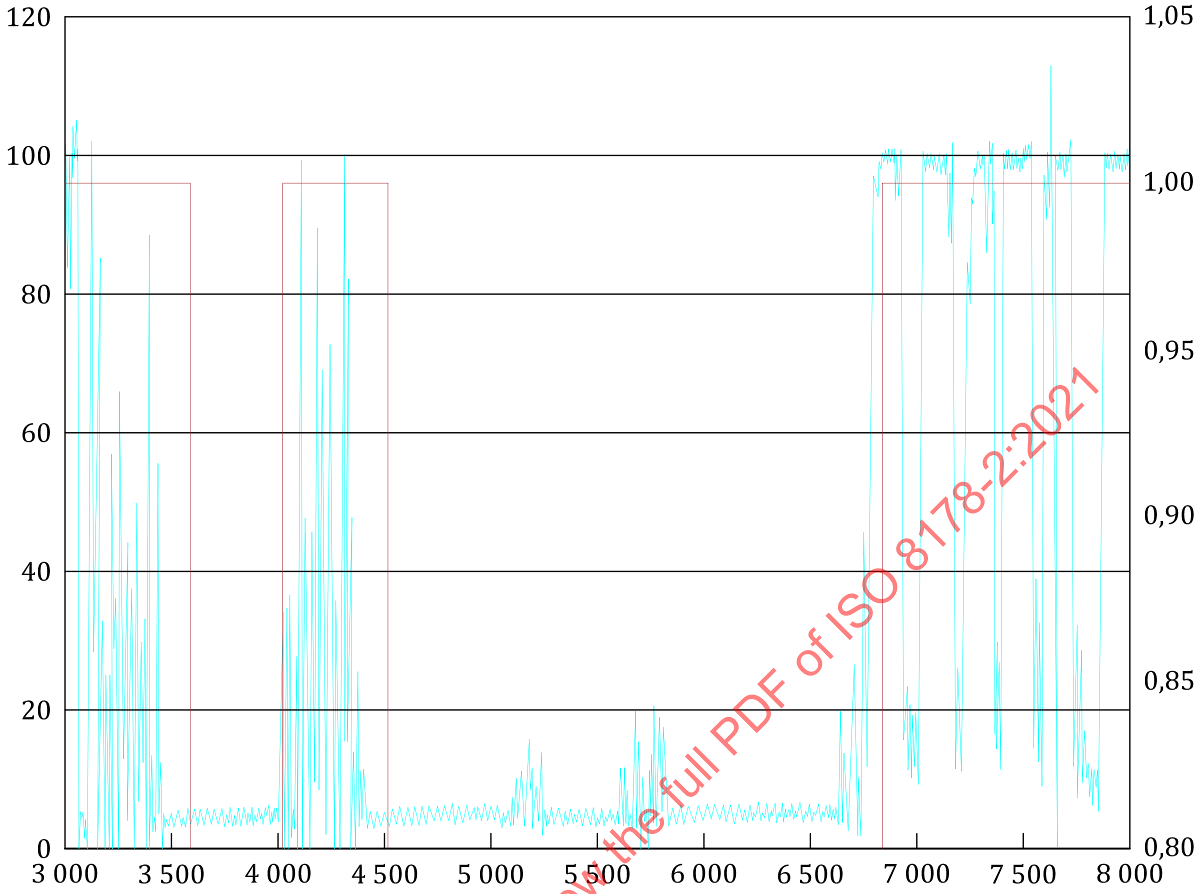


Key

% of Max. Power

Working[1]/non-working[0]

Figure E.3 — Exclusions of non-working data at the end of Step 3



Key

% of Max. Power

Working[1]/non-working[0]

Figure E.4 — End of Step 4 – Final

Annex F
(normative)

Determination of the instantaneous proxy power from CO_2 mass flow rate

F.1 General provisions

This annex defines how to determine the instantaneous proxy power for engines designed without a communication interface capable to provide torque and speed data according to Table I.1.

The determination is based on the assumptions that for all engine types within an engine family:

a) The ratio of work to CO_2 mass on a reference test cycle and the ratio of work to CO_2 mass during in use operation are similar;

b) There is a linear relationship between power and CO_2 mass flow rate;

c) An operating engine that produces no net power emits no CO_2.

Due to the assumptions on which the calculation is based, proxy power shall be used solely for the determination of working events during in-service testing as described in Annex E.

F.2 Calculation of the instantaneous proxy power

For the sole purpose of the calculations in Annex E, an instantaneous power for the engine under test can be computed from the measured CO_2 mass flow at a time increment equal to the data sampling period. For this calculation a simplified engine-family-specific CO_2 ("veline") constant shall be used.

The veline constant shall be calculated from the reference work and reference CO_2 mass obtained from the parent engine bench-test for the non-road transient test cycle (hot-start NRTC run or LSI-NRTC as applicable), or, where a non-road transient test cycle does not apply, from the reference work and reference CO_2 mass determined according to Annex C.

The veline constant, K_{veline}, is computed from the reference mass of CO_2 emitted divided by the reference work using Formula (F.1).

$$K_{veline} = \frac{m_{CO_2,ref}}{W_{ref}} \tag{F.1}$$

where:

K_{veline} is the veline constant [g/kWh];

$m_{CO_2,ref}$ is the reference mass of CO_2 emitted by the parent engine in the applicable cycle [g];

W_{ref} is the reference work performed by the parent engine in the applicable cycle [kWh].

The instantaneous proxy power of the engine under test is calculated from the instantaneous CO_2 mass flow rate using Formula (F.2)

$$P_{proxy,i} = 3600 \cdot \frac{\dot{m}_{CO_2,i}}{K_{veline}} \quad \text{(F.2)}$$

where:

$P_{proxy,i}$ is the instantaneous proxy power [kW];

$\dot{m}_{CO_2,i}$ is the instantaneous mass flow rate of CO_2 emitted by the engine under test [g/s].

Annex G
(normative)

Gaseous pollutant emissions calculations

G.1 Calculation of the instantaneous gaseous pollutant emissions

The instantaneous mass of the gaseous pollutant emissions shall be calculated on the basis of the instantaneous concentration of the gaseous pollutant emissions measured during the test and in accordance with the procedure set out in ISO 8178-4:2020, Clause 9 or Annex H.

G.2 Determination of averaging windows' gaseous pollutant emissions and conformity factors

G.2.1 Averaging window method

G.2.1.1 General

This method is illustrated in Figure G.1.

The averaging window is the sub-set of the complete calculated data set during the in-service test whose work or CO_2 mass is equal to the engine work or CO_2 mass measured over the reference laboratory test cycle.

The mass of the gaseous pollutant emissions and the conformity factors shall be calculated using the moving averaging window method, based on the reference work (procedure set out G.2.2) and the reference CO2 mass (procedure set out in G.2.3) measured over the reference laboratory test cycle.

The calculations shall be conducted in accordance with the following general requirements:

a) Any data excluded, in accordance with Annex E, shall not be considered for the calculations of the work or CO_2 mass and the gaseous pollutant emissions and conformity factors of the averaging windows;

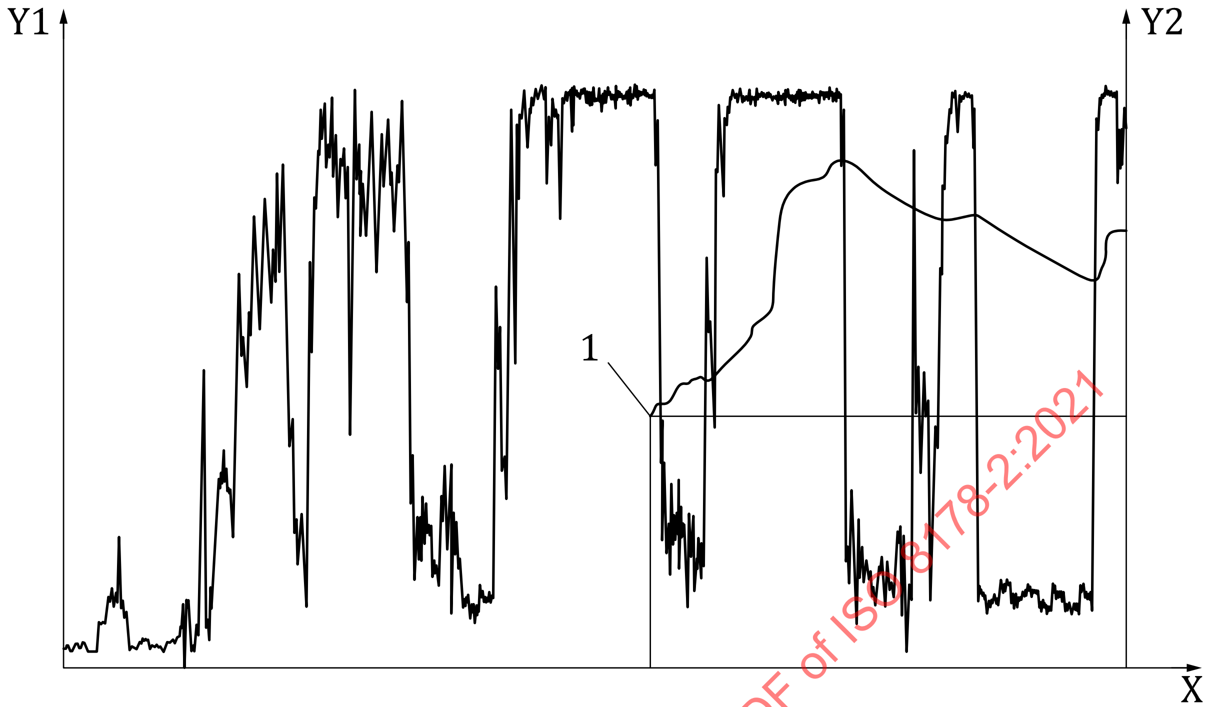
b) The moving averaging window calculations shall be conducted with a time increment Δt equal to the data sampling period; the start of the moving average window shall be incremented by that amount at each iteration;

c) The mass of the gaseous pollutant emissions for each averaging window (mg/averaging window) shall be obtained by integrating the mass of the instantaneous gaseous pollutant emissions in the averaging window;

d) In the case of engines with an ECU that were not designed with a communication interface intended to permit the collection of the engine torque and speed data as specified in Table I.1, the calculations shall only be conducted, and results reported, for the CO_2 mass based method.

G.2.1.2 Reference values

The reference work and reference CO_2 mass shall be obtained from the parent engine bench-test for the non-road transient test cycle (hot-start NRTC run or LSI-NRTC as applicable), or, where a non-road transient test cycle does not apply, from the reference work and reference CO_2 mass determined according to Annex C.



Key

X time

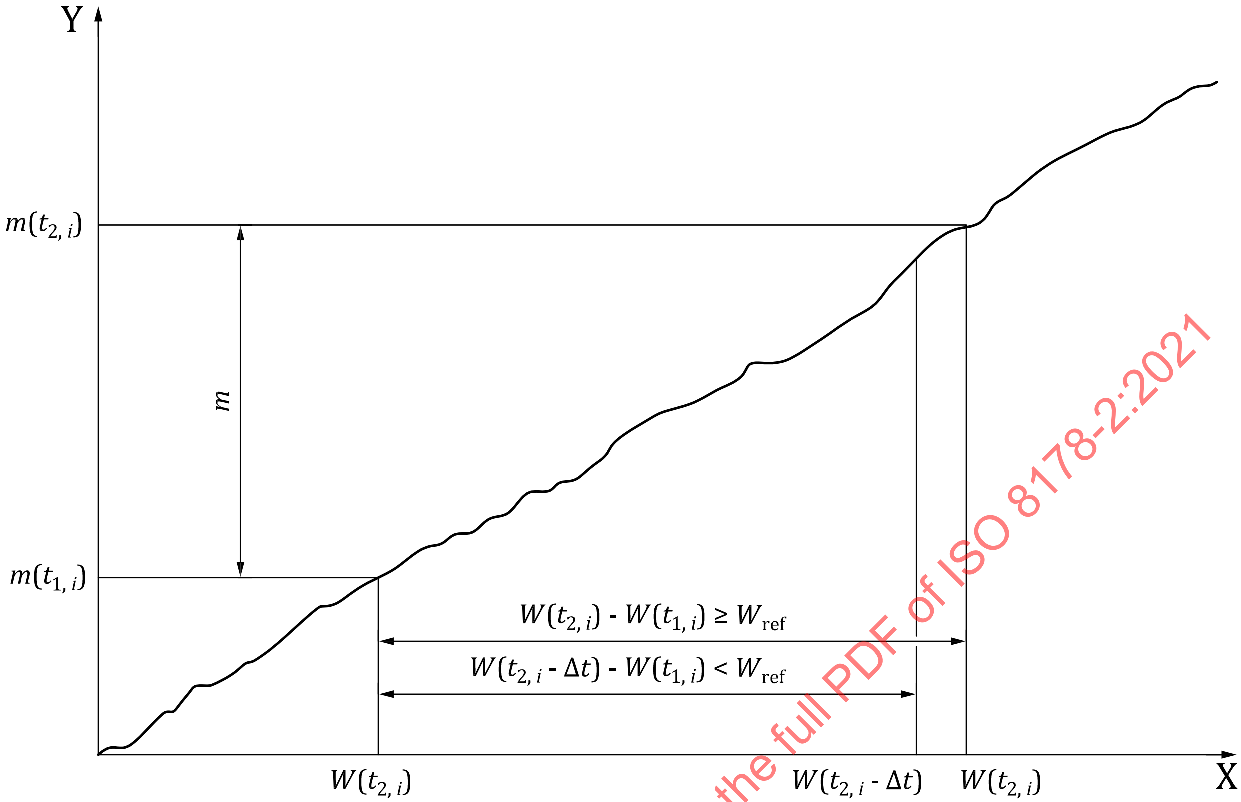
Y1 engine power [%]

Y2 averaging window emissions

1 emissions of the first window

Figure G.1 — Engine power versus time and averaging window gaseous pollutant emissions, starting from the first averaging window, versus time

G.2.2 Work based method



Key

X work [kWh]

Y emissions [g]

Figure G.2 — Work based method

This method is illustrated in Figure G.2.

The duration $(t_{2,i} - t_{1,i})$ of the i^{th} averaging window is determined by Formula (G.1):

$$W\left(t_{2,i}\right) - W\left(t_{1,i}\right) \geq W_{ref} \tag{G.1}$$

where

$W\left(t_{j,i}\right)$ is the engine work measured between the start and time $t_{j,i}$, kWh;

W_{ref} is the engine reference work determined according to G.2.1.2, kWh;

$t_{2,i}$ shall be selected such that, in accordance with Formula (G.2):

$$W\left(t_{2,i} - \Delta t\right) - W\left(t_{1,i}\right) < W_{ref} \leq W\left(t_{2,i}\right) - W\left(t_{1,i}\right) \tag{G.2}$$

where Δt is the data sampling period, equal to 1 s or less.

G.2.2.1 Calculations of the brake specific gaseous pollutant emissions

The brake specific gaseous pollutant emissions e_{gas} (g/kWh) shall be calculated for each averaging window and each gaseous pollutant using Formula (G.3):

$$e_{gas} = \frac{m}{W(t_{2,i}) - W(t_{1,i})} \qquad \text{(G.3)}$$

where

m is the mass emission of the gaseous pollutant, g/averaging window;

$W(t_{2,i}) - W(t_{1,i})$ is the engine work during the i^{th} averaging window, kWh.

G.2.2.2 Selection of valid averaging windows

The valid averaging windows are the averaging windows whose average power exceeds the power threshold of 20 % of the engine rated power for engine types, or where applicable engine families, for which the reference bench test cycle is D1, D2, E2 or E4, or exceeds the power threshold of 20 % of maximum power in all other cases maximum engine power for the engine type subject to ISM test. The percentage of valid averaging windows shall be equal or greater than 50 %.

If the percentage of valid windows is less than 50 %, the data evaluation shall be repeated using lower power thresholds. The power threshold shall be reduced from 20 % in steps of 1 % until the percentage of valid windows is equal to or greater than 50 %.

In any case, the lower power threshold shall not be lower than 15 %.

The test shall be considered void if the percentage of valid averaging windows is less than 50 % at a power threshold of 15 %.

G.2.2.3 Calculations of the conformity factors

In the case that the in-service test results are to be compared with an engine exhaust emission limit value, the conformity factors f_{CF} shall be calculated for each individual valid averaging window and each individual gaseous pollutant using Formula (G.4):

$$f_{CF} = \frac{e}{L} \qquad \text{(G.4)}$$

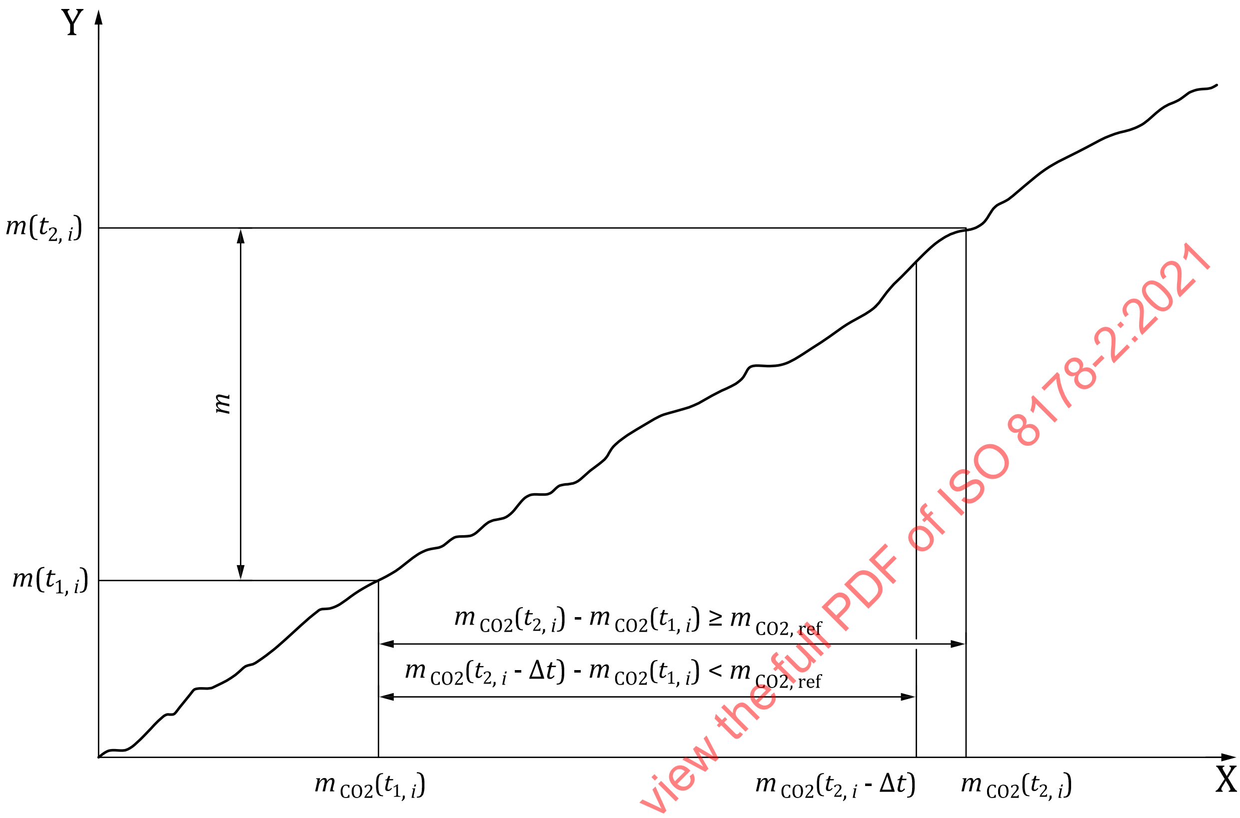
where

e is the brake-specific emission of the gaseous pollutant, g/kWh;

L is the applicable limit, g/kWh.

G.2.3 CO_2 mass based method

G.2.3.1 General



Key

X CO_2 emissions [kg]

Y emissions [g]

Figure G.3 — CO_2 mass based method

This method is illustrated in Figure G.3.

The duration $(t_{2,i} - t_{1,i})$ of the i^{th} averaging window is determined by Formula (G.5):

$$m_{CO_2}(t_{2,i}) - m_{CO_2}(t_{1,i}) \geq m_{CO_2,ref} \tag{G.5}$$

where

$m_{CO_2}(t_{2,i})$ is the CO_2 mass measured between the test start and time $t_{j,i}$, g;

$m_{CO_2,ref}$ is the reference CO_2 mass determined according to G.2.1.2, g;

$t_{2,i}$ shall be selected such that, in accordance with Formula (G.6):

$$m_{CO_2}(t_{2,i} - \Delta t) - m_{CO_2}(t_{1,i}) < m_{CO_2,ref} \leq m_{CO_2}(t_{2,i}) - m_{CO_2}(t_{1,i}) \tag{G.6}$$

where Δt is the data sampling period, equal to 1 s or less.

The CO_2 masses are calculated in the averaging windows by integrating the instantaneous gaseous pollutant emissions calculated according to the requirements introduced in Clause G.1.

G.2.3.2 Selection of valid averaging windows

The valid averaging windows shall be those whose duration does not exceed the maximum duration calculated from Formula (G.7):

$$D_{max} = 3\ 600 \times \frac{W_{ref}}{0{,}2 \times P_{max}} \tag{G.7}$$

where

D_{max} is the maximum averaging window duration, s;

P_{max} is the maximum engine power for the engine type subject to in-service test, kW;

W_{ref} is the engine reference work determined according to G.2.1.2, kWh.

The percentage of valid averaging windows shall be equal or greater than 50 %.

If the percentage of valid averaging windows is less than 50 %, the data evaluation shall be repeated using longer window durations. This is achieved by decreasing the value of 0,2 in the denominator of Formula (G.7) by steps of 0,01 until the percentage of valid windows is equal to or greater than 50 %.

In any case, the lowest value used in the denominator of Formula (G.7) shall not be less than 0,15.

The test shall be void if the percentage of valid windows is less than 50 % at a value of 0,15 in the denominator of Formula (G.7)

G.2.3.3 Calculations of the conformity factors

In the case that the in-service test results are to be compared with an engine exhaust emission limit value, the conformity factors shall be calculated for each individual averaging window and each individual pollutant in accordance with Formula (G8):

$$f_{CF} = \frac{f_{CFI}}{f_{CFC}} \tag{G.8}$$

With, in accordance with Formula (G.9):

$$\text{in service ratio } f_{CFI} = \frac{m_i}{m_{CO_2}(t_{2,i}) - m_{CO_2}(t_{1,i})} \tag{G.9}$$

and, in accordance with Formula (G.10):

$$\text{certification ratio } f_{CFC} = \frac{m_L}{m_{CO_2,ref}} \tag{G.10}$$

where

m_i	is the mass emission of the gaseous pollutant in the i^{th} averaging window, g;
$m_{CO_2}(t_{2,i}) - m_{CO_2}(t_{1,i})$	is the CO_2 mass in the i^{th} averaging window, g;
$m_{CO_2,ref}$	is the reference engine CO_2 mass determined according to G.2.1.2, g;
m_L	is the mass emission of gaseous pollutant corresponding to the applicable limit on the reference test cycle, g.

m_L is determined in accordance with Formula (G.11) as follows:

$$m_L = L \cdot W_{ref} \tag{G.11}$$

where

L is the applicable limit, g/kWh

W_{ref} is the engine reference work determined according to G.2.1.2, kWh.

G.3 Rounding of gaseous pollutant emissions calculations

In accordance with ASTM E 29-06b, the final test results shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure. No rounding of intermediate values leading to the final brake-specific gaseous pollutant emission result shall be allowed.

G.4 Gaseous pollutant emission results

The following results shall be reported:

a) the instantaneous concentration of the gaseous pollutant emissions measured during the in-service test;

b) the average of the concentration of the gaseous pollutant emissions for the whole in-service test;

c) the instantaneous mass of the gaseous pollutant emissions calculated in accordance to Clause G.1;

d) the integrated mass of the gaseous pollutant emissions for the whole in-service test, calculated as the addition of the mass of the instantaneous gaseous pollutant emissions calculated in accordance to Clause G.1;

e) the distribution of the conformity factors for the valid windows, calculated in accordance with G.2.2.3 and G.2.3.3 (minimum, maximum and 90th cumulative percentile).

Annex H
(normative)

Conformity of the ECU torque signal

H.1 Maximum torque method

H.1.1 General

The maximum torque method consists of confirming that a point on the reference maximum torque curve as a function of the engine speed has been reached during the in-service test.

If a point on the reference maximum torque curve as a function of the engine speed has not been reached during the in-service test, the load activity of the non-road mobile machinery and/or the minimum test duration set out in Clause B.2 may be modified as necessary in order to perform that demonstration after the in-service test.

H.1.2 Special considerations

The maximum torque method shall not be applied in the case that, in the opinion of the manufacturer and prior agreement of the parties concerned, it is not possible to reach a point on the maximum torque curve under normal operation without overloading the engine installed in the non-road mobile machinery, or to do so would not be safe.

In this case, the manufacturer shall propose an alternative method for checking the signal. The alternative method shall be employed only if the parties concerned consider it feasible and applicable without overloading the engine or any safety risk.

H.1.3 Alternative methods

The manufacturer may propose a more accurate and complete method for checking the conformity of the ECU torque signal during the in-service test. In that case, if agreed by the parties concerned, the alternative method may be used.

H.2 Impossibility to check the conformity of the ECU torque signal

When it is not possible to check the ECU torque signal during the in-service test, the evidence arising from verification of the ECU signal on a dynamometer test bench may be used with the agreement of the parties concerned.

In that case, when conducting the mapping procedure according to ISO 8178-4:2020, 7.4.1 or 7.4.2, readings of the torque measured by the dynamometer and torque broadcast by the ECU shall be taken simultaneously at a minimum of three points on the torque curve. At least one of the readings shall be taken at a point on the curve where the torque is no less than 98 % of the maximum value.

In the case of engines not subject to the mapping procedure of ISO 8178-4:2020, 7.4.1 or 7.4.2, alternative evidence may be used with the agreement of the parties concerned.

The torque broadcast by the ECU shall be accepted without correction if, at each point where measurements were taken, the factor calculated from dividing the torque value from the dynamometer by the torque value from the ECU is not less than 0,93 (i.e. a maximum difference of 7 %). Where the factor at one or more test points is less than 0,93 the average correction factor shall be determined from all the points where readings were taken and shall be applied to the torque broadcast by the ECU when conducting in-service tests.

Annex I
(normative)

ECU data stream information requirements

I.1 Data to be provided

The ECU shall provide at a minimum the measurement data listed in Table I.1.

Table I.1 — Measurement data

Parameter	Unit [a]
Engine torque [b]	Nm
Engine speed	r/min
Engine coolant temperature	°C

[a] Where the available data stream uses different units to those required by the table, that data stream shall be transformed into the required units during the data pre-processing set out in Annex D.

[b] The provided value shall be either (a) the net brake engine torque; or (b) the net brake engine torque calculated from other appropriate torque values as defined in the corresponding protocol standard set out in point 2.1.1. The basis for the net torque shall be uncorrected net torque delivered by the engine inclusive of the equipment and auxiliaries to be included for an emissions test in accordance with of ISO 8178-4:2020, Annex G.

Where either ambient pressure or ambient temperature are not measured by external sensors, they shall be provided by the ECU according to Table I.2.

Table I.2 — Additional measurement data

Parameter	Unit [a]
Ambient temperature [b]	°C
Ambient pressure	kPa
Engine fuel flow	g/s

[a] Where the available data stream uses different units to those required by the table, that data stream shall be transformed into the required units during the data pre-processing set out in Annex D.

[b] Use of an intake air temperature sensor shall comply with the requirements set out in the second paragraph of B.5.1.

Where exhaust mass flow is not measured directly, the engine fuel flow shall be provided according to Table B.1.

I.2 Communication requirements

I.2.1 Access to data stream information

Access to data stream information shall be provided in accordance with at least one of the following list items [a), b) or c)]:

a) ISO 27145-4 with ISO 15765-4 (CAN-based);

b) ISO 27145-4 with ISO 13400 (TCP/IP-based);

c) SAE J1939-73.