



BSI Standards Publication

# **Reciprocating internal combustion engines — Exhaust emission measurement**

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Part 4: Steady-state and transient test cycles for different engine applications

## National foreword

This British Standard is the UK implementation of ISO 8178-4:2017. It supersedes BS ISO 8178-4:2007, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/14/-/3, RIC engines - Emissions.

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

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© The British Standards Institution 2017  
Published by BSI Standards Limited 2017

ISBN 978 0 580 92540 5

ICS 27.020; 13.040.50

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2017.

### Amendments/corrigenda issued since publication

| Date | Text affected |
|------|---------------|
|------|---------------|

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**Reciprocating internal combustion  
engines — Exhaust emission  
measurement —**

**Part 4:  
Steady-state and transient test cycles  
for different engine applications**

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

*Partie 4: Cycles d'essai en régime permanent pour différentes  
applications des moteurs*





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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](http://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](http://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 on 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 the following URL: [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

The committee responsible for this document is ISO/TC 70, *Reciprocating internal combustion engines*, Subcommittee SC 8, *Exhaust emission measurement*.

This third edition cancels and replaces the second edition (ISO 8178-4:2007) which has been technically revised.

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

## Introduction

In comparison with engines for on-road applications, engines for non-road use are made in a much wider range of power output and configuration and are used in a great number of different applications.

The objective of this document is to rationalize the test procedures for non-road engines in order to simplify and make more cost effective the drafting of legislation, the development of engine specifications and the certification of engines to control gaseous and particulate emissions.

This document embraces three concepts in order to achieve the objectives.

The first principle is to group applications with similar engine operating characteristics in order to reduce the number of test cycles to a minimum, but ensure that the test cycles are representative of actual engine operation.

The second principle is to express the emissions results on the basis of brake power as defined in ISO 8178-1. This ensures that alternative engine applications do not result in a multiplicity of tests.

The third principle is the incorporation of an engine family concept in which engines with similar emission characteristics and of similar design may be represented by the highest emitting engine within the group.



# Reciprocating internal combustion engines — Exhaust emission measurement —

## Part 4: Steady-state and transient test cycles for different engine applications

### 1 Scope

This document specifies the test cycles, the test procedures and the evaluation of gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines coupled to a dynamometer. With certain restrictions, this document can also be used for measurements at site. The tests are carried out under steady-state and transient operation using test cycles which are representative of given applications.

This document is applicable to RIC engines for mobile, transportable and stationary use, excluding engines for on-road transport of passengers and goods. It may be applied to engines for non-road use, e.g. for earth-moving machines, generating sets and for other applications. For engines used in machinery covered by additional requirements (e.g. occupational health and safety regulations, regulations for power plants) additional test conditions and special evaluation methods may apply.

### 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, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

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

### 3 Terms and definitions

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

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

#### 3.1

##### **adjustment factors**

additive (upward adjustment factor and downward adjustment factor) or multiplicative factors to be used for engines equipped with emission controls, that are regenerated on an infrequent (periodic) basis

#### 3.2

##### **applicable emission limit**

emission limit to which an engine is subject

### 3.3 aqueous condensation

precipitation of water-containing constituents from a gas phase to a liquid phase

Note 1 to entry: Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulphuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition - including the amount of hydrogen and sulphur in the fuel

### 3.4 atmospheric pressure

wet, absolute, atmospheric static pressure

Note 1 to entry: If the atmospheric pressure is measured in a duct, negligible pressure losses shall be ensured between the atmosphere and the measurement location, and changes in the duct's static pressure resulting from the flow shall be accounted for

### 3.5 calibration

process of setting a measurement system's response so that its output agrees with a range of reference signals

Note 1 to entry: Contrast with *verification* ([3.80](#))

### 3.6 calibration gas

purified gas mixture used to calibrate gas analysers meeting the specifications of ISO 8178-1, 9.2

Note 1 to entry: Calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analysers and sample handling components might refer to either calibration gases or span gases

### 3.7 certification

relating to the process of obtaining a certificate of conformity

### 3.8 compression ignition engine CI engine

engine that works on the compression-ignition principle

### 3.9 constant-speed engine

engine whose type approval or certification is limited to constant-speed operation

Note 1 to entry: Engines whose constant-speed governor function is removed or disabled are no longer constant-speed engines

### 3.10 constant-speed operation

engine operation with a governor that automatically controls the operator demand to maintain engine speed, even under changing load

Note 1 to entry: Governors do not always maintain speed exactly constant. Typically, speed can decrease (0,1 to 10) % below the speed at zero load, such that the minimum speed occurs near the engine's point of maximum power

### 3.11 continuous regeneration

regeneration process of an exhaust after-treatment system that occurs either in a sustained manner or at least once over the applicable transient test cycle or ramped-modal cycle; in contrast to infrequent (periodic) regeneration

**3.12****conversion efficiency of non-methane cutter (NMC)****E**

efficiency of the conversion of an NMC that is used for the removal of the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane

Note 1 to entry: Ideally, the conversion for methane is 0 % ( $E_{\text{CH}_4} = 0$ ) and for the other hydrocarbons represented by ethane 100 % ( $E_{\text{C}_2\text{H}_6} = 100$  %). For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate for methane and ethane. Contrast with *penetration fraction* ([3.54](#))

**3.13****delay time**

difference in time between the change of the component to be measured at the reference point and a system response of 10 % of the final reading ( $t_{10}$ ) with the sampling probe being defined as the reference point

Note 1 to entry: For the gaseous components, this is the transport time of the measured component from the sampling probe to the detector (see [Figure 1](#))

**3.14****deNO<sub>x</sub> system**

exhaust after-treatment system designed to reduce emissions of oxides of nitrogen (NO<sub>x</sub>)

EXAMPLE passive and active lean NO<sub>x</sub> catalysts, NO<sub>x</sub> adsorbers and selective catalytic reduction (SCR) systems

**3.15****dew point**

measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity

Note 1 to entry: Dew point is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured

**3.16****discrete-mode**

relating to a discrete-mode type of steady-state test, as described in [7.5.1](#) and [Annex A](#)

**3.17****drift**

difference between a zero or calibration signal and the respective value reported by a measurement instrument immediately after it was used in an emission test, as long as the instrument was zeroed and spanned just before the test

**3.18****dual-fuel engine**

engine system that is designed to simultaneously operate with liquid fuel and a gaseous fuel, both fuels being metered separately, where the consumed amount of one of the fuels relative to the other one may vary depending on the operation

**3.19****emission-control system**

device, system, or element of design that controls or reduces the emissions of regulated pollutants from an engine

**3.20****engine family**

manufacturers grouping of engines which, through their design as defined in ISO 8178-7, have similar exhaust emission characteristics

Note 1 to entry: All members of the family shall comply with the applicable emission limit values.

**3.21**

**engine governed speed**

engine operating speed when it is controlled by the installed governor

**3.22**

**engine type**

category of engines which do not differ in essential engine characteristics

**3.23**

**exhaust after-treatment system**

catalyst, particulate filter, deNO<sub>x</sub> system, combined deNO<sub>x</sub> particulate filter or any other emission-reducing device that is installed downstream of the engine

Note 1 to entry: This definition excludes exhaust gas recirculation (EGR) and turbochargers, which are considered an integral part of the engine.

**3.24**

**exhaust-gas recirculation**

technology that reduces emissions by routing exhaust gases that had been exhausted from the combustion chamber(s) back into the engine to be mixed with incoming air before or during combustion

Note 1 to entry: The use of valve timing to increase the amount of residual exhaust gas in the combustion chamber(s) that is mixed with incoming air before or during combustion is not considered exhaust-gas recirculation for the purposes of this standard

**3.25**

**full flow dilution method**

process of mixing the total exhaust flow with dilution air prior to separating a fraction of the diluted exhaust stream for analysis

**3.26**

**gas energy ratio**

**GER**

the energy content (for a dual-fuel engine) of the gaseous fuel divided by the energy content of both fuels (liquid and gaseous), the energy content of the fuels being defined as the lower heating value

**3.27**

**gaseous fuel**

fuel which is wholly gaseous at standard ambient conditions

Note 1 to entry: Ambient temperature 298 K (25 °C), absolute ambient pressure 101,3 kPa.

**3.28**

**gaseous pollutants**

carbon monoxide, hydrocarbons and/or non-methane hydrocarbons (assuming a ratio of CH<sub>1,85</sub> for diesel), methane and oxides of nitrogen (expressed as nitrogen dioxide (NO<sub>2</sub>) equivalent)

**3.29**

**good engineering judgement**

judgement made consistent with generally accepted scientific and engineering principles and available relevant information

**3.30**

**governor**

device or control strategy that automatically controls engine speed or load that is not an over-speed limiter

### 3.31 hydrocarbon HC

THC, NMHC as applicable

Note 1 to entry: Hydrocarbon generally means the hydrocarbon group on which the emission standards are based for each type of fuel and engine.

### 3.32 high speed

$n_{hi}$

highest engine speed where 70 % of the maximum power occurs

### 3.33 idle speed

engine speed declared by the manufacturer that conforms to the requirements of [7.2.4](#)

### 3.34 infrequent (periodic) regeneration

regeneration process of an exhaust after-treatment system that occurs periodically in typically less than 100 hours of normal engine operation

Note 1 to entry: During cycles where regeneration occurs, emission standards may be exceeded

### 3.35 intermediate speed

engine speed declared by the manufacturer that conforms to the requirements of [7.2.3](#)

### 3.36 internationally traceable recognized standard

international standard which includes but is not limited to the list quoted in the following table:

**Table 1 — Internationally traceable recognized standard**

| Internationally recognized standard                   | Where copies of the documents may be purchased                                                                                                                                 |
|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| American Society for Testing and Materials (ASTM)     | American Society for Testing and Materials, 100 Barr Harbour Dr., P.O. Box C700, West Conshohocken, PA 19428 or <a href="http://www.astm.com">www.astm.com</a>                 |
| International Organization for Standardization (ISO)  | International Organization for Standardization, Case Postale 401, CH-1214 Vernier, Geneva, Switzerland or <a href="http://www.iso.org">www.iso.org</a>                         |
| National Institute of Standards and Technology (NIST) | Government Printing Office, Washington, DC 20402 or download them free from the Internet at <a href="http://www.nist.gov">www.nist.gov</a>                                     |
| Society of Automotive Engineering (SAE)               | Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096 or <a href="http://www.sae.org">www.sae.org</a>                                                  |
| Institute of Petroleum                                | Energy Institute, 61 New Cavendish Street, London, W1G 7AR, UK, +44 (0)20 7467 7100 or <a href="http://www.energyinst.org.uk">www.energyinst.org.uk</a>                        |
| The National Metrology Institute of Japan (NMIJ)      | AIST Tsukuba Headquarters, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan or <a href="http://www.nmij.jp/english/info/">www.nmij.jp/english/info/</a>                         |
| Japanese Industrial Standards (JIS)                   | Japanese Standards Association (JSA), 4-1-12 Akasaka, Minato-ku, 107-8440, Japan or <a href="http://www.jsa.org.jp/default_english.asp">www.jsa.org.jp/default_english.asp</a> |

### 3.37 linearity

degree to which measured values agree with respective reference values quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing

**3.38**

**liquid fuel**

fuel which exists in the liquid state under standard ambient conditions (298K, absolute ambient pressure 101,3 kPa)

**3.39**

**low speed**

$n_{lo}$

lowest engine speed where 50 % of the maximum power occurs

**3.40**

**maximum no load speed**

engine speed at which an engine governor function controls engine speed with operator demand at maximum and with zero load applied

**3.41**

**maximum power**

maximum power in kW as designed by the manufacturer

**3.42**

**maximum test speed**

engine speed determined from the curve of engine speed versus power according to [7.2.1](#)

**3.43**

**maximum torque speed**

engine speed at which the maximum torque is obtained from the engine, as designed by the manufacturer

**3.44**

**mode**

engine operating point characterized by a speed and a torque (or a power output)

**3.45**

**mode length**

time between leaving the speed and/or torque of the previous mode or the preconditioning phase and the beginning of the following mode

Note 1 to entry: It includes the time during which speed and/or torque is being changed and the stabilization at the beginning of each mode.

**3.46**

**non-methane hydrocarbons**

**NMHC**

sum of all hydrocarbon species except methane

**3.47**

**normalized speed and torque**

speed and torque values expressed as a percentage of a maximum value

**3.48**

**open crankcase emissions**

flow from an engine's crankcase that is emitted directly into the environment

Note 1 to entry: Crankcase emissions are not "open crankcase emissions" if the engine is designed to always route all crankcase emissions back into the engine (for example, through the intake system or an aftertreatment system) such that all the crankcase emissions, or their products, are emitted into the environment only through the engine exhaust system.

**3.49****operator demand**

engine operator's input to control engine output

Note 1 to entry: The "operator" may be a person (i.e. manual), or a governor (i.e. automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal. Output means engine power,  $P$ , which is the product of engine speed,  $n$ , and engine torque,  $T$ .

**3.50****oxides of nitrogen**

compounds containing only nitrogen and oxygen as measured by the procedures specified in this document

Note 1 to entry: Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO<sub>2</sub>, such that an effective molar mass is used for all oxides of nitrogen equivalent to that of NO<sub>2</sub>.

**3.51****partial pressure**

pressure,  $p$ , attributable to a single gas in a gas mixture

Note 1 to entry: For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration,  $x$ .

**3.52****partial flow dilution method**

process of separating a part from the total exhaust flow, then mixing it with an appropriate amount of dilution air prior to the particulate sampling filter

**3.53****particulate matter****PM**

material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature and a point as specified in ISO 8178-1, 8.1.3

Note 1 to entry: This is primarily carbon, condensed hydrocarbons, and sulphates with associated water.

**3.54****penetration fraction****PF**

deviation from ideal functioning of a non-methane cutter

Note 1 to entry: See *conversion efficiency of non-methane cutter (NMC) E*, [3.12](#).

Note 2 to entry: An ideal non-methane cutter would have a methane penetration factor,  $PF_{CH_4}$ , of 1,000 (that is, a methane conversion efficiency  $E_{CH_4}$  of 0), and the penetration fraction for all other hydrocarbons would be 0,000, as represented by  $PF_{C_2H_6}$  (that is, an ethane conversion efficiency  $E_{C_2H_6}$  of 1). The relationship is:  $PF_{CH_4} = 1 - E_{CH_4}$  and  $PF_{C_2H_6} = 1 - E_{C_2H_6}$

**3.55****per cent load**

fraction of the maximum available torque at an engine speed

**3.56****probe**

first section of the transfer line which transfers the sample to the next component in the sampling system

**3.57****procedures**

all aspects of engine testing, including the equipment specifications, calibrations, calculations and other protocols and specifications needed to measure emissions, unless otherwise specified

**3.58**

**ramped modal steady state test cycle**

test cycle with a sequence of steady state engine test modes with defined speed and torque criteria at each mode and defined speed and torque ramps between these modes

**3.59**

**rated power**

value of the power, declared by the manufacturer, which an engine will deliver under the specified test conditions

Note 1 to entry: For details see ISO 14396.

**3.60**

**rated speed**

engine speed at which, according to the statement of the engine manufacturer, and conforming to the requirements of [7.2.2](#), the rated power is delivered

Note 1 to entry: For details see ISO 14396.

**3.61**

**regeneration**

event during which emissions levels change while the after treatment performance is being restored by design

Note 1 to entry: Two types of regeneration can occur: continuous regeneration (see [5.5.1.2.1](#)) and infrequent (periodic) regeneration (see [5.5.1.2.2](#)).

**3.62**

**response time**

difference in time between the change of the component to be measured at the reference point and a system response of 90 % of the final reading ( $t_{90}$ ) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 % full scale (FS) and the devices for gas switching shall be specified to perform the gas switching in less than 0,1 s

Note 1 to entry: The system response time consists of the delay time to the system and of the rise time of the system.

**3.63**

**rise time**

difference in time of the 10 % and 90 % response of the final reading ( $t_{90} - t_{10}$ )

**3.64**

**shared atmospheric pressure meter**

atmospheric pressure meter whose output is used as the atmospheric pressure for an entire test facility that has more than one dynamometer test cell

**3.65**

**shared humidity measurement**

humidity measurement that is used as the humidity for an entire test facility that has more than one dynamometer test cell

**3.66**

**span (verb)**

adjust an instrument so that it gives a proper response to a calibration standard that represents between 75 % and 100 % of the maximum value in the instrument range or expected range of use

**3.67**

**span gas**

purified gas mixture used to span gas analysers meeting the specifications of ISO 8178-1, 9.2

Note 1 to entry: Calibration gases and span gases are qualitatively the same, but differ in terms of their primary function. Various performance verification checks for gas analysers and sample handling components might refer to either calibration gases or span gases.

**3.68****spark ignition engine****SI engine**

engine that works on the spark-ignition principle

**3.69****specific emissions**

mass emissions expressed in g/kWh

**3.70****steady-state**

emission tests in which engine speed and load are held at a finite set of nominally constant values

Note 1 to entry: Steady-state tests are either discrete-mode tests or ramped-modal tests.

**3.71****stoichiometric**

particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen

**3.72****test (or duty) cycle**

sequence of test points each with a defined speed and torque to be followed by the engine under steady state or transient operating conditions

Note 1 to entry: Duty cycles are specified in [Annexes A, B and C](#). A single duty cycle may consist of one or more test intervals.

**3.73****test interval**

duration of time over which brake-specific emissions are determined

Note 1 to entry: In cases where multiple test intervals occur over a duty cycle, the standard may specify additional calculations that weigh and combine results to arrive at composite values for comparison against the applicable emission limits.

**3.74****tolerance**

interval in which 95 % of a set of recorded values of a certain quantity shall lie, with the remaining 5 % of the recorded values deviating from the tolerance interval only due to measurement variability

Note 1 to entry: The specified recording frequencies and time intervals shall be used to determine if a quantity is within the applicable tolerance. For parameters not subject to measurement variability, tolerance means an absolute allowable range.

**3.75****total hydrocarbon****THC**

combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon

Note 1 to entry: Total hydrocarbon is expressed as a hydrocarbon with a hydrogen-to-carbon mass ratio of 1,85:1 (Diesel), 1,93 (petrol (E10)), 2,525 (LPG), 4,0 (NG/biomethane) or 2,74 (ethanol (E85)).

**3.76****transformation time**

difference in time between the change of the component to be measured at the reference point and a system response of 50 % of the final reading ( $t_{50}$ ) with the sampling probe being defined as the reference point

Note 1 to entry: The transformation time is used for the signal alignment of different measurement instruments (see [Figure 1](#)).

**3.77**

**transient test cycle**

test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time (NRTC)

**3.78**

**type approval**

approval of an engine type with regard to its emissions measured in accordance with the procedures specified in this document

**3.79**

**variable-speed engine**

engine that is not a constant-speed engine

**3.80**

**verification**

evaluation of whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance

Note 1 to entry: Contrast with *calibration* (3.5).

**3.81**

**zero** (verb)

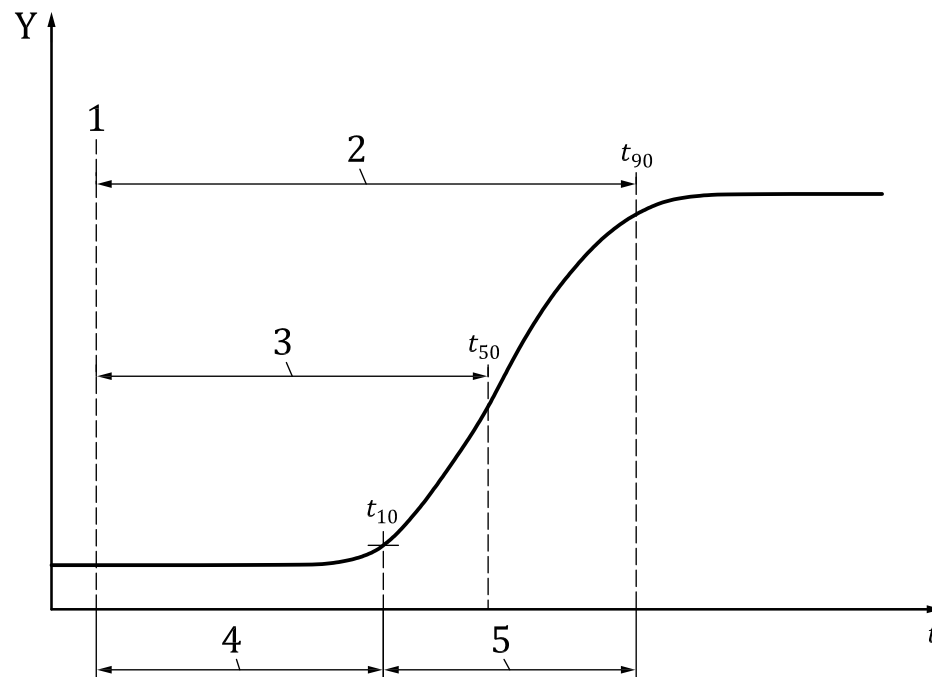
adjust an instrument so it gives a zero response to a zero calibration standard, such as purified nitrogen or purified air for measuring concentrations of emission constituents

**3.82**

**zero gas**

gas that yields a zero response in an analyser

Note 1 to entry: This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen.



#### Key

- 1 step input time
- 2 response time
- 3 transformation time
- 4 delay time
- 5 rise time
- $t$  Time
- $Y$  response

**Figure 1 — Definitions of system response: delay time (3.13), response time (3.62), rise time (3.63) and transformation time (3.76)**

## 4 Symbols and abbreviated terms

### 4.1 Quantities and units — Numbers

To facilitate the reading of numbers with many digits the following conventions apply in this document:

- The decimal sign is a comma on the line (,).

EXAMPLE 1      1 234,567 8

- If the magnitude (absolute value) of the number is less than 1, the decimal sign is preceded by a zero.

EXAMPLE 2      0,567 8

- An exponential number is expressed, as follows:

EXAMPLE 3       $1 \times 10^{12}$

## 4.2 General symbols

Table 2 — General symbols

| Symbol     | Term                                                                                         | Unit              |
|------------|----------------------------------------------------------------------------------------------|-------------------|
| $A/F_{st}$ | Stoichiometric air to fuel ratio                                                             | —                 |
| $a_0$      | y intercept of the regression line                                                           | —                 |
| $a_1$      | Slope of the regression line                                                                 | —                 |
| $A$        | Relative Atomic mass                                                                         | g/mol             |
| $c_d$      | Concentration in the dilution air                                                            | % (V/V)           |
| $C_d$      | CFV discharge coefficient [-]                                                                | —                 |
| $D$        | Dilution factor                                                                              | —                 |
| $\rho$     | Density                                                                                      | kg/m <sup>3</sup> |
| $d$        | Diameter                                                                                     | m                 |
| $E$        | Conversion efficiency                                                                        | %                 |
| $e_{gas}$  | Specific emission of gaseous components                                                      | g/kWh             |
| $e_{PM}$   | Specific emission of particulates                                                            | g/kWh             |
| $e_{PN}$   | Number of particles emitted                                                                  | #/kWh             |
| $e_w$      | Weighted specific emission                                                                   | g/kWh             |
| $f$        | Data sampling rate                                                                           | Hz                |
| $f_a$      | Laboratory atmospheric factor                                                                | —                 |
| $f_c$      | Carbon factor                                                                                | —                 |
| $f_{fd}$   | Fuel specific factor for exhaust flow calculation on dry basis                               | —                 |
| $f_{fh}$   | Fuel specific factor used for the calculations of wet concentrations from dry concentrations | —                 |
| $f_{fw}$   | Fuel specific factor for exhaust flow calculation on wet basis                               | kg/ms             |
| $F_S$      | stoichiometric factor                                                                        | —                 |
| $\mu$      | Dynamic viscosity of exhaust gas                                                             | Pa*s              |
| $H_a$      | Absolute humidity of the intake air (g water/kg dry air)                                     | g/kg              |
| $H_d$      | Absolute humidity of the dilution air (g water/kg dry air)                                   | g/kg              |
| $i$        | Subscript denoting an individual mode                                                        | —                 |
| $i$        | Subscript denoting an instantaneous measurement (e.g. - Hz)                                  | —                 |
| $k_{Dr}$   | Additive downward adjustment factor                                                          | —                 |
| $k_f$      | Fuel specific factor                                                                         | —                 |
| $k_{h,D}$  | Humidity correction factor for NO <sub>x</sub> for CI engines                                | —                 |
| $k_{h,G}$  | Humidity correction factor for NO <sub>x</sub> for SI engines                                | —                 |
| $k_{MDr}$  | Multiplicative downward adjustment factor                                                    | —                 |
| $k_{MUr}$  | Multiplicative upward adjustment factor                                                      | —                 |
| $k_r$      | Multiplicative regeneration factor                                                           | —                 |
| $k_{Ur}$   | Additive upward adjustment factor                                                            | —                 |
| $k_w$      | Dry to wet correction factor for the raw exhaust gas                                         | —                 |
| $k_{w,d}$  | Dry to wet correction factor for the dilution air                                            | —                 |
| $k_{w,e}$  | Dry to wet correction factor for the diluted exhaust gas                                     | —                 |
| $k_{w,r}$  | Dry to wet correction factor for the raw exhaust gas                                         | —                 |
| $\lambda$  | Excess air ratio                                                                             | —                 |
| $L$        | %torque                                                                                      | —                 |
| $m$        | Mass                                                                                         | kg                |

Table 2 (continued)

| Symbol     | Term                                                                                                           | Unit                 |
|------------|----------------------------------------------------------------------------------------------------------------|----------------------|
| $m_d$      | Mass of the dilution air sample passed through the particulate sampling filters                                | kg                   |
| $m_{edf}$  | Mass of equivalent diluted exhaust gas over the cycle                                                          | kg                   |
| $m_f$      | Particulate sample mass collected                                                                              | mg                   |
| $m_{ed}$   | mass of diluted exhaust gas over the cycle                                                                     | kg                   |
| $m_{f,d}$  | Particulate sample mass of the dilution air collected                                                          | mg                   |
| $M_{gas}$  | Molar mass of gaseous components                                                                               | g/mol                |
| $m_{gas}$  | Mass of gaseous emissions over the test cycle                                                                  | g                    |
| $m_{PM}$   | Mass of particulate emissions over the test cycle                                                              | g                    |
| $M$        | Molar mass                                                                                                     | g/mol                |
| $m_{se}$   | Exhaust sample mass over the cycle                                                                             | kg                   |
| $m_{sed}$  | Mass of diluted exhaust gas passing the dilution tunnel                                                        | kg                   |
| $m_{sep}$  | Mass of the diluted exhaust sample passed through the particulate sampling filters                             | kg                   |
| $n$        | Engine speed                                                                                                   | min <sup>-1</sup>    |
| $n_{hi}$   | High engine speed                                                                                              | min <sup>-1</sup>    |
| $n_{lo}$   | Low engine speed                                                                                               | min <sup>-1</sup>    |
| $P$        | Power                                                                                                          | kW                   |
| $p$        | Pressure                                                                                                       | kPa                  |
| $P_{AUX}$  | Declared total power absorbed by auxiliaries fitted for the test and not required by ISO – 4396                | kW                   |
| $p_a$      | Saturation vapour pressure of the intake air                                                                   | kPa                  |
| $p_b$      | Total atmospheric pressure                                                                                     | kPa                  |
| $p_d$      | Saturation vapour pressure of the dilution air                                                                 | kPa                  |
| $PF$       | Penetration fraction                                                                                           | %                    |
| $P_{max}$  | Maximum observed or declared power at the test speed under the test conditions (specified by the manufacturer) | kW                   |
| $p_r$      | Water vapor pressure after cooling bath                                                                        | kPa                  |
| $p_s$      | Dry atmospheric pressure                                                                                       | kPa                  |
| $q_{mad}$  | Dry intake air flow rate                                                                                       | kg/s                 |
| $q_{maw}$  | Intake air mass flow rate on wet basis                                                                         | kg/s                 |
| $q_{mdew}$ | Diluted exhaust gas mass flow rate on wet basis                                                                | kg/s                 |
| $q_{mdw}$  | Dilution air mass flow rate on wet basis                                                                       | kg/s                 |
| $q_{medf}$ | Equivalent diluted exhaust gas mass flow rate on wet basis                                                     | kg/s                 |
| $q_{mew}$  | Exhaust gas mass flow rate on wet basis                                                                        | kg/s                 |
| $q_{mf}$   | Fuel mass flow rate                                                                                            | kg/s                 |
| $q_{mgas}$ | Emission mass flow rate of individual gas                                                                      | g/h                  |
| $q_{mp}$   | Sample flow of exhaust gas into partial flow dilution system                                                   | kg/s                 |
| $q_{sw}$   | mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction               | kg/s                 |
| $q_v$      | Volume flow rate                                                                                               | m <sup>3</sup> /s    |
| $q_{vt}$   | Tracer gas flow rate                                                                                           | cm <sup>3</sup> /min |
| $r^2$      | Coefficient of determination                                                                                   | —                    |
| $r_d$      | Dilution ratio                                                                                                 | —                    |
| $R$        | molar gas constant                                                                                             | J/(mol K)            |
| $RF$       | Response factor                                                                                                | —                    |

Table 2 (continued)

| Symbol    | Term                                                      | Unit             |
|-----------|-----------------------------------------------------------|------------------|
| $rs$      | Average sample ratio                                      | —                |
| $S$       | Dynamometer setting                                       | kW               |
| $SEE$     | Standard error of estimate of $y$ on $x$                  | —                |
| $T$       | Temperature                                               | °C               |
| $T$       | Engine torque                                             | Nm               |
| $t$       | Time                                                      | s                |
| $t_{10}$  | Time between step input and 10 % of final reading         | s                |
| $t_{50}$  | Time between step input and 50 % of final reading         | s                |
| $t_{90}$  | Time between step input and 90 % of final reading         | s                |
| $T_a$     | Absolute temperature of the intake air                    | K                |
| $T_{dew}$ | Absolute dewpoint temperature                             | K                |
| $T_{ref}$ | Absolute reference temperature (of combustion air: 298 K) | K                |
| $u_{gas}$ | Ratio between densities of gas component and exhaust gas  | —                |
| $V$       | Volume                                                    | m <sup>3</sup>   |
| $V_m$     | Molar volume                                              | l/mol            |
| $W$       | Work                                                      | kWh              |
| $W_{act}$ | Actual cycle work of the respective test cycle            | kWh              |
| $WF$      | Weighting factor                                          | —                |
| $x$       | Concentration                                             | μmol/mol<br>or % |
| $\bar{y}$ | Arithmetic mean                                           |                  |

### 4.3 Symbols and abbreviated terms for fuel composition

|                                                                        |                                      |
|------------------------------------------------------------------------|--------------------------------------|
| $w_H$                                                                  | hydrogen content of fuel, % mass     |
| $w_C$                                                                  | carbon content of fuel, % mass       |
| $w_S$                                                                  | sulfur content of fuel, % mass       |
| $w_N$                                                                  | nitrogen content of fuel, % mass     |
| $w_O$                                                                  | oxygen content of fuel, % mass       |
| $\alpha$                                                               | molar hydrogen-to-carbon ratio (H/C) |
| $\beta$                                                                | molar carbon-to-carbon ratio (C/C)   |
| $\gamma$                                                               | molar sulphur-to-carbon ratio (S/C)  |
| $\delta$                                                               | molar nitrogen-to-carbon ratio (N/C) |
| $\varepsilon$                                                          | molar oxygen-to-carbon ratio (O/C)   |
| referring to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$ |                                      |

#### 4.4 Symbols and abbreviated terms for chemical components

|                                  |                                 |
|----------------------------------|---------------------------------|
| Ar                               | Argon                           |
| C <sub>1</sub>                   | Carbon 1 equivalent hydrocarbon |
| C <sub>2</sub> H <sub>6</sub>    | Ethane                          |
| C <sub>2</sub> H <sub>5</sub> OH | Ethanol                         |
| C <sub>3</sub> H <sub>8</sub>    | Propane                         |
| CH <sub>3</sub> OH               | Methanol                        |
| CH <sub>4</sub>                  | Methane                         |
| CO                               | Carbon monoxide                 |
| CO <sub>2</sub>                  | Carbon dioxide                  |
| H                                | Atomic hydrogen                 |
| H <sub>2</sub>                   | Molecular hydrogen              |
| H <sub>2</sub> O                 | Water                           |
| HC                               | Hydrocarbon                     |
| HCHO                             | Formaldehyde                    |
| He                               | Helium                          |
| N <sub>2</sub>                   | Molecular nitrogen              |
| N <sub>2</sub> O                 | Nitrous oxide                   |
| NH <sub>3</sub>                  | Ammonia                         |
| NMHC                             | Non-methane hydrocarbon         |
| NO                               | Nitric oxide                    |
| NO <sub>2</sub>                  | Nitrogen dioxide                |
| NO <sub>x</sub>                  | Oxides of nitrogen              |
| O <sub>2</sub>                   | Oxygen                          |
| PM                               | Particulate matter              |
| RME                              | Rapeseed oil methylester        |
| S                                | Sulphur                         |
| SO <sub>2</sub>                  | Sulphur dioxide                 |
| THC                              | Total hydrocarbon               |

#### 4.5 Abbreviated terms

|                                                    |                                                                  |
|----------------------------------------------------|------------------------------------------------------------------|
| ASTM                                               | American Society for Testing and Materials                       |
| CFV                                                | Critical flow venturi                                            |
| CI                                                 | Compression-ignition                                             |
| CNG                                                | Compressed Natural Gas                                           |
| CVS                                                | Constant volume sampling                                         |
| deNO <sub>x</sub>                                  | NO <sub>x</sub> after-treatment system                           |
| EGR                                                | Exhaust gas recirculation                                        |
| FID                                                | Flame ionization detector                                        |
| FS                                                 | Full scale                                                       |
| GER                                                | Gas Energy Ratio                                                 |
| G <sub>R</sub> , G <sub>23</sub> , G <sub>25</sub> | Gaseous EU reference fuels according to ISO 8178-5               |
| IEC                                                | International Electrotechnical Commission                        |
| ISO                                                | International Organization for Standardization                   |
| LNG                                                | Liquefied Natural Gas                                            |
| LPG                                                | Liquefied Petroleum Gas                                          |
| NMC                                                | Non-methane cutter                                               |
| NRMM                                               | Non-road mobile machinery                                        |
| NRTC                                               | Non Road Transient Cycle                                         |
| PDP                                                | Positive displacement pump                                       |
| PF                                                 | Penetration fraction                                             |
| PFS                                                | Partial Flow System                                              |
| PM                                                 | Particulate matter                                               |
| PTFE                                               | Polytetrafluoroethylene (commonly known as Teflon®) <sup>a</sup> |
| RIC                                                | Reciprocating internal combustion (engines)                      |
| RMC                                                | Ramped-modal cycle                                               |
| SAE                                                | Society of Automotive Engineers                                  |
| SSV                                                | Subsonic venture                                                 |

<sup>a</sup> Teflon® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

## 5 Test conditions

### 5.1 Engine test conditions

#### 5.1.1 Laboratory test conditions

The absolute temperature ( $T_a$ ) of the engine air at the inlet to the engine expressed in Kelvin, and the dry atmospheric pressure ( $p_s$ ), expressed in kPa shall be measured and the parameter  $f_a$  shall be determined according to the following provisions. In multi-cylinder engines having distinct groups of intake manifolds, such as in a "V" engine configuration, the average temperature of the distinct groups shall be taken. The parameter  $f_a$  shall be reported with the test results.

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left[ \frac{99}{p_s} \right] \times \left[ \frac{T_a}{298} \right]^{0,7} \quad (1)$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left[ \frac{99}{p_s} \right]^{0,7} \times \left[ \frac{T_a}{298} \right]^{1,5} \quad (2)$$

#### 5.1.2 Test validity

- a) For the test to be considered valid both the following conditions must be met:
  - 1)  $f_a$  shall be within the range  $0,93 \leq f_a \leq 1,07$  except as permitted by b) and d);
  - 2) The temperature of intake air shall be maintained to  $(25 \pm 5) ^\circ\text{C}$ , as measured upstream of any engine component, except as permitted by c) and d).
- b) Where the altitude of the laboratory in which the engine is being tested exceeds [600] m, with the agreement of the manufacturer  $f_a$  may exceed 1,07 on the condition that  $p_s$  shall not be less than 80 kPa.
- c) Where the power of the engine being tested is greater than 560 kW, with the agreement of the manufacturer the maximum value of intake air temperature may exceed  $30 ^\circ\text{C}$  on the condition that it shall not exceed  $35 ^\circ\text{C}$ .
- d) Where the altitude of the laboratory in which the engine is being tested exceeds [300] m and the power of the engine being tested is greater than 560 kW, with the agreement of the manufacturer  $f_a$  may exceed 1,07 on the condition that  $p_s$  shall not be less than 80 kPa and the maximum value of intake air temperature may exceed  $30 ^\circ\text{C}$  on the condition that it shall not exceed  $35 ^\circ\text{C}$ .

The following is allowed:

- a) A shared atmospheric pressure meter as long as the equipment for handling intake air maintains ambient pressure, where the engine is tested, within  $\pm 1$  kPa of the shared atmospheric pressure;
- b) A shared humidity measurement for intake air as long as the equipment for handling intake air maintains dew point, where the engine is tested, within  $\pm 0,5 ^\circ\text{C}$  of the shared humidity measurement.

### 5.2 Engine power

The basis of specific emissions measurement is uncorrected brake power as defined in ISO 14396. The engine shall be submitted for testing with the auxiliaries needed for operating the engine.

### 5.2.1 Auxiliaries to be fitted

During the test, the auxiliaries necessary for the engine operation shall be installed on the test bench according to the requirements of [Annex G](#).

Where the necessary auxiliaries cannot be fitted for the test, the power they absorb shall be determined and subtracted from the measured engine power.

### 5.2.2 Auxiliaries to be removed

Certain auxiliaries whose definition is linked with the operation of the machine and which may be mounted on the engine shall be removed for the test.

Where auxiliaries cannot be removed, the power they absorb in the unloaded condition may be determined and added to the measured engine power (see [Table G.1](#), footnote <sup>h)</sup>). If this value is greater than 3 % of the maximum power at the test speed it may be verified by the parties involved. The power absorbed by auxiliaries shall be used to adjust the set values and to calculate the work produced by the engine over the test cycle.

### 5.2.3 Determination of auxiliary power

The power absorbed by the auxiliaries/equipment needs only be determined, if:

- a) Auxiliaries/equipment required according to [Annex G](#) are not fitted to the engine; and/or
- b) Auxiliaries/equipment not required according to [Annex G](#) are fitted to the engine.

The values of auxiliary power and the measurement/calculation method for determining auxiliary power shall be submitted by the engine manufacturer for the whole operating area of the applicable test cycles, and approved by the parties involved.

### 5.2.4 Engine cycle work

The calculation of reference and actual cycle work (see [8.6.3.5](#)) shall be based upon engine power according to [5.2.1](#). In this case,  $P_f$  and  $P_r$  of [Formula \(3\)](#) are zero, and  $P$  equals  $P_m$ .

If auxiliaries/equipment are installed according to [5.2.1](#) and/or [5.2.2](#), the power absorbed by them shall be used to correct each instantaneous cycle power value  $P_{m,i}$ , as follows:

$$P_i = P_{m,i} + P_{AUX} \quad (3)$$

where

$P_{m,i}$  is the measured engine power, kW;

$P_{AUX} = P_{r,i} - P_{f,i}$

$P_{f,i}$  is the power absorbed by auxiliaries/equipment to be fitted for the test but that were not installed, kW;

$P_{r,i}$  is the power absorbed by auxiliaries/equipment to be removed for the test but that were installed, kW.

## 5.3 Engine intake air

### 5.3.1 Introduction

The intake-air system installed on the engine or one that represents a typical in-use configuration shall be used. This includes the charge-air cooling and exhaust gas recirculation systems.

### 5.3.2 Intake air restriction

An engine air intake system or a test laboratory system shall be used presenting an air intake restriction within  $\pm 300$  Pa of the maximum value specified by the manufacturer for a clean air cleaner at the rated speed and full load. Where this is not possible due to the design of the test laboratory air supply system a restriction not exceeding the value specified by the manufacturer for a dirty filter shall be permitted subject to prior approval of the parties involved. The static differential pressure of the restriction shall be measured at the location specified by the manufacturer. If the manufacturer does not specify a location, this pressure shall be measured upstream of any turbocharger or exhaust gas recirculation system connection to the intake air system.

When the maximum test speed (MTS) defined in 3.42 is being used in place of rated speed to run the test cycle then this speed may be used in place of rated speed when setting the intake air restriction.

### 5.3.3 Engines with charge air cooling

A charge-air cooling system with a total intake-air capacity that represents the production engine's in-use installation shall be used. Any laboratory charge-air cooling system shall be designed to minimize accumulation of condensate. Any accumulated condensate shall be drained and all drains shall be completely closed before emission testing. The drains shall be kept closed during the emission test. Coolant conditions shall be maintained as follows:

- a) A coolant temperature of at least 20 °C shall be maintained at the inlet to the charge-air cooler throughout testing;
- b) At the rated speed and full load, the coolant flow rate shall be set to achieve an air temperature within  $\pm 5$  °C of the value designed by the manufacturer after the charge-air cooler's outlet. The air-outlet temperature shall be measured at the location specified by the manufacturer. This coolant flow rate set point shall be used throughout testing;
- c) If the engine manufacturer specifies pressure-drop limits across the charge-air cooling system, it shall be ensured that the pressure drop across the charge-air cooling system at engine conditions specified by the manufacturer is within the manufacturer's specified limit(s). The pressure drop shall be measured at the manufacturer's specified locations;

When the maximum test speed (MTS) defined in 3.42 is being used in place of rated speed to run the test cycle then this speed may be used in place of rated speed when setting the charge air temperature.

The objective is to produce emission results that are representative of in-use operation. If good engineering judgment indicates that the specifications in this clause would result in unrepresentative testing (such as overcooling of the intake air), with the prior agreement of the parties involved more sophisticated set points and controls of charge-air pressure drop, coolant temperature, and flow rate may be used to achieve more representative results.

## 5.4 Engine exhaust system

### 5.4.1 Introduction

The exhaust system installed with the engine or one that represents a typical in-use configuration shall be used. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in ISO 8178-1, 5.2.1.

### 5.4.2 Exhaust restriction

An engine exhaust system or a test laboratory system shall be used presenting a static exhaust backpressure within 80 % to 100 % of the maximum exhaust restriction specified by the manufacturer at the rated speed and full load. The restriction may be set using a valve. If the maximum restriction is 5 kPa or less, the set point shall not be more than 1,0 kPa from the maximum.

When the maximum test speed (MTS) defined in [3.42](#) is being used in place of rated speed to run the test cycle then this speed may be used in place of rated speed when setting the exhaust restriction.

### 5.4.3 Engine with exhaust after-treatment system

If the engine is equipped with an exhaust after-treatment system, the exhaust pipe shall have the same diameter as found in-use, or as specified by the manufacturer, for at least four pipe diameters upstream of the expansion section containing the after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment system shall be the same as in the in-use configuration or within the distance specifications of the manufacturer. Where other installation requirements are specified by the manufacturer these shall also be respected for the test configuration. The exhaust restriction shall be set according to [5.4.2](#). For variable-restriction after-treatment devices, the maximum exhaust restriction used in [5.4.2](#) is defined at the after-treatment condition (degreening/ageing and regeneration/loading level) specified by the manufacturer. The after-treatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

## 5.5 Specific test conditions

### 5.5.1 Engine with exhaust after-treatment system

The emissions measured on the test cycle shall be representative of the emissions in the field.

#### 5.5.1.1 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 declared by the manufacturer.

#### 5.5.1.2 Regeneration

For engines equipped with exhaust after-treatment systems that are regenerated on an infrequent (periodic) basis, as described in [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. After-treatment systems with continuous regeneration according to [5.5.1.2.1](#) do not require a special test procedure.

If the exhaust aftertreatment has a security mode that works on an infrequent (periodic) regeneration mode, it shall be checked according to [5.5.1.2.2](#). For that specific case, the applicable emission limits could be exceeded and the measured emissions would not be weighted.

##### 5.5.1.2.1 Continuous regeneration

For an exhaust aftertreatment system based on a continuous regeneration process the emissions shall be measured on an aftertreatment system that has been stabilized so as to result in repeatable emissions behaviour. The regeneration process shall occur at least once during the NRTC hot start test, LSI-NRTC or NRSC test, and the manufacturer shall declare the normal conditions under which regeneration occurs (soot load, temperature, exhaust back-pressure, etc.). In order to demonstrate that the regeneration process is continuous, at least three NRTC hot start tests, LSI-NRTC or NRSC tests shall be conducted. In case of NRTC hot start test, the engine shall be warmed up in accordance with [8.4.2](#), the engine shall be soaked according to [8.6.3](#) and the first NRTC hot start test run. The subsequent NRTC hot start tests shall be started after soaking according to [8.6.3](#). During the tests, exhaust temperatures and pressures shall be recorded (temperature before and after the after-treatment system, exhaust back pressure, etc.). The aftertreatment system is considered to be satisfactory if the conditions declared by the manufacturer occur during the test during a sufficient time and the emission results do not scatter by more than  $\pm 25\%$  from the mean value or 0,005 g/kWh, whichever is greater. If the exhaust aftertreatment has a security mode that shifts to an infrequent (periodic) regeneration mode, it shall be checked according to [5.5.1.2.2](#). For that specific case, the applicable emission limits could be exceeded and would not be weighted.

#### 5.5.1.2.2 Infrequent (periodic) regeneration

This provision only applies for engines equipped with emission controls that are regenerated on a periodic basis.

Testing and development of adjustment factors is only required for one applicable transient (NRTC or LSI-NRTC) or RMC test cycle. The factors that have been developed may be applied to results from the other applicable test cycles including discrete-mode NRSC.

In case that no suitable adjustment factors are available from testing using transient or RMC test cycles then adjustment factors shall be established using an applicable discrete-mode test. Factors developed using a discrete-mode test cycle shall only be applied to discrete-mode test cycles.

It shall not be required to conduct testing and develop adjustment factors on both RMC and discrete-mode NRSCs.

##### 5.5.1.2.2.1 Requirement for establishing adjustment factors using NRTC, LSI-NRTC or RMC NRSC testing

The emissions shall be measured on at least three NRTC hot start tests, LSI-NRTC or ramped-modal cycle (RMC) NRSC tests, one with and two without a regeneration event on a stabilized aftertreatment system. The regeneration process shall occur at least once during the NRTC, LSI-NRTC or RMC NRSC test with a regeneration event. If regeneration takes longer than one NRTC, LSI-NRTC or RMC NRSC test, consecutive NRTC, LSI-NRTC or RMC NRSC tests shall be run and emissions continued to be measured without shutting the engine off until regeneration is completed and the average of the tests shall be calculated. If regeneration is completed during any test, the test shall be continued over its entire length.

An appropriate adjustment factor shall be determined for the entire applicable cycle using [Formulae \(5\) to \(8\)](#).

##### 5.5.1.2.2.2 Requirement for establishing adjustment factors using discrete-mode NRSC testing

Starting with a stabilized after-treatment system the emissions shall be measured on at least three runs of each test mode of the applicable discrete-mode NRSC on which the conditions for regeneration can be met, one with and two without a regeneration event. The measurement of PM shall be conducted using the multiple filter method. If regeneration has started but is not complete at the end of the sampling period for a specific test mode extend the sampling period until regeneration is complete. Where there are multiple runs for the same mode an average result shall be calculated. The process shall be repeated for each test mode.

An appropriate adjustment factor shall be determined using [Formulae \(5\) to \(8\)](#) for those modes of the applicable cycle for which regeneration occurs.

##### 5.5.1.2.2.3 General procedure for developing infrequent regeneration adjustment factors (IRAFs)

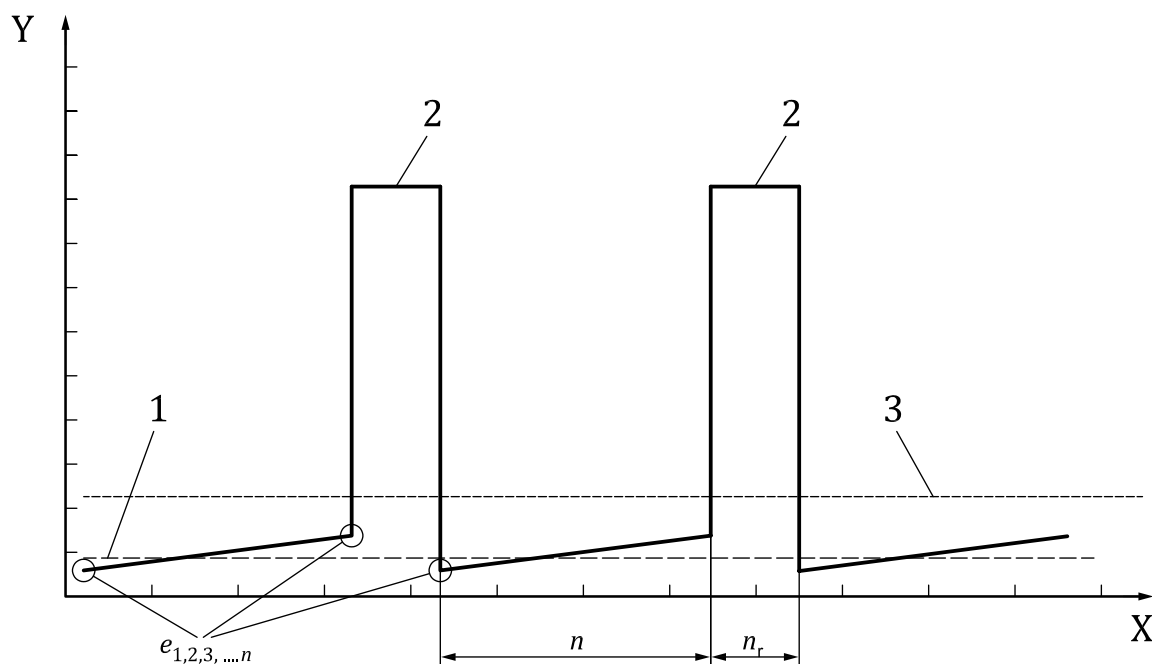
The engine may be equipped with a switch capable of preventing or permitting the regeneration process provided this operation has no effect on the original engine calibration.

The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust back pressure, etc.). The manufacturer shall also provide the frequency of the regeneration event in terms of number of tests during which the regeneration occurs. The exact procedure to determine this frequency shall be agreed by the parties involved based upon good engineering judgement.

For a regeneration test, the manufacturer shall provide an aftertreatment system that has been loaded. Regeneration shall not occur during this engine conditioning phase. As an option, the manufacturer may run consecutive tests of the applicable cycle until the aftertreatment system is loaded. Emissions measurement is not required on all tests.

Average emissions between regeneration phases shall be determined from the arithmetic mean of several approximately equidistant tests of the applicable cycle. As a minimum, at least one applicable cycle as close as possible prior to a regeneration test and one applicable cycle immediately after a regeneration test shall be conducted.

During the regeneration test, all the data needed to detect regeneration shall be recorded (CO or NO<sub>x</sub> emissions, temperature before and after the after-treatment system, exhaust back pressure, etc.). During the regeneration process, the applicable emission limits may be exceeded. The test procedure is schematically shown in [Figure 2](#).



#### Key

- X number of test cycles
- Y emissions (g/kWh or #/kWh)
- 1 mean emissions during sampling  $e_{1,2,3,...,n}$
- 2 emissions during regeneration  $e_r$
- 3 weighted emissions of sampling and regeneration  $e_w$
- $n$  number of tests cycles in which regeneration does not occur
- $n_r$  number of tests cycles in which regeneration occurs (minimum one test)

**Figure 2 — Scheme of infrequent (periodic) regeneration with  $n$  number of measurements and  $n_r$  number of measurements during regeneration**

The average specific emission rate related to the test runs conducted according to [5.5.1.2.2.1](#) or [5.5.1.2.2.2](#) [g/kWh or #/kWh] shall be weighted as follows (see [Figure 2](#)):

$$\bar{e}_w = \frac{n \cdot \bar{e} + n_r \cdot \bar{e}_r}{n + n_r} \quad (4)$$

where

- $n$  number of tests in which regeneration does not occur;
- $n_r$  number of tests in which regeneration occurs (minimum one test);
- $\bar{e}_w$  average specific emission from a test in which the regeneration does not occur [g/kWh or #/kWh];
- $\bar{e}_r$  average specific emission from a test in which the regeneration occurs [g/kWh or #/kWh].

At the choice of the manufacturer and based on upon good engineering analysis, the regeneration adjustment factor  $k_r$ , expressing the average emission rate, may be calculated either multiplicative or additive for all gaseous pollutants, and, where there is an applicable limit for PM and PN, as follows:

#### Multiplicative

$$k_{MUr} = \frac{\bar{e}_w}{\bar{e}} \text{ (upward adjustment factor)} \quad (5)$$

$$k_{MDr} = \frac{\bar{e}_w}{\bar{e}_r} \text{ (downward adjustment factor)} \quad (6)$$

#### Additive

$$k_{Ur} = \bar{e}_w - \bar{e} \text{ (upward adjustment factor)} \quad (7)$$

$$k_{Dr} = \bar{e}_w - \bar{e}_r \text{ (downward adjustment factor)} \quad (8)$$

Upward adjustment factors are multiplied with or added to measured emission rates for all tests in which the regeneration does not occur. Downward adjustment factors are multiplied with or added to measured emission rates for all tests in which the regeneration occurs. The occurrence of the regeneration shall be identified in a manner that is readily apparent during all testing. Where no regeneration is identified, the upward adjustment factor shall be applied.

With reference to [Clause 9](#) and [Annex H](#) on brake specific emission calculations, the regeneration adjustment factor:

- a) When established for an entire weighted cycle, shall be applied to the results of the applicable weighted NRTC, LSI-NRTC and NRSC tests;
- b) When established specifically for the individual modes of the applicable discrete-mode cycle, shall be applied to the results of those modes of the applicable discrete-mode NRSC cycle for which regeneration occurs prior to calculating the cycle weighted emission result. In this case the multiple filter method shall be used for PM measurement;
- c) May be extended to other members of the same engine family;
- d) May be extended to other engine families within the same engine aftertreatment system family with the prior approval of the parties involved based on technical evidence to be supplied by the manufacturer that the emissions are similar.

The following options shall be considered:

- a) A manufacturer may elect to omit adjustment factors for one or more of its engine families (or configurations) because the effect of the regeneration is small, or because it is not practical to identify when regenerations occur. In these cases, no adjustment factor shall be used, and the manufacturer is liable for compliance with the emission limits for all tests, without regard to whether a regeneration occurs;

- b) Upon request by the manufacturer, the parties involved may account for regeneration events differently than is provided in a). However, this option only applies for events that occur extremely infrequently, and which cannot be practically addressed using the adjustment factors described in a).

### 5.5.2 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

- a) physically or
- b) mathematically.

When using method a), manufacturers shall install the engines on the test-bed in a manner that all crankcase emissions are routed into the exhaust system as described in this clause. For the purpose of this clause, crankcase emissions that are routed into the exhaust upstream of exhaust after-treatment during all operation are not considered to be discharged directly into the ambient atmosphere.

Open crankcase emissions shall be routed into the exhaust system for emission measurement, as follows:

- c) The tubing materials shall be smooth-walled, electrically conductive, and not reactive with crankcase emissions. Tube lengths shall be minimized as far as possible. The tube may optionally be heated or thin-walled or insulated with an air-gap to minimize temperature differences between the wall and the crankcase emissions constituents.
- d) The number of bends in the laboratory crankcase tubing shall be minimized, and the radius of any unavoidable bend shall be maximized;
- e) The laboratory crankcase exhaust tubing shall meet the engine manufacturer's specifications for crankcase back pressure;
- f) The crankcase exhaust tubing shall connect into the raw exhaust downstream of any aftertreatment system, downstream of any installed exhaust restriction, and sufficiently upstream of any sample probes to ensure complete mixing with the engine's exhaust before sampling. The crankcase exhaust tube shall extend into the free stream of exhaust to avoid boundary-layer effects and to promote mixing. The crankcase exhaust tube's outlet may orient in any direction relative to the raw exhaust flow.

Method b) is permitted with the prior approval of the parties involved.

### 5.6 Cooling system

An engine cooling system with sufficient capacity to maintain the engine, with its intake-air, oil, coolant, block and head temperatures, at normal operating temperatures prescribed by the manufacturer shall be used. Laboratory auxiliary coolers and fans may be used.

### 5.7 Lubricating oil

The lubricating oil shall be specified by the manufacturer and be representative of lubricating oil available in the market; the specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

## 6 Test fuels

Fuel characteristics influence the engine exhaust gas emission. Therefore, the characteristics of the fuel used for the test should be determined, recorded and presented with the results of the test. Where fuels

designated in ISO 8178-5 as reference fuels are used, the reference code and the analysis of the fuel shall be provided. For all other fuels the characteristics to be recorded are those listed in the appropriate universal data sheets in ISO 8178-5.

**Table 3 — Selection of fuel**

| Test purpose                                                                                                                                                                              | Interested parties                                                                        | Fuel selection                                                                       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Type approval<br>(Certification)                                                                                                                                                          | 1. Certification body<br>2. Manufacturer or supplier                                      | Reference fuel, if one is defined<br>Commercial fuel if no reference fuel is defined |
| Acceptance test                                                                                                                                                                           | 1. Manufacturer or supplier<br>2. Customer or inspector                                   | Commercial fuel as specified by the manufacturer <sup>a</sup>                        |
| Research/development                                                                                                                                                                      | One or more of:<br>Manufacturer, research organization, fuel and lubricant supplier, etc. | To suit the purpose of the test                                                      |
| <sup>a</sup> Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily comply with limits specified when using reference fuels. |                                                                                           |                                                                                      |

## 7 Test cycles

### 7.1 Introduction

The following duty cycles are described in this clause: discrete mode steady-state cycles, ramped modal steady-state cycles and transient cycle. The cycles and their applicability are described in [7.5](#) (steady-state) and [7.6](#) (transient), while the method to determine the appropriate test points (speed, torque, power) are described in [7.2](#) to [7.4](#). The tabulated cycles are contained in [Annex A](#) to [Annex C](#).

### 7.2 Test speeds

Test speeds shall be determined according to the test cycle(s) to be used. In certain cases a rated speed will be used to represent 100 % speed, as declared by the manufacturer according to [3.61](#). In other cases the MTS (maximum test speed) will be used to represent 100 % speed, as determined from the curve of engine speed versus power according to [7.2.1](#). Where applicable, an intermediate speed will be determined according to [3.35](#). Where intermediate speed is not used the other speeds will be determined as a percentage of the rated speed or MTS.

For constant speed engines the 100 % speed shall be determined according to [7.2.5](#).

#### 7.2.1 Maximum test speed (MTS)

For engines that are tested with a transient cycle the MTS shall be determined according to this clause. In this case the 100 % test speed is equal to the MTS. For engines that are tested with both a steady state cycle (discrete or ramped modal) and also a transient cycle, the MTS shall also be used in place of the rated speed for operating the steady state cycle.

##### 7.2.1.1 Calculation of MTS

In order to calculate the MTS for variable speed engines the transient mapping procedure shall be performed according to [7.4](#). The MTS is then determined from the mapped values of engine speed versus power. For the calculation of the MTS one of the following formulations shall be used:

$$a) \quad MTS = n_{lo} + 0,95 \cdot (n_{hi} - n_{lo}) \quad (9)$$

where:

$n_{hi}$  is high speed (see 3.32);

$n_{lo}$  is low speed (see 3.39).

$$b) \quad MTS = n_i \text{ at the average of the lowest and highest speeds at which } (n_{normi}^2 + P_{normi}^2) \text{ is equal to 98 \% of the maximum value of } (n_{normi}^2 + P_{normi}^2). \text{ If there is only one speed at which the value of } (n_{normi}^2 + P_{normi}^2) \text{ is equal to 98 \% of the maximum value of } (n_{normi}^2 + P_{normi}^2) \text{ then } MTS = n_i \text{ at which the maximum value of } (n_{normi}^2 + P_{normi}^2) \text{ occurs.} \quad (10)$$

where:

$n$  is engine speed;

$i$  is an indexing variable that represents one recorded value of an engine map;

$n_{normi}$  is an engine speed normalized by dividing it by  $n_{P_{max}}$ ;

$P_{normi}$  is an engine power normalized by dividing it by  $P_{max}$ ;

$n_{P_{max}}$  is the average of the lowest and highest speeds at which power is equal to 98 % of  $P_{max}$ . Linear interpolation shall be used between the mapped values to determine the speeds where power is equal to 98 % of  $P_{max}$ . If there is only one speed at which power is equal to 98 % of  $P_{max}$  then  $n_{P_{max}}$  shall be the speed at  $P_{max}$ .

Linear interpolation shall be used between the mapped values to determine the speeds where  $(n_{normi}^2 + P_{normi}^2)$  is equal to 98 % of the maximum value of  $(n_{normi}^2 + P_{normi}^2)$ .

#### 7.2.1.2 Use of a declared MTS

If the MTS calculated according to 7.2.1.1 is within  $\pm 3$  % of the MTS declared by the manufacturer, the declared MTS may be used for the emissions test. If the tolerance is exceeded, the calculated MTS shall be used for the emissions test.

#### 7.2.1.3 Use of an adjusted MTS for correct driving of the NRTC

If the falling part of the full load curve has a very steep edge, this may cause problems to drive the 105 % speeds of the NRTC test cycle correctly. In this case it is allowed, with prior agreement of the parties involved, to use an alternative value of MTS determined using one of the following methods:

- reduce the MTS slightly (maximum 3 %) in order to make correct driving of the NRTC possible.
- Calculate an alternative MTS using the following formulation:

$$MTS = (n_{max} - n_{idle}) / 1,05 + n_{idle} \quad (11)$$

where

$n_{max}$  is maximum no load speed;

$n_{idle}$  is idle speed.

### 7.2.2 Rated speed

The rated speed is defined in 3.61 and will normally be the maximum full load speed allowed by the governor, as designed by the manufacturer, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as designed by the manufacturer.

For variable speed engines that are not tested with a transient cycle the 100 % test speed is equal to the rated speed.

At manufacturers' discretion, maximum test speed may be used instead of rated speed for any steady state test cycle.

### 7.2.3 Intermediate speed

The maximum torque speed used for the determination of intermediate speed shall be obtained from the maximum torque curve established from the engine mapping conducted according to one of the procedures in 7.4.

The maximum torque speed is either:

- a) The speed at which the highest torque was recorded; or,
- b) The average of the lowest and highest speeds at which the torque is equal to 98% of the maximum torque. Where necessary, linear interpolation shall be used to determine the speeds at which the torque is equal to 98% of the maximum.

If the maximum torque speed determined from the maximum torque curve is within  $\pm 4$  % of the maximum torque speed declared by the manufacturer for SI engines  $< 56$  kW, or  $\pm 2,5$  % of the maximum torque speed declared by the manufacturer for all other engines, the declared value may be used. If the tolerance is exceeded, the maximum torque speed determined from the maximum torque curve shall be used.

The intermediate speed shall meet one of the following requirements:

- a) For engines that are designed to operate over a speed range on a full load torque curve, the intermediate speed shall be the maximum torque speed if it occurs between 60 % and 75 % of rated speed;
- b) If the maximum torque speed is less than 60 % of rated speed, then the intermediate speed shall be 60 % of the rated speed;
- c) If the maximum torque speed is greater than 75 % of the rated speed then the intermediate speed shall be 75 % of rated speed. Where the engine is only capable of operation at speeds higher than 75 % of rated speed the intermediate speed shall be the lowest speed at which the engine can be operated.
- d) For engines that are not designed to operate over a speed range on a full-load torque curve at steady-state conditions, the intermediate speed will typically be between 60 % and 70 % of the rated speed.
- e) For engines to be tested on cycle G1, the intermediate speed shall be 85 % of the rated speed.

In the case that the maximum test speed (MTS) is used in place of rated speed for the 100 % test speed, MTS shall also replace rated speed when determining the intermediate speed.

### 7.2.4 Idle speed

The idle speed is the lowest engine speed with minimum load (greater than or equal to zero load), where an engine governor function controls engine speed. For engines without a governor function that controls idle speed, idle speed means the manufacturer-declared value for lowest engine speed possible with minimum load. Note that warm idle speed is the idle speed of a warmed-up engine.

### 7.2.5 Test speed for constant speed engines

The governors of constant speed engines may not always maintain speed exactly constant. Typically, speed can decrease (0,1 to 10) % below the speed at zero load, such that the minimum speed occurs near the engine's point of maximum power. The test speed for constant speed engines may be commanded by using the governor installed on the engine or using a test-bed speed demand where this represents the engine governor.

Where the governor installed on the engine is used the 100 % speed shall be the engine governed speed.

Where a test-bed speed demand signal is used to simulate the governor, the 100 % speed at zero load shall be the no load speed specified by the manufacturer for that governor setting and the 100 % speed at full load shall be the rated speed for that governor setting. Interpolation shall be used to determine the speed for the other test modes.

In the case that the governor has an isochronous operation setting, or the nominal rated speed and no-load speed declared by the manufacturer differ by no more than 3 %, a single value declared by the manufacturer may be used for the 100 % speed at all load points.

## 7.3 Torque and power

### 7.3.1 Torque

The torque figures given in the test cycles are percentage values that represent, for a given test mode, one of the following:

- a) The ratio of the required torque to the maximum possible torque at the specified test speed (all cycles except D1, D2, E2, E4).
- b) The ratio of the required torque to the torque corresponding to the continuous rated power (cycle D1) declared by the manufacturer as defined in ISO 8528-1.
- c) The ratio of the required torque to the torque corresponding to the rated power declared by the manufacturer as defined in ISO 8528-1 (cycle D2).
- d) For cycle E2 % torque is relative to the torque corresponding to the rated power declared by the manufacturer.
- e) For the test cycle E4 the torque figures are percentage values of the torque at rated power. This cycle is based on the theoretical propeller characteristic curve representing typical pleasure craft spark ignition engine operation.

[Figure 3](#) shows torque scales for engines operating on a non-propeller curve.

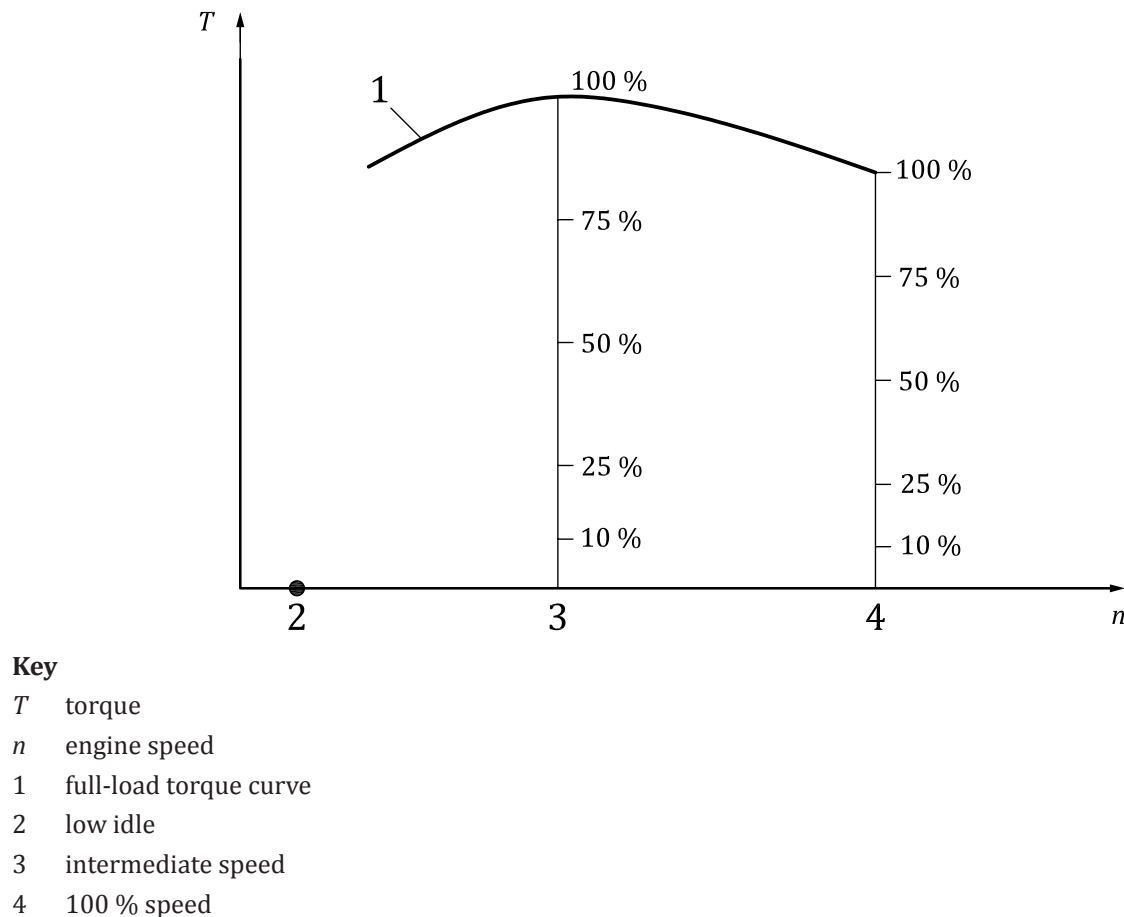


**Figure 3 — Torque scales: Percentage of full-load torque at each engine speed**

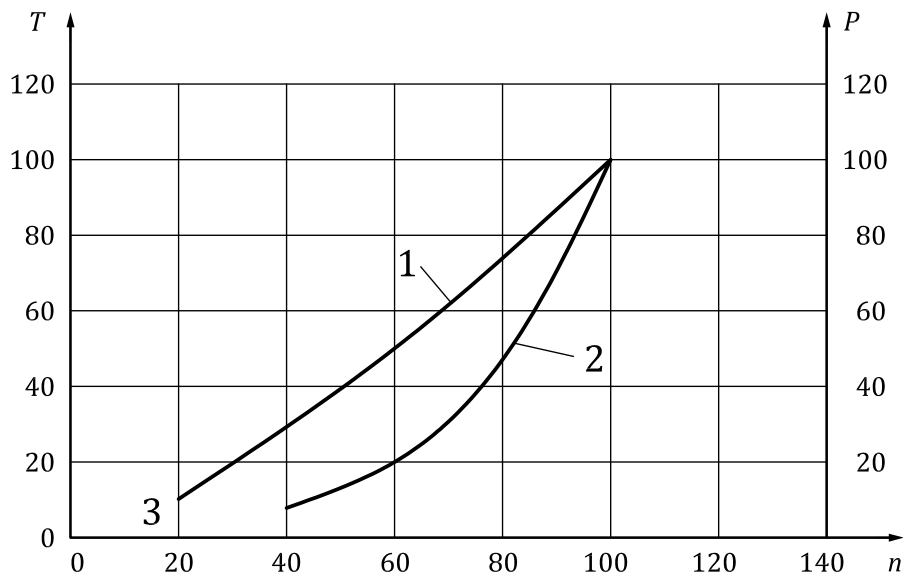
### 7.3.2 Power

The power figures given in the test cycles are percentage values that represent, for a given test mode, one of the following:

- a) For the test cycle E3 the power figures are percentage values of the maximum rated power at the 100 % speed as this cycle is based on a theoretical propeller characteristic curve for vessels driven by heavy-duty engines without limitation of length.
- b) For the test cycle E5 the power figures are percentage values of the maximum rated power at the 100 % speed as this cycle is based on a theoretical propeller characteristic curve for vessels of less than 24 m in length driven by diesel engines.
- c) For the test cycle F the power figures are percentage values of the maximum power at the given test speed, except for idle speed where it is a percentage of the maximum rated power at the 100 % speed.

[Figure 4](#) shows an example of two representative propeller curves:

NOTE Other propeller characteristic curves exist.

**Key**

- $T$  torque  
 $n$  engine speed  
 $P$  power  
 1 torque E4  
 2 power E3  
 3 idling

NOTE The values of  $n$ ,  $T$  and  $P$  are expressed in % of rated speed, maximum torque and maximum power respectively.

**Figure 4 — Examples of torque and power scales for propeller curves**

## 7.4 Engine mapping

Before starting the engine mapping, the engine shall be warmed up and towards the end of the warm up it shall be operated for at least 10 min at maximum power or according to the recommendation of the manufacturer and good engineering judgement in order to stabilize the engine coolant and lube oil temperatures. When the engine is stabilized, the engine mapping shall be performed.

Except constant speed engines, engine mapping shall be performed with fully open fuel lever or governor using discrete speeds in ascending order. The minimum and maximum mapping speeds are defined as follows:

- Minimum mapping speed = warm idle speed;
- Maximum mapping speed =  $n_{hi} \times 1,02$  or speed where max torque drops off to zero, whichever is smaller.

where

$n_{hi}$  is high speed (see [3.32](#)).

If the highest speed is unsafe or unrepresentative (e.g. for ungoverned engines), good engineering judgement shall be used to map up to the maximum safe speed or the maximum representative one.

### 7.4.1 Engine mapping for transient cycles

The engine mapping shall be performed according to the following procedure:

- a) The engine shall be unloaded and operated at idle speed;
  - 1) For engines with a low-speed governor, the operator demand shall be set to the minimum, the dynamometer or another loading device shall be used to target a torque of zero on the engine's primary output shaft and the engine shall be allowed to govern the speed. This warm idle speed shall be measured;
  - 2) For engines without a low-speed governor, the dynamometer shall be set to target a torque of zero on the engine's primary output shaft, and the operator demand shall be set to control the speed to the manufacturer-declared lowest engine speed possible with minimum load (also known as manufacturer-declared warm idle speed);
  - 3) The manufacturer declared idle torque may be used for all variable-speed engines (with or without a low-speed governor), if a nonzero idle torque is representative of in-use operation;
- b) Operator demand shall be set to maximum and engine speed shall be controlled to between warm idle and 95 % of its warm idle speed. For engines with reference duty cycles, which lowest speed is greater than warm idle speed, the mapping may be started at between the lowest reference speed and 95 % of the lowest reference speed;
- c) The engine speed shall be increased at an average rate of  $(8 \pm 1) \text{ min}^{-1}/\text{s}$  or the engine shall be mapped by using a continuous sweep of speed at a constant rate such that it takes 4 min to 6 min to sweep from minimum to maximum mapping speed. The mapping speed range shall be started between warm idle and 95 % of warm idle and ended at the highest speed above maximum power at which less than 70 % of maximum power occurs. If this highest speed is unsafe or unrepresentative (e.g. for ungoverned engines), good engineering judgment shall be used to map up to the maximum safe speed or the maximum representative speed. Engine speed and torque points shall be recorded at a sample rate of at least 1 Hz;
- d) If a manufacturer believes that the above mapping techniques are unsafe or unrepresentative for any given engine, alternate mapping techniques may be used. These alternate techniques shall satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this clause for reasons of safety or representativeness shall be approved by the parties involved along with the justification for their use. In no case, however, the torque curve shall be run by descending engine speeds for governed or turbocharged engines;
- e) An engine need not be mapped before each and every test cycle. An engine shall be remapped if:
  - 1) An unreasonable amount of time has transpired since the last map, as determined by good engineering judgement; or
  - 2) Physical changes or recalibrations have been made to the engine which potentially affect engine performance; or
  - 3) The atmospheric pressure near the engine's air inlet is not within  $\pm 5 \text{ kPa}$  of the value recorded at the time of the last engine map.

### 7.4.2 Engine mapping for variable speed steady-state cycles

In the case of engine mapping for a steady-state cycle (only for engines which have not to run a transient cycle), good engineering judgment shall be used to select a sufficient number of evenly spaced set-points. At each set-point, speed shall be stabilized and torque allowed to stabilize for at least 15 s. The mean speed and torque shall be recorded at each set-point. Where feasible the mean speed and torque should be calculated using the recorded data from the last 4 s to 6 s. Linear interpolation shall be used to determine the steady-state test speeds and torques if needed.

Except as set-out in 7.2, if the derived test speeds and torques do not deviate for more than  $\pm 3\%$  from the speeds and torques indicated by the manufacturer, the manufacturer defined speeds and torques shall be applied. When engines are additionally required to run a transient cycle, then the transient mapping curve shall be used to determine steady-state test speeds and torques.

At the choice of the manufacturer the engine mapping may alternatively be conducted according to the procedure in 7.4.1.

#### 7.4.3 Engine mapping for constant-speed engines

The engine may be operated with a production constant-speed governor or a constant-speed governor maybe simulated by controlling engine speed with an operator demand control system. Either isochronous or speed-droop governor operation shall be used, as appropriate.

The following mapping procedure shall be applied:

- a) With the governor or simulated governor controlling speed using operator demand, the engine shall be operated at no-load governed speed (at high speed, not low idle) for at least 15 s, unless the specific engine is unable to perform this task.
- b) The dynamometer shall be used to increase torque at a constant rate. The map shall be conducted such that it takes no less than 2 min to sweep from no-load governed speed to the torque corresponding to rated power for engines to be tested on cycle D1, D2 or E2 or to maximum torque in the case of other constant speed test cycles. During the engine mapping actual speed and torque shall be recorded with at least 1 Hz;
- c) In case of a constant speed engine with a governor that can be reset to alternative speeds, the engine shall be tested at each applicable constant speed.
- d) For constant speed engines good engineering judgment shall be used to apply other methods to record torque corresponding to rated power at the defined operating speed(s). Other suitable methods shall include but not be limited to the following:
  - 1) For constant-speed engines subject only to steady-state testing, an engine map may be performed by using a series of discrete torques. At least five evenly spaced torque setpoints from no-load to 80 % of the manufacturer-declared test torque or to a torque derived from the published maximum power level shall be selected if the declared test torque is not available. Starting at the 80 % torque point, setpoints in 2,5 % or smaller intervals are selected, stopping at the endpoint torque. The endpoint torque is defined as the first discrete mapped torque value greater than the torque at maximum observed power where the engine outputs 90 % of the maximum observed power; or the torque when engine stall has been determined. Torque and speed shall be allowed to stabilize at each setpoint and the mean feedback speed and torque at each setpoint shall be recorded. Mapping at higher torque setpoints may be carried out if desired. From this series of mean feedback speed and torque values, intermediate values are determined by using linear interpolation. These series of mean speeds and torques are used to generate the power map.
  - 2) For any constant-speed engine, an engine map may be performed with a continuous torque sweep by continuing to record the mean feedback speed and torque at 1 Hz or higher frequency. The reference torque shall be increased by the dynamometer at a constant rate from no-load to the endpoint torque. The torque sweep rate is targeted to be equal to the manufacturer-declared test torque (or a torque derived from the published power level) divided by 180 s. It shall be verified, that the average torque sweep rate over the entire map is within  $\pm 7\%$  of the target torque sweep rate. From this series of mean feedback speed and torque values, intermediate values are determined by using linear interpolation. These series of mean speeds and torques are used to generate the power map.
  - 3) For any isochronous governed (0 % speed droop) constant-speed engine, the engine may be mapped with two points. After stabilizing at the no-load governed speed, the mean feedback speed and torque is recorded.

The engine shall be operated with the governor or simulated governor controlling engine speed using operator demand, and the dynamometer shall be used to target a speed of 99,5 % of the recorded mean no-load governed speed. Torque and speed shall be allowed to stabilize at each setpoint. The mean feedback speed and torque at each setpoint and the target speed shall be recorded.

The absolute value of the speed error (the mean feedback speed minus the target speed) must be no greater than 0,1 % of the recorded mean no-load governed speed. From this series of mean feedback speed and torque values, intermediate values are determined by using linear interpolation. These series of two mean feedback speeds and torques are used to generate the power map. Note that the measured maximum test torque will be the mean feedback torque recorded on the second point.

For engines tested on cycles other than D1, D2 or E2, when both measured and declared values are available for the maximum torque, the declared value may be used instead of the measured value if it is within 95 to 100 % of the measured value.

## 7.5 Steady-state test cycles

Steady-state test cycles are specified as a list of discrete modes (operating points), where each operating point has one value of speed and one value of torque. A steady-state test cycle shall be measured with a warmed up and running engine according to manufacturer's specification.

At the choice of the manufacturer, a steady-state test cycle may be run as a discrete-mode cycle or a ramped-modal cycle (RMC), as explained in [7.5.1](#) and [7.5.2](#).

Performing an RMC emission test according to [7.5.2](#) shall be optional. There may be technical reasons why an engine may not be able to operate according to the test cycles in [7.5.2](#). It shall not be required to conduct an emission test according to both [7.5.1](#) and [7.5.2](#).

### 7.5.1 Discrete mode test cycles

#### 7.5.1.1 General remarks

The exhaust emission measurement and evaluation shall be carried out using the appropriate test cycle for the application as described in general in [7.5.3](#). The corresponding test cycles are tabulated in [Annex A](#).

The particulate emission may be measured by either the multiple filter or the single filter method according to ISO 8178-1, 8.6.1.2. To evaluate the particulate emission by the multiple filter method, it is necessary to measure the particulate concentration and the particulate mass emission of each test mode at stabilized engine operation. The time needed for stabilization of the engine depends on engine size and ambient conditions.

#### 7.5.1.2 Requirements for conduct of test using discrete mode cycle

##### 7.5.1.2.1 Test sequence

Each test shall be performed with a warmed-up and running engine in the given sequence of the test modes for a particular test cycle.

##### 7.5.1.2.2 Mode length

The minimum test mode length is 10 min, which is the standard, except when testing spark ignition engines using cycles "G". If necessary the mode length may be extended e.g. to collect sufficient particulate sample mass or to achieve stabilization with large engines.

For spark ignition engines when only gaseous emissions are measured using cycles "G", each mode time shall be at least 3 min.

The mode length shall be recorded and reported.

#### 7.5.1.2.3 Emission measurement

Except when testing spark ignition engines using test cycles “G”, the gaseous exhaust emission concentration values shall be measured and recorded for at least 3 min anywhere in the mode if the engine is stabilized and meets the speed and torque requirements of the respective mode.

For spark ignition engines when only gaseous emissions are measured using cycles “G”, the gaseous exhaust emission concentration values shall be measured and recorded for the last 2 min of the respective test mode.

Only the last 60 s of the measurement period shall be used for emission calculation in accordance with [Clause 9](#) or [Annex H](#).

Particulate sampling shall not commence before engine stabilization, as defined by the manufacturer, has been achieved, and shall preferably be conducted at the same time as gaseous emissions are measured. For the single filter method, the completion of particulate sampling shall be within  $\pm 5$  s of the completion of the gaseous emission measurement.

#### 7.5.1.2.4 Repeat measurements

For the multiple filter method only, particulate sampling and gaseous emissions measurement may be repeated during the mode until a valid sample is obtained as long as the speed and torque requirements are met.

Test modes may be repeated, as long as the engine is pre-conditioned by running the previous or current mode. In the case of the first mode of any cycle, the engine shall be preconditioned according to [8.4.2](#).

#### 7.5.1.2.5 Validation criteria

During each mode of the given steady-state test cycle after the initial transition period, the measured speed shall not deviate from the reference speed for more than  $\pm 1$  % of rated speed or  $\pm 3$  min<sup>-1</sup>, whichever is greater except for idle which shall be within the tolerances declared by the manufacturer. The measured torque shall not deviate from the reference torque for more than  $\pm 2$  % of the maximum torque at the test speed.

#### 7.5.1.2.6 Equipment malfunction

If at any time during a test mode, the test equipment malfunctions or the engine speed and load do not meet the requirements of [7.5.1.2.5](#), the test mode is void and may be aborted. The test mode may be restarted by preconditioning with the previous or current mode.

### 7.5.2 Ramped modal test cycles

#### 7.5.2.1 General remarks

An RMC is intended to provide a method for performing a steady-state test in a pseudo-transient manner. Each RMC consists of a series of steady state modes with a linear transition between them. The relative total time at each mode and its preceding transition match the weighting of the discrete mode steady state cycles. In some cases modes are not run in the same order as the discrete mode steady state cycles or are split to prevent extreme changes in temperature.

The exhaust emission measurement and evaluation shall be carried out using the appropriate test cycle for the application as described in general in [7.5.3](#). The corresponding test cycles are tabulated in [Annex B](#). Where available the RMCs are numbered to correspond to the equivalent discrete mode cycle. Where no RMC exists for a given application the steady state test shall be conducted using the appropriate discrete mode cycle.

### 7.5.2.2 Requirements for conduct of test using RMC

#### 7.5.2.2.1 Test sequence

Each test shall be performed with a warmed-up and running engine in the given sequence of the test modes for a particular test cycle.

#### 7.5.2.2.2 Mode length

The engine shall be continuously controlled by the test bed control unit during the RMC test cycle. The mode length is defined in the respective table in [Annex B](#). Advance from one mode to the next within a 20-second transition phase. During the transition phase, command a linear progression from the torque setting of the current mode to the torque setting of the next mode, and simultaneously command a similar linear progression for engine speed if there is a change in speed setting.

#### 7.5.2.2.3 Emission measurement

The gaseous and particulate emissions shall be measured and sampled continuously during the RMC test cycle in the same way as in a transient cycle.

#### 7.5.2.2.4 Repeat measurements

Due to the fact that emissions are measured continuously during the RMC test cycle, repeat measurements within the test cycle are not permitted.

In case of engine stall during the test the entire test is void and may be aborted. The entire test shall be restarted.

#### 7.5.2.2.5 Equipment malfunction

If at any time during a test mode, the test equipment malfunctions or the engine speed and load do not meet the requirements of [7.5.1.2.5](#), the entire test is void and shall be aborted. The entire test shall be restarted.

### 7.5.3 Cycle types and applicability

This clause provides a general description of the test cycles for different engine applications.

#### 7.5.3.1 Test cycles type C “Non-road machinery and industrial equipment”

##### 7.5.3.1.1 Test cycle type C1 “Compression-ignition engine powered non-road machinery and industrial equipment”

General-purpose variable speed test cycle. Tables of discrete and RMC test modes are listed in [A.1](#) and [B.1](#) respectively.

Typical examples of applications are:

- industrial drilling rigs, compressors etc.;
- construction equipment including wheel loaders, bulldozers, crawler tractors, crawler loaders, truck-type loaders, dumpers, hydraulic excavators etc.;
- agricultural equipment, rotary tillers;
- forestry equipment;
- self-propelled agricultural vehicles (including tractors);

- material handling equipment;
- fork-lift trucks;
- road maintenance equipment (graders, road rollers, asphalt finishers);
- snow plough equipment;
- snow tractors;
- airport supporting equipment;
- aerial lifts;
- mobile cranes.

This list is not exhaustive.

NOTE 1 Compression-ignition engines with rated power typically below 19 kW intended for applications listed under [7.5.3.5](#) (test cycles G), can be tested according to the test cycles given in [7.5.3.1](#) (test cycles C).

NOTE 2 Compression-ignition engines that operate within  $\pm 15\%$  of the rated speed and spend less than 15 % of their time at idle speed can be tested according to test cycle D2.

This test cycle may optionally be used for spark-ignition engines  $>56$  kW.

#### **7.5.3.1.2 Cycle C2 “Spark ignition engine powered non-road machinery and industrial equipment”, $>19$ kW**

Variable speed test cycle with focus on intermediate speed operation. Tables of discrete and RMC test modes are listed in [A.1](#) and [B.1](#) respectively.

Typical examples of applications are:

- fork-lift trucks;
- airport supporting equipment;
- material handling equipment;
- road maintenance equipment;
- agricultural equipment.

This list is not exhaustive.

Test cycle C1 may optionally be used for spark-ignition engines  $>56$  kW.

#### **7.5.3.2 Test cycles type D “Constant speed”**

Test cycles for engine applications where the load is driven at constant speed. Tables of discrete and RMC test modes are listed in [A.2](#) and [B.2](#) respectively.

Typical examples of applications are:

cycle D1:

- power plants;

cycle D2:

- gas compressors;
- irrigation pumps;

- generating sets with intermittent load including generating sets on board of ships and trains (not for propulsion), welding sets;
- turf care, chippers, snow removal equipment, sweepers.

This list is not exhaustive.

NOTE 1 Diesel engines with rated power typically below 19 kW intended for application listed under [7.5.3.5](#) (test cycles G) can be tested according to the test cycles given in [7.5.3.2](#) (test cycles D).

NOTE 2 Diesel engines that operate within  $\pm 15\%$  of the rated speed and spend less than 15 % of their time at idle speed can be tested according to test cycle D2.

### 7.5.3.3 Test cycles type E “Marine applications”

Test cycles for marine propulsion engines. Tables of discrete and RMC test modes are listed in [A.3](#) and [B.3](#) respectively.

Selection of test cycles shall conform to the following criteria:

- cycle E1: compression ignition engines for propulsion of craft less than 24 m in length except tug boats and push boats;
- cycle E2: constant-speed heavy duty engines for propulsion of ships of any length including diesel-electric drive and variable-pitch propeller applications;
- cycle E3: propeller-law heavy duty engines for propulsion of ships of any length;
- cycle E4: spark ignition engines for propulsion of craft less than 24 m in length except tug boats and push boats;
- cycle E5: compression ignition engines for propulsion of craft less than 24 m in length when operated on a propeller law except for tug boats and push boats.

For compression ignition engines in craft less than 24 m in length, test cycle E1 or E5 can be applied depending on which cycle is closer to the actual operation.

For constant-speed marine propulsion engines cycle E2 applies. For variable pitch propeller sets cycle E2 or E3 may be used depending on which cycle is closer to the actual operation; usually the operation is closer to constant speed operation (cycle E2).

For spark ignition engines in craft less than 24 m in length test cycle E4 applies.

### 7.5.3.4 Test cycle type F “Rail traction”

Test cycle for rail propulsion. Tables of discrete and RMC test modes are listed in [A.4](#) and [B.4](#) respectively.

Typical examples of applications are:

- locomotives;
- rail cars;
- shunting locomotives.

This list is not exhaustive.

NOTE Diesel engines for railcars can be tested according to the cycle given in [7.5.3.1.1](#) (C1).

### 7.5.3.5 Test cycles type G “Utility, lawn and garden”; typically <19 kW

Tables of discrete and RMC test modes are listed in [A.5](#) and [B.5](#) respectively.

If the primary end use of an engine model is known then the test cycle may be chosen based on the examples given in [7.5.3.5](#). If the primary end use of an engine model is uncertain then the appropriate test cycle should be chosen based upon the engine specification. Both compression ignition and spark ignition engines may be tested in any of the three cycles; whichever is most appropriate.

Typical examples of applications are:

- cycle G1:
  - pedestrian-controlled rotary or cylinder lawn mowers;
  - front or rear engine riding lawn mowers;
  - rotary tillers;
  - edge trimmers;
  - lawn sweepers;
  - waste disposers;
  - sprayers;
  - snow removal equipment;
  - golf carts;
- cycle G2:
  - portable generators, pumps, welders, air compressors;
  - may also include lawn and garden equipment that operates at engine-rated speed;
- cycle G3:
  - edge trimmers;
  - string trimmers;
  - blowers;
  - vacuum equipment;
  - chain saws;
  - portable saw mills.

These lists are not exhaustive.

NOTE Diesel engines of any rated power intended for applications listed in other test cycles can be tested according to that cycle (e.g. cycles D and C1).

### 7.5.3.6 Test cycle type H “Snowmobile”

Test cycle for snowmobile engines. Tables of discrete and RMC test modes are listed in [A.6](#) and [B.6](#) respectively.

### 7.5.3.7 Test cycle type I “Transport refrigeration unit”

Test cycle for transport refrigeration unit applications that operate at two speeds. Tables of discrete and RMC test modes are listed in [A.7](#) and [B.7](#) respectively.

## 7.6 Transient cycles

### 7.6.1 Introduction

Transient cycles are listed in [Annex C](#) as a second-by-second sequence of normalized speed and torque values. In order to perform the test on an engine test cell, the normalized values shall be converted to their equivalent reference values for the individual engine to be tested, based on specific speed and torque values identified in the engine mapping curve. The conversion is referred to as denormalization, and the resulting test cycle so developed as the reference cycle of the engine to be tested. With those reference speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test. For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle. For cycle validation, the actual cycle work must be within prescribed limits of the cycle work of the reference cycle (reference cycle work).

### 7.6.2 Non-road transient cycle (NRTC)

The non-road transient cycle (NRTC) may be applied to variable-speed compression-ignition or spark ignition engines for mobile use (NRMM) with a maximum power output between 19 kW and 560 kW that are also subject to the C1 steady-state (discrete or ramped modal) cycle. This cycle does not apply to non-road engines for applications that are not subject to the C1 test cycle.

The sequence of normalized speed and torque values is given in [C.1](#).

#### 7.6.2.1 Test sequence for NRTC

The transient test cycle shall be run twice after completion of pre-conditioning:

- a) As cold start after the engine and aftertreatment systems have cooled down to room temperature after natural engine cool down, or as cold start after forced cool down and the engine, coolant and oil temperatures, aftertreatment systems and all engine control devices are stabilized between 20 °C and 30 °C. The measurement of the cold start emissions shall be started with the start of the cold engine;
- b) Hot soak period – Immediately upon completion of the cold start phase, the engine shall be shut-down and conditioned for the hot start by a 20 min  $\pm$  1 min hot soak period;
- c) The hot-start shall be started immediately after the soak period with the cranking of the engine. The gaseous analysers shall be switched on at least 10 s before the end of the soak period to avoid switching signal peaks. The measurement of emissions shall be started in parallel with the start of the hot start phase including the cranking of the engine.

Brake specific emissions expressed in (g/kWh) shall be determined by using the procedures of [Clause 9](#) or [H.7](#) for both the cold and hot start test cycles. Composite weighted emissions shall be computed by weighting the cold start results by 10 % and the hot start results by 90 % as detailed in [Clause 9](#) or [H.7](#).

### 7.6.3 Large spark-ignition non-road transient cycle

The large spark-ignition non-road transient cycle (LSI-NRTC) may be applied to variable-speed spark-ignition engines for mobile use (NRMM) that are also subject to the C2 steady-state (discrete or ramped modal) cycle and conform to all of the following characteristics:

- a) A maximum power output between 19 kW and 30 kW with a swept volume  $\geq$  1 litre
- b) A maximum power output greater than 30 kW but less than 560 kW
- c) A maximum engine speed  $\leq$  3 400 rpm

This cycle does not apply to non-road engines that are not subject to the C2 test cycle and does not apply to engines for non-road utility vehicles with displacement  $\leq 1$  litre and maximum power  $\leq 30$  kW, snowmobiles, off-highway motorcycles or all-terrain vehicles (ATVs).

The sequence of normalized speed and torque values is given in [C.2](#).

#### 7.6.3.1 Test sequence for LSI-NRTC

The transient test cycle shall be run once after completion of pre-conditioning:

- a) Warm up the test engine by starting and operating for the first 180 s of the duty cycle, then operate at idle without load for 30 s. Emissions are not measured during this warm-up sequence.
- b) At the end of the 30-second idling period start measuring emissions and operate the engine over the entire duty cycle starting from the beginning.

Brake specific emissions expressed in (g/kWh) shall be determined by using the procedures of [Clause 9](#) or [H.7](#).

If the engine was already operating before the test, use good engineering judgment to let the engine cool down enough so measured emissions will accurately represent those from an engine starting at room temperature. For example, if an engine starting at room temperature warms up enough in 3 min to start closed-loop operation and achieve full catalyst activity, then minimal engine cooling is necessary before starting the next test.

With the agreement of the parties involved, the engine warm-up procedure may include up to 15 min of operation over the duty cycle.

### 7.7 Test cycle generation

#### 7.7.1 Generation of steady-state discrete-mode or RMC test cycles

This clause shall be used to generate the engine speeds and loads over which the engine shall be operated during steady-state discrete-mode or RMC tests.

##### 7.7.1.1 Generation of test speeds for engines tested with both transient and steady-state cycles

For engines that are tested with a transient cycle in addition to a steady-state cycle the MTS specified in [7.2.1](#) shall be used as the 100 % speed for both transient and steady state tests. A declared MTS as specified by [7.2.1.2](#) is permitted at the choice of the manufacturer.

The MTS shall be used in place of rated speed when determining intermediate speed according to [7.2.3](#).

The idle speed shall be determined according to [7.2.4](#).

##### 7.7.1.2 Generation of test speeds for engines only tested with steady-state cycles

For engines that are not tested with a transient cycle, the maximum test speed specified in [7.2.2](#) shall be used as the 100 % speed.

The rated speed shall be used to determine the intermediate speed according to [7.2.3](#). If the cycle in [Annex A](#) or [B](#) specifies additional speeds as a percentage they shall be calculated as a percentage of the rated speed.

The idle speed shall be determined according to [7.2.4](#).

At manufacturers' discretion, MTS may be used to replace rated speed for the generation of test speeds in this clause.