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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 4: Steady-state 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

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8178-4 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

This second edition cancels and replaces the first edition (ISO 8178-4:1996) which has been technically revised.

ISO 8178 consists of the following parts, under the general title *Reciprocating internal combustion engines — Exhaust emission measurement*:

— *Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

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

— *Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*

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

— *Part 5: Test fuels*

— *Part 6: Report of measuring results and test*

— *Part 7: Engine family determination*

— *Part 8: Engine group determination*

— *Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

— *Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

— *Part 11: Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions*

Introduction

In comparison with engines for on-road applications, engines for off-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 part of ISO 8178 is to rationalize the test procedures for off-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 part of ISO 8178 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 8178-1:2006, 3.9. 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 test cycles for different engine applications

1 Scope

This part of ISO 8178 specifies the test cycles for the measurement and the evaluation of gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines coupled to a dynamometer. With certain restrictions, this part of ISO 8178 can also be used for measurements at site. The tests are carried out under steady-state operation using test cycles which are representative of given applications.

This part of ISO 8178 is applicable to RIC engines for mobile, transportable and stationary use, excluding engines for motor vehicles primarily designed for road use. It may be applied to engines used, 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 powerplants) additional test conditions and special evaluation methods may apply.

2 Normative references

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

ISO 8178-1:2006, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

ISO 8178-2:1996, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 2: Measurement of gaseous and particulate exhaust emissions at site*

ISO 8178-3:1994, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*

ISO 8178-5:1997, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels*

ISO 8178-6:2000, *Reciprocating internal combustion engines — Exhaust emission measuremen — Part 6: Report of measuring results and test*

ISO 8178-7:1996, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 7: Engine family determination*

ISO 8178-8:1996, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 8: Engine group determination*

ISO 8528-1:2005, *Reciprocating internal combustion engine driven alternating current generating sets — Part 1: Application, ratings and performance*

ISO 14396:2002, *Reciprocating internal combustion engines — Determination and method for the measurement of engine power — Additional requirements for exhaust emission tests in accordance with ISO 8178*

3 Terms and definitions

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

3.1
test cycle
sequence of engine test modes each with defined speed, torque and weighting factor where the weighting factors only apply if the test results are expressed in grams per kilowatt hour

3.2
preconditioning of the engine
warming up of the engine under load conditions higher than 80 %, to stabilize the engine parameters according to the recommendations of the manufacturer

NOTE A preconditioning phase also protects the actual measurement against the influence of deposits in the exhaust system from a former test. There is also a period of stabilization in the test modes which has been included to minimize point-to-point influences.

3.3
mode
engine operating point characterized by a speed and a torque (or a power output)

3.4
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 It includes the time during which speed and/or torque is being changed and the stabilization at the beginning of each mode.

3.5
rated speed
speed at which, according to the statement of the engine manufacturer, the rated power is delivered

NOTE For details see ISO 14396.

3.6
intermediate speed
speed declared by the manufacturer, taking into account the requirements governed by the torque curve

NOTE See 6.2.

3.7
low speed
lowest engine speed where 50 % of the rated or prime power is delivered

3.8
high speed
highest engine speed where 70 % of the rated or prime power is delivered

3.9
engine family
manufacturer's grouping of engines which, through their design, are expected to have similar exhaust emission characteristics where members of the family must comply with the applicable emission limit values

[ISO 8178-7:1996, definition 2.1]

4 Symbols and abbreviations

For the use of this part of ISO 8178 the symbols and abbreviations defined in ISO 8178-1, ISO 8178-2, ISO 8178-3, ISO 8178-5, ISO 8178-6, ISO 8178-7 and ISO 8178-8 shall be used.

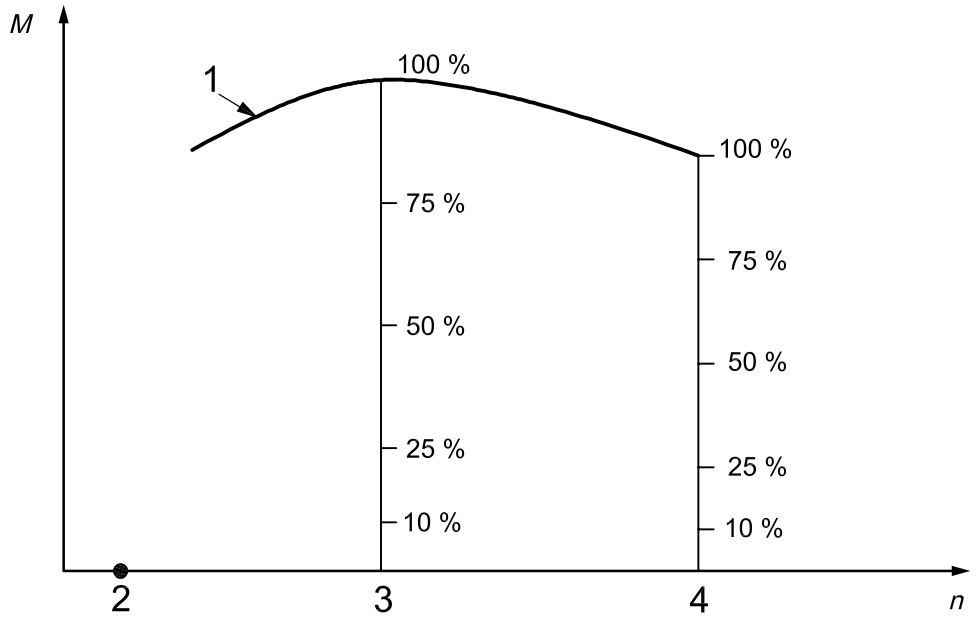
In addition, see Table 1:

Table 1 — Essential units for this part of ISO 8178

Symbol	Term	Unit
n	Engine speed	r/min
M	Torque	N·m
P	Power	kW
W_F	Weighting factor	1

5 Torque

5.1 The torque figures given in the test cycles are percentage values that represent, for a given test mode, the ratio of the required torque to the maximum possible torque (C1, C2, E1, E2, F, G1, G2, G3 and H) or of the torque corresponding to the continuous power or prime power rating as defined in ISO 8528-1 (D1, D2) at this given speed (see ISO 8178-1:2006, 12.5). Figure 1 shows torque scales for engines operating on a non-propeller curve.



Key

1 full-load torque curve
2 low idle
3 intermediate speed
4 rated speed

Figure 1 — Torque scales: percentage of full-load torque at each engine speed

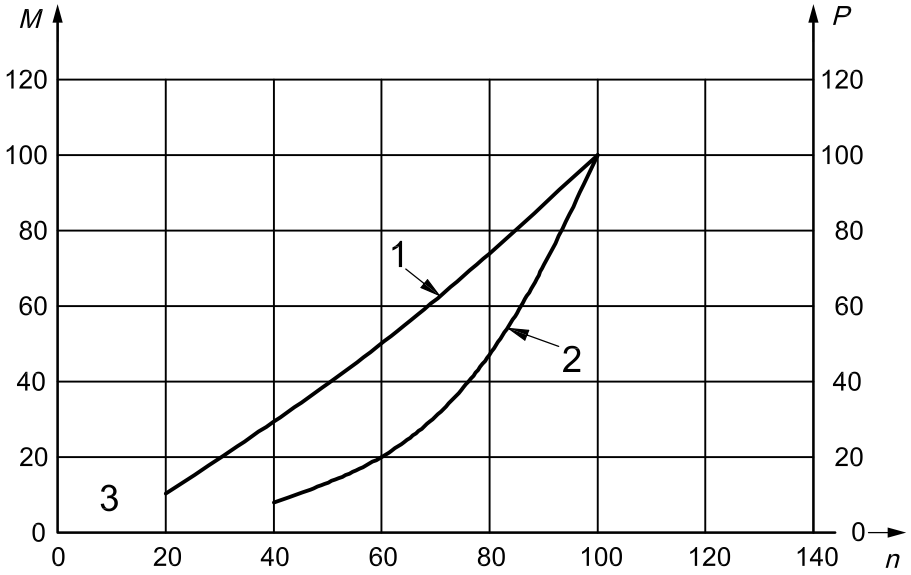
5.2 For the test cycle E3 the power figures are percentage values of the maximum rated power at the rated speed as this cycle is based on a theoretical propeller characteristic curve for vessels driven by heavy duty engines without limitation of length.

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.

For the test cycle E5 the power figures are percentage values of the maximum rated power at the rated 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.

NOTE Other propeller characteristic curves exist.

Figure 2 shows the two representative curves chosen by ISO/TC 70/SC 8.



Key

1 torque E4
2 power E3
3 idling

NOTE The values of n, M and P are expressed in percent of rated speed, maximum torque and maximum power respectively.

Figure 2 — Examples of torque and power scales for propeller curves

6 Test speeds

6.1 Rated speed

For the purposes of this part of ISO 8178, the rated speed is defined in 3.5. With the prior agreement of the parties involved, the following reference speed may replace the rated speed for running the test cycles listed in Clause 8.

Reference speed = low speed + 0,95 × (high speed − low speed)

where

low speed = lowest engine speed where 50 % of the rated or prime power is delivered;

high speed = highest engine speed where 70 % of the rated or prime power is delivered.

If the measured reference speed is within ± 3 % of the reference speed declared by the manufacturer, the declared reference speed shall be used. If the tolerance is exceeded, the measured reference speed shall be used.

6.2 Intermediate speed

6.2.1 For engines that are designed to operate over a speed range on a full-load torque curve, the intermediate speed shall be the declared maximum torque speed if it occurs between 60 % and 75 % of the rated speed, on condition that the torque observed on the test engine at the declared intermediate engine speed is not less than 96 % of the maximum torque observed between 60 % and 75 % of the rated speed.

If the declared maximum torque speed is less than 60 % of the declared rated speed, then the declared intermediate speed shall be 60 % of the rated speed.

If the declared maximum torque speed is greater than 75 % of the rated speed then the declared intermediate speed shall be 75 % of the rated speed.

If the torque observed at the declared intermediate engine speed is less than 96 % of the maximum torque observed between 60 % and 75 % of the rated speed then the observed maximum torque speed shall be the intermediate speed.

6.2.2 For engines which 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.

6.2.3 For marine application engines to be used to propel vessels with a fixed propeller, as specified in 8.5, the intermediate speeds are defined in Clause 8.

6.2.4 For engines to be tested on cycle G1, the intermediate speed shall be 85 % of the rated speed.

7 Information regarding preparation of the test

See Table 2.

Table 2 — Parameters

No.	Parameter	ISO 8178-1:2006, clause/subclause	ISO 8178-2:1996, clause/subclause
7.1	Test conditions	5	5.2
7.2	Power; brake power	3.9, 5.3	3.9, 5.3
7.3	Engine air inlet system	5.4.1	5.4
7.4	Engine exhaust system	5.4.2	5.5
7.5	Test fuels; reference fuels (ISO 8178-5)	6	6
7.6	Measurement equipment and data to be measured	7	7
7.7	Accuracy of the measuring instruments	7.4	7.3
7.8	Determination of exhaust gas flow	7.3	7.2
7.9	Determination of the gaseous components	7.5, 12.4	7.4, 15 [a]
7.10	Determination of the particulates	7.6, 17	7.5, 16 [a]
7.11	Calibration of the analytical instruments	8	8 [a]
7.11.1	Calibration procedure	8.5	8 [a]
7.11.2	Verification of the calibration	8.5.7	8 [a]
7.12	Efficiency test of the NO_x converter	8.7	8 [a]
7.13	Checking of HFID hydrocarbon response	8.8.2	8 [a]
7.14	Calibration intervals	8.10, 9.4	8 [a]
7.15	Calibration of the particulate measuring system	9	9 [a]
7.17	Test run	12	11 [a]
7.18	Data evaluation for gaseous and particulate emissions	13	12 [a]
7.19	Calculation of the gaseous emissions	14	13 [a]
7.20	Calculation of particulate emissions	15	14 [a]
7.21	Analytical and sampling systems	16	15 [a]

[a] For parameters 7.9 to 7.21 the operative clause of ISO 8178-2 contains references to the applicable clause(s) of ISO 8178-1. In some cases the necessary differences for the site conditions are described in ISO 8178-2.

8 Modes and weighting factors for test cycles

8.1 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 8.3 to 8.8. With the prior agreement of the parties involved, the universal test cycle described in Annex B may be used and the emissions values for the respective application calculated using the appropriate weighting factors. For special cases not shown, an adequate choice shall be made and agreed upon by the parties concerned. Most of the following test cycles have been derived from and follow the same principles as the UN-ECE R49 [17] 13-mode steady-state test cycle.

The particulate emission may be measured by either the multiple filter or the single filter method according to 13.3 of ISO 8178-1:2006. 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.

The test equipment and test cycles of ISO 8178-1 and this part of ISO 8178 may also be used for the measurement of particulate emissions from spark ignition engines.

8.2 Requirements

Each test shall be performed in the given sequence of the test modes for a particular test cycle. The minimum test mode length is 10 min which is the standard, except for cycles “G” (see 8.7.3). If necessary the mode length may be extended e.g. to collect sufficient particulate sample mass or to achieve stabilization with large engines.

The mode length shall be recorded and reported.

Except for test cycles “G” (see 8.7.3), 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. Only the last 60 s of the 3 min period shall be used for emission calculation in accordance with 13.2 of ISO 8178-1:2006.

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.

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 preconditioned by running the previous mode. In case of the first mode of any cycle, the engine shall be preconditioned according to 12.3 of ISO 8178-1:2006. If a delay of more than 20 min, but less than 4 h, occurs between the end of one mode and the beginning of another mode, the engine shall be preconditioned by running the previous mode. If the delay exceeds 4 h, the engine shall be preconditioned according to 12.3 of ISO 8178-1:2006.

If at any time during a test mode, the test equipment malfunctions or the engine speed and load do not meet the requirements of 12.7.1 of ISO 8178-1:2006, the test mode is void and may be aborted. The test mode may be restarted by preconditioning with the previous mode.

8.3 Test cycles type C "Off-road vehicles and industrial equipment"

8.3.1 Cycle type C1 "Off-road vehicles, diesel-powered off-road industrial equipment"

8.3.1.1 Test modes and weighting factors

See Table 3.

Table 3 — Cycle C1 test modes and weighting factors

Mode number	1	2	3	4	5	6	7	8
Speed [a]	Rated speed				Intermediate speed			Low-idle speed
Torque [a], %	100	75	50	10	100	75	50	0
Weighting factor	0,15	0,15	0,15	0,1	0,1	0,1	0,1	0,15

[a] See ISO 8178-1:2006, 12.5 and 3.5, 3.6, 5 and 6 of this part of ISO 8178.

8.3.1.2 Performing the test

The test shall be performed in ascending order of mode numbers of cycle C1.

The provisions of 8.2 shall be taken into account.

8.3.1.3 Criteria for the application of this test

Typical examples 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 Diesel engines with rated power typically below 20 kW intended for applications listed under 8.7.4 (test cycles G), can be tested according to the test cycles given in 8.3 (test cycles C).

NOTE 2 Diesel engines with hydrostatic or hydraulic transmission which operate within ± 15 % of the rated speed and spend less than 15 % of their time at low idle speed can be tested according to test cycle D2 (see 8.4).

8.3.2 Cycle C2 "Off-road vehicles, spark ignition powered off-road industrial equipment", > 20 kW

8.3.2.1 Test modes and weighting factors

See Table 4.

Table 4 — Cycle C2 test modes and weighting factors

Mode number	1	2	3	4	5	6	7
Speed [a]	Rated speed	Intermediate speed					Low-idle speed
Torque [a], %	25	100	75	50	25	10	0
Weighting factor	0,06	0,02	0,05	0,32	0,30	0,10	0,15
[a] See ISO 8178-1:2006, 11.5 and 3.5, 3.6, 5 and 6 of this part of ISO 8178.							

8.3.2.2 Performing the test

The test shall be performed in ascending order of mode numbers of cycle C2.

The provisions of 8.2 shall be taken into account.

8.3.2.3 Criteria for the application of this test

Typical examples are:

— fork-lift trucks;

— airport supporting equipment;

— material handling equipment;

— road maintenance equipment;

— agricultural equipment.

This list is not exhaustive.

8.4 Test cycles type D "Constant speed"

8.4.1 Applications

— cycle D1: power plants;

— cycle D2: generating sets with intermittent load.

8.4.2 Test modes and weighting factors

See Table 5.

Table 5 — Cycles type D test modes and weighting factors

Mode number (cycle D1)	**1**	**2**	**3**								
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque, [a] %	100	75	50								
Weighting factor	0,3	0,5	0,2								
Mode number (cycle D2)	**1**	**2**	**3**	**4**	**5**						
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque, [a] %	100	75	50	25	10						
Weighting factor	0,05	0,25	0,3	0,3	0,1						

[a] See ISO 8178-1:2006, 12.5 and 3.5, 3.6, 5 and 6 of this part of ISO 8178

8.4.3 Performing the test

Test cycles D1 and D2 shall be performed in ascending order of mode numbers of cycle D1 and of cycle D2.

The provisions of 8.2 shall be taken into account.

For test cycle D1 the torque figures are percentage values of the torque corresponding to the continuous power rating as defined in ISO 8528-1.

For the test cycle D2 the torque figures are percentage values of the torque corresponding to the prime power rating as defined in ISO 8528-1.

8.4.4 Criteria for the application of these tests

Typical examples 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), refrigerating units, welding sets;

— turf care, chippers, snow removal equipment, sweepers.

This list is not exhaustive.

NOTE 1 Diesel engines with rated power typically below 20 kW intended for application listed under 8.7.4 (test cycles G) can be tested according to the test cycles given in 8.4 (test cycles D).

NOTE 2 Diesel engines with hydrostatic or hydraulic transmission with load sensing can be tested according to the cycle given in 8.4 (test cycle D2). See also 8.3.1.3.

8.5 Test cycles type E "Marine applications"

8.5.1 Applications

Five test cycles are described:

— cycle E1: diesel engines for craft less than 24 m in length;

— cycle E2: heavy-duty constant speed engines for ship propulsion;

— cycle E3: heavy-duty marine engines (propeller law);

— cycle E4: pleasure craft spark ignition engines for craft less than 24 m in length;

— cycle E5: diesel engines for craft less than 24 m in length (propeller law).

8.5.2 Test modes and weighting factors

See Table 6.

8.5.3 Performing the test

The test cycles E1, E2, E3, E4 or E5 shall be performed in ascending order of the mode number of the cycle in question.

The provisions of 8.2 shall be taken into account.

For diesel 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 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 the 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.

8.5.4 Criteria for the application of these tests

Typical examples are:

— cycle E1: diesel-engines for craft less than 24 m in length except those of tug boats and push boats;

— cycle E2: constant-speed heavy duty engines for ship propulsion without limitation of length;

— cycle E3: propeller-law heavy duty engines for ship propulsion without limitation of length;

— cycle E4: spark ignition engines for craft less than 24 m in length except for tug boats and push boats;

— cycle E5: diesel engines for craft less than 24 m in length when operated on a propeller law except for tug boats and push boats.

This list is not exhaustive.

Table 6 — Cycles type E test modes and weighting factors

Mode number (cycle E1)	**1**	**2**					**3**	**4**			**5**
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque [a], %	100	75					75	50			0
Weighting factor	0,08	0,11					0,19	0,32			0,3
Mode number (cycle E2)	**1**	**2**	**3**	**4**							
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque [a], %	100	75	50	25							
Weighting factor	0,2	0,5	0,15	0,15							
Mode number (cycle E3)	**1**					**2**		**3**		**4**	
Speed [a], %	100					91		80		63	
Power, %	100					75		50		25	
Weighting factor	0,2					0,5		0,15		0,15	
Mode number (cycle E4)	1					2		3		4	5
Speed [a], %	100					80		60		40	Idle
Torque [a], %	100					71,6		46,5		25,3	0
Weighting factor	0,06					0,14		0,15		0,25	0,40
Mode number (cycle E5)	**1**					**2**		**3**		**4**	**5**
Speed [a], %	100					91		80		63	Idle
Power, %	100					75		50		25	0
Weighting factor	0,08					0,13		0,17		0,32	0,3

[a] See ISO 8178-1:2006, 12.5 and 3.5, 3.6, 5 and 6 of this part of ISO 8178.

8.6 Test cycles type F “Rail traction”

8.6.1 Test modes and weighting factors

See Table 7.

Table 7 — Cycles type F test modes and weighting factors

Mode number	**1**	**2**	**3**
Speed [a]	Rated speed	Intermediate speed	Low-idle speed
Torque [a], %	100	50	5
Weighting factor	0,25	0,15	0,6

[a] See ISO 8178-1:2006, 12.5 and 3.5, 3.6, 5 and 6 of this part of ISO 8178.

8.6.2 Performing the test

The test shall be performed in ascending order of modes of cycle F.

The provisions of 8.2 shall be taken into account.

NOTE For engines using a discrete control system (i.e. notch type controls) mode 2 is defined as an operation in the notch closest to mode 2 or 35 % of the rated power.

8.6.3 Criteria for the application of this test

Typical examples 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 8.3.1.1 (C1).

8.7 Test cycles type G “Utility, lawn and garden”; typically < 20 kW

8.7.1 Applications

Three test cycles are described:

— cycle G1: non-hand-held intermediate speed applications;

— cycle G2: non-hand-held rated speed applications;

— cycle G3: hand-held rated speed applications.

8.7.2 Test modes and weighting factors

See Table 8.

Table 8 — Cycles type G test modes and weighting factors

Mode number (cycle G1)						**1**	**2**	**3**	**4**	**5**	**6**
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque [a], %						100	75	50	25	10	0
Weighting factor						0,09	0,20	0,29	0,30	0,07	0,05
Mode number (cycle G2)	**1**	**2**	**3**	**4**	**5**						**6**
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque [a], %	100	75	50	25	10						0
Weighting factor	0,09	0,20	0,29	0,30	0,07						0,05
Mode number (cycle G3)	**1**										**2**
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque [a], %	100										0
Weighting factor	0,85										0,15

[a] See ISO 8178-1:2006, 12.5, and 3.5, 3.6, 5 and 6 of this part of ISO 8178.

8.7.3 Performing the test

The test cycles G1, G2 or G3 shall be performed in ascending order of mode number of the cycle in question.

The provisions of 8.2 shall be taken into account.

For spark ignition engines when only gaseous emissions are measured, each mode time shall be 3 min. The gaseous exhaust emission concentration values shall be measured and recorded for the last 2 min of the respective test mode.

For spark ignition engines the gaseous emissions shall only be measured in one of the specific cycles G1, G2 or G3. It is not permitted to calculate the emission results from the test cycle type B.

8.7.4 Criteria for the application of these tests

8.7.4.1 Choosing an appropriate test cycle

If the primary end use of an engine model is known then the test cycle may be chosen based on the examples given in 8.7.4.2. 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.

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).

8.7.4.2 Examples

Typical examples 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.

8.8 Test cycle type H "Snowmobile"

8.8.1 Test modes and weighting factors

See Table 9.

Table 9 — Cycle type H test modes and weighting factors

Mode number	1	2	3	4	5
Speed [a], %	100	85	75	65	Idle
Torque [a], %	100	51	33	19	0
Weighting factor	0,12	0,27	0,25	0,31	0,05

[a] See ISO 8178-1:2006, 12.5 and 3.5, 3.6, 5 and 6 of this part of ISO 8178.

8.8.2 Performing the test

The test cycle H shall be performed in ascending order of mode number of cycle H.

The provisions of 8.2 shall be taken into account.

8.8.3 Criteria for the application of this test

Typical examples are:

— snowmobiles.

9 Engine control area

9.1 General remarks

The exhaust emissions are measured using the appropriate test cycles in accordance with 8.3 to 8.8. The emission results will therefore be representative for the respective application. In addition, certain regulators require that the emissions from the engine be controlled in areas not covered by the test cycle. While this part of ISO 8178 does not specify any emission limits in those areas, it defines the engine control area depending on the engine operation described in 9.2 to 9.4.

9.2 Multiple speed engines

This subclause applies to engines typically covered by test cycles C1, C2, E1 and H. The control area, as shown in Figure 3, is defined as follows:

— speed range: speed A to high speed;

— torque range: 30 % to 100 %;

where:

— speed A = low speed + 15% (high speed − low speed);

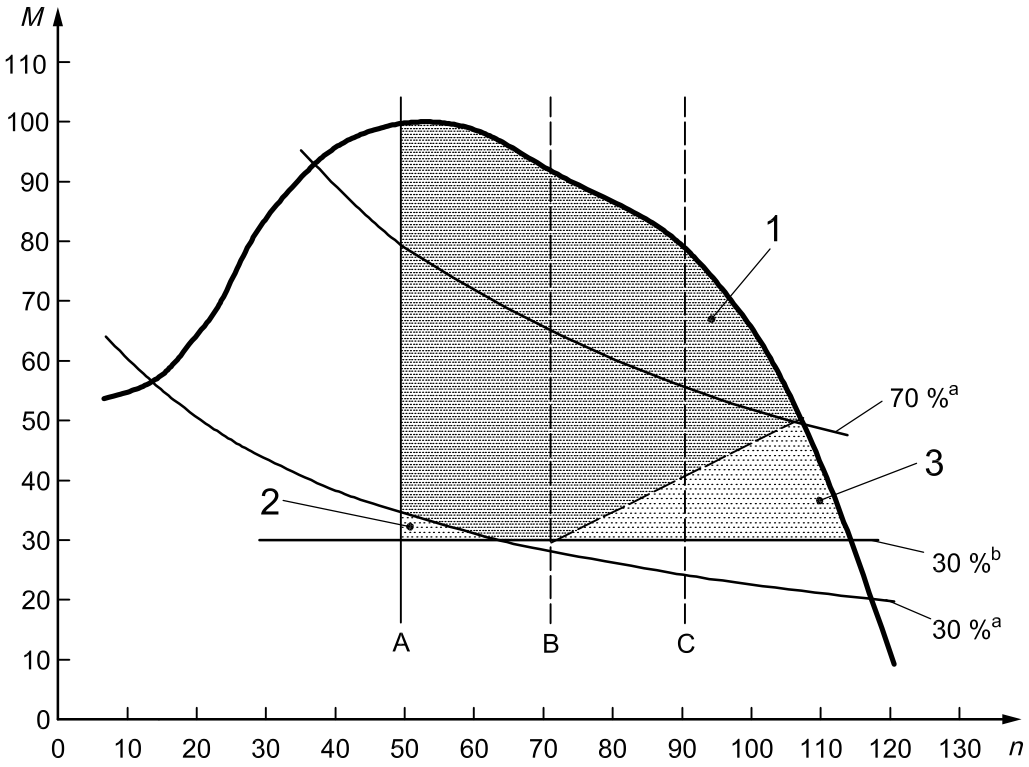
— speed B = low speed + 50 % (high speed − low speed);

— speed C = low speed + 75 % (high speed − low speed);

with

low speed = lowest engine speed where 50 % of the rated or prime power is delivered;

high speed = highest engine speed where 70 % of the rated or prime power is delivered.



Key

1 control area

2 all emissions carve-out

3 PM carve-out

a Percentage of maximum power.

b Percentage of maximum torque.

NOTE n is expressed as a percentage of rated speed (100 %), (idle = 0 %); M is expressed as a percentage of maximum torque.

Figure 3 — Engine control area for multiple speed engines

If the measured engine speeds A, B and C are within ± 3 % of the engine speeds declared by the manufacturer, the declared engine speeds shall be used. If the tolerance is exceeded for any of the test speeds, the measured engine speeds shall be used.

The following speed and torque points shall be excluded from the control area:

— points below 30 % of maximum power;

— for particulate matter only, if the C speed is below 2 400 r/min, points to the right of or below the line formed by connecting the points of 30 % of maximum torque or 30 % of maximum power, whichever is greater, at the B speed and 70 % of maximum power at the high speed;

— for particulate matter only, if the C speed is above 2 400 r/min, points to the right of the line formed by connecting the points of 30 % of maximum torque or 30 % of maximum power, whichever is greater, at the B speed, 50 % of maximum power at 2 400 r/min, and 70 % of maximum power at the high speed.

9.3 Constant speed engines

This subclause applies to engines typically covered by test cycles D1, D2, E2, G1, G2 and G3. Since those engines are mainly operated very close to their designed operating speed, the control area is defined as:

— speed: operating speed within the speed drop tolerance specified by the engine manufacturer;

— load: 50 % to 100 %.

9.4 Engines operated on a propeller curve

9.4.1 CI engines

This subclause applies to engines typically covered by test cycles E3, E5 and F. Since those engines are mainly operated slightly above and below their propeller curve or at constant speed, the control area is related to the propeller curve and is defined as follows where a, b, c, x and y are exponents of mathematical equations defining the boundaries of the control area.

For E3 test cycle of marine engines:

low speed limit: 63 %;

low power limit: 45 % for control area A; 25 % for control area B.

For marine engines with an individual cylinder displacement $<$ 5 liter:

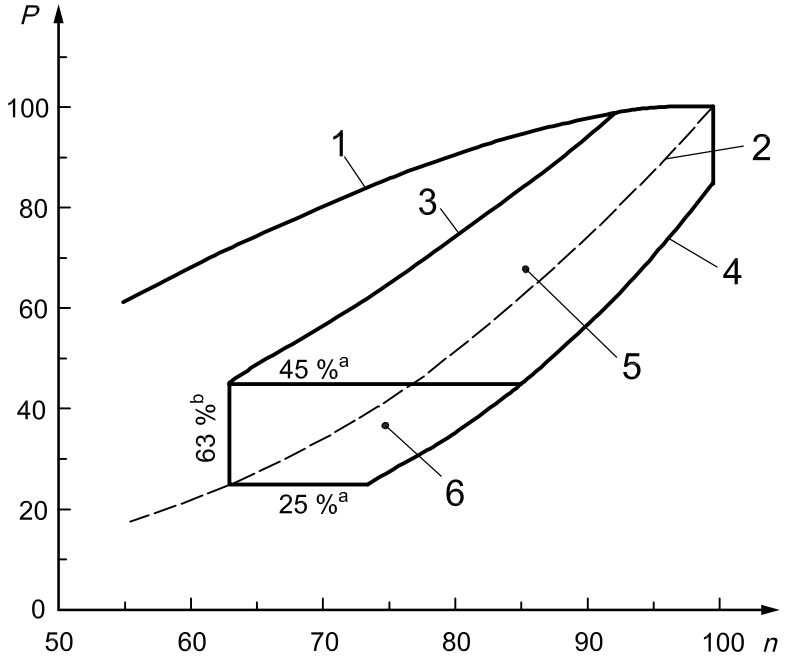
$a = 1{,}15$; $b = 0{,}85$; $c = 1$; $x = 2$; $y = 4$.

For marine engines with an individual cylinder displacement $\geqslant$ 5 liter:

$a = 1{,}04$; $b = 0{,}76$; $c = 0{,}9$; $x = 2$; $y = 4$.

For F test cycle of locomotive engines:

$a = 1{,}15$; $b = 0{,}85$; $c = 1$; $x = 2{,}5$; $y = 4$.



Key

1 power curve

2 $c \times n^3$

3 $a \times n^x$

4 $b \times n^y$

5 area A

6 area B

a Low power limit for control area A and B (% of maximum power).

b Low speed limit (% of maximum rated speed).

NOTE n is expressed as a percentage of rated speed (100 %), (idle = 0 %); P is expressed as a percentage of maximum power.

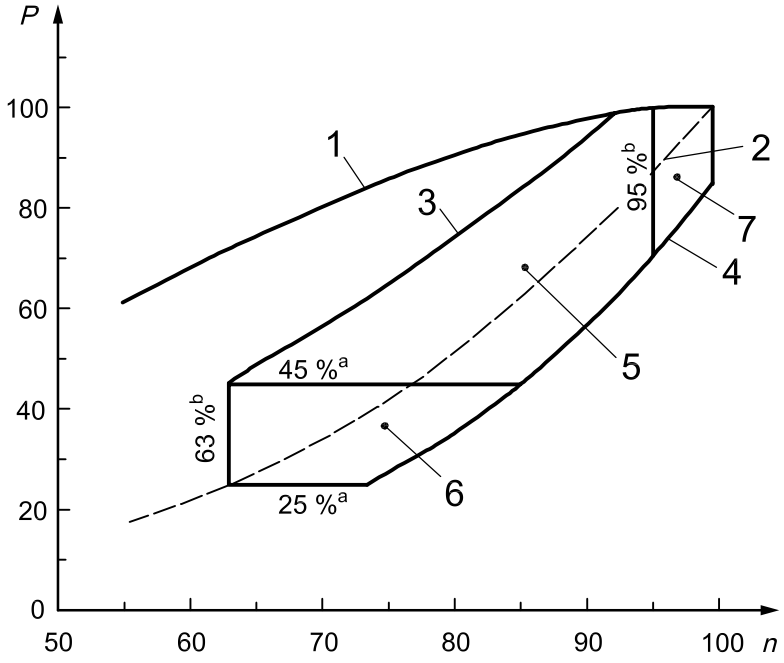
Figure 4 — Engine control area for E3 cycle marine engines

For E5 test cycle of marine engines with an individual cylinder displacement < 5 liter:

— low speed limit: 63 % for control areas A and B; 95 % for control area C;

— low power limit: 45 % for control area A; 25 % for control area B;

— $a = 1{,}15$; $b = 0{,}85$; $c = 1$; $x = 2$; $y = 4$.



Key

1 power curve
2 $c \times n^3$
3 $a \times n^x$
4 $b \times n^y$
5 area A
6 area B
7 area C

a Low power limit for control areas A and B (% of maximum power).

b Low speed limit for control areas A, B and C (% of maximum rated speed).

NOTE 1 n is expressed as a percentage of rated speed (100 %), (idle = 0 %); P is expressed as a percentage of maximum power.

NOTE 2 Emission requirement for areas B and C is less stringent than for area A.

Figure 5 — Engine control area for E5 cycle marine engines

9.4.2 Spark ignition (SI) engines

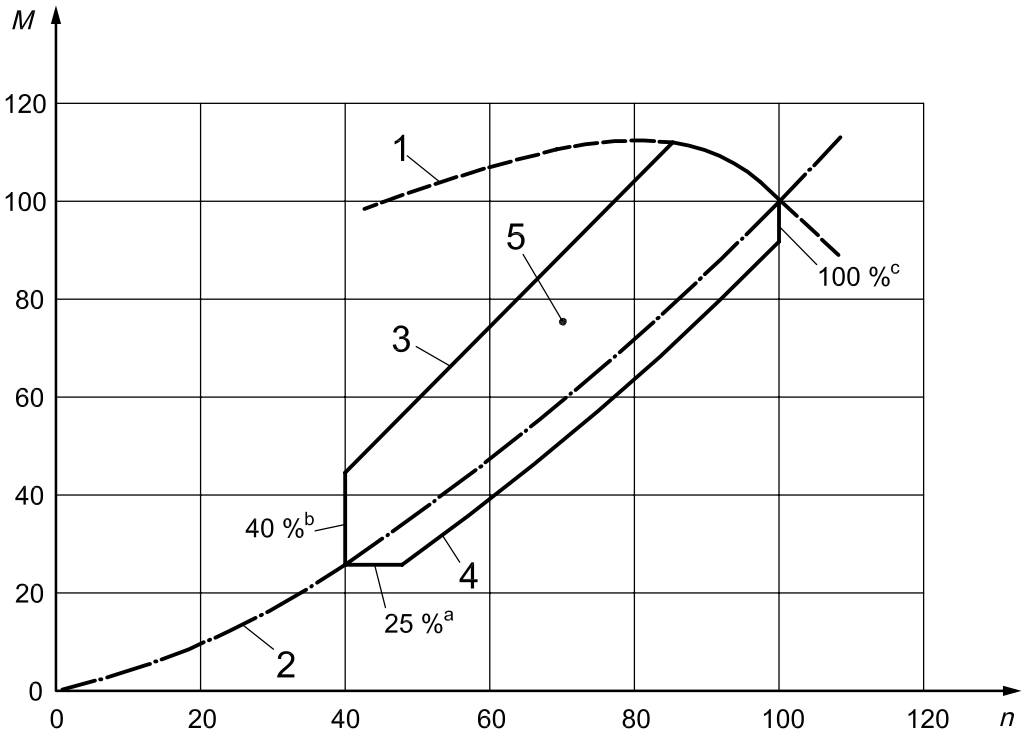
This subclause applies to engines typically covered by test cycle E4. Since those engines are mainly operated slightly above and below their propeller curve, the control area is related to the propeller curve and is defined as follows:

— low speed limit: 40 %;

— low torque limit: 25 %;

— upper propeller curve boundary: 1,5 n – 0,16;

— lower propeller curve boundary: 1,5 n – 0,08.



Key

1 torque curve

2 n^3 (propeller curve)

3 $1{,}5 \times n - 0{,}16$

4 $n^{1{,}5} - 0{,}08$

5 control area

a Low torque limit for control area (% of maximum torque at rated speed).

b Low speed limit for control area (% of rated speed).

c Upper speed limit for control area (% of rated speed).

NOTE n is expressed as a percentage of rated speed (100 %), (idle = 0 %); M is expressed as a percentage of maximum torque.

Figure 6 — Engine control area for SI marine engines

Annex A
(informative)

Combined table of the weighting factors

Torque	**100**	**75**	**50**	**25**	**10**	**100**	**75**	**50**	**25**	**10**	**0**	**Clause/ subclause**
Speed	rated speed					intermediate speed					low idle	
Off-road vehicles												
Cycle C1	0,15	0,15	0,15		0,1	0,1	0,1	0,1			0,15	8.3.1
Cycle C2				0,06		0,02	0,05	0,32	0,30	0,10	0,15	8.3.2
Constant speed												
Cycle D1	0,3	0,5	0,2									8.4
Cycle D2	0,05	0,25	0,3	0,3	0,1							8.4
Locomotives												
Cycle F	0,25							0,15			0,6	8.6
Utility, lawn and garden												
Cycle G1						0,09	0,2	0,29	0,3	0,07	0,05	8.7
Cycle G2	0,09	0,2	0,29	0,3	0,07						0,05	8.7
Cycle G3	0,85										0,15	8.7
Marine application												
Cycle E1	0,08	0,11					0,19	0,32			0,3	8.5
Cycle E2	0,2	0,5	0,15	0,15								8.5
Marine application propeller law												
Mode number E3	**1**					**2**		**3**		**4**		
Power (%)	100					75		50		25		8.5
Speed (%)	100					91		80		63		8.5
Weighting factor	0,2					0,5		0,15		0,15		8.5
Mode number E4	**1**					**2**		**3**		**4**	**5**	**8.5**
Speed (%)	100					80		60		40	idle	8.5
Torque (%)	100					71,6		46,5		25,3	0	8.5
Weighting factor	0,06					0,14		0,15		0,25	0,40	8.5
Mode number E5	**1**					**2**		**3**		**4**	**5**	
Power (%)	100					75		50		25	0	8.5
Speed (%)	100					91		80		63	idle	8.5
Weighting factor	0,08					0,13		0,17		0,32	0,3	8.5
Snowmobile												
Mode number H	**1**					**2**		**3**		**4**	**5**	**8.8**
Speed (%)	100					85		75		65	idle	
Torque (%)	100					51		33		19	0	
Weighting factor	0,12					0,27		0,25		0,31	0,05	

Annex B
(normative)

Universal test cycle

Apart from the test modes of cycles E3, E4, E5 and H, which are calculated from propeller curves, the test modes of the other cycles can be combined into a universal cycle without weighting factors. From emissions data for each of the modes of this cycle, emission values for each of the other cycles may be calculated using the appropriate weighting factors for the respective application. By doing so, duplication of test runs can be avoided if the same engine is used in different applications. The universal test cycle is shown below:

Mode number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Speed [a]	Rated speed					Intermediate speed					Low-idle speed
Torque [a], %	100	75	50	25	10	100	75	50	25	10	0
Weighting factor [b]											

[a] See ISO 8178-1:2006, 12.5 and 3.5, 3.6, 5 and 6 of this part of ISO 8178.

[b] To be used in accordance with 8.3 to 8.7 for the intended application.

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