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Road vehicles — Smoke measurement of compression-ignition (diesel) engines — Survey of short in-service tests

Véhicules routiers — Mesure des émissions de fumée des moteurs à allumage par compression (diesel) — Étude sur les essais simplifiés en service

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ISO/TR 9310 was prepared by Technical Committee ISO/TC 22, *Road vehicles*.

This type 3 Technical Report only describes and assesses the different short in-service test methods which exist in different countries according to laws, rules or preferences. This report cannot and does not give any recommendation as to which of the methods should be used internationally.

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1 SCOPE

The purpose of this Technical Report is to describe and assess the different simplified short tests for the determination of the exhaust smoke emission of diesel engines of vehicles in service .

2 FIELD OF APPLICATION

The test methods described shall serve for checking and quantitatively evaluating the exhaust smoke emissions of passenger cars and commercial vehicles as defined in ISO 3833, and equipped with diesel engines when they are in service.

3 REFERENCES

ISO 1585 - Road vehicles - Engine test code - Net power
ISO 3173 - Road vehicles - Apparatus for measurements of the opacity of exhaust gas from diesel engines operating under steady state conditions
ISO 3534 - Statistics - Vocabulary and symbols
ISO 3833 - Road vehicles - Types - Terms and definitions
ISO 7644 - Road vehicles - Measurement of opacity of exhaust gas from diesel-engined vehicles - Lug-down test
ISO 7645 - Road vehicles - Measurement of opacity of exhaust gas from diesel-engined vehicles - Steady single-speed test

4 DEFINITIONS

4.1 Smoke

Visible constituents of exhaust emissions.

4.2 Comparability

The possibility of drawing conclusions on the smoke emission as it would be determined according to ISO 1585 in spite of the differing methods of quantitative evaluation of these emissions.

4.3 Repeatability

As defined in ISO 3534.

4.4 Reproducibility

As defined in ISO 3534.

4.5 Speed gradient

This term, unit s^{-2}, gives the rate of change of engine speed per unit time (revolutions per second per second). A test method approaches the steady speed conditions more closely the lower the speed gradient is.

4.6 Roadside test

Test which can be carried out withe the vehicle stationary, using simple and transportable equipment.

Two levels of equipment transportability are envisaged:

4.6.1 Equipment readily handled by one or two persons and suitable for carrying in a passenger car.

4.6.2 Equipment which is transportable but is heavier and bulkier than as defined under subclause 4.6.1 and may require trailer or light truck for transport.

4.7 Road test

Test involving driving the vehicle on a public road or on test track.

4.8 Inspection station test

Test carried out where the equipment may be more complex and permanently installed.

5 PARAMETERS

In order to be able to evaluate the individual test methods, it is necessry to take into account those parameters which effect the applicability of the method including the precision of measurement.

5.1 Technical parameters and aspects

5.1.1 The comparability is influenced by the engine speed range,
the speed gradient and the load conditions of the engine during the test.

5.1.2 The repeatability of test results depends upon the consistency of test parameters in particular:

- Atmospheric conditions
- Engine temperature
- Duration
- Speed and speed gradient
- Load
- Experience of test personnel.

5.1.3 The reproducibility depends:

- on the scatter in the manufacturing of the test devices;
- on the experience of the test personnel.

5.1.4 The risk of damage to the vehicle, especially of the brake of the vehicle, must be included as an important aspect into the comparison considerations of the different short in-service tests. The risk of damage affects the test costs (material and personnel) (5.2.1) and the legal situation (5.2.2).

5.2 Non-technical aspects

The technical aspects are not the only items to be considered when choosing a test method but economic and legal situations also have to be taken into account.

These economic and legal situations change from one country to another and cannot be studied in detail, but some are listed below:

5.2.1 Economic situation

- Costs of investments for measuring apparatus and test equipment.
- Personnel costs (the number of personnel and level of skill).
- Amount of time for the whole test.

5.2.2 Legal situation

The two different problems have to be considered:

- Conformity of the short in-service test with regard to the national existing legal requirements.
- Definition of the liability of the test personnel in cases of damages of the vehicle.

6 LOADING OF THE DIESEL ENGINE

In order to be able to compare measured smoke values with those as determined according to ISO 1585, it is necessary when effecting short in-service tests to have full load condition during the measurement of smoke.

The table below shows the test methods according to Annex A and their loading means indicated by a cross (only the positive loading of the engine has been regarded):

Test methods	Engine loaded by: engine inertia (rotating) [1]	drive line inertia (rotating) [2]	vehicle inertia (linear)	roller inertia (rotating) [3]	service brakes	rolling resistance	air resistance	force of gravity (slope gradient)
free acceleration	x							
inertia controlled acceleration	x	x		x		x		
lug down					x	x		
single steady speed on rollers					x	x		
single steady speed on road					x	x	x	x
road test on slope	x	x	x			x	x	x

[1] Including any coupled gears

[2] Including wheels

[3] Including flywheels

7 MEASURING METHODS

7.1 Exhaust sampling

7.1.1 Full flow

The whole exhaust volume is conducted through the measuring instrument. Full flow offers the greatest confidence that the measuring is representative of the whole exhaust gas flow.

7.1.2 Partial flow

A certain test volume, mostly conditioned by the type of the apparatus, is taken from the exhaust gas and conducted to the measuring instrument. For this sampling method, special conditions must be met in order to ensure that the sample measured is representative of the whole exhaust gas volume.

7.1.3 Free flow

Measuring is carried out across the exhaust plume. The application in practice is achieved relatively simply. However, due to dilution of the exhaust gas plume with air, it is very difficult to define the effective length of measurement "L" (as defined in ISO 3173), which effects the measuring results.

All three types of sampling can in theory be combined with the test methods mentioned under clause 8 but in Annex C only those measuring apparatus called for in particular published descriptions are mentioned.

7.1 Measuring instruments

7.2.1 Opacimeter

The device is meant to be according to ISO 3173. Opacimeters measure continuously and record all components of exhaust gas which lead to an impairment of visibility (4.1). Opacimeters are available with all types of sampling mentioned above.

ISO 3173 deals with steady state measurements, but some of the short in-service tests require transient measurements and in these cases the additional specifications of opacimeter response are required (electrical and physical).

7.2.2 Filter type measuring apparatus

This measuring method is based upon the evaluation of the blackening of a filter paper by the exhaust gases. To this purpose, a certain volume of exhaust gases is sucked through the filter by means of a suitable device. The evaluation of the blackening is made by photometric means.

The apparatus is suitable for measuring of black smoke (soot) and, for the time being, measuring cannot be carried out continuously.

As sampling, only partial flow (7.1.2) is feasible.

Only in the absence of lubcrication oil and high concentration of hydrocarbon does a fair correlation exist in steady speed or quasi steady speed conditions between filter paper and opacity measurement.

8 TEST METHODS AND EVALUATION

The different test methods are tabled in the Annexes.

Only methods based on published proposals (see Annex K) have been taken into account.

Annex A - Description of the test methods
Annex B - Working conditions of the engine during the measurement
Annex C - Loading of the engine, sampling and measuring apparatus
Annex D - Basis for evaluation and the investments
Annex E - Risks of damaging the vehicle during the test
Annex F - Evaluation relative to the possibility of comparison with ISO 1585
Annex G - Evaluation relative to repeatability
Annex H - Evaluation relative to advantages and disadvantages
Annex J - Application of the test methods for short in-service tests in the different countries.

Due to the fact that the results depend on:

- method of loading of the engine
- methods for sampling of exhaust gas
- measuring instruments
- smoke composition,

these results may be only compared with great caution.

9 LEGAL ASSESSMENT

Legal aspects have not been introduced in the table, because they differ from country to country.

In particular, in some countries problems exist for government test station officials driving operators' vehicles on the road or on the test tracks. Problems may also arise where a vehicle failure occurs subsequent to the test, since it may be claimed as a failure resulting from the test.

10 RESUME

The survey presented in the Annexes show the following:

For the definition of the best test method, it is necessary that internationally a scale of evaluation should be attributed to the different parameters of clause 5. However, such a scale is not available at present, because of differences between countries as:

- Rights of the testing personnel (police) with regards to regulation;
- Availability of network of test stations;
- Economic considerations;
- Legal requirements on smoke emissions alread in application (in particular on new vehicles).

ANNEX A

TEST METHODS - Description

A.1 Free acceleration test A.1.1 from idle (see Annex K.1.1) A.1.2 from raised idle (see Annex K.1.2)	The vehicle is stationary. The gear lever is in its neutral position. The engine is either at idle or at raised idle. The accelerator pedal is depressed fully and quickly, but not violently, so as to obtain maximum delivery from the injection pump. This position is maintained until maximum engine speed is reached and the govenor is in action. This test is applicable to clause 4.6 "Roadside test" and clause 4.8 "Inspection station test".
A.2 Inertia controlled acceleration test (see Annex K.2)	The vehicle is stationary. The driving wheels are on free rolls, the inertia of which is increased by flywheel masses. The gear is engaged in a position which gives the maximum engine speed for a vehicle speed of 50 to 70 km/h for trucks and 50 to 80 km/h for passenger cars and light duty vehicles. The engine is at idle. The accelerator pedal is depressed fully and quickly, but not violently, so as to obtain maximum delivery from the injection pump. This position is maintained until maximum engine speed is reached and the governor is in action. This test is applicable to clause 4.8 "Inspection station test" only.
A.3 Lug-down test (see Annex K.3)	The vehicle is stationary, the driving wheels are on free rolls. The gear is engaged in a position which gives the maximum engine speed for a vehicle speed of 50 to 70 km/h for trucks and 50 to 80 km/h for passenger cars and light duty vehicles. The accelerator pedal is fully depressed so that the engine reaches its maximum speed and the governor is in action. Then by actuating the service brake, the engine is decelerated as uniformly as possible for 10 s until reaching about 40 % of the maximum speed, the acceleration pedal remaining fully drepressed for the duration of the test. This test is applicable to "Roadside test" (subclause 4.6.2) and clause 4.8 "Inspection station test".
A.4 Single steady speed test A.4.1 on the road (see Annex K.4.1) A.4.2 on free rolls (see Annex K.4.2)	The vehicle is driven on the road (possible in the case of Annex K.4.1) or is stationary with the driving wheels on free rolls. The gear is engaged in the highest position compatible with obtaining the chosen engine speed within any vehicle speed limits set by the road conditions of free roll equipment. The accelerator pedal is fully depressed and, by actuation of the service brake, the engine is brought to and maintained at a chosen speed as constant as possible. Duration of the test: about 8 to 12 s in the case of Annex K.4.1 or max. 8 s in the case of Annex K.4.2. This test is applicable to "Roadside test" (subclause 4.6.2) and clause 4.8 "Inspection station test". Test according to Annex K.4.1 also to clause 4.7 "Road test".
A.5 Road test on slope (see Annex K.5)	The vehicle is driven on the road up a gradient of more than 3 % at full load. The gear is engaged in the highest possible position for minimum acceleration. This test is applicable to clause 4.7 "Road test".

ANNEX B

TEST METHODS - Working conditions of the engine during the measurement [1)]

B.1 Free acceleration test B.1.1 from idle (see Annex K.1.1) B.1.2 from raised idle (see Annex K.1.2)	The engine is in a transient phase. The The loading of the engine during this phase depends on the type of engine.	- Speed range from idle or raised idle to maximum speed - Speed gradient: from about 15 to 50 s^{-2}
B.2 Inertia controlled acceleration test (see Annex K.2)	The engine is in a transient phase under full load conditions.	- Speed range between idle and maximum speed. - Speed gradient: by using the suitable flywheel masses the speed gradient can be reduced to between 1,0 s^{-2} and 2,0 s^{-2}.
B.3 Lug-down test (see Annex K.3)	The engine is in a transient phase under full load conditions.	- Speed range from maximum speed down to about 40 % of the maximum speed (see Annex K.3), or a higher speed of limited by drive line vibrations or automatic transmission. - Speed gradient: from 2,5 to 6 s^{-2}
B.4 Single steady speed test B.4.1 on the road (see Annex K.4.1) B.4.2 on free rolls (see Annex K.4.2)	The engine is in a quasi stationary phase under full load conditions.	4.1 - Speed: in the range between 50 and 75 % of the maximum speed. - Speed gradient: 1,0 (s^{-2}) 4.2 - Speed: that gave the highest smoke value during the test according to ISO 1585 or nearest stable speed. - Speed gradient: 1,0 (s^{-2})
B.5 Road test on slope (see Annex K.5)	The engine is in a transient phase under full load conditions.	- Speed range from 75 to 100 % of the maximum speed. - Speed gradient: The minimum permitted by the given gear box, expected to be < 2,0 s^{-2}

1) General: For all tests, oil and water temperatures must be at normal stabilized levels,but it is accepted for all short tests (even when the speed is constant) that other temperatures (air inlet, combustion chamber, etc.) may not be the same as fully stabilized levels.

ANNEX C

TEST METHODS - Loading of the engine, sampling and measuring apparatus

The results of transient tests are affected by the time response of the opacimeters and by the triggering and suction time of the filter type apparatus.

	Principal means of loading the engine[1]	Sampling[2]	Measuring apparatus[3]
C.1 Free acceleration test C.1.1 from idle (see Annex K.1.1) C.1.2 from raised idle (see Annex K.1.2)	By acceleration of the rotating masses of the engine and of the additional masses when the gear box is in neutral position.	Full flow or partial flow	Opacimeter with an electrical response of about 1 s and a physical response not more than 0,4 s (see Annex K.1.1) Filter-type measuring apparatus.
C.2 Inertia controlled acceleration test (see Annex K.2)	By acceleration of the rolls and of the connected flywheels	Partial flow	Opacimeter (response not specified)
C.3 Lug-down test (see Annex K.3)	By service brake	Partial flow	Opacimeter with electrical and physical responses of less than 0,5 s (see Annex K.3).
C.4 Single steady speed test C.4.1 on the road (see Annex K.4.1) C.4.2 on free rolls (see Annex K.4.2)	By service brake	Partial flow	Opacimeter or filter-type measuring apparatus
C.5 Road test on slope (see Annex K.5)	By the slope of the road	Partial flow	Filter-type measuring apparatus

1) See also clause 6 "Loading of the Diesel engine"

2) See clause 7.1 "Exhaust sampling"

3) See clause 7.2 "Measuring instruments"

ANNEX D

TEST METHODS – Basis for evaluation and the investments

	Basis for evaluation	Investments
D.1 Free acceleration test D.1.1 from idle (see Annex K.1.1) D.1.2 from raised idle (see Annex K.1.2)	Highest opacity value measured (see Annex K.1.1 a) and K.1.2).	Opacimeter with accessories (with or without tachometer; see Annex K.1.2)
	Blackening of the filter: integrated value over the sampling time (see Annex K.1.1 b) and c)).	Filter-type measuring apparatus (see Annex K.1.1 b) and c)).
D.2 Inertia controlled acceleration test (see Annex K.2)	Comparison of the curves recorded with the full load curve according to ISO 1585 within the part of the speed range used by the vehicle.	Opacimeter, recorder, test stand with free rolls, and flywheel masses.
D.3 Lug-down test (see Annex K.3)	Comparison of the curves recorded with the full load curve according to ISO 1585 within the part of the speed range used by the vehicle.	Opacimeter, recorder, deceleration measuring apparatus, time measuring apparatus, test stand with free rolls.
D.4 Single steady speed test D.4.1 on the road (see Annex K.4.1) D.4.2 on free rolls (see Annex K.4.2)	- When measured with opacimeter, the average value of the measured opacities; - When measured with a filter-type measuring apparatus, blackening of the filter: integrated value over the sampling time.	Opacimeter or filter-type measuring apparatus, and, when measured with stationary vehicle, a test stand with free rolls (see Annex K.4.1). Additionally tachometer (with recording instruments for monitoring the speed if required) (See Annex K.4.2)
D.5 Road test on slope (see Annex K.5)	Blackening of the filter: integrated value over the sampling time.	Filter-type measuring apparatus

ANNEX E

TEST METHODS - Risks of damaging the vehicle and other safety problems

(The comments below assume that vehicles are in road-worthy conditions and that general safety precautions are respected, with special attention to the risks to personnel that could result from a vehicle running of the rolls where used.

E.1 Free acceleration test E.1.1 from idle (see Annex K.1.1) E.1.2 from raised idle (see Annex K.1.2)	None
E.2 Inertia controlled acceleration test (see Annex K.2)	Generally none for the vehicle, if well fixed; hoewever, risk for the tyres can not be excluded.[2]
E.3 Lug-down test (see Annex K.3)	In practical application, no problems have been encountered for vehicles of more than 3,5 t G.V.W. For light duty vehicles and especially passenger cars, overheating of the brakes is possible.[1] [2]
E.4 Single steady speed test E.4.1 on the road (see Annex K.4.1) E.4.2 on free rolls (see Annex K.4.2)	The time limit for brake loading must be respected. On road (see Annex K.4.1), there is no risk if the test is run on a dry road with little traffic. A slippery road can result in locked brakes on non-driven wheels, and in this case test on free rolls are recommended. On free rolls there is no risk for heavy vehicles over 3,5 t G.V.W. For light duty vehicles and passenger cars, a risk of overheating the brakes is present if testing at high speed is necessary and test duration is not respected.[1] [2]
E.5 Road test on slope (see Annex K.5)	None

1) This test was developed for vehicle of more than 3,5 t G.V.W. and there is less experience with lighter vehicles. Some cases of brake fade have occured with lighter vehicles when the power to weight ratio is high. These occurences may be because the test was improperly run (e.g. lug down time too long).

2) Specific devices will be necessary to retain the vehicle on the rolls or to protect personnel. Where rolls are used on the road side, devices may be necessary for preventing roll frame movement.

ANNEX F

TEST METHODS – Evaluation – Possibility of comparison with ISO 1585 (see clause 4.2 "Comparibility"

F.1	Free acceleration test	The possibility of comparison is impaired by measurement under transient speed conditions and by the speed gradient being high. Therefore, any general possibility of comparison with smoke values measured according to ISO 1585 has not been found. This fact appears in particular when testing super-charged engines.
F.1.1	from idle (see Annex K.1.1)	
F.1.2	from raised idle (see Annex K.1.2)	The part of the test speed range immediately above idle or raised idle is not relevant for ISO 1585[1] (see Annex K.1.1 a) and b) , F.1.1 only)
F.2	Inertia controlled acceleration test (see Annex K.2)	The possibility of comparison is impaired by measurement under transient speed conditions, however, due to the low speed gradient, an approach to the smoke values according to ISO 1585 can be reached.
F.3	Lug-down test (see Annex K.3)	The possibility of comparison is impaired by measurement under transient speed conditions. However, the speed gradient is relatively low and in most cases close comparison to ISO 1585 is possible. Since the whole speed range according ISO 1585 is covered and the permanent record is obtained, identification of the maximum smoke is facilitated.
F.4	Single steady speed test	For the possibility of comparison, it is advantageous that measurements are carried out under quasi-stationary conditions, speed gradient near zero with or without a well defined speed. In the case of a well defined speed (see Annex K.4.2) identification of maximum smoke is impaired, because in service this speed is not always known; even when known it is not always possible for practical reasons to measure at this speed. In case of a not-well defined speed (see Annex K.4.1), the maximum smoke may occur at some other speed than the measurements speed.
F.4.1	on the road (see Annex K.4.1)	
F.4.2	on free rolls (see Annex K.4.2)	
F.5	Road test on slope (see Annex K.5)	For the possibility of comparison, the smoke values recorded are similar to those when testing at the same speed according to ISO 1585; it is however, not assured when testing at the same speed according to ISO 1585; it is however, not assured when testing on the road that measurements are made at the speed at which peak smoke occurs.

1) Correspondingly for ECE-R 24-02 (see Annex K.1.1.a) the part of the speed range between idle or raised idle and 45 % of maximum power speed is not generally relevant.

ANNEX G

TEST METHODS - Evaluation - Repeatability (see clause 4.3)

The repeatability of these methods demands identical measuring conditions (pressure and temperature) in the measuring apparatus. Also environmental conditions have an influence on the repeatability.

G.1 Free acceleration test G.1.1 from idle (see Annex K.1.1) G.1.2 from raised idle (see Annex K.1.2)	Repeatability demands consistent operation of the accelerator control and depends, therefore, on the test personnel.
G.2 Inertia controlled acceleration test (see Annex K.2)	
G.3 Lug-down test (see Annex K.3)	Repeatability demands a constant braking gradient and depends, therefore, on test personnel. Two safeguards prevent invalid test if deceleration is too great or total time is outside the limits. Assessment is made after repeatability of three tests has been ensured.
G.4 Single steady speed test	Repeatability is promoted by the low speed gradient, however, it is necessary that the same speed is chosen within the speed range. Repeatability depends on the ability of test personnel to set the desired speed within the specified time and maintain the speed constant during the measurement.
G.5 Road test on slope (see Annex K.5)	The repeatability depends on test being made under the same conditions, which may be difficult when testing on the road.

ANNEX H

TEST METHODS - Evaluation - Advantages and disadvantages

Except for H.5 these tests - especially H.1 - are not suitable for raising the engine temperature significantly except possibly for H.2.

	ADVANTAGES	DISADVANTAGES
H.1 Free acceleration test H.1.1 from idle (see Annex K.1.1) H.1.2 from raised idle (see Annex K.1.2)	The simplicity of its realization (particularly for road side tests where it conforms with clause 4.6.1), the low costs of installation and the short duration of the test, the absence of risk of damaging the vehicle and therefore, the harmless legal situation.	Not generally representative of real operating conditions and full load conditions particularly with super charged engines.
H.2 Inertia controlled acceleration test (see Annex K.2)	A low speed gradient when passenger cars are tested.[1]	- The realization of this test method is difficult because of the large number and sizes of flywheels required and the difficulty of ensuring that the speed gradient is between 1,0 and 2,0 s^{-2}. - Does not necessarily cover the full engine speed range with automatic transmission.[2]
H.3 Lug-down test (see Annex K.3)	It shows the behaviour of the engine concerning smoke under full load conditions over the whole speed range down to 40 % of the maximum speed and that it has a low speed gradient. A record permits confirmation of the result (pass or failure) and to verify if conditions of test have been met.[1]	- Some risks to brakes on vehicles with high power to weight ratios (see Annex E). - In certain cases, not representative of full load and steady state conditions. - Does not necessarily cover the full engine speed range with automatic transmission.[2]

H.4 <u>Single steady speed test</u> H.4.1 (see Annex K.4.1) H.4.2 (see Annex K.4.2)	The measurement under quasi stationary conditions and where possible at the speed where the maximum smoke occured when testing according to ISO 1585 and this may be possible with relatively low expenditures.[1]	- Only measures at one speed which may not be the speed of maximum smoke in service. - In some cases, difficult to hold steady engine speed particularly with automatic transmission. - On rollers: Some risks to brakes on vehicles with high power to weight ratios (see Annex E).[2] - On road: Test is subject to road conditions (dry, wet) and traffic conditions.
H.5 <u>Road test on slope</u> (see Annex K.5)	The absence of risk of damaging the vehicle and in most cases it is easy to carry out under normal driving conditions providing that traffic density is light.	Test is subject to traffic conditions.

1) Problems may arise with vehicles with more than one driven axle requiring extra rolls and coupling. This applies only to a minority of vehicles.

2) In order to comply with safety requirements (see Annex E), the time needed for the test could be considerably increased, depending on the device, with a reduction of the test number capability.