CHAPTER III

TEST PROCEDURE

1. INTRODUCTION

1.1. This Chapter describes the methods of determining emissions of gaseous components, particulates and smoke from the engines to be tested. Three test cycles are described that shall be applied according to the provisions of Chapter-I, section 6.2:

- the ESC which consists of a steady state 13-mode cycle,
- the ELR which consists of transient load steps at different speeds, which are integral parts of one test procedure, and are run concurrently,
- the ETC which consists of a second-by-second sequence of transient modes.

1.2. The test shall be carried out with the engine mounted on a test bench and connected to a dynamometer.

1.3. Measurement principle

The emissions to be measured from the exhaust of the engine include the gaseous components (carbon monoxide, total hydrocarbons, oxides of nitrogen, particulates & Non-methane hydrocarbons (gas-engines only) for diesel & gas-engines on the ESC test only; and smoke (diesel engines on the ELR test only). Additionally, carbon dioxide is often used as a tracer gas for determining the dilution ratio of partial and full flow dilution systems. Good engineering practice recommends the general measurement of carbon dioxide as an excellent tool for the detection of measurement problems during the test run.

1.3.1. ESC Test

During a prescribed sequence of warmed-up engine operating conditions the amounts of the above exhaust emissions shall be examined continuously by taking a sample from the raw exhaust gas. The test cycle consists of a number of speed and power modes which cover the typical operating range of diesel engines. During each mode the concentration of each gaseous pollutant, exhaust flow and power output shall be determined, and the measured values weighted. The particulate sample shall be diluted with conditioned ambient air. One sample over the complete test procedure shall be taken, and collected on suitable filters. The grams of each pollutant emitted per kilo-Watt hour shall be calculated as described in Appendix 1 to this Chapter.

Additionally, NOx shall be measured at three test points within the control area (Only for Diesel Engines) selected by the Technical Service (1) and the measured values compared to the values calculated from those modes of the test cycle enveloping the selected test points. The NOx control check ensures the

---

(1) The test points shall be selected using approved statistical methods of randomization.

effectiveness of the emission control of the engine within the typical engine operating range. .

1.3.2. ELR Test

During a prescribed load response test, the smoke of a warmed-up engine shall be determined by means of an opacimeter. The test consists of loading the engine at constant speed from 10 % to 100 % load at three different engine speeds. Additionally, a fourth load step selected by the Technical Service(1) shall be run, and the value compared to the values of the previous load steps. The smoke peak shall be determined using an averaging algorithm, as described in Appendix 1 to this Chapter.

1.3.3. ETC Test

During a prescribed transient cycle of warmed-up engine operating conditions, which is based closely on road-type-specific driving patterns of heavy-duty engines installed in trucks and buses, the above pollutants shall be examined after diluting the total exhaust gas with conditioned ambient air. Using the engine torque and speed feedback signals of the engine dynamometer, the power shall be integrated with respect to time of the cycle resulting in the work produced by the engine over the cycle. The concentration of NOx and HC shall be determined over the cycle by integration of the analyser signal. The concentration of CO, CO2, and NMHC may be determined by integration of the analyser signal or by bag sampling. For particulates, a proportional sample shall be collected on suitable filters. The diluted exhaust gas flow rate shall be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values shall be related to the engine work to get the grams of each pollutant emitted per kilowatt hour, as described in Appendix 2 to this Chapter.

2. TEST CONDITIONS

2.1. Engine Test Conditions

2.1.1. The absolute temperature (Ta) of the engine air at the inlet to the engine expressed in Kelvin, and the dry atmospheric pressure (ps), expressed in kPa shall be measured and the parameter F shall be determined according to the following provisions:

(a) for diesel engines:

Naturally aspirated and mechanically supercharged engines:

---

(1) The test points shall be selected using approved statistical methods of randomisation.

$$F = \left(\frac{99}{Ps}\right) \times \left(\frac{Ta}{298}\right)^{0.7}$$

Turbocharged engines with or without cooling of the intake air:

$$F = \left(\frac{99}{Ps}\right)^{0.7} \times \left(\frac{Ta}{298}\right)^{1.5}$$

(b) for gas engines:

$$F = \left(\frac{99}{Ps}\right)^{1.2} \times \left(\frac{Ta}{298}\right)^{0.6}$$

2.1.2. Test Validity

For a test to be recognised as valid, the parameter F shall be such that:

$$0.96 \leq F \leq 1.06$$

2.2. Engines with Charge Air Cooling

The charge air temperature shall be recorded and shall be, at the speed of the declared maximum power and full load, within ± 5 K of the maximum charge air temperature specified by the manufacturer in the application. The temperature of the cooling medium shall be at least 293 K (20 °C).

If a test shop system or external blower is used, the charge air temperature shall be within ± 5 K of the maximum charge air temperature specified by the manufacturer at the speed of the declared maximum power and full load. The setting of the charge air cooler for meeting the above conditions shall be used for the whole test cycle.

2.3. Engine Air Intake System

An engine air intake system shall be used presenting an air intake restriction within ± 100 Pa of the upper limit of the engine operating at the speed at the declared maximum power and full load.

2.4. Engine Exhaust System

An exhaust system shall be used presenting an exhaust back pressure within ± 1000 Pa of the upper limit of the engine operating at the speed of declared maximum power and full load and a volume within ± 40 % of that specified by the manufacturer. A test shop system may be used, provided it represents actual engine operating conditions. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in Chapter III, Appendix 4, section 3.4 and in Chapter V, section 2.2.1, EP and section 2.3.1, EP.

If the engine is equipped with an exhaust aftertreatment device, the exhaust pipe must have the same diameter as found in-use for at least 4 pipe diameters upstream to the inlet of the beginning of the expansion section containing the aftertreatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust aftertreatment device shall be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust backpressure or restriction shall follow the same criteria as above, and may be set with a valve. The aftertreatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

2.5. Cooling System

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer shall be used.

2.6. Lubricating Oil

Specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test, as specified in the application.

2.7. Fuel

The fuel shall be the reference fuel specified in Annexure IV of the notification.
The fuel temperature and measuring point shall be specified by the manufacturer within the limits given in the application. The fuel temperature shall not be lower than 306 K (33 °C). If not specified, it shall be 311 K ± 5 K (38 °C ± 5 °C) at the inlet to the fuel supply.

For NG and LPG fuelled engines, the fuel temperature and measuring point shall be within the limits given in application.

2.8. Testing of Exhaust Aftertreatment Systems

If the engine is equipped with an exhaust aftertreatment system, the emissions measured on the test cycle(s) shall be representative of the emissions in the field. If this cannot be achieved with one single test cycle (e.g. for particulate filters with periodic regeneration), several test cycles shall be conducted and the test results averaged and/or weighted. The exact procedure shall be agreed by the engine manufacturer and the Technical Service (1) based upon good engineering judgement.

(1) The test points shall be selected using approved statistical methods of randomisation.

APPENDIX 1

ESC AND ELR TEST CYCLES

1. ENGINE AND DYNAMOMETER SETTINGS

1.1.1 Determination of Engine Speeds A, B and C

The engine speeds A, B and C shall be declared by the manufacturer in accordance with the following provisions:

The high speed nhi shall be determined by calculating 70 % of the declared maximum net power P(n), as determined in Chapter II. The highest engine speed where this ower value occurs on the power curve is defined as nhi.

The low speed n_{lo} shall be determined by calculating 50 % of the declared maximum net power P(n), as determined in Chapter II. The lowest engine speed where this power value occurs on the power curve is defined as n_{lo}.

The engine speeds A, B and C shall be calculated as follows:

Speed A = $n_{lo} + 25\% (n_{hi} – n_{lo})$

Speed B = $n_{lo} + 50\% (n_{hi} – n_{lo})$

Speed C = $n_{lo} + 75\% (n_{hi} – n_{lo})$

The engine speeds A, B and C may be verified by either of the following methods

a) Additional test points shall be measured during engine power approval according to MoRTH /CMVR/TAP-115 / 116 for an accurate determination of n_{hi} and n_{lo}. The maximum power, n_{hi} and n_{lo} shall be determined from the power curve, and engine speeds A, B and C shall be calculated according to the above provisions.

b) The engine shall be mapped along the full load curve, from maximum no load speed to idle speed, using at least 5 measurement points per 1000 rpm intervals and measurement points within ± 50 rpm of the speed at declared maximum power. The maximum power, n_{hi} and n_{lo} shall be determined from this mapping curve, and engine speeds A, B and C shall be calculated according to the above provisions.

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

1.2. Determination of Dynamometer Settings

The torque curve at full load shall be determined by experimentation to calculate the torque values for the specified test modes under net conditions, as specified in Chapter II. The power absorbed by engine-driven equipment, if applicable, shall be taken into account. The dynamometer setting for each test mode shall be calculated using the formula:

$$s = P(n) \times \frac{L}{100} \quad \text{if tested under net conditions}$$

$$s = P(n) \times \frac{L}{100} + (P(a) - P(b)) \quad \text{if not tested under net conditions}$$

where:

s = dynamometer setting, kW

P(n) = net engine power as indicated in Chapter II, kW

L = per cent load as indicated in Section 2.7.1, %

P(a) = power absorbed by auxiliaries to be fitted as indicated in Chapter II.

P(b) = power absorbed by auxiliaries to be removed as indicated in Chapter II.

2. ESC TEST RUN

At the manufacturers request, a dummy test may be run for conditioning of the engine and exhaust system before the measurement cycle.

2.1. Preparation of the Sampling Filters

At least one hour before the test, each filter (pair) shall be placed in a closed, but unsealed petri dish and placed in a weighing chamber for stabilisation. At the end of the stabilisation period, each filter (pair) shall be weighed and the tare weight shall be recorded. The filter (pair) shall then be stored in a closed petri dish or sealed filter holder until needed for testing. If the filter (pair) is not used within eight hours of its removal from the weighing chamber, it must be conditioned and reweighed before use.

2.2. Installation of the Measuring Equipment

The instrumentation and sample probes shall be installed as required. When using a full flow dilution system for exhaust gas dilution, the tailpipe shall be connected to the system.

2.3. Starting the Dilution System and the Engine

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised at maximum power according to the recommendation of the manufacturer and good engineering practice.

2.4. Starting the Particulate Sampling System

The particulate sampling system shall be started and running on by-pass. The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not filtered, measurements at the beginning and at the end of the cycle, may be done, and the values averaged.

2.5. Adjustment of the Dilution Ratio

The dilution air shall be set such that the temperature of the diluted exhaust gas measured immediately prior to the primary filter shall not exceed 325 K (52 °C) at any mode. The dilution ratio (q) shall not be less than 4.
For systems that use CO2 or NOx concentration measurement for dilution ratio control, the CO2 or NOx content of the dilution air must be measured at the beginning and at the end of each test. The pre- and post test background CO2 or NOx concentration measurements of the dilution air must be within 100 ppm or 5 ppm of each other, respectively.

2.6. Checking the Analysers

The emission analysers shall be set at zero and spanned.

2.7 Test Cycle

2.7.1 The following 13-mode cycle shall be followed in dynamometer operation on the test engine

Mode Number	Engine speed	Percent load	Weighting factor	Mode length
1	Idle	--	0.15	4 minutes
2	A	100	0.08	2 minutes
3	B	50	0.10	2 minutes
4	B	75	0.10	2 minutes
5	A	50	0.05	2 minutes
6	A	75	0.05	2 minutes
7	A	25	0.05	2 minutes
8	B	100	0.09	2 minutes
9	B	25	0.10	2 minutes
10	C	100	0.08	2 minutes
11	C	25	0.05	2 minutes
12	C	75	0.05	2 minutes
13	C	50	0.05	2 minutes

2.7.2. Test Sequence

The test sequence shall be started. The test shall be performed in the order of the mode numbers as set out in section 2.7.1.

The engine must be operated for the prescribed time in each mode, completing engine speed and load changes in the first 20 seconds. The specified speed shall be held to within ± 50 rpm and the specified torque shall be held to within ± 2 % of the maximum torque at the test speed.

At the manufacturers request, the test sequence may be repeated a sufficient number of times for sampling more particulate mass on the filter. The manufacturer shall supply a detailed description of the data evaluation and calculation procedures. The gaseous emissions shall only be determined on the first cycle.

2.7.3. Analyser Response

The output of the analysers shall be recorded on a strip chart recorder or measured with an equivalent data acquisition system with the exhaust gas flowing through the analysers throughout the test cycle.

2.7.4. Particulate Sampling

One pair of filters (primary and back-up filters, see Chapter III, Appendix 4) shall be used for the complete test procedure. The modal weighting factors specified in the test cycle procedure shall be taken into account by taking a sample proportional to the exhaust mass flow during each individual mode of the cycle. This can be achieved by adjusting sample flow rate, sampling time, and/or dilution ratio, accordingly, so that the criterion for the effective weighting factors in section 5.6 is met.

The sampling time per mode must be at least 4 seconds per 0,01 weighting factor. Sampling must be conducted as late as possible within each mode. Particulate sampling shall be completed no earlier than 5 seconds before the end of each mode.

2.7.5. Engine Conditions

The engine speed and load, intake air temperature and depression, exhaust temperature and backpressure, fuel flow and air or exhaust flow, charge air temperature, fuel temperature and humidity shall be recorded during each mode, with the speed and load requirements (see section 2.7.2) being met during the time of particulate sampling, but in any case during the last minute of each mode. Any additional data required for calculation shall be recorded (see sections 4 and 5).

2.7.6 NOx Check within the Control Area

The NOx check within the control area (Only for Diesel Engine) shall be performed immediately upon completion of mode 13.

The engine shall be conditioned at mode 13 for a period of three minutes before the start of the measurements. Three measurements shall be made at different locations within the control area, selected by the Technical Service(1). The time for each measurement shall be 2 minutes.

The measurement procedure is identical to the NOx measurement on the 13-mode cycle, and shall be carried out in accordance with sections 2.7.3, 2.7.5, and 4.1 of this Appendix, and Chapter III, Appendix 4, section 3.

The calculation shall be carried out in accordance with section 4.

2.7.7. Rechecking the Analysers

After the emission test a zero gas and the same span gas shall be used for rechecking. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 % of the span gas value.

3. ELR TEST RUN

3.1. Installation of the Measuring Equipment

The opacimeter and sample probes, if applicable, shall be installed after the exhaust silencer or any aftertreatment device, if fitted, according to the general installation procedures specified by the instrument manufacturer. Additionally, the requirements of section 10 of ISO IDS 11614 shall be observed, where appropriate.

Prior to any zero and full scale checks, the opacimeter shall be warmed up and stabilised according to the instrument manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the meter optics, this system shall also be activated and adjusted according to the manufacturer's recommendations.

3.2. Checking of the Opacimeter

The zero and full scale checks shall be made in the opacity readout mode, since the opacity scale offers two truly definable calibration points, namely 0 % opacity and 100 % opacity. The light absorption coefficient is then correctly calculated based upon the measured opacity and the L_A, as submitted by the opacimeter manufacturer, when the instrument is returned to the k readout mode for testing.

---

(1) The test points shall be selected using approved statistical methods of randomisation.

With no blockage of the opacimeter light beam, the readout shall be adjusted to 0,0 % ± 1,0 % opacity. With the light being prevented from reaching the receiver, the readout shall be adjusted to 100,0 % ± 1,0 % opacity.

3.3. Test Cycle

3.3.1. Conditioning of the Engine

Warming up of the engine and the system shall be at maximum power in order to stabilise the engine parameters according to the recommendation of the manufacturer. The preconditioning phase should also protect the actual measurement against the influence of deposits in the exhaust system from a former test.

When the engine is stabilised, the cycle shall be started within 20 ± 2 s after the preconditioning phase. At the manufacturers request, a dummy test may be run for additional conditioning before the measurement cycle.

3.3.2. Test Sequence

The test consists of a sequence of three load steps at each of the three engine speeds A (cycle 1), B (cycle 2) and C (cycle 3) determined in accordance with Chapter III, section 1.1, followed by cycle 4 at a speed within the control area and a load between 10 % and 100 %, selected by the Technical Service(1). The following sequence shall be followed in dynamometer operation on the test engine, as shown in Figure 3.

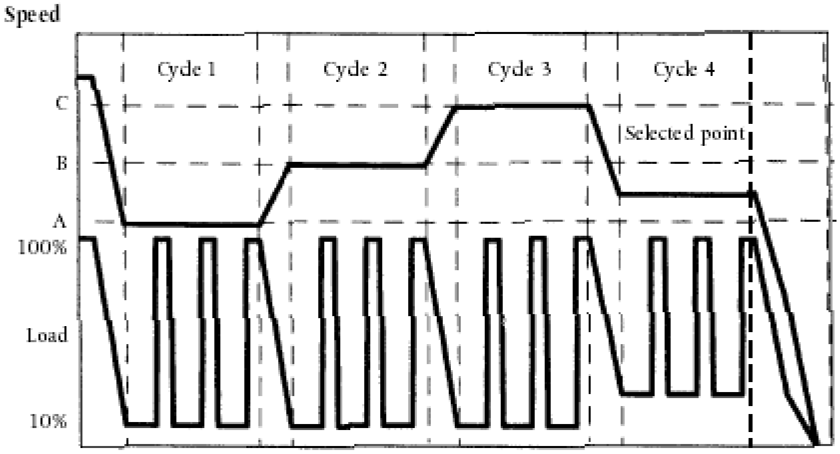

Figure 3
Sequence of ELR Test

[1] The test points shall be selected using approved statistical methods of randomisation.

(a) The engine shall be operated at engine speed A and 10 per cent load for 20 ± 2 s.
The specified speed shall be held to within ± 20 rpm and the specified torque shall be held to within ± 2 % of the maximum torque at the test speed.

(b) At the end of the previous segment, the speed control lever shall be moved rapidly to, and held in, the wide open position for 10 ± 1 s. The necessary dynamometer load shall be applied to keep the engine speed within ± 150 rpm during the first 3 s, and within ± 20 rpm during the rest of the segment.

(c) The sequence described in (a) and (b) shall be repeated two times.

(d) Upon completion of the third load step, the engine shall be adjusted to engine speed B and 10 per cent load within 20 ± 2 s.

(e) The sequence (a) to (c) shall be run with the engine operating at engine speed B.

(f) Upon completion of the third load step, the engine shall be adjusted to engine speed C and 10 per cent load within 20 ± 2 s.

(g) The sequence (a) to (c) shall be run with the engine operating at engine speed C.

(h) Upon completion of the third load step, the engine shall be adjusted to the selected engine speed and any load above 10 per cent within 20 ± 2 s.

(i) The sequence (a) to (c) shall be run with the engine operating at the selected engine speed.

3.4. Cycle Validation

The relative standard deviations of the mean smoke values at each test speed (SV_A, SV_B, SV_C, as calculated in accordance with section 6.3.3 of this Appendix from the three successive load steps at each test speed) shall be lower than 15 % of the mean value, or 10 % of the limit value shown in Table 1 of Chapter I, whichever is greater. If the difference is greater, the sequence shall be repeated until 3 successive load steps meet the validation criteria.

3.5. Rechecking of the Opacimeter

The post-test opacimeter zero drift value shall not exceed ± 5,0 % of the limit value shown in Table 1 of Chapter I.

4. CALCULATION OF THE GASEOUS EMISSIONS

4.1. Data Evaluation

For the evaluation of the gaseous emissions, the chart reading of the last 30 seconds of each mode shall be averaged, and the average concentrations (conc) of HC, CO and NO_x during each mode shall be determined from the average chart readings and the corresponding calibration data. A different type of recording can be used if it ensures an equivalent data acquisition.

For the NO_x check within the control area, the above requirements apply for NO_x, only.

The exhaust gas flow G_{EXHW} or the diluted exhaust gas flow G_{TOTW}, if used optionally, shall be determined in accordance with Chapter III, Appendix 4, section 2.3.

4.2. Dry/wet correction

The measured concentration shall be converted to a wet basis according to the following formulae, if not already measured on a wet basis.

Conc (wet) = Kw,r × Conc (dry)

For the raw exhaust gas:

For Diesel Engine:

Dry to Wet Correction Factor:

$$K_{w,r} = \left(1 - F_{FH} \times \frac{G_{FUEL}}{G_{AIRD}}\right) - K_{W,2}$$

$$F_{FH} = \frac{1.969}{1 + \frac{G_{FUEL}}{G_{AIRW}}}$$

For Gas-Engines:

$$K_{wr} = \left(\frac{V_{exhD}}{V_{exhW}} \right)$$

Where: -

V_{exhD} $= V_{dry} - 1.35 * G_{fuel}$

V_{exhW} $= V_{dry} + 1.36 * G_{fuel}$

Where: -

$$V_{dry} = \left(0.287 * G_{AirD} * (T_d + 273) \middle/ P_{AirD} \right)$$

Here,

VexhD is Dry Exhaust volume.
VexhW is Wet Exhaust volume.
T_d is Dry Bulb Temperature of Intake Air in Deg C.
P_{airD} is Dry air Pressure of Intake Air in kPa. “

4.3. NOx Correction for Humidity and Temperature

As the NOx emission depends on ambient air conditions, the NOx concentration shall be corrected for ambient air temperature and humidity with the factors given in the following formulae:

For Diesel Engine:

$$K_{HD} = \frac{1}{1 + A \times (Ha - 10.71) + B \times (T_a - 298)}$$

A = $0{,}309\ G_{FUEL}/G_{AIRD} - 0{,}0266$

B = $-\ 0{,}209\ G_{FUEL}/G_{AIRD} + 0{,}00954$

Where: -

Ta = temperature of the air, K

Ha = humidity of the intake air, g water per kg dry air

$$H_a = \frac{6.220 \times Ra \times Pa}{PB - Pa \times Ra \times 10^{-2}}$$

in which.

Ra = relative humidity of the intake air, %

Pa = saturation vapour pressure of the intake air, kPa

PB = total barometric pressure, kPa

For Gas-Engines:

$K_{HD} = 0.6272 + 0.04403 * Ha - 0.0008625 * Ha^2$

Where:

Ha is Humidity of Intake Air in g of water per kg of Dry Air.

4.4. Calculation of the Emission Mass Flow Rates

For Diesel Engines:

The emission mass flow rates (g/h) for each mode shall be calculated as follows, assuming the exhaust gas density to be 1.293 kg/m3 at 273 K (0 °C) and 101.3 kPa:

$NO_{x\ mass} = 0.001587 \times NO_{xconc} \times K_{H,D} \times G_{EXHW}$

$CO_{x\ mass} = 0.000966 \times CO_{conc} \times GEXHW$

$HC_{mass} = 0.000479 \times HC_{conc} \times GEXHW$

Where NO_{xconc}, CO_{conc}, HC_{conc} are the average concentrations (ppm) in the raw exhaust gas, as determined as in section 4.1.

For Gas-Engines:

The emission mass flow rates (g/h) for NG Engine and for each mode shall be calculated as follows, assuming the exhaust gas density to be 1.249 kg/m3 at 273 K (0 °C) and 101.3 kPa:

$NO_{x\ mass} = 0.001641 \times NO_{xconc} \times K_{H,D} \times G_{EXHW}$

$CO_{x\ mass} = 0.001001 \times CO_{conc} \times G_{EXHW}$

$HC_{mass} = 0.000563 \times HC_{conc} \times G_{EXHW}$

Where NO_{xconc}, CO_{conc}, HC_{conc} are the average concentrations (ppm) in the raw exhaust gas, as determined as in section 4.1.”

4.5. Calculation of the Specific Emissions

The emissions (g/kWh) shall be calculated for all individual components in the following way:

$$\overline{NO_X} = \frac{\sum NO_{x,mass} \times WF_i}{\sum P(n)_i \times WF_i}$$

$$\overline{CO} = \frac{\sum CO_{mass} \times WF_i}{\sum P(n)_i \times WF_i}$$

$$\overline{HC} = \frac{\sum HC_{mass} \times WF_i}{\sum P(n)_i \times WF_i}$$

The weighting factors (WF) used in the above calculation are according to section 2.7.1.

4.6. Calculation of the Area Control Values

For the three control points selected according to section 2.7.6, the NOx emission shall be measured and calculated according to section 4.6.1 and also determined by interpolation from the modes of the test cycle closest to the respective control point according to section 4.6.2. The measured values are then compared to the interpolated values according to section 4.6.3.

4.6.1. Calculation of the Specific Emission

The NOx emission for each of the control points (Z) shall be calculated as follows:

$$NO_{x,mass,z} = 0.001587 \times NO_{x,conc,Z} \times K_{H,D} \times G_{EXHW}$$

$NO_{x,Z}$ = $NO_{x,mass,Z}$/ $P(n)_Z$

4.6.2. Determination of the Emission Value from the Test Cycle

The NO_x emission for each of the control points shall be interpolated from the four closest modes of the test cycle that envelop the selected control point Z as shown in Figure 4. For these modes (R, S, T, U), the following definitions apply:

Speed(R) = Speed(T) = n_{RT}

Speed(S) = Speed(U) = n_{SU}

Per cent load(R) = Per cent load(S)

Per cent load(T) = Per cent load(U).

The NOx emission of the selected control point Z shall be calculated as follows:

$E_Z = E_{RS} + (E_{TU} - E_{RS}) \times (M_Z - M_{RS}) / (M_{TU} - M_{RS})$

and:

$E_{TU} = E_T + (E_U - E_r) \times (n_Z - n_{RT}) / (n_{su} - n_{RT})$

$E_{RS} = E_R + (E_s - E_R) \times (n_Z - n_{RT}) / (n_{su} - n_{RT})$

$M_{TU} = M_T + (M_U - M_T) \times (n_Z - n_{RT}) / (n_{su} - n_{RT})$

$M_{RS} = M_R + (M_S - M_R) \times (n_Z - n_{RT}) / (n_{su} - n_{RT})$

where,

E_R, E_S, E_T, E_U = specific NO_x emission of the enveloping modes Calculated in accordance with Section 4.6.1.
M_R, M_S, M_T, M_U = engine torque of the enveloping modes

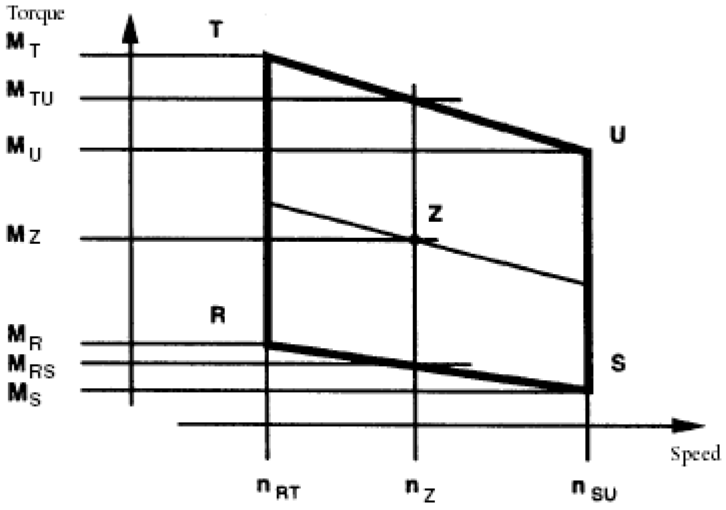

Figure 4
Interpolation of NOx Control Point

4.6.3. Comparison of NOx Emission Values

The measured specific NOx emission of the control point Z ($NO_{x,Z}$) is compared to the interpolated value (EZ) as follows:

$$NO_{x.diff} = 100 \times (NO_{x,Z} - E_Z) / E_Z$$

5. CALCULATION OF THE PARTICULATE EMISSION

5.1. Data Evaluation

For the evaluation of the particulates, the total sample masses ($M_{SAM,\ i}$) through the filters shall be recorded for each mode.

The filters shall be returned to the weighing chamber and conditioned for at least one hour, but not more than 80 hours, and then weighed. The gross weight of the filters shall be recorded and the tare weight (see section 1 of this Appendix) subtracted. The particulate mass Mf is the sum of the particulate masses collected on the primary and back-up filters.

If background correction is to be applied, the dilution air mass (M_{DIL}) through the filters and the particulate mass (Md) shall be recorded. If more than one measurement was made, the quotient Md/M_{DIL} must be calculated for each single measurement and the values averaged.

5.2. Partial Flow Dilution System

The final reported test results of the particulate emission shall be determined through the following steps. Since various types of dilution rate control may be used, different calculation methods for G_{EDFW} apply. All calculations shall be based upon the average values of the individual modes during the sampling period.

5.2.1. *Isokinetic Systems*

$$G_{EDFW,i} = G_{EXHW,i} \times q_i$$

$$q_i = \frac{G_{DILW,i} + (G_{EXHW,i} \times r)}{(G_{EXHW,i} \times r)}$$

where r corresponds to the ratio of the cross sectional areas of the isokinetic probe and the exhaust pipe:

$$R = \frac{A_p}{A_T}$$

5.2.2. Systems with Measurement of CO2 or NOx Concentration

$$G_{EDFW,i} = G_{EXHW,i} \times q_i$$

$$q_i = \frac{conc_{E,i} - conc_{A,i}}{conc_{D,i} - conc_{A,i}}$$

where:

$conc_E$= wet concentration of the tracer gas in the raw exhaust
$conc_D$= wet concentration of the tracer gas in the diluted exhaust
$conc_A$= wet concentration of the tracer gas in the dilution air

Concentrations measured on a dry basis shall be converted to a wet basis according to Section 4.2 of this Appendix.

5.2.3. Systems with CO_2 Measurement and Carbon Balance Method

$$G_{EDFW,i} = \frac{206.5 - G_{FUEL,i}}{CO_{2D,i} - CO_{2A,i}}$$

where:

CO_{2D} = CO_2 concentration of the diluted exhaust
CO_{2A} = CO_2 concentration of the dilution air

(concentrations in vol % on wet basis)

This equation is based upon the carbon balance assumption (carbon atoms supplied to the engine are emitted as CO_2) and determined through the following steps:

$$G_{EDFW,i} = G_{EXHW,i} \text{ x } q_i$$

and

$$q_i = \frac{206.5 x G_{FUEL}, i}{G_{EXHW,i} \times -(CO_{2D,i} - CO_{ZA,i})}$$

5.2.4 Systems with Flow Measurement

$$G_{EDFW,i} = G_{EXHW,i} \text{ x } q_i$$

$$q_i = \frac{G_{TOTW,i}}{(G_{TOTW,i} - G_{DILW,i})}$$

5.3. Full Flow Dilution System

The reported test results of the particulate emission shall be determined through the following steps. All calculations shall be based upon the average values of the individual modes during the sampling period.

$$G_{EDFW,i} = G_{TOTW,i}$$

5.4. Calculation of the Particulate Mass Flow Rate

The particulate mass flow rate shall be calculated as follows:

$$PT\ mass = \frac{Mf}{M_{SAM}} \times \frac{\overline{G_{EDFW}}}{1000}$$

where

$$\overline{G_{EDFW}} = \sum_{i=1}^{i=n} G_{EDFW,i} \times WF_i$$

$$M_{SAM} = \sum_{i=1}^{i=n} M_{SAM,i}$$

i = 1, ... n.

determined over the test cycle by summation of the average values of the individual modes during the sampling period.

The particulate mass flow rate may be background corrected as follows:

$$PT\ mass = \left[\frac{M_f}{M_{SAM}} - \left(\frac{M_d}{M_{DIL}} \times \left(\sum_{i=1}^{i=n} \left(1 - \frac{1}{DF_i} \right) \times WF_i \right) \right) \right] \times \frac{\overline{G_{EDFW}}}{1000}$$

If more than one measurement is made, M_d / M_{DIL} shall be replaced with $\overline{(M_d / M_{DIL})}$

$DF_i = 13{,}4/(concCO2 + (concCO + concHC)*10^{-4})$ for the individual modes

or,

$DF_i = 13{,}4/concCO2$ for the individual modes.

5.5. Calculation of the Specific Emission

The particulate emission shall be calculated in the following way:

$$\overline{PT} = \frac{PT_{mass}}{\sum P(n)i \times WF_i}$$

5.6. Effective Weighting Factor

The effective weighting factor $WF_{E,i}$ for each mode shall be calculated in the following way:

$$WF_{E,i} = \frac{M_{SAM}}{M_{SAM}} \times \frac{\overline{G_{EDFW}}}{G_{EDFW,i}}$$

The value of the effective weighting factors shall be within ± 0,003 (± 0,005 for the idle mode) of the weighting factors listed in Section 2.7.1.

6. CALCULATION OF THE SMOKE VALUES

6.1. Bessel Algorithm

The Bessel algorithm shall be used to compute the 1 s average values from the instantaneous smoke readings, converted in accordance with section 6.3.1. The algorithm emulates a low pass second order filter, and its use requires iterative calculations to determine the coefficients. These coefficients are a function of the response time of the opacimeter system and the sampling rate. Therefore, section 6.1.1 must be repeated whenever the system response time and/or sampling rate changes.

6.1.1. Calculation of Filter Response Time and Bessel Constants

The required Bessel response time (t_F) is a function of the physical and electrical response times of the opacimeter system, as specified in Chapter III, Appendix 4, section 5.2.4, and shall be calculated by the following equation:

t_F = $\sqrt{1-(t_p{}^2 + t_e{}^2)}$

where:

t_p = physical response time, s

t_e = electrical response time, s

The calculations for estimating the filter cut-off frequency (f_c) are based on a step input 0 to 1 in < = 0,01 s (see Chapter VII). The response time is defined as the time between when the Bessel output reaches 10 % (t_{10}) and when it reaches 90 % (t_{90}) of this step function. This must be obtained by iterating on f_c until t_{90}-t_{10} $\approx t_F$. The first iteration for f_c is given by the following formula:

$$f_c = \Pi / (10 \times t_F)$$

The Bessel constants E and K shall be calculated by the following equations:

$$E = \frac{1}{1 + \Omega \times \sqrt{3 \times D} + D \times \Omega^2}$$

$$K = 2 \times E \times (D \times \Omega^2 \text{ -1}) \text{ -1}$$

where:

D = 0,618034

Δt = 1/sampling rate

Ω = 1/[tan (Π x Δt * f_c)]

6.1.2. *Calculation of the Bessel Algorithm*

Using the values of E and K, the 1 s Bessel averaged response to a step input S_i shall be calculated as follows:

$$Y_i = Y_{i-1} + E \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + K \times (Y_{i-1} - Y_{i-2})$$

where:

S_{i-2} = S_{i-1} = 0

S_i = 1

Y_{i-2} = Y_{i-1} = 0

The times t_{10} and t_{90} shall be interpolated. The difference in time between t_{90} and t_{10} defines the response time t_F for that value of f_c. If this response time is not close enough to the required response time, iteration shall be continued until the actual response time is within 1 % of the required response as follows:

$$\left| (t_{90} - t_{10}) - t_F \right| \leq 0.01 \times t_F$$

6.2. Data Evaluation

The smoke measurement values shall be sampled with a minimum rate of 20 Hz.

6.3. Determination of Smoke

6.3.1. Data Conversion

Since the basic measurement unit of all opacimeters is transmittance, the smoke values shall be converted from transmittance (τ) to the light absorption coefficient (k) as follows:

$$k = -\frac{1}{L_A} \times \ln\left(1 - \frac{N}{100}\right)$$

and

$$N = 100 - \tau$$

where:

k = light absorption coefficient, m-1

LA = effective optical path length, as submitted by instrument manufacturer, m

N = opacity, %

τ = transmittance, %

The conversion shall be applied, before any further data processing is made.

6.3.2. Calculation of Bessel Averaged Smoke

The proper cut-off frequency fc is the one that produces the required filter response time tF. Once this frequency has been determined through the iterative process of section 6.1.1, the proper Bessel algorithm constants E and K shall be calculated. The Bessel algorithm shall then be applied to the instantaneous smoke trace (k-value), as described in section 6.1.2:

$$Y_i = Y_{i-1} + E \times (S_i + 2 \times S_{i-1} + S_{i-2} - 4 \times Y_{i-2}) + K \times (Y_{i-1} - Y_{i-2})$$

The Bessel algorithm is recursive in nature. Thus, it needs some initial input values of S_{i-1} and S_{i-2} and initial output values Y_{i-1} and Y_{i-2} to get the algorithm started. These may be assumed to be 0.

For each load step of the three speeds A, B and C, the maximum 1s value Y_{max} shall be selected from the individual Y_i values of each smoke trace.

6.3.3. Final Result

The mean smoke values (SV) from each cycle (test speed) shall be calculated as follows:

For test speed A:

$$SV_A = (Y_{max1,A} + Y_{max2,A} + Y_{max3,A}) / 3$$

For test speed B:

$$SV_B = (Y_{max1,B} + Y_{max2,B} + Y_{max3,B}) / 3$$

For test speed C:

$$SV_C = (Y_{max1,C} + Y_{max2,C} + Y_{max3,C}) / 3$$

where:

Y_{max1}, Y_{max2}, Y_{max3} = highest 1 s Bessel averaged smoke value at each of the three load steps

The final value shall be calculated as follows:

$$SV = (0{,}43 * SV_A) + (0{,}56 * SV_B) + (0{,}01 * SV_C)$$

APPENDIX 2

ETC TEST CYCLE

1. ENGINE MAPPING PROCEDURE

1.1. Determination of the Mapping Speed Range

For generating the ETC on the test cell, the engine needs to be mapped prior to the test cycle for determining the speed vs. torque curve. The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed = idle speed

Maximum mapping speed = n_{hi} * 1,02 or speed where full load torque drops off to zero, whichever is lower

1.2. Performing the Engine Power Map

The engine shall be warmed up at maximum power in order to stabilise the engine parameters according to the recommendation of the manufacturer and good engineering practice. When the engine is stabilised, the engine map shall be performed as follows:

(a) the engine shall be unloaded and operated at idle speed;

(b) the engine shall be operated at full load setting of the injection pump at minimum mapping speed;

(c) the engine speed shall be increased at an average rate of 8 ± 1 min-1 /s from minimum to maximum mapping speed. Engine speed and torque points shall be recorded at a sample rate of a least one point per second.

1.3. Mapping Curve Generation

All data points recorded under section 1.2 shall be connected using linear interpolation between points. The resulting torque curve is the mapping curve and shall be used to convert the normalised torque values of the engine cycle into actual torque values for the test cycle, as described in section 2.

1.4. Alternate Mapping

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 must 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 section for reasons of safety or representativeness shall be approved by the Technical Service along with the justification for their use. In no case, however, shall descending continual sweeps of engine speed be used for governed or turbocharged engines.

1.5. Replicate Tests

An engine need not be mapped before each and every test cycle. An engine shall be remapped prior to a test cycle if:

- an unreasonable amount of time has transpired since the last map, as determined by engineering judgments,

or,

- physical changes or recalibrations have been made to the engine which may potentially affect engine performance.

2 GENERATION OF THE REFERENCE TEST CYCLE

The transient test cycle is described in Appendix 3 to this Chapter. The normalised values for torque and speed shall be changed to the actual values, as follows, resulting in the reference cycle.

2.1. Actual Speed

The speed shall be unnormalised using the following equation:

$$\text{Actual speed} = \frac{\%speed(reference\_speed - idle\_speed)}{100} + idle\_speed$$

The reference speed (n_{ref}) corresponds to the 100 % speed values specified in the engine dynamometer schedule of Appendix 3. It is defined as follows (see Figure 1 of Chapter I):

$$n_{ref} = n_{lo} + 95\% \times (n_{hi} - n_{lo})$$

where n_{hi} and n_{lo} are either specified according to Chapter I, section 2 or determined according to Chapter III, Appendix 1, section 1.1.

2.2. Actual torque

The torque is normalised to the maximum torque at the respective speed. The torque values of the reference cycle shall be unnormalised, using the mapping curve determined according to section 1.3, as follows:

$$\text{Actual torque} = \frac{\%\ torque \times \max.torque}{100}$$

for the respective actual speed as determined in Section 2.1. The negative torque values of the motoring points ("m") shall take on, for purposes of reference cycle generation, unnormalised values determined in either of the following ways:

- negative 40 % of the positive torque available at the associated speed point,
- mapping of the negative torque required to motor the engine from minimum to maximum mapping speed,
- determination of the negative torque required to motor the engine at idle and reference speeds and linear interpolation between these two points.

2.3. Example of the Unnormalisation Procedure

As an example, the following test point shall be unnormalised:

% speed = 43

% torque = 82

Given the following values:

reference speed = 2200 min^{-1}

idle speed = 600 min^{-1}

results in,

$$\text{actual speed} = \frac{43 \times (2200 - 600)}{100} + 600 = 1288\,\text{min}^{-1}$$

$$\text{actual torque} = \frac{82 \times 700}{100} 574\,Nm$$

where the maximum torque observed from the mapping curve at 1288 min^{-1} is 700 Nm.

3. EMISSIONS TEST RUN

At the manufacturers request, a dummy test may be run for conditioning of the engine and exhaust system before the measurement cycle.

NG and LPG fuelled engines shall be run-in using the ETC test. The engine shall be run over a minimum of two ETC cycles and until the CO emission measured over one ETC cycle does not exceed by more than 10 % the CO emission measured over the previous ETC cycle.

3.1. Preparation of the Sampling Filters (Diesel Engines Only)

At least one hour before the test, each filter (pair) shall be placed in a closed, but unsealed petri dish and placed in a weighing chamber for stabilisation. At the end of the stabilisation period, each filter (pair) shall be weighed and the tare weight shall be recorded. The filter (pair) shall then be stored in a closed petri dish or sealed filter holder until needed for testing. If the filter (pair) is not used within eight hours of its removal from the weighing chamber, it must be conditioned and reweighed before use.

3.2. Installation of the Measuring Equipment

The instrumentation and sample probes shall be installed as required. The tailpipe shall be connected to the full flow dilution system.

3.3. Starting the Dilution System and the Engine

The dilution system and the engine shall be started and warmed up until all temperatures and pressures have stabilised at maximum power according to the recommendation of the manufacturer and good engineering practice.

3.4. Starting the Particulate Sampling System (Diesel Engines Only)

The particulate sampling system shall be started and running on by-pass. The particulate background level of the dilution air may be determined by passing dilution air through the particulate filters. If filtered dilution air is used, one measurement may be done prior to or after the test. If the dilution air is not filtered, measurements at the beginning and at the end of the cycle, may be done, and the values averaged.

3.5. Adjustment of the Full Flow Dilution System

The total diluted exhaust gas flow shall be set to eliminate water condensation in the system, and to obtain a maximum filter face temperature of 325 K (52 °C) or less (see Chapter V, section 2.3.1, DT).

3.6. Checking the Analysers

The emission analysers shall be set at zero and spanned. If sample bags are used, they shall be evacuated.

3.7. Engine Starting Procedure

The stabilised engine shall be started according to the manufacturer's recommended starting procedure in the owner's manual, using either a production starter motor or the dynamometer. Optionally, the test may start directly from the engine preconditioning phase without shutting the engine off, when the engine has reached the idle speed.

3.8. Test Cycle

3.8.1. Test Sequence

The test sequence shall be started, if the engine has reached idle speed. The test shall be performed according to the reference cycle as set out in section 2 of this Appendix. Engine speed and torque command set points shall be issued at 5 Hz (10 Hz recommended) or greater. Feedback engine speed and torque shall be recorded at least once every second during the test cycle, and the signals may be electronically filtered.

3.8.2. Analyser Response

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the measuring equipment shall be started, simultaneously:

- start collecting or analysing dilution air;
- start collecting or analysing diluted exhaust gas;
- start measuring the amount of diluted exhaust gas (CVS) and the required temperatures and pressures;
- start recording the feedback data of speed and torque of the dynamometer.

HC and NO_x shall be measured continuously in the dilution tunnel with a frequency of 2 Hz. The average concentrations shall be determined by integrating the analyser signals over the test cycle. The system response time shall be no greater than 20 s, and shall be coordinated with CVS flow fluctuations and sampling time/test cycle offsets, if necessary. CO, CO_2, NMHC and CH_4 shall be determined by integration or by analysing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the dilution air shall be determined by integration or by collecting into the background bag. All other values shall be recorded with a minimum of one measurement per second (1 Hz).

3.8.3. Particulate Sampling (Diesel Engines Only)

At the start of the engine or test sequence, if the cycle is started directly from the preconditioning, the particulate sampling system shall be switched from by-pass to collecting particulates.

If no flow compensation is used, the sample pump(s) shall be adjusted so that the flow rate through the particulate sample probe or transfer tube is maintained at a value within ± 5 % of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it must be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ± 5 % of its set value (except for the first 10 seconds of sampling).

Note: For double dilution operation, sample flow is the net difference between the flow rate through the sample filters and the secondary dilution air flow rate.

The average temperature and pressure at the gas meter(s) or flow instrumentation inlet shall be recorded. If the set flow rate cannot be maintained over the complete cycle (within ± 5 %) because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower flow rate and/or a larger diameter filter.

3.8.4. Engine Stalling

If the engine stalls anywhere during the test cycle, the engine shall be preconditioned and restarted, and the test repeated. If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided.

3.8.5. Operations After Test

At the completion of the test, the measurement of the diluted exhaust gas volume, the gas flow into the collecting bags and the particulate sample pump shall be stopped. For an integrating analyser system, sampling shall continue until system response times have elapsed.

The concentrations of the collecting bags, if used, shall be analysed as soon as possible and in any case not later than 20 minutes after the end of the test cycle.

After the emission test, a zero gas and the same span gas shall be used for re-checking the analysers. The test will be considered acceptable if the difference between the pre-test and post-test results is less than 2 % of the span gas value.

For diesel engines only, the particulate filters shall be returned to the weighing chamber no later than one hour after completion of the test and shall be conditioned in a closed, but unsealed petri dish for at least one hour, but not more than 80 hours before weighing.

3.9. Verification of the Test Run

3.9.1. Data Shift

To minimise the biasing effect of the time lag between the feedback and reference cycle values, the entire engine speed and torque feedback signal sequence may be advanced or delayed in time with respect to the reference speed and torque sequence. If the feedback signals are shifted, both speed and torque must be shifted the same amount in the same direction.

3.9.2. Calculation of the Cycle Work

The actual cycle work W_{act} (kWh) shall be calculated using each pair of engine feedback speed and torque values recorded. This shall be done after any feedback data shift has occurred, if this option is selected. The actual cycle work W_{act} is used for comparison to the reference cycle work W_{ref} and for calculating the brake specific emissions (see sections 4.4 and 5.2). The same methodology shall be used for integrating both reference and actual engine power. If values are to be determined between adjacent reference or adjacent measured values, linear interpolation shall be used.

In integrating the reference and actual cycle work, all negative torque values shall be set equal to zero and included. If integration is performed at a frequency of less than 5 Hertz, and if, during a given time segment, the torque value changes from positive to negative or negative to positive, the negative portion shall be computed and set equal to zero. The positive portion shall be included in the integrated value.

W_{act} shall be between - 15 % and + 15 % of W_{ref}

3.9.3. Validation Statistics of the Test Cycle

Linear regressions of the feedback values on the reference values shall be performed for speed, torque and power. This shall be done after any feedback data shift has occurred, if this option is selected. The method of least squares shall be used, with the best fit equation having the form:

$$Y = mx + b$$

where:

y = feedback (actual) value of speed (min^{-1}), torque (Nm), or power (kW)
m = slope of the regression line
x = reference value of speed (min^{-1}), torque (Nm), or power (kW)
b = y intercept of the regression line

The standard error of estimate (SE) of y on x and the coefficient of determination (r^2) shall be calculated for each regression line.

It is recommended that this analysis be performed at 1 Hertz. All negative reference torque values and the associated feedback values shall be deleted from the calculation of cycle torque and power validation statistics. For a test to be considered valid, the criteria of table 6 must be met.

Table 6

Regression Line Tolerances

	Speed	Torque	Power
Standard error of Estimate (SE) of Y on X	Max.100 min-1	Max.13% of power Map maximum engine torque	Max. 8% of power Map maximum engine power
Slope of the regression line, m	0.95 to 1.03	0.83 – 1,03	0.89 – 1,03
Coefficient of determination, 12	Min. 0,9700	Min. 0,8800	Min. 0,9100
Y intercept of the regression line, b	± 50 min-1	± 20 Nm or ± 2% max. torque whichever is greater	± 4kW or ± 2% of max. power whichever is greater

Point deletions from the regression analyses are permitted where noted in Table 7.

Table 7

Permitted Point Deletions From Regression Analysis

Conditions	Points to be deleted
Full load and torque feedback < torque reference	Torque and/or power
No load, not an idle point, and torque feedback > torque reference	Torque and/or power
No load/closed throttle, idle point and sped > reference idle speed	Speed and/or power

4. CALCULATION OF THE GASEOUS EMISSIONS

4.1. Determination of the Diluted Exhaust Gas Flow

The total diluted exhaust gas flow over the cycle (kg/test) shall be calculated from the measurement values over the cycle and the corresponding calibration data of the flow measurement device (V0 for PDP or KV for CFV, as determined in Chapter III, Appendix 5, section 2). The following formulae shall be applied, if the temperature of the diluted exhaust is kept constant over the cycle by using a heat exchanger (± 6 K for a PDP-CVS, ± 11 K for a CFV-CVS, see Chapter V, section 2.3).

For the PDP-CVS system:

$$M_{TOTW} = 1,293 \times V_0 \times N_P \times (PB - P1) \times 273 / (101,3 \times T)$$

where:

M_{TOTW} = mass of the diluted exhaust gas on wet basis over the cycle, kg

V_0 = volume of gas pumped per revolution under test conditions, m3/rev

NP = total revolutions of pump per test

PB = atmospheric pressure in the test cell, kPa

P1 = pressure depression below atmospheric at pump inlet, kPa

T = average temperature of the diluted exhaust gas at pump inlet over the cycle, K

For the CFV-CVS system:

$$M_{TOTW} = 1.293 \times t \times K_v \times P_A / T^{0.5}$$

where:

M_{TOTW} = mass of the diluted exhaust gas on wet basis over the cycle, kg

t = cycle time, s

K_v = calibration coefficient of the critical flow venturi for standard conditions

P_A = absolute pressure at venturi inlet, kPa

T = absolute temperature at venturi inlet, K

If a system with flow compensation is used (i.e. without heat exchanger), the instantaneous mass emissions shall be calculated and integrated over the cycle. In this case, the instantaneous mass of the diluted exhaust gas shall be calculated as follows.

For the PDP-CVS system:

$$M_{TOTW,i} = 1.293 \times V_0 \times N_{p,i} \times (P_B - P_1) \times 273 / (101.3 \times T)$$

where,

$M_{TOTW,i}$ = instantaneous mass of the diluted exhaust gas on wet basis, kg

$N_{p,i}$ = total revolutions of pump per time interval

For the CFV-CVS system:

$M_{TOTW,i}$ = 1,293 x Δt_i x Kv x PA/$T^{0.5}$

where:

$M_{TOTW,i}$ = instantaneous mass of the diluted exhaust gas on wet basis, kg

Δt_i = time interval, s

If the total sample mass of particulates (M_{SAM}) and gaseous pollutants exceeds 0,5 % of the total CVS flow (M_{TOTW}), the CVS flow shall be corrected for M_{SAM} or the particulate sample flow shall be returned to the CVS prior to the flow measuring device (PDP or CFV).

4.2. NOx Correction for Humidity

As the NOx emission depends on ambient air conditions, the NOx concentration shall be corrected for ambient air humidity with the factors given in the following formulae.

(a) for diesel engines:

$$K_{HD} = \frac{1}{1-0{,}0182\times(H_a-10{,}71)}$$

(b) for gas engines:

$$K_{HG} = \frac{1}{1-0{,}0329\times(H_a-10{,}71)}$$

where:

H_a = humidity of the intake air water per kg dry air in which:

$$H_a = \frac{6{,}220\times R_a\times P_a}{P_B-P_a\times R_a\times 10^{-2}}$$

R_a= relative humidity of the intake air, %

P_a= saturation vapour pressure of the intake air, kPa

P_B= total barometric pressure, kPa

4.3. Calculation of the Emission Mass Flow

4.3.1. Systems with Constant Mass Flow

For systems with heat exchanger, the mass of the pollutants (g/test) shall be determined from the following equations:

(1) $NO_{x\ mass}$ = $0{,}001587 \times NO_{x\ conc} \times K_{H,D} \times M_{TOTW}$ (diesel engines)

(2) $NO_{x\ mass}$ = $0{,}001587 \times NO_{x\ conc} \times K_{H,G} \times M_{TOTW}$ (gas engines)

(3) CO_{mass} = $0{,}000966 \times CO_{conc} \times M_{TOTW}$

(4) HC_{mass} = $0{,}000479 \times HC_{conc} \times M_{TOTW}$ (diesel engines)

(5) HC_{mass} = $0{,}000502 \times HC_{conc} \times M_{TOTW}$ (LPG fuelled engines)

(6) $NMHC_{mass}$ = $0{,}000516 \times NMHC_{conc} \times M_{TOTW}$ (NG fuelled engines)

(7) $CH_{4\ mass}$ = $0{,}000552 \times CH_{4\ mass} \times M_{TOTW}$ (NG fuelled engines)

where:

$NO_{x\ conc}$, CO_{conc}, HC_{conc} (1), $NMHC_{conc}$ = average background corrected concentrations over the cycle from integration (mandatory for NOx and HC) or bag measurement, ppm

M_{TOTW} = total mass of diluted exhaust gas over the cycle as determined in Section 4.1, kg

$K_{H,D}$ = humidity correction factor for diesel engines as determined in Section 4.2

$K_{H,G}$ = humidity correction factor for gas engines as determined in Section 4.2

Concentrations measured on a dry basis shall be converted to a wet basis in accordance with Chapter III, Appendix 1, section 4.2.

The determination of $NMHC_{conc}$ depends on the method used (see Chapter III, Appendix 4, section 3.3.4). In both cases, the CH4 concentration shall be determined and subtracted from the HC concentration as follows:

---

(1) Based on C1 equivalent.

$$NMHC_{conc} = HC_{conc} - CH_{4\,conc}$$

(b) NMC method

$$NMHC_{conc} = \frac{HC(w/oCutter) \times (1 - CE_M) - HC(wCutter)}{CE_E - CE_M}$$

where:

HC(wCutter) = HC concentration with the sample gas flowing through the NMC.

HC(w/oCutter) = HC concentration with the sample gas bypassing the NMC

CE_M = methane efficiency as determined per Chapter III, Appendix 5, Section 1.8.4.1

CE_E = ethane efficiency as determined per Chapter III, Appendix 5, Section 1.8.4.2

4.3.1.1. Determination of the Background Corrected Concentrations

The average background concentration of the gaseous pollutants in the dilution air shall be subtracted from measured concentrations to get the net concentrations of the pollutants. The average values of the background concentrations can be determined by the sample bag method or by continuous measurement with integration. The following formula shall be used.

$$Conc = conc_e - conc_d \times (1 - (1/DF))$$

where:

conc = con centration of the respective pollutant in the diluted exhaust gas, corrected by the amount of the respective pollutant contained in the dilution air, ppm

$conc_e$ = concentration of the respective pollutant measured in the diluted exhaust gas, ppm

$conc_d$ = concentration of the respective pollutant measured in the dilution air, ppm

DF = dilution factor

The dilution factor shall be calculated as follows:

(a) for diesel and LPG fuelled gas engines

$$DF = \frac{F_s}{CO_{2conce} + (HC_{conce} + CO_{conce}) \times 10^{-4}}$$

(b) for NG-fuelled gas engines

$$DF = \frac{F_s}{CO_{2conce} + (NMHC_{conce} + CO_{conce}) \times 10^{-4}}$$

where:

$CO_{2,\ conce}$ = concentration of CO2 in the diluted exhaust gas, % vol

HC_{conce} = concentration of HC in the diluted exhaust gas, ppm C1

$NMHC_{conce}$ = concentration of NMHC in the diluted exhaust gas, ppm C1

CO_{conce} = concentration of CO in the diluted exhaust gas, ppm

F_S = stoichiometric factor

Concentrations measured on dry basis shall be converted to a wet basis in accordance with Chapter III, Appendix 1, Section 4.2.

The stoichiometric factor shall be calculated as follows:

$$F_s = 100 \times \frac{x}{x + \frac{y}{2} + 3.76 \times (x + \frac{y}{4})}$$

where:

x, y = fuel composition C_xH_y

Alternatively, if the fuel composition is not known, the following stoichiometric factors may be used:

F_S (diesel) = 13.4

F_S (LPG) = 11.6

F_S (NG) = 9.5

4.3.2. Systems with Flow Compensation

For systems without heat exchanger, the mass of the pollutants (g/test) shall be determined by calculating the instantaneous mass emissions and integrating the instantaneous values over the cycle. Also, the background correction shall be applied directly to the instantaneous concentration value. The following formulae shall be applied:

(1) NO_{xmass}

$$= \sum_{i=1}^{n} (M_{TOTW,i} \times NO_{xconce,i} \times 0.001587 \times K_{H,D}) -$$
$$(M_{TOTW} \times NO_{xconcd} \times (1-1/DF) \times 0.001587 \times K_{H,D})(diesel\ engines)$$

(2) NO_{xmass} = $$\sum_{i=1}^{n}(M_{TOTW,i} \times NO_{xconce,i} \times 0.001587 \times K_{H,G}) -$$

$$(M_{TOTW} \times NO_{xconcd} \times (1-1/DF) \times 0.001587 \times K_{H,G})(gas\ engines)$$

(3) CO_{mass} = $$\sum_{i=1}^{n}(M_{TOTW,i} \times CO_{xconce,i} \times 0.000966) -$$

$$(M_{TOTW} \times CO_{xconcd} \times (1-1/DF) \times 0.000966)$$

(4) HC_{mass} = $$\sum_{i=1}^{n}(M_{TOTW,i} \times HC_{conce,i} \times 0.000479) -$$

$$(M_{TOTW} \times HC_{xconcd} \times (1-1/DF) \times 0.000479)(diesel\ engines)$$

(5) HC_{mass} = $$\sum_{i=1}^{n}(M_{TOTW,i} \times HC_{conce,i} \times 0.000502) -$$

$$(M_{TOTW} \times HC_{xconcd} \times (1-1/DF) \times 0.000502)(LPG\ engines)$$

(6) $NMHC_{mass}$ = $$\sum_{i=1}^{n}(M_{TOTW,i} \times NMHC_{conce,i} \times 0.000516) -$$

$$(M_{TOTW} \times HC_{xconcd} \times (1-1/DF) \times 0.000516)(NG\ engines)$$

(7) CH_{4mass} = $$\sum_{i=1}^{n}(M_{TOTW,i} \times CH4_{conce,i} \times 0.000552) -$$

$$(M_{TOTW} \times HC_{xconcd} \times (1-1/DF) \times 0.000552)(NG\ engines)$$

where:

$conc_e$ = concentration of the respective pollutant measured in the diluted exhaust gas, ppm
$conc_d$ = concentration of the respective pollutant measured in the dilution air, ppm
$M_{TOTW,i}$ = instantaneous mass of the diluted exhaust gas (see Section 4.1), Kg
M_{TOTW} = total mass of diluted exhaust gas over the cycle (see Section 4.1), kg
$K_{H,D}$ = humidity correction factor for diesel engines as determined in Section 4.2
$K_{H,G}$ = humidity correction factor for gas engines as determined in Section 4.2
DF = dilution factor as determined in Section 4.3.1.1

4.4. Calculation of the Specific Emissions

The emissions (g/kWh) shall be calculated for all individual components in the following way:

$\overline{NOx}$ = NO_{xmass} / W_{act} (diesel and gas engines)

$\overline{CO}$ = CO_{mass} / W_{act} (diesel and gas engines)

$\overline{HC}$ = HC_{mass} / W_{act} (diesel and LPG fuelled gas engines)

$\overline{NMHC}$ = HC_{mass} / W_{act} (NG fuelled gas engines)

$\overline{CH4}$ = CH_4 / W_{act} (NG fuelled gas engines)

where:

W_{act} = actual cycle work as determined in Section 3.9.2, kWh

5. CALCULATION OF THE PARTICULATE EMISSION (DIESEL ENGINES ONLY)

5.1. Calculation of the Mass Flow

The particulate mass (g/test) shall be calculated as follows:

$$PT_{mass} = \frac{M_f}{M_{SAM}} \times \frac{M_{TOTW}}{1000}$$

where:

M_f = particulate mass sampled over the cycle, mg

M_{TOTW} = total mass of diluted exhaust gas over the cycle as determined in section 4.1, kg

M_{SAM} = mass of diluted exhaust gas taken from the dilution tunnel for collecting particulates, kg

and:

M_f = $M_{f,p} + M_{f,b}$ if weighed separately, mg

$M_{f,p}$ = particulate mass collected on the primary filter, mg

$M_{f,b}$ = particulate mass collected on the back-up filter, mg

If a double dilution system is used, the mass of the secondary dilution air shall be subtracted from the total mass of the double diluted exhaust gas sampled through the particulate filters.

$$M_{SAM} = M_{TOT} - M_{SEC}$$

where:

M_{TOT} = mass of double diluted exhaust gas through particulate filter, kg

M_{SEC} = mass of secondary dilution air, kg

If the particulate background level of the dilution air is determined in accordance with section 3.4, the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$PT_{mass} = \left[\frac{M_f}{M_{SAM}} - \left(\frac{M_d}{M_{DIL}} \times \left(1 - \frac{1}{DF}\right)\right)\right] \times \frac{M_{TOTW}}{1000}$$

where:

M_f, M_{SAM}, M_{TOTW} = see above

M_{DIL}= mass of primary dilution air sampled by background particulate sampler, kg

M_d= mass of the collected background particulates of the primary dilution air, mg

DF= dilution factor as determined in section 4.3.1.1

5.2. Calculation of the Specific Emission

The particulate emission (g/kWh) shall be calculated in the following way:

$$\overline{PT} = PT_{mass} / W_{act}$$

where:

W_{act} = actual cycle work as determined in Section 3.9.2, kWh.

APPENDIX 3

ETC DYNAMOMETER SCHEDULE

Time (s)	Normal Speed %	Normal Torque %	Time (s)	Normal Speed %	Normal Torque %	Time (s)	Normal Speed %	Normal Torque %
1	0	0	43	20.4	‘m’	85	58,3	11,8
2	0	0	44	14.1	0	86	56,2	‘m’
3	0	0	45	6.5	0	87	52	‘m’
4	0	0	46	0	0	88	43,3	‘m’
5	0	0	47	0	0	89	36,1	‘m’
6	0	0	48	0	0	90	27,6	‘m’
7	0	0	49	0	0	91	21,1	‘m’
8	0	0	50	0	0	92	8	0
9	0	0	51	0	0	93	0	0
10	0	0	52	0	0	94	0	0
11	0	0	53	0	0	95	0	0
12	0	0	54	0	0	96	0	0
13	0	0	55	0	0	97	0	0
14	0	0	56	0	0	98	0	0
15	0	0	57	0	0	99	0	0
16	0,1	1,5	58	0	0	100	0	0
17	23,1	21,5	59	0	0	101	0	0
18	12,6	28,5	60	0	0	102	0	0
19	21,8	71	61	0	0	103	0	0
20	0	76,8	62	25,5	11,1	104	0	0
21	54,6	80,9	63	28,5	20,9	105	0	0
22	71,3	4,9	64	32	73,9	106	0	0
23	55,9	18,1	65	4	82,3	107	0	14,8
24	72	85,4	66	34,5	80,4	108	11,6	14,8
25	86,7	61,8	67	64,1	86	109	0	0
26	51,7	0	68	58	0	110	27,2	74,8
27	53,4	48,9	69	50,3	83,4	111	17	76,9
28	34,2	87,6	70	66,4	99,1	112	36	78
29	45,5	92,7	71	81,4	99,6	113	59,7	86
30	54,6	99,5	72	88,7	73,4	114	80,8	17,9
31	64,5	96,8	73	52,5	0	115	49,7	0
32	71,7	85,4	74	46,4	58,5	116	65,6	86
33	79,4	54,8	75	48,6	90,9	117	78,6	72,2
34	89,7	99,4	76	55,2	99,4	118	64,9	‘m’
35	57,4	0	77	62,3	99	119	44,3	‘m’
36	59,7	30,6	78	68,4	91,5	120	51,4	83,4
37	90,1	‘m’	79	74,5	73,7	121	58,1	97
38	82,9	‘m’	80	38	0	122	69,3	99,3
39	51,3	‘m’	81	41,8	89,6	123	72	20,8
40	28,5	‘m’	82	47,1	99,2	124	72,1	‘m’
41	29,3	‘m’	83	52,5	99,8	125	65,3	‘m’
42	26,7	‘m’	84	56,9	80,8	126	64	‘m’

Time (s)	Normal Speed %	Normal Torque %	Time (s)	Normal Speed %	Normal Torque %	Time (s)	Normal Speed %	Normal Torque %
127	59,7	‘m’	174	54,6	64,8	221	0	0
128	52,8	‘m’	175	56,6	76,5	222	0	0
129	45,9	‘m’	176	58	‘m’	223	0	0
130	38,7	‘m’	177	53,6	‘m’	224	0	0
131	32,4	‘m’	178	40,8	‘m’	225	21,2	62,7
132	27	‘m’	179	32,9	‘m’	226	30,8	75,1
133	21,7	‘m’	180	26,3	‘m’	227	5,9	82,7
134	19,1	0,4	181	20,9	‘m’	228	34,6	80,3
135	34,7	14	182	10	0	229	59,9	87
136	16,4	48,6	183	0	0	230	84,3	86,2
137	0	11,2	184	0	0	231	68,7	‘m’
138	1,2	2,1	185	0	0	232	43,6	‘m’
139	30,1	19,3	186	0	0	233	41,5	85,4
140	30	73,9	187	0	0	234	49,9	94,3
141	54,4	74,4	188	0	0	235	60,8	99
142	77,2	55,6	189	0	0	236	70,2	99,4
143	58,1	0	190	0	0	237	81,1	92,4
144	45	82,1	191	0	0	238	49,2	0
145	68,7	98,1	192	0	0	239	56	86,2
146	85,7	67,2	193	0	0	240	56,2	99,3
147	60,2	0	194	0	0	241	61,7	99
148	59,4	98	195	0	0	242	69,2	99,3
149	72,7	99,6	196	0	0	243	74,1	99,8
150	79,9	45	197	0	0	244	72,4	8,4
151	44,3	0	198	0	0	245	71,3	0
152	41,5	84,4	199	0	0	246	71,2	9,1
153	56,2	98,2	200	0	0	247	67,1	‘m’
154	65,7	99,1	201	0	0	248	65,5	‘m’
155	74,4	84,7	202	0	0	249	64,4	‘m’
156	54,4	0	203	0	0	250	62,9	25,6
157	47,9	89,7	204	0	0	251	62,2	35,6
158	54,5	99,5	205	0	0	252	62,9	24,4
159	62,7	96,8	206	0	0	253	58,8	‘m’
160	62,3	0	207	0	0	254	56,9	‘m’
161	46,2	54,2	208	0	0	255	54,5	‘m’
162	44,3	83,2	209	0	0	256	51,7	17
163	48,2	13,3	210	0	0	257	56,2	78,7
164	51	‘m’	211	0	0	258	59,5	94,7
165	50	‘m’	212	0	0	259	65,5	99,1
166	49,2	‘m’	213	0	0	260	71,2	99,5
167	49,3	‘m’	214	0	0	261	76,6	99,9
168	49,9	‘m’	215	0	0	262	79	0
169	51,6	‘m’	216	0	0	263	52,9	97,5
170	49,7	‘m’	217	0	0	264	53,1	99,7
171	48,5	‘m’	218	0	0	265	59	99,1
172	50,3	72.5	219	0	0	266	62,2	99
173	51,1	84.5	220	0	0	267	65	99,1

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
268	69	83,1	315	66,4	60,9	362	53,4	95,2
269	69,9	28,4	316	65,8	‘m’	363	58,4	99,2
270	70,6	12,5	317	59	‘m’	364	61,5	99
271	68,9	8,4	318	50,7	‘m’	365	64,8	99
272	69,8	9,1	319	41,8	‘m’	366	68,1	99,2
273	69,6	7	320	34,7	‘m’	367	73,4	99,7
274	65,7	‘m’	321	28,7	‘m’	368	73,3	29,8
275	67,1	‘m’	322	25,2	‘m’	369	73,5	14,6
276	66,7	‘m’	323	43	24,8	370	68,3	0
277	65,6	‘m’	324	38,7	0	371	45,4	49,9
278	64,5	‘m’	325	48,1	31,9	372	47,2	75,7
279	62,9	‘m’	326	40,3	61	373	44,5	9
280	59,3	‘m’	327	42,4	52,1	374	47,8	10,3
281	54,1	‘m’	328	46,4	47,7	375	46,8	15,9
282	51,3	‘m’	329	46,9	30,7	376	46,9	12,7
283	47,9	‘m’	330	46,1	23,1	377	46,8	8,9
284	43,6	‘m’	331	45,7	23,2	378	46,1	6,2
285	39,4	‘m’	332	45,5	31,9	379	46,1	‘m’
286	34,7	‘m’	333	46,4	73,6	380	45,5	‘m’
287	29,8	‘m’	334	51,3	60,7	381	44,7	‘m’
288	20,9	73,4	335	51,3	51,1	382	43,8	‘m’
289	36,9	‘m’	336	53,2	46,8	383	41	‘m’
290	35,5	‘m’	337	53,9	50	384	41,1	6,4
291	20,9	‘m’	338	53,4	52,1	385	38	6,3
292	49,7	11,9	339	53,8	45,7	386	35,9	0,3
293	42,5	‘m’	340	50,6	22,1	387	33,5	0
294	32	‘m’	341	47,8	26	388	53,1	48,9
295	23,6	‘m’	342	41,6	17,8	389	48,3	‘m’
296	19,1	0	343	38,7	29,8	390	49,9	‘m’
297	15,7	73,5	344	35,9	71,6	391	48	‘m’
298	25,1	76,8	345	34,6	47,3	392	45,3	‘m’
299	34,5	81,4	346	34,8	80,3	393	41,6	3,1
300	44,1	87,4	347	35,9	87,2	394	44,3	79
301	52,8	98,6	348	38,8	90,8	395	44,3	89,5
302	63,6	99	349	41,5	94,7	396	43,4	98,8
303	73,6	99,7	350	47,1	99,2	397	44,3	98,9
304	62,2	‘m’	351	53,1	99,7	398	43	98,8
305	29,2	‘m’	352	46,4	0	399	42,2	98,8
306	46,4	22	353	42,5	0,7	400	42,7	98,8
307	47,3	13,8	354	43,6	58,6	401	45	99
308	47,2	12,5	355	47,1	87,5	402	43,6	98,9
309	47,9	11,5	356	54,1	99,5	403	42,2	98,8
310	47,8	35,5	357	62,9	99	404	44,8	99
311	49,2	83,3	358	72,6	99,6	405	43,4	98,8
312	52,7	96,4	359	82,4	99,5	406	45	99
313	57,4	99,2	360	88	99,4	407	42,2	54,3
314	61,8	99	361	46,4	0	408	61,2	31,9

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
409	56,3	72,3	456	44,1	92,6	503	21,9	'm'
410	59,7	99,1	457	46,8	99,2	504	12,8	0
411	62,3	99	458	47,2	99,3	505	0	0
412	67,9	99,2	459	51	100	506	0	0
413	69,5	99,3	460	53,2	99,7	507	0	0
414	73,1	99,7	461	53,1	99,7	508	0	0
415	77,7	99,8	462	55,9	53,1	509	0	0
416	79,7	99,7	463	53,9	13,9	510	0	0
417	82,5	99,5	464	52,5	'm'	511	0	0
418	85,3	99,4	465	51,7	'm'	512	0	0
419	86,6	99,4	466	51,5	52,2	513	0	0
420	89,4	99,4	467	52,8	80	514	30,5	25,6
421	62,2	0	468	54,9	95	515	19,7	56,9
422	52,7	96,4	469	57,3	99,2	516	16,3	45,1
423	50,2	99,8	470	60,7	99,1	517	27,2	4,6
424	49,3	99,6	471	62,4	'm'	518	21,7	1,3
425	52,2	99,8	472	60,1	'm'	519	29,7	28,6
426	51,3	100	473	53,2	'm'	520	36.6	73,7
427	51,3	100	474	44	'm'	521	61,3	59,5
428	51,1	100	475	35,2	'm'	522	40,8	0
429	51,1	100	476	30,5	'm'	523	36,6	27,8
430	51,8	99,9	477	26,5	'm'	524	39,4	80,4
431	51,3	100	478	22,5	'm'	525	51,3	88,9
432	51,1	100	479	20,4	'm'	526	58,5	11,1
433	51,3	100	480	19,1	'm'	527	60,7	'm'
434	52,3	99,8	481	19,1	'm'	528	54,5	'm'
435	52,9	99,7	482	13,4	'm'	529	51,3	'm'
436	53,8	99,6	483	6,7	'm'	530	45,5	'm'
437	51,7	99,9	484	3,2	63,8	531	40,8	'm'
438	53,5	99,6	485	14,3	0	532	38,9	'm'
439	52	99,8	486	34,1	75,7	533	36,6	'm'
440	51,7	99,9	487	23,9	79,2	534	36,1	72,7
441	53,2	99,7	488	31,7	19,4	535	44,8	78,9
442	54,2	99,5	489	32,1	5,8	536	51,6	91,1
443	55,2	99,4	490	35,9	0,8	537	59,1	99,1
444	53,8	99,6	491	36,6	'm'	538	66	99,1
445	53,1	99,7	492	38,7	'm'	539	75,1	99,9
446	55	99,4	493	38,4	'm'	540	81	8
447	57	99,2	494	39,4	'm'	541	39,1	0
448	61,5	99	495	39,7	'm'	542	53,8	89,7
449	59	5,7	496	40,5	'm'	543	59,7	99,1
450	59	0	497	40,8	'm'	544	64,8	99
451	57,3	59,8	498	39,7	'm'	545	70,6	96,1
452	64,1	99	499	39,2	'm'	546	72,6	19,6
453	70,9	90,5	500	38,7	'm'	547	72	6,3
454	58	0	501	32,7	'm'	548	68,9	0,1
455	41,5	59,8	502	30,1	'm'	549	67,7	'm'

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
550	66,8	‘m’	597	32,9	70,2	644	48,6	‘m’
551	64,3	16,97	598	43	79	645	47,5	‘m’
552	64,9	12,5	599	57,4	98,9	646	46,5	‘m’
553	63,6	7,7	600	72,1	73,8	647	46	11,3
554	63	38,2	601	53	0	648	45,6	42,8
555	64,4	11,8	602	48,1	86	649	47,1	83
556	63	0	603	56,2	99	650	46,2	99,3
557	63,6	5	604	65,4	98,9	651	47,9	99,7
558	63,3	9,1	605	72,9	99,7	652	49,5	99,9
559	60,1	8,4	606	67,5	‘m’	653	50,6	99,7
560	61	0,9	607	39	‘m’	654	51	99,6
561	59,7	‘m’	608	41,9	38,1	655	53	99,3
562	58,7	‘m’	609	44,1	80,4	656	54,9	99,1
563	56	‘m’	610	46,8	99,4	657	55,7	99
564	53,9	‘m’	611	48,7	99,9	658	56	99
565	52,1	‘m’	612	50,5	99,7	659	56,1	9,3
566	49,9	‘m’	613	52,5	90,3	660	55,6	‘m’
567	46,4	‘m’	614	51	1,8	661	55,4	‘m’
568	43,6	‘m’	615	50	‘m,	662	54,9	51,3
569	40,8	‘m’	616	49,1	‘m	663	54,9	59,8
570	37,5	‘m’	617	47	‘m	664	54	39,3
571	27,8	‘m’	618	43,1	‘m	665	53,8	‘m’
572	17,1	0,6	619	39,2	‘m	666	52	‘m’
573	12,2	0,9	620	40,6	0,5	667	50,4	‘m’
574	11,5	1,1	621	41,8	53,4	668	50,6	0
575	8,7	0,5	622	44,4	65,1	669	49,3	41,7
576	8	0,9	623	48,1	67,8	670	50	73,2
577	5,3	0,2	624	53,8	99,2	671	50,4	99,7
578	4	0	625	58,6	98,9	672	51,9	99,5
579	3,9	0	626	63,6	98,8	673	53,6	99,3
580	0	0	627	68,5	99,2	674	54,6	99,1
581	0	0	628	72,2	89,4	675	56	99
582	0	0	629	77,1	0	676	55,8	99
583	0	0	630	57,8	79,1	677	58,4	98,9
584	0	0	631	60,3	98,8	678	59,9	98,8
585	0	0	632	61,9	98,8	679	60,9	98,8
586	0	0	633	63,8	98,8	680	63	98,8
587	8,7	22,8	634	64,7	98,9	681	64,3	98,9
588	16,2	49,4	635	65,4	46,5	682	64,8	64
589	23,6	56	636	65,7	44,5	683	65,9	46,5
590	21,1	56,1	637	65,6	3,5	684	66,2	28,7
591	23,6	56	638	49,1	0	685	65,2	1,8
592	46,2	68,8	639	50,4	73,1	686	65	6,8
593	68,4	61,2	640	50,5	‘m’	687	63,6	53,6
594	58,7	‘m’	641	51	‘m’	688	62,4	82,5
595	31,6	‘m’	642	49,4	‘m’	689	61,8	98,8
596	19,9	8,8	643	49,2	‘m’	690	59,8	98,8

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
691	59,2	98,8	738	39,9	89,8	785	56,6	52,4
692	59,7	98,8	739	42,3	98,6	786	58	50,3
693	61,2	98,8	740	43,7	98,8	787	58,6	20,6
694	62,2	49,4	741	45,5	99,1	788	58,7	'm'
695	62,8	37,2	742	45,6	99,2	789	59,3	'm'
696	63,5	46,3	743	48,1	99,7	790	58,6	'm'
697	64,7	72,3	744	49	100	791	60,5	9,7
698	64,7	72,3	745	49,8	99,9	792	59,2	9,6
699	65,4	77,4	746	49,8	99,9	793	59,9	9,6
700	66,1	69,3	747	51,9	99,5	794	59,6	9,6
701	64,3	'm'	748	52,3	99,4	795	59,9	6,2
702	64,3	'm'	749	53,3	99,3	796	59,9	9,6
703	63	'm'	750	52,9	99,3	797	60,5	13,1
704	62,2	'm'	751	54,3	99,2	798	60,3	20,7
705	61,6	'm'	752	55,5	99,1	799	59,9	31
706	62,4	'm'	753	56,7	99	800	60,5	42
707	62,2	'm'	754	61,7	98,8	801	61,5	52,5
708	61	'm'	755	64,3	47,4	802	60,9	51,4
709	58,7	'm'	756	64,7	1,8	803	61,2	57,7
710	55,5	'm'	757	66,2	'm'	804	62,8	98,8
711	51,7	'm'	758	49,1	'm'	805	63,4	96,1
712	49,2	'm'	759	52,1	46	806	64,6	45,4
713	48,8	40,4	760	52,6	61	807	64,1	5
714	47,9	'm'	761	52,9	0	808	63	3,2
715	46,2	'm'	762	52,3	20,4	809	62,7	14,9
716	45,6	9,8	763	54,2	56,7	810	63,5	35,8
717	45,6	34,5	764	55,4	59,8	811	64,1	73,3
718	45,5	37,1	765	56,1	49,2	812	64,3	37,4
719	43,8	'm'	766	56,8	33,7	813	64,1	21
720	41,9	'm'	767	57,2	96	814	63,7	21
721	41,3	'm'	768	58,6	98,9	815	62,9	18
722	41,4	'm'	769	59,5	98,8	816	62,4	32,7
723	41,2	'm'	770	61,2	98,8	817	61,7	46,2
724	41,8	'm'	771	62,1	98,8	818	59,8	45,1
725	41,8	'm'	772	62,7	98,8	819	57,4	43,9
726	43,2	17,4	773	62,8	98,8	820	54,8	42,8
727	45	29	774	64	98,9	821	54,3	65,2
728	44,2	'm'	775	63,2	46,3	822	52,9	62,1
729	43,9	'm'	776	62,4	'm'	823	52,4	30,6
730	36	'm'	777	60,3	'm'	824	50,4	'm'
731	56,8	10,7	778	58,7	'm'	825	48,6	'm'
732	57,1	'm'	779	57,2	'm'	826	47,9	'm'
733	52	'm'	780	56,1	'm'	827	46,8	'm'
734	44,4	'm'	781	56	9,3	828	46,9	9,4
735	40,2	'm'	782	55,2	26,3	829	49,5	41,7
736	39,2	16,5	783	54,8	42,8	830	50,5	37,8
737	38,9	73,2	784	55,7	47,1	831	52,3	20,4

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
832	54,1	30,7	879	60,3	1,2	926	56,4	38
833	56,3	41,8	880	60,5	2,9	927	56,4	11
834	58,7	26,5	881	61,2	34,1	928	56,4	35,1
835	57,3	‘m’	882	61,6	13,2	929	54	7,3
836	59	‘m’	883	61,5	16,4	930	53,4	5,4
837	59,8	‘m’	884	61,2	16,4	931	52,3	27,6
838	60,3	‘m’	885	61,3	‘m’	932	52,1	32
839	61,2	‘m’	886	63,1	‘m’	933	52,3	33,4
840	61,8	‘m’	887	63,2	4,8	934	52,2	34,9
841	62,5	‘m’	888	62,3	22,3	935	52,8	60,1
842	62,4	‘m’	889	62	38,5	936	53,7	69,7
843	61,5	‘m’	890	61,5	29,6	937	54	70,7
844	63,7	‘m’	891	61,6	29,6	938	55,1	71,7
845	61,9	‘m’	892	61,8	28,1	939	55,2	46
846	61,6	29,7	893	62	29,6	940	54,7	12,6
847	60,3	‘m’	894	62	16,3	941	52,5	0
848	59,2	‘m’	895	61,1	‘m’	942	51,8	24,7
849	57,3	‘m’	896	61,2	‘m’	943	51,4	43,9
850	52,3	‘m’	897	60,7	19,2	944	50,9	71,1
851	49,3	‘m’	898	60,7	32,5	945	51,2	76,8
852	47,3	‘m’	899	60,9	17,8	946	50,3	87,5
853	46,3	38,8	900	60,1	19,2	947	50,2	99,8
854	46,8	35,1	901	59,3	38,2	948	50,9	100
855	46,6	‘m’	902	59,9	45	949	49,9	99,7
856	44,3	‘m’	903	59,4	32,4	950	50,9	100
857	43,1	‘m’	904	59,9	23,5	951	49,8	99,7
858	42,4	2,1	905	59,2	40,8	952	50,4	99,8
859	41,8	2,4	906	59,5	‘m’	953	50,4	99,8
860	43,8	68,8	907	58,2	‘m’	954	49,7	99,7
861	44,6	89,2	908	57,6	‘m’	955	51	100
862	46	99,2	909	57,1	‘m’	956	50,3	99,8
863	46,9	99,4	910	57	0,6	957	50,2	99,8
864	47,9	99,7	911	57	26,3	958	49,9	99,7
865	50,2	99,8	912	56,5	29,2	959	50,9	100
866	51,2	99,6	913	56,3	20,5	960	50	99,7
867	52,3	99,4	914	56,1	‘m’	961	50,2	99,8
868	53	99,3	915	55,2	‘m’	962	50,2	99,8
869	54,2	99,2	916	54,7	17,5	963	49,9	99,7
870	55,5	99,1	917	55,2	29,2	964	50,4	99,8
871	56,7	99	918	55,2	29,2	965	50,2	99,8
872	57,3	98,9	919	55,9	16	966	50,3	99,8
873	58	98,9	920	55,9	26,3	967	49,9	99,7
874	60,5	31,1	921	56,1	36,5	968	51,1	100
875	60,2	‘m’	922	55,8	19	969	50,6	99,9
876	60,3	‘m’	923	55,9	9,2	970	49,9	99,7
877	60,5	6,3	924	55,8	21,9	971	49,6	99,6
878	61,4	19,3	925	56,4	42,8	972	49,4	99,6

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
973	49	99,5	1020	49,1	‘m’	1067	45,5	‘m’
974	49,8	99,7	1021	49,4	‘m’	1068	45,5	‘m’
975	50,9	100	1022	48,3	‘m’	1069	44,2	‘m’
976	50,4	99,8	1023	49,4	‘m’	1070	43	‘m’
977	49,8	99,7	1024	48,5	‘m’	1071	42.5	‘m’
978	49,1	99,5	1025	48,7	‘m’	1072	41	‘m’
979	50,4	99,8	1026	48,7	‘m’	1073	39,9	‘m’
980	49,8	99,7	1027	49,1	‘m’	1074	39,9	38,2
981	49,3	99,5	1028	49	‘m’	1075	40,1	48,1
982	49,1	99,5	1029	49,8	‘m’	1076	39,9	48
983	49,9	99,7	1030	48,7	‘m’	1077	39,4	59,3
984	49,1	99,5	1031	48,5	‘m’	1078	43,8	19,8
985	50,4	99,8	1032	49,3	31,3	1079	52,9	0
986	50,9	100	1033	49,7	45,3	1080	52,8	88,9
987	51,4	99,9	1034	48,3	44,5	1081	53,4	99,5
988	51,5	99,9	1035	49,8	61	1082	54,7	99,3
989	52,2	99,7	1036	49,4	64,3	1083	56,3	99,1
990	52,8	74,1	1037	49,8	64,4	1084	57,5	99
991	53,3	46	1038	50,5	65,6	1085	59	98,9
992	53,6	36,4	1039	50,3	64,5	1086	59,8	98,9
993	53,4	33,5	1040	51,2	82,9	1087	60,1	98,9
994	53,9	58,9	1041	50,5	86	1088	61,8	48,3
995	55,2	73,8	1042	50,6	89	1089	61,8	55,6
996	55,8	52,4	1043	50,4	81,4	1090	61,7	59,8
997	55,7	9,2	1044	49,9	49,9	1091	62	55,6
998	55,8	2,2	1045	49,1	20,1	1092	62,3	29,6
999	56,4	33,6	1046	47,9	24	1093	62	19,3
1000	55,4	‘m’	1047	48,1	36,2	1094	61,3	7,9
1001	55,2	‘m’	1048	47,5	34,5	1095	61,1	19,2
1002	55,8	26,3	1049	46,9	30,3	1096	61,2	43
1003	55,8	23,3	1050	47,7	53,5	1097	61,1	59,7
1004	56,4	50,2	1051	46,9	61,6	1098	61,1	98,8
1005	57,6	68,3	1052	46,5	73,6	1099	61,3	98,8
1006	58,8	90,2	1053	48	84,6	1100	61,3	26,6
1007	59,9	98,9	1054	47,2	87,7	1101	60,4	‘m’
1008	62,3	98,8	1055	48,7	80	1102	58,8	‘m’
1009	63,1	74,4	1056	48,7	50,4	1103	57,7	‘m’
1010	63,7	49,4	1057	47,8	38,6	1104	56	‘m’
1011	63,3	9,8	1058	48,8	63,1	1105	54,7	‘m’
1012	48	0	1059	47,4	5	1106	53,3	‘m’
1013	47,9	73,5	1060	47,3	47,4	1107	52,6	23,2
1014	49,9	99,7	1061	47,3	49,8	1108	53,4	84,2
1015	49,9	48,8	1062	46,9	23,9	1109	53,9	99,4
1016	49,6	2,3	1063	46,7	44,6	1110	54,9	99,3
1017	49,9	‘m’	1064	46,8	65,2	1111	55,8	99,2
1018	49,3	‘m’	1065	46,9	60,4	1112	57,1	99
1019	49,7	47,5	1066	46,7	61,5	1113	56,5	99,1

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
1114	58,9	98,9	1161	47,8	59,4	1208	57	70,1
1115	58,7	98,9	1162	48,1	77,1	1209	56,4	59,6
1116	59,8	98,9	1163	48,4	87,6	1210	56,7	39
1117	61	98,8	1164	49,6	87,5	1211	55,9	68,1
1118	60,7	19,2	1165	51	81,4	1212	56,3	79,1
1119	59,4	'm'	1166	51,6	66,7	1213	56,7	89,7
1120	57,9	'm'	1167	53,3	63,2	1214	56	89,4
1121	57,6	'm'	1168	55,2	62	1215	56	93,1
1122	56,3.	'm'	1169	55,7	43,9	1216	56,4	93,1
1123	55	'm'	1170	56,4	30,7	1217	56,7	94,4
1124	53,7	'm'	1171	56,8	23,4	1218	56,9	94,8
1125	52,1	'm'	1172	57	'm'	1219	57	94,1
1126	51,1	'm'	1173	57,6	'm'	1220	57,7	94,3
1127	49,7	25,8	1174	56,9	'm'	1221	57,5	93,7
1128	49,1	46,1	1175	56,4	4	1222	58,4	93,2
1129	48,7	46,9	1176	57	23,4	1223	58,7	93,2
1130	48,2	46,7	1177	56,4	41,7	1224	58,2	93,7
1131	48	70	1178	57	49,2	1225	58,5	93,1
1132	48	70	1179	57,7	56,6	1226	58,8	86,2
1133	47,2	67,6	1180	58,6	56,6	1227	59	72,9
1134	47,3	67,6	1181	58,9	64	1228	58,2	59,9
1135	46,6	74,7	1182	59,4	68,2	1229	57,6	8,5
1136	47,4	13	1183	58,8	71,4	1230	57,1	57,6
1137	46,3	'm'	1184	60,1	71,3	1231	57,2	74,4
1138	45,4	'm'	1185	60,6	79,1	1232	57	79,1
1139	45,5	24,8	1186	60,7	83,3	1233	56,7	67,2
1140	44,8	73,8	1187	60,7	77,1	1234	56,8	69,1
1141	46,6	99	1188	60	73,5	1235	56,9	71,3
1142	46,3	98,9	1189	60,2	55,5	1236	57	77,3
1143	48,5	99,4	1190	59,7	54,4	1237	57,4	78,2
1144	49,9	99,7	1191	59,8	73,3	1238	57,3	70,6
1145	49,1	99,5	1192	59,8	77,9	1239	57,7	64
1146	49,1	99,5	1193	59,8	73,9	1240	57,5	55,6
1147	51	100	1194	60	76,5	1241	58,6	49,6
1148	51,5	99,9	1195	59,5	82,3	1242	58,2	41,1
1149	50,9	100	1196	59,9	82,8	1243	58,8	40,6
1150	51,6	99,9	1197	59,8	65,8	1244	58,3	21,1
1151	52,1	99,7	1198	59	48,6	1245	58,7	24,9
1152	50,9	100	1199	58,9	62,2	1246	59,1	24,8
1153	52,2	99,7	1200	59,1	70,4	1247	58,6	'm'
1154	51,5	98,3	1201	58,9	62,1	1248	58,8	'm'
1155	51,5	47,2	1202	58,4	67,4	1249	58,8	'm'
1156	50,8	78,4	1203	58,7	58,9	1250	58,7	'm'
1157	50,3	83	1204	58,3	57,7	1251	59,1	'm'
1158	50,3	31,7	1205	57,5	57,8	1252	59,1	'm'
1159	49,3	31,3	1206	57,2	57,6	1253	59,4	'm'
1160	48,8	21,5	1207	57,1	42,6	1254	60,6	2,6

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
1255	59,6	'm'	1302	59,5	16,2	1349	60,7	59,1
1256	60,1	'm'	1303	59,7	50	1350	60,9	56,8
1257	60,6	'm'	1304	59,7	31,4	1351	60,7	58,1
1258	59,6	4,1	1305	60,1	43,1	1352	59,6	78,4
1259	60,7	7,1	1306	60,8	38,4	1353	59,6	84,6
1260	60,5	'm'	1307	60,9	40,2	1354	59,4	66,6
1261	59,7	'm'	1308	61,3	49,7	1355	59,3	75,5
1262	59,6	'm'	1309	61,6	45,9	1356	58,9	49,6
1263	59,8	'm'	1310	62	45,9	1357	59,1	75,8
1264	59,6	4,9	1311	62,2	45,8	1358	59	77,6
1265	60,1	5,9	1312	62,6	46,8	1359	59	67,8
1266	59,9	6,1	1313	62,7	44,3	1360	59	56,7
1267	59,7	'm'	1314	62,9	44,4	1361	58,8	54,2
1268	59,6	'm'	1315	63,1	43,7	1362	58,9	59,6
1269	59,7	22	1316	63,5	46,1	1363	58,9	60,8
1270	59,6	10,3	1317	63,6	40,7	1364	59,3	56,1
1271	59,9	10	1318	64,3	49,5	1365	58,9	48,5
1272	60,6	6,2	1319	63,7	27	1366	59,3	42,9
1273	60,5	7,3	1320	63,8	15	1367	59,4	41,4
1274	60,2	14,8	1321	63,6	18,7	1368	59,6	38,9
1275	60,6	8,2	1322	63,4	8,4	1369	59,4	32,9
1276	60,6	5,5	1323	63,2	8,7	1370	59,3	30,6
1277	61	14,3	1324	63,3	21,6	1371	59,4	30
1278	61	12	1325	62,9	19,7	1372	59,4	25,3
1279	61,3	34,2	1326	63	22,1	1373	58,8	18,6
1280	61,2	17,1	1327	63,1	20,3	1374	59,1	18
1281	61,5	15,7	1328	61,8	19,1	1375	58,5	10,6
1282	61	9,5	1329	61,6	17,1	1376	58,8	10,5
1283	61,1	9,2	1330	61	0	1377	58,5	8,2
1284	60,5	4,3	1331	61,2	22	1378	58,7	13,7
1285	60,2	7,8	1332	60,8	40,3	1379	59,1	7,8
1286	60,2	5,9	1333	61,1	34,3	1380	59,1	6
1287	60,2	5,3	1334	60,7	16,1	1381	59,1	6
1288	59,9	4,6	1335	60,6	16,6	1382	59,4	13,1
1289	59,4	21,5	1336	60,5	18,5	1383	59,7	22,3
1290	59,6	15,8	1337	60,6	29,8	1384	60,7	10,5
1291	59,3	10,1	1338	60,9	19,5	1385	59,8	9,8
1292	58,9	9,4	1339	60,9	22,3	1386	60,2	8,8
1293	58,8	9	1340	61,4	35,8	1387	59,9	8,7
1294	58,9	35,4	1341	61,3	42,9	1388	61	9,1
1295	58,9	30,7	1342	61,5	31	1389	60,6	28,2
1296	58,9	25,9	1343	61,3	19,2	1390	60,6	22
1297	58,7	22,9	1344	61	9,3	1391	59,6	23,2
1298	58,7	24,4	1345	60,8	44,2	1392	59,6	19
1299	59,3	61	1346	60,9	55,3	1393	60,6	38,4
1300	60,1	56	1347	61,2	56	1394	59,8	41,6
1301	60,5	50,5	1348	60,9	60,1	1395	60	47,3

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
1396	60,5	55,4	1443	60,3	6,9	1490	58,7	‘m’
1397	60,9	58,7	1444	60,8	7	1491	57,9	‘m’
1398	61,3	37,9	1445	60,2	9,2	1492	58,2	‘m’
1399	61,2	38,3	1446	60,5	21,7	1493	57,6	‘m’
1400	61,4	58,7	1447	60,2	22,4	1494	58,3	9,5
1401	61,3	51,3	1448	60,7	31,6	1495	57,2	6
1402	61,4	71,1	1449	60,9	28,9	1496	57,4	27,3
1403	61,1	51	1450	59,6	21,7	1497	58,3	59,9
1404	61,5	56,6	1451	60,2	18	1498	58,3	7,3
1405	61 .	60,6	1452	59,5	16,7	1499	58,8	21,7
1406	61,1	75,4	1453	59,8	15,7	1500	58,8	38,9
1407	61,4	69,4	1454	59,6	15,7	1501	59,4	26,2
1408	61,6	69,9	4155	59,3	15,7	1502	59,1	25,5
1409	61,7	59,6	1456	59	7,5	1503	59,1	26
1410	61,8	54,8	1457	58,8	7,1	1504	59	39,1
1411	61,6	53,6	1458	58,7	16,5	1505	59,5	52,3
1412	61,3	53,5	1459	59,2	50,7	1506	59,4	31
1413	61,3	52,9	1460	59,7	60,2	1507	59,4	27
1414	61,2	54,1	1461	60,4	44	1508	59,4	29,8
1415	61,3	53,2	1462	60,2	35,3	1509	59,4	23,1
1416	61,2	52,2	1463	60,4	17,1	1510	58,9	16
1417	61,2	52,3	1464	59,9	13,5	1511	59	31,5
1418	61	48	1465	59,9	12,8	1512	58,8	25,9
1419	60,9	41,5	1466	59,6	14,8	1513	58,9	40,2
1420	61	32,2	1467	59,4	15,9	1514	58,8	28,4
1421	60,7	22	1468	59,4	22	1515	58,9	38,9
1422	60,7	23,3	1469	60,4	38,4	1516	59,1	35,3
1423	60,8	38,8	1470	59,5	38,8	1517	58,8	30,3
1424	61	40,7	1471	59,3	31,9	1518	59	19
1425	61	30,6	1472	60,9	40,8	1519	58,7	3
1426	61,3	62,6	1473	60,7	39	1520	57,9	0
1427	61,7	55,9	1474	60,9	30,1	1521	58	2,4
1428	62,3	43,4	1475	61	29,3	1522	57,1	‘m’
1429	62,3	37,4	1476	60,6	28,4	1523	56,7	‘m’
1430	62,3	35,7	1477	60,9	36,3	1524	56,7	5,3
1431	62,8	34,4	1478	60,8	30,5	1525	56,6	2,1
1432	62,8	31,5	1479	60,7	26,7	1526	56,8	‘m’
1433	62,9	31,7	1480	60,1	4,7	1527	56,3	‘m’
434	62,9	29,9	1481	59,9	0	1528	56,3	‘m’
435	62,8	29,4	1482	60,4	36,2	1529	56	‘m’
436	62,7	28,7	1483	60,7	32,5	1530	56,7	‘m’
437	61,5	14,7	1484	59,9	3,1	1531	56,6	3,8
438	61,9	17,2	1485	59,7	‘m’	1532	56,9	‘m’
439	61,5	6,1	1486	59,5	‘m’	1533	56,9	‘m’
440	61	9,9	1487	59,2	‘m’	1534	57,4	‘m’
441	60,9	4,8	1488	58,8	0,6	1535	57,4	‘m’
442	60,6	11,1	1489	58,7	‘m’	1536	58,3	13,9

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
1537	58,5	'm'	1584	59,6	84,6	1631	62,8	21,9
1538	59,1	'm'	1585	59,4	76,1	1632	62,2	22,2
1539	59,4	'm'	1586	60,1	76,9	1633	62,5	31
1540	59,6	'm'	1587	59,5	84,6	1634	62,3	31,3
1541	59,5	'm'	1588	59,8	77,5	1635	62,6	31,7
1542	59,6	0,5	1589	60,6	67,9	1636	62,3	22,8
1543	59,3	9,2	1590	59,3	47,3	1637	62,7	12,6
1544	59,4	11,2	1591	59,3	43,1	1638	62,2	15,2
1545	59,1	26,8	1592	59,4	38,3	1639	61,9	32,6
1546	59	11,7	1593	58,7	38,2	1640	62,5	23,1
1547	58,8	6,4	1594	58,8	39,2	1641	61,7	19,4
1548	58,7	5	1595	59,1	67,9	1642	61,7	10,8
1549	57,5	'm'	1596	59,7	60,5	1643	61,6	10,2
1550	57,4	'm'	1597	59,5	32,9	1644	61,4	'm'
1551	57,1	1,1	1598	59,6	20	1645	60,8	'm'
1552	57,1	0	1599	59,6	34,4	1646	60,7	'm'
1553	57	4,5	1600	59,4	23,9	1647	61	12,4
1554	57,1	3,7	1601	59,6	15,7	1648	60,4	5,3
1555	57,3	3,3	1602	59,9	41	1649	61	13,1
1556	57,3	16,8	1603	60,5	26,3	1650	60,7	29,6
1557	58,2	29,3	1604	59,6	14	1651	60,5	28,9
1558	58,7	12,5	1605	59,7	21,2	1652	60,8	27,1
1559	58,3	12,2	1606	60,9	19,6	1653	61,2	27,3
1560	58,6	12,7	1607	60,1	34,3	1654	60,9	20,6
1561	59	13,6	1608	59,9	27	1655	61,1	13,9
1562	59,8	21,9	1609	60,8	25,6	1656	60,7	13,4
1563	59,3	20,9	1610	60,6	26,3	1657	61,3	26,1
1564	59,7	19,2	1611	60,9	26,1	1658	60,9	23,7
1565	60,1	15,9	1612	61,1	38	1659	61,4	32,1
1566	60,7	16,7	1613	61,2	31,6	1660	61,7	33,5
1567	60,7	18,1	1614	61,4	30,6	1661	61,8	34,1
1568	60,7	40,6	1615	61,7	29,6	1662	61,7	17
1569	60,7	59,7	1616	61,5	28,8	1663	61,7	2,5
1570	61,1	66,8	1617	61,7	27,8	1664	61,5	5,9
1571	61,1	58,8	1618	62,2	20,3	1665	61,3	14,9
1572	60,8	64,7	1619	61,4	19,6	1666	61,5	17,2
1573	60,1	63,6	1620	61,8	19,7	1667	61,1	'm'
1574	60,7	83,2	1621	61,8	18,7	1668	61,4	'm'
1575	60,4	82,2	1622	61,6	17,7	1669	61,4	8,8
1576	60	80,5	1623	61,7	8,7	1670	61,3	8,8
1577	59,9	78,7	1624	61,7	1,4	1671	61	18
1578	60,8	67,9	1625	61,7	5,9	1672	61,5	13
1579	60,4	57,7	1626	61,2	8,1	1673	61	3,7
1580	60,2	60,6	1627	61,9	45,8	1674	60,9	3,1
1581	59,6	72,7	1628	61,4	31,5	1675	60,9	4,7
1582	59,9	73,6	1629	61,7	22,3	1676	60,6	4,1
1583	59,8	74,1	1630	62,4	21,7	1677	60,6	6,7

Time s	Normal Speed %	Normal Torque %	Time s	Normal Speed %	Normal Torque %	Time s	Normal speed %	Normal torque %
1678	60,6	12,8	1725	60,2	18,6	1772	58,4	35,5
1679	60,7	11,9	1726	60,3	11,9	1773	58,4	29,3
1680	60,6	12,4	1727	60,4	11,6	1774	59	33,8
1681	60,1	12,4	1728	60,6	10,6	1775	59	18,7
1682	60,5	12	1729	60,8	16	1776	58,8	9,8
1683	60,4	11,8	1730	60,9	17	1777	58,8	23,9
1684	59,9	12,4	1731	60,9	16,1	1778	59,1	48,2
1685	59,6	12,4	1732	60,7	11,4	1779	59,4	37,2
1686	59,6	9,1	1733	60,9	11,3	1780	59,6	29,1
1687	59,9	0	1734	61,1	11,2	1781	50	25
1688	59,9	20,4	1735	61,1	25,6	1782	40	20
1689	59,8	4,4	1736	61	14,6	1783	30	15
1690	59,4	3,1	1737	61	10,4	1784	20	10
1691	59,5	26,3	1738	60,6	‘m’	1785	10	5
1692	59,6	20,1	1739	60,9	‘m’	1786	0	0
1693	59,4	35	1740	60,8	4,8	1787	0	0
1694	60,9	22,1	1741	59,9	‘m’	1788	0	0
1695	60,5	12,2	1742	59,8	‘m’	1789	0	0
1696	60,1	11	1743	59,1	‘m’	1790	0	0
1697	60,1	8,2	1744	58,8	‘m’	1791	0	0
1698	60,5	6,7	1745	58,8	‘m’	1792	0	0
1699	60	5,1	1746	58,2	‘m’	1793	0	0
1700	60	5,1	1747	58,5	14,3	1794	0	0
1701	60	9	1748	57,5	4,4	1795	0	0
1702	60,1	5,7	1749	57,9	0	1796	0	0
1703	59,9	8,5	1750	57,8	20,9	1797	0	0
1704	59,4	6	1751	58,3	9,2	1798	0	0
1705	59,5	5,5	1752	57,8	8,2	1799	0	0
1706	59,5	14,2	1753	57,5	15,3	1800	0	0
1707	59,5	6,2	1754	58,4	38			
1708	59,4	10,3	1755	58,1	15,4			
1709	59,6	13,8	1756	58,8	11,8			
1710	59,5	13,9	1757	58,3	8,1			
1711	60,1	18,9	1758	58,3	5,5			
1712	59,4	13,1	1759	59	4,1			
1713	59,8	5,4	1760	58,2	4,9			
1714	59,9	2,9	1761	57,9	10,1			
1715	60,1	7,1	1762	58,5	7,5			
1716	59,6	12	1763	57,4	7			
1717	59,6	4,9	1764	58,2	6,7			
1718	59,4	22,7	1765	58,2	6,6			
1719	59,6	22	1766	57,3	17,3			
1720	60,1	17,4	1767	58	11,4			
1721	60,2	16,6	1768	57,5	47,4			
1722	59,4	28,6	1769	57,4	28,8			
1723	60,3	22,4	1770	58,8	24,3			
1724	59,9	20	1771	57,7	25,5			

ETC ENGINE DYNAMOMETER SCHEDULE
"m"= motoring.

ETC dynamometer schedule

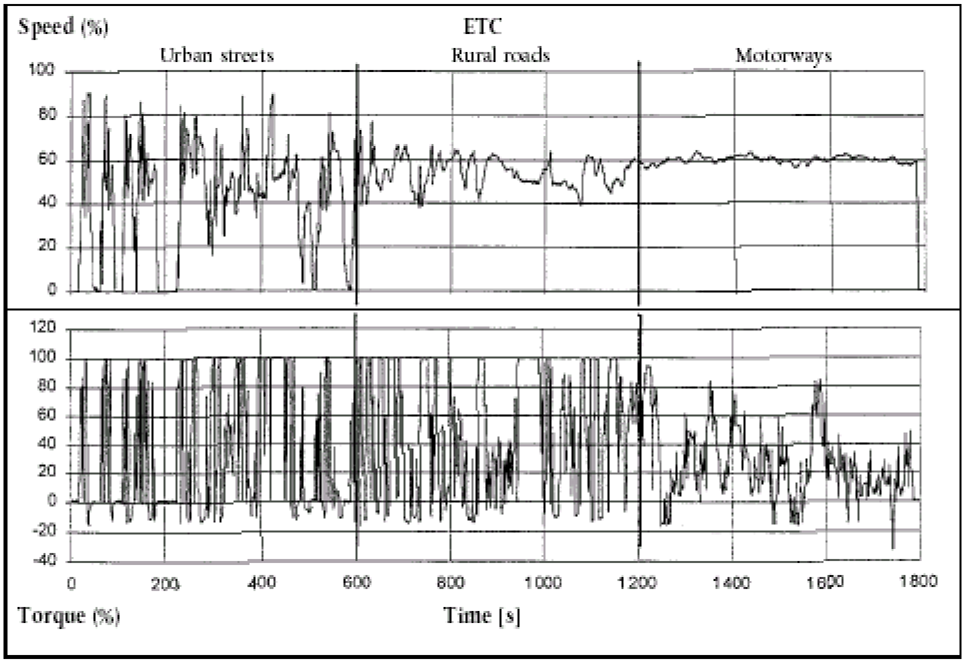

Figure 5 :- ETC dynamometer schedule

A Graphical display of the ETC dynamometer schedule is shown in figure 5

APPENDIX 4

MEASUREMENT AND SAMPLING PROCEDURES

1. INTRODUCTION

Gaseous components, particulates, and smoke emitted by the engine submitted for testing shall be measured by the methods described in Chapter V. The respective sections of Chapter V describe the recommended analytical systems for the gaseous emissions (section 1), the recommended particulate dilution and sampling systems (section 2), and the recommended opacimeters for smoke measurement (section 3).

For the ESC, the gaseous components shall be determined in the raw exhaust gas. Optionally, they may be determined in the diluted exhaust gas, if a full flow dilution system is used for particulate determination. Particulates shall be determined with either a partial flow or a full flow dilution system.

For the ETC, only a full flow dilution system shall be used for determining gaseous and particulate emissions, and is considered the reference system. However, partial flow dilution systems may be approved by the Technical Service, if their equivalency according to section 6.2 to Chapter I is proven, and if a detailed description of the data evaluation and calculation procedures is submitted to the Technical Service.

2. DYNAMOMETER AND TEST CELL EQUIPMENT

The following equipment shall be used for emission tests of engines on engine dynamometers.

2.1. Engine dynamometer

An engine dynamometer shall be used with adequate characteristics to perform the test cycles described in Appendices 1 and 2 to this Chapter. The speed measuring system shall have an accuracy of ± 2 % of reading. The torque measuring system shall have an accuracy of ± 3 % of reading in the range > 20 % of full scale, and an accuracy of ± 0,6 % of full scale in the range < = 20 % of full scale.

2.2. Other instruments

Measuring instruments for fuel consumption, air consumption, temperature of coolant and lubricant, exhaust gas pressure and intake manifold depression, exhaust gas temperature, air intake temperature, atmospheric pressure, humidity and fuel temperature shall be used, as required. These instruments shall satisfy the requirements given in table 8:

Table 8

Accuracy of Measuring Instruments

Measuring instrument	Accuracy
Fuel consumption	± 2% of engine's maximum value
Air consumption	± 2% of engine's maximum value
Temperatures ≤ 600 K (327 °C)	± 2K absolute
Temperatures > 600 K (327 °C)	± 1% of reading
Atmospheric pressure	± 0,1 kPa absolute
Exhaust gas pressure	± 0,2 kPa absolute
Intake depression	± 0,05 kPa absolute
Other pressures	± 0,1kPa absolute
Relative humidity	± 3% absolute
Absolute humidity	± 5% of reading

2.3. Exhaust Gas Flow

For calculation of the emissions in the raw exhaust, it is necessary to know the exhaust gas flow (see section 4.4 of Appendix 1). For the determination of the exhaust flow either of the following methods may be used:

a) Direct measurement of the exhaust flow by flow nozzle or equivalent metering system;

b) Measurement of the air flow and the fuel flow by suitable metering systems and
calculation of the exhaust flow by the following equation:

$$G_{EXHW} = G_{AIRW} + G_{FUEL} \text{ (for wet exhaust mass)}$$

The accuracy of exhaust flow determination shall be ± 2,5 % of reading or better.

2.4. Diluted exhaust gas flow

For calculation of the emissions in the diluted exhaust using a full flow dilution system (mandatory for the ETC), it is necessary to know the diluted exhaust gas flow (see section 4.3 of Appendix 2). The total mass flow rate of the diluted exhaust (G_{TOTW}) or the total mass of the diluted exhaust gas over the cycle (M_{TOTW}) shall be measured with a PDP or CFV (Chapter V, section 2.3.1). The accuracy shall be ± 2 % of reading or better, and shall be determined according to the provisions of Chapter III, Appendix 5, section 2.4.

3. DETERMINATION OF THE GASEOUS COMPONENTS

3.1. General analyser specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (section 3.1.1). It is recommended that the analysers be operated such that the measured concentration falls between 15 % and 100 % of full scale.

If read-out systems (computers, data loggers) can provide sufficient accuracy and resolution below 15 % of full scale, measurements below 15 % of full scale are also acceptable. In this case, additional calibrations of at least 4 non-zero nominally equally spaced points are to be made to ensure the accuracy of the calibration curves according to Chapter III, Appendix 5, section 1.5.5.2.

The electromagnetic compatibility (EMC) of the equipment shall be on a level as to minimise additional errors.

3.1.1. Measurement Error

The total measurement error, including the cross sensitivity to other gases (see Chapter III, Appendix 5, section 1.9), shall not exceed ± 5 % of the reading or ± 3,5 % of full scale, whichever is smaller. For concentrations of less than 100 ppm the measurement error shall not exceed ± 4 ppm.

3.1.2. Repeatability

The repeatability, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, has to be not greater than ± 1 % of full scale concentration for each range used above 155 ppm (or ppmC) or ± 2 % of each range used below 155 ppm (or ppmC).

3.1.3. Noise

The analyser peak-to-peak response to zero and calibration or span gases over any 10 seconds period shall not exceed 2 % of full scale on all ranges used.

3.1.4. Zero Drift

The zero drift during a one hour period shall be less than 2 % of full scale on the lowest range used. The zero response is defined as the mean response, including noise, to a zero gas during a 30 seconds time interval.

3.1.5. Span Drift

The span drift during a one hour period shall be less than 2 % of full scale on the lowest range used. Span is defined as the difference between the span response and the zero response. The span response is defined as the mean response, including noise, to a span gas during a 30 seconds time interval.

3.2. Gas Drying

The optional gas drying device must have a minimal effect on the concentration of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

3.3. Analysers

Sections 3.3.1 to 3.3.4 describe the measurement principles to be used. A detailed description of the measurement systems is given in Chapter V. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearising circuits is permitted.

3.3.1. Carbon Monoxide (CO) Analysis

The carbon monoxide analyser shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

3.3.2. Carbon Dioxide (CO2) Analysis

The carbon dioxide analyser shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

3.3.3. Hydrocarbon (HC) analysis

For diesel and LPG fuelled gas engines, the hydrocarbon analyser shall be of the Heated Flame Ionisation Detector (HFID) type with detector, valves, pipework, etc. heated so as to maintain a gas temperature of 463K ± 10K (190 ± 10 °C). For NG fuelled gas engines, the hydrocarbon analyser may be of the non heated Flame Ionisation Detector (FID) type depending upon the method used (see Chapter V, section 1.3).

3.3.4. Non-Methane Hydrocarbon (NMHC) Analysis (NG Fuelled Gas Engines Only)

Non-methane hydrocarbons shall be determined by either of the following methods:

3.3.4.1. Gas Chromatographic (GC) Method

Non-methane hydrocarbons shall be determined by subtraction of the methane analysed with a Gas Chromatograph (GC) conditioned at 423 K (150 °C) from the hydrocarbons measured according to section 3.3.3.

3.3.4.2. Non-Methane Cutter (NMC) Method

The determination of the non-methane fraction shall be performed with a heated NMC operated in line with an FID as per section 3.3.3 by subtraction of the methane from the hydrocarbons.

3.3.5. Oxides of Nitrogen (NOx) Analysis

The oxides of nitrogen analyser shall be of the ChemiLuminescent Detector (CLD) or Heated ChemiLuminescent Detector (HCLD) type with a NO2/NO converter, if measured on a dry basis. If measured on a wet basis, a HCLD with converter maintained above 328 K (55 °C) shall be used, provided the water quench check (see Chapter III, Appendix 5, section 1.9.2.2) is satisfied.

3.4. Sampling of Gaseous Emissions

3.4.1. Raw Exhaust Gas (ESC only)

The gaseous emissions sampling probes must be fitted at least 0,5 m or 3 times the diameter of the exhaust pipe-whichever is the larger-upstream of the exit of the exhaust gas system as far as applicable and sufficiently close to the engine as to ensure an exhaust gas temperature of at least 343 K (70 °C) at the probe. In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation the total exhaust mass flow must be used.

If the engine is equipped with an exhaust aftertreatment system, the exhaust sample shall be taken downstream of the exhaust aftertreatment system.

3.4.2. Diluted Exhaust Gas (mandatory for ETC, optional for ESC)

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements of Chapter V, section 2.3.1, EP. The gaseous emissions sample probe(s) shall be installed in the dilution tunnel at a point where the dilution air and exhaust gas are well mixed, and in close proximity to the particulates sampling probe.

For the ETC, sampling can generally be done in two ways:

- the pollutants are sampled into a sampling bag over the cycle and measured after completion of the test;

- the pollutants are sampled continuously and integrated over the cycle; this method is mandatory for HC and NOx.

4. DETERMINATION OF THE PARTICULATES

The determination of the particulates requires a dilution system. Dilution may be accomplished by a partial flow dilution system (ESC only) or a full flow dilution system (mandatory for ETC). The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems, and maintain the temperature of the diluted exhaust gas at or below 325K (52 °C) immediately upstream of the filter holders. Dehumidifying the dilution air before entering the dilution system is permitted, and especially useful if dilution air humidity is high. The temperature of the dilution air shall be 298 K ± 5 K (25 °C ± 5 °C). If the ambient temperature is below 293K (20 °C), dilution air pre-heating above the upper temperature limit of 303K (30 °C) is recommended. However, the dilution air temperature must not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel.

The partial flow dilution system has to be designed to split the exhaust stream into two fractions, the smaller one being diluted with air and subsequently used for particulate measurement. For this it is essential that the dilution ratio be determined very accurately. Different splitting methods can be applied, whereby the type of splitting used dictates to a significant degree the sampling hardware and procedures to be used (Chapter V, section 2.2). The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, and the installation shall comply with the provisions of section 3.4.1.

To determine the mass of the particulates, a particulate sampling system, particulate sampling filters, a microgram balance, and a temperature and humidity controlled weighing chamber, are required.

For particulate sampling, the single filter method shall be applied which uses one pair of filters (see section 4.1.3) for the whole test cycle. For the ESC, considerable attention must be paid to sampling times and flows during the sampling phase of the test.

4.1. Particulate Sampling Filters

4.1.1. Filter Specification

Fluorocarbon coated glass fibre filters or fluorocarbon based membrane filters are required. All filter types shall have a 0,3 μ DOP (di-octylphthalate) collection efficiency of at least 95 % at a gas face velocity between 35 and 80 cm/s.

4.1.2. Filter Size

Particulate filters must have a minimum diameter of 47 mm (37 mm stain diameter). Larger diameter filters are acceptable (section 4.1.5).

4.1.3. Primary and Back-up Filters

The diluted exhaust shall be sampled by a pair of filters placed in series (one primary and one back-up filter) during the test sequence. The back-up filter shall be located no more than 100 mm downstream of, and shall not be in contact with the primary filter. The filters may be weighed separately or as a pair with the filters placed stain side to stain side.

4.1.4. Filter Face Velocity

A gas face velocity through the filter of 35 to 80 cm/s shall be achieved. The pressure drop increase between the beginning and the end of the test shall be no more than 25 kPa.

4.1.5. Filter Loading

The recommended minimum filter loading shall be 0,5 mg/1075 mm^2 stain area. For the most common filter sizes the values are shown in Table 9.

Table 9

Recommended Filter Loadings

Filter Diameter (mm)	Recommended Stain (mm)	Recommended Minimum loading (mg)
47	37	0,5
70	60	1,3
90	80	2,3
110	100	3,6

4.2. Weighing Chamber and Analytical Balance Specifications

4.2.1. Weighing Chamber Conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within 295K ± 3 K (22 °C ± 3 °C) during all filter conditioning and weighing. The humidity shall be maintained to a dewpoint of 282,5K ± 3 K (9,5 °C ± 3 °C) and a relative humidity of 45 % ± 8 %.

4.2.2. Reference Filter Weighing

The chamber (or room) environment shall be free of any ambient contaminants (such as dust) that would settle on the particulate filters during their stabilisation. Disturbances to weighing room specifications as outlined in section 4.2.1 will be allowed if the duration of the disturbances does not exceed 30 minutes. The weighing room should meet the required specifications prior to personal entrance into the weighing room. At least two unused reference filters or reference filter pairs shall be weighed within 4 hours of, but preferably at the same time as the sample filter (pair) weighings. They shall be the same size and material as the sample filters.

If the average weight of the reference filters (reference filter pairs) changes between sample filter weighings by more than ± 5 % (± 7,5 % for the filter pair respectively) of the recommended minimum filter loading (section 4.1.5.), then all sample filters shall be discarded and the emissions test repeated.

If the weighing room stability criteria outlined in section 4.2.1 is not met, but the reference filter (pair) weighings meet the above criteria, the engine manufacturer has the option of accepting the sample filter weights or voiding the tests, fixing the weighing room control system and rerunning the test.

4.2.3. Analytical Balance

The analytical balance used to determine the weights of all filters shall have a precision (standard deviation) of 20 μg and a resolution of 10 μg (1 digit = 10 μg). For filters less than 70 mm diameter, the precision and resolution shall be 2 μg and μg, respectively.

4.3. **Additional Specifications for Particulate Measurement**

All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, must be designed to minimise deposition or alteration of the particulates. All parts must be made of electrically conductive materials that do not react with exhaust gas components, and must be electrically grounded to prevent electrostatic effects.

5. DETERMINATION OF SMOKE

This section provides specifications for the required and optional test equipment to be used for the ELR test. The smoke shall be measured with an opacimeter having an opacity and a light absorption coefficient readout mode. The opacity readout mode shall only be used for calibration and checking of the opacimeter. The smoke values of the test cycle shall be measured in the light absorption coefficient readout mode.

5.1. General Requirements

The ELR requires the use of a smoke measurement and data processing system which includes three functional units. These units may be integrated into a single component or provided as a system of interconnected components. The three functional units are:

An opacimeter meeting the specifications of Chapter V, section 3.

- A data processing unit capable of performing the functions described in Chapter III, Appendix 1, section 6.

- A printer and/or electronic storage medium to record and output the required smoke values specified in Chapter III, Appendix 1, section 6.3.

5.2. Specific Requirements

5.2.1. Linearity

The linearity shall be within ± 2 % opacity.

5.2.2. Zero Drift

The zero drift during a one hour period shall not exceed ± 1 % opacity.

5.2.3. Opacimeter Display and Range

For display in opacity, the range shall be 0-100 % opacity, and the readability 0,1 % opacity. For display in light absorption coefficient, the range shall be 0-30 m-1 light absorption coefficient, and the readability 0,01 m-1 light absorption coefficient.

5.2.4. Instrument Response Time

The physical response time of the opacimeter shall not exceed 0,2 s. The physical response time is the difference between the times when the output of a rapid response receiver reaches 10 and 90 % of the full deviation when the opacity of the gas being measured is changed in less than 0,1 s.

The electrical response time of the opacimeter shall not exceed 0,05 s. The electrical response time is the difference between the times when the opacimeter output reaches 10 and 90 % of the full scale when the light source is interrupted or completely extinguished in less than 0,01 s.

5.2.5. Neutral Density Filters

Any neutral density filter used in conjunction with opacimeter calibration, linearity measurements, or setting span shall have its value known to within 1,0 % opacity. The filter's nominal value must be checked for accuracy at least yearly using a reference traceable to a national or international standard.

Neutral density filters are precision devices and can easily be damaged during use. Handling should be minimised and, when required, should be done with care to avoid scratching or soiling of the filter.

APPENDIX 5

CALIBRATION PROCEDURE

1. CALIBRATION OF THE ANALYTICAL INSTRUMENTS

1.1. Introduction

Each analyser shall be calibrated as often as necessary to fulfil the accuracy requirements of this Directive. The calibration method that shall be used is described in this section for the analysers indicated in Chapter III, Appendix 4, section 3 and Chapter V, section 1.

1.2. Calibration Gases

The shelf life of all calibration gases must be respected.

The expiration date of the calibration gases stated by the manufacturer shall be recorded.

1.2.1. Pure Gases

The required purity of the gases is defined by the contamination limits given below. The following gases must be available for operation:

Purified nitrogen

(Contamination $\leq$ 1 ppm C1, $\leq$ 1 ppm CO, $\leq$ 400 ppm CO_2, $\leq$ 0,1 ppm NO)

Purified oxygen

(Purity > 99,5 % vol O_2)

Hydrogen-helium mixture

(40 ± 2 % hydrogen, balance helium)

(Contamination $\leq$ 1 ppm C1, $\leq$ 400 ppm CO_2)

Purified synthetic air

(Contamination $\leq$ 1 ppm C1, $\leq$ 1 ppm CO, $\leq$ 400 ppm CO_2, $\leq$ 0,1 ppm NO)

(Oxygen content between 18-21 % vol.)

Purified propane or CO for the CVS verification

1.2.2. Calibration and Span Gases

Mixtures of gases having the following chemical compositions shall be available:

C_3H_8 and purified synthetic air (see section 1.2.1);

CO and purified nitrogen;

NOx and purified nitrogen (the amount of NO_2 contained in this calibration gas must not exceed 5 % of the NO content);

CO_2 and purified nitrogen

CH_4 and purified synthetic air

C_2H_6 and purified synthetic air

Note: Other gas combinations are allowed provided the gases do not react with one another.

The true concentration of a calibration and span gas must be within ± 2 % of the nominal value. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

The gases used for calibration and span may also be obtained by means of a gas divider, diluting with purified N_2 or with purified synthetic air. The accuracy of the mixing device must be such that the concentration of the diluted calibration gases may be determined to within ± 2 %.

1.3. Operating Procedure for Analysers and Sampling System

The operating procedure for analysers shall follow the start-up and operating instructions of the instrument manufacturer. The minimum requirements given in sections 1.4 to 1.9 shall be included.

1.4. Leakage test

A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilisation period all flow meters should read zero. If not, the sampling lines shall be checked and the fault corrected.

The maximum allowable leakage rate on the vacuum side shall be 0,5 % of the in-use flow rate for the portion of the system being checked. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

Another method is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas. If after an adequate period of time the reading shows a lower concentration compared to the introduced concentration, this points to calibration or leakage problems.

1.5. Calibration Procedure

1.5.1. Instrument Assembly

The instrument assembly shall be calibrated and calibration curves checked against standard gases. The same gas flow rates shall be used as when sampling exhaust.

1.5.2. Warming-up Time

The warming-up time should be according to the recommendations of the manufacturer. If not specified, a minimum of two hours is recommended for warming up the analysers.

1.5.3. NDIR and HFID Analyser

The NDIR analyser shall be tuned, as necessary, and the combustion flame of the HFID analyser shall be optimised (section 1.8.1).

1.5.4. Calibration

Each normally used operating range shall be calibrated.

Using purified synthetic air (or nitrogen), the CO, CO_2, NO_x and HC analysers shall be set at zero.

The appropriate calibration gases shall be introduced to the analysers, the values recorded, and the calibration curve established according to section 1.5.5.

The zero setting shall be rechecked and the calibration procedure repeated, if necessary.

1.5.5. Establishment of the Calibration Curve

1.5.5.1. General Guidelines

The analyser calibration curve shall be established by at least five calibration points (excluding zero) spaced as uniformly as possible. The highest nominal concentration must be equal to or higher than 90 % of full scale.

The calibration curve shall be calculated by the method of least squares. If the resulting polynomial degree is greater than 3, the number of calibration points (zero included) must be at least equal to this polynomial degree plus 2.

The calibration curve must not differ by more than ± 2 % from the nominal value of each calibration point and by more than ± 1 % of full scale at zero.

From the calibration curve and the calibration points, it is possible to verify that the calibration has been carried out correctly. The different characteristic parameters of the analyser must be indicated, particularly:

- the measuring range;
- the sensitivity;
- the date of carrying out the calibration.

1.5.5.2. Calibration below 15 % of Full Scale

The analyser calibration curve shall be established by at least 4 additional calibration points (excluding zero) spaced nominally equally below 15 % of full scale.

The calibration curve is calculated by the method of least squares.

The calibration curve must not differ by more than ± 4 % from the nominal value of each calibration point and by more than ± 1 % of full scale at zero.

1.5.5.3. Alternative Methods

If it can be shown that alternative technology (e.g. computer, electronically controlled range switch, etc.) can give equivalent accuracy, then these alternatives may be used.

1.6. Verification of the Calibration

Each normally used operating range shall be checked prior to each analysis in accordance with the following procedure.

The calibration shall be checked by using a zero gas and a span gas whose nominal value is more than 80 % of full scale of the measuring range.

If, for the two points considered, the value found does not differ by more than ± 4 % of full scale from the declared reference value, the adjustment parameters may be modified. Should this not be the case, a new calibration curve shall be established in accordance with section 1.5.5.

1.7. Efficiency test of the NOx Converter

The efficiency of the converter used for the conversion of NO2 into NO shall be tested as given in sections 1.7.1 to 1.7.8 (Figure 6).

1.7.1. Test Set-up

Using the test set-up as shown in Figure 6 (see also Chapter III, Appendix 4, section 3.3.5) and the procedure below, the efficiency of converters can be tested by means of an ozonator.

1.7.2. Calibration

The CLD and the HCLD shall be calibrated in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which must amount to about 80 % of the operating range and the NO2 concentration of the gas mixture to less than 5 % of the NO concentration). The NOx analyser must be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

1.7.3. Calculation

The efficiency of the NOx converter is calculated as follows:

$$\text{Efficiency (\%)} = \left(1 + \frac{a-b}{c-d}\right) \times 100$$

where,

a is the NOx concentration according to section 1.7.6

b is the NOx concentration according to section 1.7.7

c is the NO concentration according to section 1.7.4

d is the NO concentration according to section 1.7.5

1.7.4. Adding of Oxygen

Via a T-fitting, oxygen or zero air is added continuously to the gas flow until the concentration indicated is about 20 % less than the indicated calibration concentration given in section 1.7.2 (The analyser is in the NO mode). The indicated concentration c shall be recorded. The ozonator is kept deactivated throughout the process.

1.7.5. Activation of the Ozonator

The ozonator is now activated to generate enough ozone to bring the NO concentration down to about 20 % (minimum 10 %) of the calibration concentration given in section 1.7.2. The indicated concentration d shall be recorded (The analyser is in the NO mode).

1.7.6. NOx Mode

The NO analyser is then switched to the NO_x mode so that the gas mixture (consisting of NO, NO_2, O_2 and N_2) now passes through the converter. The indicated concentration a shall be recorded. (The analyser is in the NOx mode).

1.7.7. Deactivation of the Ozonator

The ozonator is now deactivated. The mixture of gases described in section 1.7.6 passes through the converter into the detector. The indicated concentration b shall be recorded. (The analyser is in the NO_x mode).

1.7.8. NO Mode

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air is also shut off. The NO_x reading of the analyser shall not deviate by more than ± 5 % from the value measured according to section 1.7.2. (The analyser is in the NO mode).

1.7.9. Test Interval

The efficiency of the converter must be tested prior to each calibration of the NOx analyser.

1.7.10. Efficiency Requirement

The efficiency of the converter shall not be less than 90 %, but a higher efficiency of 95 % is strongly recommended
.

Note: If, with the analyser in the most common range, the ozonator cannot give a reduction from 80 % to 20 % according to section 1.7.5, then the highest range which will give the reduction shall be used.

Schematic of NO_x converter efficiency device

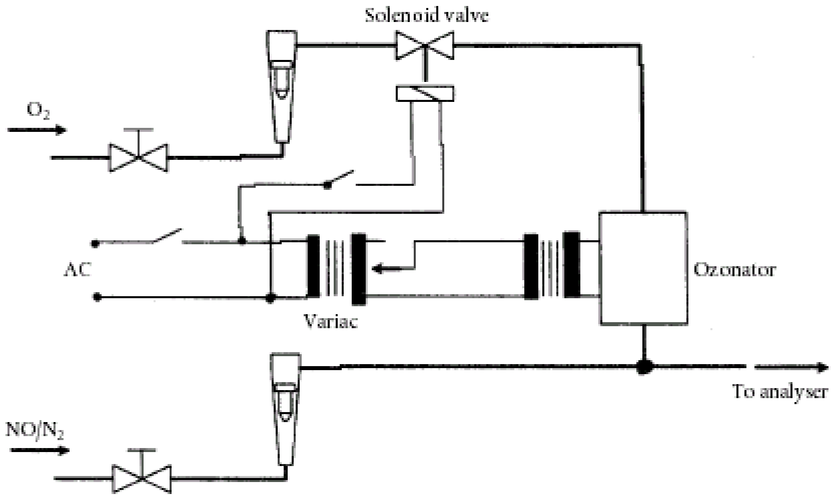

Figure 6

Schematic of NOx converter efficiency device

1.8. Adjustment of the FID

1.8.1. Optimisation of the Detector Response

The FID must be adjusted as specified by the instrument manufacturer. A propane in air span gas should be used to optimise the response on the most common operating range.

With the fuel and air flow rates set at the manufacturer's recommendations, a 350 ± 75 ppm C span gas shall be introduced to the analyser. The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response. The fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows shall be recorded. The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve.

1.8.2. Hydrocarbon Response Factors

The analyser shall be calibrated using propane in air and purified synthetic air, according to section 1.5.

Response factors shall be determined when introducing an analyser into service and after major service intervals. The response factor (Rf) for a particular hydrocarbon species is the ratio of the FID C1 reading to the gas concentration in the cylinder expressed by ppm C1.

The concentration of the test gas must be at a level to give a response of approximately 80 % of full scale. The concentration must be known to an accuracy of ± 2 % in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder must be preconditioned for 24 hours at a temperature of 298 K ± 5 K (25 °C ± 5 °C).

The test gases to be used and the recommended relative response factor ranges are as follows:

Methane and purified synthetic air 1,00 < = Rf < = 1,15

Propylene and purified synthetic air 0,90 < = Rf < = 1,10

Toluene and purified synthetic air 0,90 < = Rf < = 1,10

These values are relative to the response factor (Rf) of 1,00 for propane and purified synthetic air.

1.8.3. Oxygen Interference Check

The oxygen interference check shall be determined when introducing an analyser into service and after major service intervals.

The response factor is defined and shall be determined as described in section 1.8.2. The test gas to be used and the recommended relative response factor range are as follows:

Propane and nitrogen $0,95 \leq R_f \leq 1,05$

This value is relative to the response factor (R_f) of 1,00 for propane and purified synthetic air.

The FID burner air oxygen concentration must be within ± 1 mole% of the oxygen concentration of the burner air used in the latest oxygen interference check. If the difference is greater, the oxygen interference must be checked and the analyser adjusted, if necessary.

1.8.4. Efficiency of the Non-Methane Cutter (NMC, For NG Fuelled Gas Engines Only)

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidising all hydrocarbons except methane. Ideally, the conversion for methane is 0 %, and for the other hydrocarbons represented by ethane is 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 (see Chapter III, Appendix 2, section 4.3).

1.8.4.1. Methane Efficiency

Methane calibration gas shall be flown through the FID with and without bypassing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$CE_M = 1 - \frac{conc_w}{conc_{w/o}}$$

where,

$conc_w$ = HC concentration with CH_4 flowing through the NMC

$conc_{w/o}$ = HC concentration with CH_4 bypassing the NMC

1.8.4.2. Ethane Efficiency

Ethane calibration gas shall be flown through the FID with and without bypassing the NMC and the two concentrations recorded. The efficiency shall be determined as follows:

$$CE_M = 1 - \frac{conc_W}{conc_{w/o}}$$

where,

$conc_w$ = HC concentration with C_2H_6 flowing through the NMC

$conc_{w/o}$ = HC concentration with C_2H_6 bypassing the NMC

1.9. Interference Effects with CO, CO2, and NO_x Analysers

Gases present in the exhaust other than the one being analysed can interfere with the reading in several ways. Positive interference occurs in NDIR instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the radiation. The interference checks in sections 1.9.1 and 1.9.2 shall be performed prior to an analyser's initial use and after major service intervals.

1.9.1. CO Analyser Interference Check

Water and CO_2 can interfere with the CO analyser performance. Therefore, a CO_2 span gas having a concentration of 80 to 100 % of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyser response recorded. The analyser response must not be more than 1 % of full scale for ranges equal to or above 300 ppm or more than 3 ppm for ranges below 300 ppm.

1.9.2. NO_x Analyser Quench Checks

The two gases of concern for CLD (and HCLD) analysers are CO_2 and water vapour. Quench responses to these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

1.9.2.1. CO_2 Quench Check

A CO_2 span gas having a concentration of 80 to 100 % of full scale of the maximum operating range shall be passed through the NDIR analyser and the CO_2 value recorded as A. It shall then be diluted approximately 50 % with NO span gas and passed through the NDIR and (H)CLD, with the CO_2 and NO values recorded as B and C, respectively. The CO_2 shall then be shut off and only the NO span gas be passed through the (H)CLD and the NO value recorded as D.

The quench, which must not be greater than 3 % of full scale, shall be calculated as follows:

$$\% \text{ quench} = \left[1 - \left(\frac{C \times A}{(D \times A) - (D \times B)}\right)\right] \times 100$$

where,

A is the undiluted CO_2 concentration measured with NDIR in %

B is the diluted CO_2 concentration measured with NDIR in %

C is the diluted NO concentration measured with (H)CLD in ppm

D is the undiluted NO concentration measured with (H)CLD in ppm

Alternative methods of diluting and quantifying of CO_2 and NO span gas values such as dynamic mixing/blending can be used.

1.9.2.2. Water Quench Check

This check applies to wet gas concentration measurements only. Calculation of water quench must consider dilution of the NO span gas with water vapour and scaling of water vapour concentration of the mixture to that expected during testing.

A NO span gas having a concentration of 80 to 100 % of full scale of the normal operating range shall be passed through the (H)CLD and the NO value recorded as D. The NO span gas shall then be bubbled through water at room temperature and passed through the (H)CLD and the NO value recorded as C. The analyser's absolute operating pressure and the water temperature shall be determined and recorded as E and F, respectively. The mixture's saturation vapour pressure that corresponds to the bubbler water temperature F shall be determined and recorded as G. The water vapour concentration (H, in %) of the mixture shall be calculated as follows:

$$H = 100 \times (G/E)$$

The expected diluted NO span gas (in water vapour) concentration (D_e) shall be calculated as follows:

$$D_e = D \times (1 - H/100)$$

For diesel exhaust, the maximum exhaust water vapour concentration (H_m, in %) expected during testing shall be estimated, under the assumption of a fuel atom H/C ratio of 1,8:1, from the undiluted CO_2 span gas concentration (A, as measured in section 1.9.2.1) as follows:

$$H_m = 0,9 \times A$$

The water quench, which must not be greater than 3 %, shall be calculated as follows:

$$\% \text{ Quench} = 100 \times ((D_e - C)/D_e) \times H_m/H)$$

where,

D_e= is the expected diluted NO concentration in ppm

C= is the diluted NO concentration in ppm

H_m= is the maximum water vapour concentration in %

H= is the actual water vapour concentration in %

Note: It is important that the NO span gas contains minimal NO_2 concentration for this check, since absorption of NO_2 in water has not been accounted for in the quench calculations.

1.10. Calibration Intervals

The analysers shall be calibrated according to section 1.5 at least every 3 months or whenever a system repair or change is made that could influence calibration.

2. CALIBRATION OF THE CVS-SYSTEM

2.1. General

The CVS system shall be calibrated by using an accurate flow meter traceable to national or international standards and a restricting device. The flow through the system shall be measured at different restriction settings, and the control parameters of the system shall be measured and related to the flow. Various types of flow meters may be used, e.g. calibrated venturi, calibrated laminar flow meter, calibrated turbine meter.

2.2. Calibration of the Positive Displacement Pump (PDP)

All parameters related to the pump shall be simultaneously measured with the parameters related to the flow meter, which is connected in series with the pump. The calculated flow rate (in m3/min at pump inlet, absolute pressure and temperature) shall be plotted versus a correlation function, which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall then be determined. If a CVS has a multiple speed drive, the calibration shall be performed for each range used. Temperature stability shall be maintained during calibration.

2.2.1. Data Analysis

The air flowrate (Q_s) at each restriction setting (minimum 6 settings) shall be calculated in standard m^3/min from the flowmeter data using the manufacturer's prescribed method. The air flow rate shall then be converted to pump flow (V_0) in m3/rev at absolute pump inlet temperature and pressure as follows:

$$V_o = \frac{Q_s}{n} \times \frac{T}{273} \times \frac{101.3}{PA}$$

where,

Q_s = air flow rate at standard conditions (101,3 kPa, 273 K), m3/s

T = temperature at pump inlet, K

p_A = absolute pressure at pump inlet (pB-p1), kPa

n = pump speed, rev/s

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function (X0) between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated as follows:

$$Xo = \frac{1}{n} \times \sqrt{\frac{\Delta Pp}{P_A}}$$

where,

Δ pp = pressure differential from pump inlet to pump outlet, kPa

pA = absolute outlet pressure at pump outlet, kPa

A linear least-square fit shall be performed to generate the calibration equation as follows:

$$Vo = Do - m \times (Xo)$$

D_0 and m are the intercept and slope constants, respectively, describing the regression lines.

For a CVS system with multiple speeds, the calibration curves generated for the different pump flow ranges shall be approximately parallel, and the intercept values (D0) shall increase as the pump flow range decreases.

The calculated values from the equation shall be within ± 0,5 % of the measured value of V0. Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m. Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification (section 2.4) indicates a change of the slip rate.

2.3. Calibration of the Critical Flow Venturi (CFV)

Calibration of the CFV is based upon the flow equation for a critical venturi. Gas flow is a function of inlet pressure and temperature, as shown below:

$$Qs = \frac{K_V \times P_A}{\sqrt{T}}$$

where,

Kv = calibration coefficient

PA = absolute pressure at venturi inlet, kPa

T= temperature at venturi inlet, K

2.3.1. Data Analysis

The air flowrate (Qs) at each restriction setting (minimum 8 settings) shall be calculated in standard m3/min from the flowmeter data using the manufacturer's prescribed method. The calibration coefficient shall be calculated from the calibration data for each setting as follows:

$$K_V = \frac{Q_s \sqrt{T}}{PA}$$

where,

Qs = air flow rate at standard conditions (101,3 kPa, 273 K), m3/s

T = temperature at the venturi inlet, K

pA = absolute pressure at venturi inlet, kPa

To determine the range of critical flow, Kv shall be plotted as a function of venturi inlet pressure. For critical (choked) flow, Kv will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and Kv decreases, which indicates that the CFV is operated outside the permissible range.

For a minimum of eight points in the region of critical flow, the average Kv and the standard deviation shall be calculated. The standard deviation shall not exceed ± 0,3 % of the average KV.

2.4. Total System Verification

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analysed, and the mass calculated according to Chapter III, Appendix 2, section 4.3 except in the case of propane where a factor of 0,000472 is used in place of 0,000479 for HC. Either of the following two techniques shall be used.

2.4.1. Metering with a Critical Flow Orifice

A known quantity of pure gas (carbon monoxide or propane) shall be fed into the CVS system through a calibrated critical orifice. If the inlet pressure is high enough, the flow rate, which is adjusted by means of the critical flow orifice, is independent of the orifice outlet pressure ([equiv] critical flow). The CVS system shall be operated as in a normal exhaust emission test for about 5 to 10 minutes. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within ± 3 % of the known mass of the gas injected.

2.4.2. Metering by Means of a Gravimetric Technique

The weight of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ± 0,01 gram. For about 5 to 10 minutes, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated. The mass so determined shall be within ± 3 % of the known mass of the gas injected.

3. CALIBRATION OF THE PARTICULATE MEASURING SYSTEM

3.1. Introduction

Each component shall be calibrated as often as necessary to fulfil the accuracy requirements of this Directive. The calibration method to be used is described in this section for the components indicated in Chapter III, Appendix 4, section 4 and Chapter V, section 2.

3.2. Flow Measurement

The calibration of gas flow meters or flow measurement instrumentation shall be traceable to international and/or national standards. The maximum error of the measured value shall be within ± 2 % of reading.
If the gas flow is determined by differential flow measurement, the maximum error of the difference shall be such that the accuracy of GEDF is within ± 4 % (see also

Chapter V, section 2.2.1, EGA). It can be calculated by taking the Root-Mean-Square of the errors of each instrument.

3.3. Checking the Partial Flow Conditions

The range of the exhaust gas velocity and the pressure oscillations shall be checked and adjusted according to the requirements of Chapter V, section 2.2.1, EP, if applicable.

3.4. Calibration Intervals

The flow measurement instrumentation shall be calibrated at least every 3 months or whenever a system repair or change is made that could influence calibration.

4. CALIBRATION OF THE SMOKE MEASUREMENT EQUIPMENT

4.1. Introduction

The opacimeter shall be calibrated as often as necessary to fulfil the accuracy requirements of this Directive. The calibration method to be used is described in this section for the components indicated in Chapter III, Appendix 4, section 5 and Chapter V, section 3.

4.2. Calibration Procedure

4.2.1. Warming-up Time

The opacimeter shall be warmed up and stabilised according to the manufacturer's recommendations. If the opacimeter is equipped with a purge air system to prevent sooting of the instrument optics, this system should also be activated and adjusted according to the manufacturer's recommendations.

4.2.2. Establishment of the Linearity Response

The linearity of the opacimeter shall be checked in the opacity readout mode as per the manufacturer's recommendations. Three neutral density filters of known transmittance, which shall meet the requirements of Chapter III, Appendix 4, section 5.2.5, shall be introduced to the opacimeter and the value recorded. The neutral density filters shall have nominal opacities of approximately 10 %, 20 % and 40 %.

The linearity must not differ by more than ± 2 % opacity from the nominal value of the neutral density filter. Any non-linearity exceeding the above value must be corrected prior to the test.

4.3. Calibration Intervals

The opacimeter shall be calibrated according to section 4.2.2 at least every 3 months or whenever a system repair or change is made that could influence calibration.