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Items 4(a) and 4(d) of the provisional agenda

Worldwide harmonized Heavy Duty Certification procedure (WHDC)

Proposal for draft Amendment 3 to global technical regulation (gtr) No. 4: Test procedure for compression-ignition (C.I.) engines and positive-ignition (P.I.) engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG) with regard to the emission of pollutants

Submitted by the the GRPE working group on HDH¹

The text reproduced below was prepared by the GRPE working group on HDH to add the test procedure on heavy duty hybrids. The text has been prepared as a consolidated version of the gtr. The modifications are marked in **bold** characters. The provisions for hybrid vehicles have not been finally completed, at this time. The missing parts will be introduced into the final document. In addition, amendments will be introduced into the final document to further align gtr No. 4 with gtr No. 11. In this informal document, only the relevant sections, which will be amended, are marked in ***bold italic*** characters.

¹ In accordance with the programme of work of the Inland Transport Committee for 2006-2010 (ECE/TRANS/166/Add.1, programme activity 02.4), the World Forum will develop, harmonize and update Regulations in order to enhance performance of vehicles. The present document is submitted in conformity with that mandate.

A. STATEMENT OF TECHNICAL RATIONALE AND JUSTIFICATION

1. TECHNICAL AND ECONOMIC FEASIBILITY

The objective of this proposal is to extend the global technical regulation (GTR) No 4 to the type-approval for exhaust emissions from heavy-duty engines in hybrid vehicle applications, and to further harmonize this gtr with gtr No.11.

Regulations governing the exhaust emissions from heavy-duty engines have been in existence for many years, but the introduction of hybrid powertrain technology requires adaptation of the testing procedures to better reflect the hybrid engine load conditions. To be able to correctly determine the impact of a heavy-duty hybrid vehicle on the environment in terms of its exhaust pollutant emissions, a test procedure, and consequently the gtr, needs to be adequately representative of real-world (hybrid) vehicle operation.

The proposed regulation is based on the existing Japanese HILS method for heavy-duty hybrid vehicle certification and on the existing US procedure of powertrain testing. This HILS procedure is documented in Kokujikan No.281. After thorough research and discussion, it was selected as basis for the development of the gtr HILS procedure in annex 8. This gtr reflects the adoption including enhancement of the method to allow the HILS procedure for hybrid engine emission certification and implementation in legislation. The US procedure is documented in 40 CFR § 1037.550.

The test procedures reflect engine operation in heavy-duty hybrid vehicle operation as closely as possible, and provide for the first time methods for measuring the emission performance of hybrid engines. The HILS procedure for the first time introduces the concept of simulation into an emissions regulation. In summary, the procedures were developed so that they would be:

- (a) Representative of engine operation in a heavy-duty hybrid vehicle application**
- (b) Corresponding to state-of-the-art testing, sampling and measurement technology**
- (c) Applicable in practice to existing and foreseeable future hybrid technologies, and**
- (d) Capable of providing a reliable ranking of exhaust emission levels from different (hybrid) engine types**

At this stage, the gtr is being presented without limit values. In this way, the test procedure can be given a legal status, based on which the Contracting Parties are required to start the process of implementing it into their national law. The limit values shall be developed by the Contracting Parties according to their own rules of procedure.

When implementing the test procedure contained in this gtr as part of their national legislation or regulation, Contracting Parties are invited to use limit values which represent at least the same level of severity as their existing regulations, pending the development of harmonized limit values by the Executive Committee (AC.3) under the 1998 Agreement administered by the World Forum for Harmonization of Vehicle Regulations (WP.29). The performance levels

(emissions test results) to be achieved in the gtr will, therefore, be discussed on the basis of the most recently agreed legislation in the Contracting Parties, as required by the 1998 Agreement.

2. ANTICIPATED BENEFITS

Reserved.

3. POTENTIAL COST EFFECTIVENESS

Specific cost effectiveness values for this gtr have not been calculated. The decision by the Executive Committee (AC.3) to the 1998 Agreement to move forward with this gtr without limit values is the key reason why this analysis has not been completed. This common agreement has been made knowing that specific cost effectiveness values are not immediately available. However, it is fully expected that this information will be developed, generally, in response to the adoption of this regulation in national requirements and also in support of developing harmonized limit values for the next step in this gtr's development. For example, each Contracting Party adopting this gtr into its national law will be expected to determine the appropriate level of stringency associated with using these new test procedures, with these new values being at least as stringent as comparable existing requirements. Also, experience will be gained by the heavy-duty engine industry as to any costs and cost savings associated with using this test procedure. The cost and emissions performance data can then be analyzed as part of the next step in this gtr development to determine the cost effectiveness values of the test procedures being adopted today along with the application of harmonized limit values in the future. While there are no values on calculated costs per ton, the belief of the GRPE experts is that there are clear benefits associated with this regulation.

B. TEXT OF REGULATION

1. PURPOSE

This regulation aims at providing a world-wide harmonized method for the determination of the levels of pollutant emissions from engines used in heavy vehicles **and heavy hybrid vehicles** in a manner which is representative of real world vehicle operation. The results can be the basis for the regulation of pollutant emissions within regional type-approval and certification procedures.

2. SCOPE

This regulation applies to the measurement of the emission of gaseous and particulate pollutants from compression-ignition engines and positive-ignition engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG), used for propelling motor vehicles, **including hybrid vehicles**, of categories 1-2 and 2, having a design speed exceeding 25 km/h and having a maximum mass exceeding 3.5 tonnes.

3. DEFINITIONS, SYMBOLS AND ABBREVIATIONS

3.1. Definitions (to be aligned with gtr No 11)

For the purpose of this regulation,

3.1.1. "continuous regeneration" means the regeneration process of an exhaust after-treatment system that occurs either permanently or at least once per WHTC hot start test. Such a regeneration process will not require a special test procedure.

"controller-in-the-loop simulation" means a HILS where the hardware is the controller.

3.1.2. "delay time" means the difference in time between the change of the component to be measured at the reference point and a system response of 10 per cent of the final reading (t_{10}) with the sampling probe being defined as the reference point. For the gaseous components, this is the transport time of the measured component from the sampling probe to the detector.

3.1.3. "deNO_x system" means an exhaust after-treatment system designed to reduce emissions of oxides of nitrogen (NO_x) (e.g. passive and active lean NO_x catalysts, NO_x adsorbers and selective catalytic reduction (SCR) systems).

3.1.4. "diesel engine" means an engine which works on the compression-ignition principle.

3.1.5. "drift" means the difference between the zero or span responses of the measurement instrument after and before an emissions test.

“drivetrain” means the connected elements of the powertrain downstream of the final energy converter.

“electric motor” means an energy converter transferring electric energy into mechanical energy.

“electric ReESS” means an ReESS storing electrical energy

“energy converter” means the part of the powertrain converting one form of energy into a different one.

3.1.6. "engine family" means a manufacturer's grouping of engines which, through their design as defined in paragraph 5.2. of this gr, have similar exhaust emission characteristics; all members of the family shall comply with the applicable emission limit values.

“energy storage system” means the part of the powertrain that can store chemical, electrical or mechanical energy, and which can be refilled or recharged externally and/or internally.

3.1.7. "engine system" means the engine, the emission control system and the communication interface (hardware and messages) between the engine system electronic control unit(s) (ECU) and any other powertrain or vehicle control unit.

3.1.8. "engine type" means a category of engines which do not differ in essential engine characteristics.

3.1.9. "exhaust after-treatment system" means a catalyst (oxidation or 3-way), particulate filter, deNOx system, combined deNOx particulate filter or any other emission-reducing device that is installed downstream of the engine. This definition excludes exhaust gas recirculation (EGR), which is considered an integral part of the engine.

3.1.10. "full flow dilution method" means the process of mixing the total exhaust flow with diluent prior to separating a fraction of the diluted exhaust stream for analysis.

3.1.11. "gaseous pollutants" means carbon monoxide, hydrocarbons and/or non-methane hydrocarbons (assuming a ratio of $\text{CH}_{1.85}$ for diesel, $\text{CH}_{2.525}$ for LPG and $\text{CH}_{2.93}$ for NG, and an assumed molecule $\text{CH}_3\text{O}_{0.5}$ for ethanol fuelled diesel engines), methane (assuming a ratio of CH_4 for NG) and oxides of nitrogen (expressed in nitrogen dioxide (NO_2) equivalent).

“generator” means an energy converter transferring mechanical energy into electric energy.

“hardware-in-the-loop simulation (HILS)” means real time hybrid vehicle simulation running on a computer where a hardware component interacts with the simulation through an interface.

3.1.12. "high speed (n_{hi})" means the highest engine speed where 70 per cent of the declared maximum power occurs.

“hybrid vehicle” means a vehicle with a powertrain containing at least two different types of energy converters and two different types of energy storage systems.

“hybrid electric vehicle” means a hybrid vehicle with a powertrain containing electric machine(s) as energy converter(s).

“Internal Combustion Engine (ICE)” means an energy converter with intermittent or continuous oxidation of combustible fuel.

3.1.13. "low speed (n_{lo})" means the lowest engine speed where 55 per cent of the declared maximum power occurs.

3.1.14. "maximum power (P_{max})" means the maximum power in kW as specified by the manufacturer.

3.1.15. "maximum torque speed" means the engine speed at which the maximum torque is obtained from the engine, as specified by the manufacturer.

“mechanical ReESS” means an ReESS storing mechanical energy.

3.1.16. "normalized torque" means engine torque in per cent normalized to the maximum available torque at an engine speed.

3.1.17. "operator demand" means an engine operator's input to control engine output. The operator may be a person (i.e., manual), or a governor (i.e., automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal.

3.1.18. "parent engine" means an engine selected from an engine family in such a way that its emissions characteristics are representative for that engine family.

3.1.19. "particulate after-treatment device" means an exhaust after-treatment system designed to reduce emissions of particulate pollutants (PM) through a mechanical, aerodynamic, diffusional or inertial separation.

3.1.20. "partial flow dilution method" means the process of separating a part from the total exhaust flow, then mixing it with an appropriate amount of diluent prior to the particulate sampling filter.

3.1.21. "particulate matter (PM)" means any material collected on a specified filter medium after diluting exhaust with a clean filtered diluent to a temperature between 315 K (42 °C) and 325 K (52 °C); this is primarily carbon, condensed hydrocarbons, and sulphates with associated water.

- 3.1.22. "periodic regeneration" means the regeneration process of an exhaust after-treatment system that occurs periodically in typically less than 100 hours of normal engine operation. During cycles where regeneration occurs, emission standards may be exceeded.

“powertrain” means the combination of energy storage system(s), energy converter(s) and drivetrain(s) [for the purpose of vehicle propulsion], and the communication interface (hardware and messages) among the powertrain or vehicle control units.

“powertrain-in-the-loop simulation” means a HILS where the hardware is the powertrain.

- 3.1.23. "ramped steady state test cycle" means a test cycle with a sequence of steady state engine test modes with defined speed and torque criteria at each mode and defined ramps between these modes (WHSC).

- 3.1.24. "rated speed" means the maximum full load speed allowed by the governor as specified by the manufacturer in his sales and service literature, or, if such a governor is not present, the speed at which the maximum power is obtained from the engine, as specified by the manufacturer in his sales and service literature.

“rechargeable energy storage system (ReESS)” means a system storing energy carriers other than fuels.

“ReESS subsystem” means any functional assembly of ReESS components.

- 3.1.25. "response time" means the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t_{90}) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 per cent full scale (FS) and takes place in less than 0.1 second. The system response time consists of the delay time to the system and of the rise time of the system.

- 3.1.26. "rise time" means the difference in time between the 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$).

- 3.1.27. "span response" means the mean response to a span gas during a 30 s time interval.

- 3.1.28. "specific emissions" means the mass emissions expressed in g/kWh.

“State of Charge (SOC)” means the available electrical charge in a tested-device expressed as a percentage of its rated capacity.

“stop/start system” means automatic stop and start of the internal combustion engine to reduce the amount of idling.

- 3.1.29. "test cycle" means a sequence of test points each with a defined speed and torque to be followed by the engine under steady state (WHSC) or transient operating conditions (WHTC).
- 3.1.30. "transformation time" means the difference in time between the change of the component to be measured at the reference point and a system response of 50 per cent of the final reading (t_{50}) with the sampling probe being defined as the reference point. The transformation time is used for the signal alignment of different measurement instruments.
- 3.1.31. "transient test cycle" means a test cycle with a sequence of normalized speed and torque values that vary relatively quickly with time (WHTC).
- 3.1.32. "useful life" means the relevant period of distance and/or time over which compliance with the relevant gaseous and particulate emission limits has to be assured.
- 3.1.33. "zero response" means the mean response to a zero gas during a 30 s time interval.

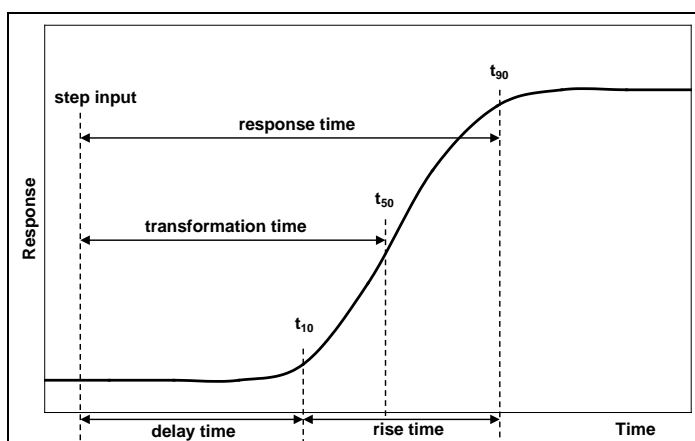


Figure 1:
Definitions of system response

3.2. General symbols

Symbol	Unit	Term
a_1	-	Slope of the regression
a_0	-	y intercept of the regression
A/F_{st}	-	Stoichiometric air to fuel ratio
c_{gas}	ppm/Vol per cent	Concentration of the gaseous components
c_d	ppm/Vol per cent	Concentration on dry basis
c_w	ppm/Vol per cent	Concentration on wet basis
c_b	ppm/Vol per cent	Background concentration
C_d	-	Discharge coefficient of SSV
d	m	Diameter

Symbol	Unit	Term
d_V	m	Throat diameter of venturi
D_0	m^3/s	PDP calibration intercept
D	-	Dilution factor
Δt	s	Time interval
e_{gas}	g/kWh	Specific emission of gaseous components
e_{PM}	g/kWh	Specific emission of particulates
e_r	g/kWh	Specific emission during regeneration
e_w	g/kWh	Weighted specific emission
E_{CO_2}	per cent	CO ₂ quench of NO _x analyzer
E_E	per cent	Ethane efficiency
E_{H_2O}	per cent	Water quench of NO _x analyzer
E_M	per cent	Methane efficiency
E_{NO_x}	per cent	Efficiency of NO _x converter
f	Hz	Data sampling rate
f_a	-	Laboratory atmospheric factor
F_s	-	Stoichiometric factor
H_a	g/kg	Absolute humidity of the intake air
H_d	g/kg	Absolute humidity of the diluent
i	-	Subscript denoting an instantaneous measurement (e.g. 1 Hz)
k_c	-	Carbon specific factor
$k_{f,d}$	m^3/kg fuel	Combustion additional volume of dry exhaust
$k_{f,w}$	m^3/kg fuel	Combustion additional volume of wet exhaust
$k_{h,D}$	-	Humidity correction factor for NO _x for CI engines
$k_{h,G}$	-	Humidity correction factor for NO _x for PI engines
$k_{r,u}$	-	Upward regeneration adjustment factor
$k_{r,d}$	-	Downward regeneration adjustment factor
$k_{w,a}$	-	Dry to wet correction factor for the intake air
$k_{w,d}$	-	Dry to wet correction factor for the diluent
$k_{w,e}$	-	Dry to wet correction factor for the diluted exhaust gas
$k_{w,r}$	-	Dry to wet correction factor for the raw exhaust gas
K_V	-	CFV calibration function
λ	-	Excess air ratio
m_b	mg	Particulate sample mass of the diluent collected
m_d	kg	Mass of the diluent sample passed through the particulate sampling filters
m_{ed}	kg	Total diluted exhaust mass over the cycle
m_{edf}	kg	Mass of equivalent diluted exhaust gas over the test cycle
m_{ew}	kg	Total exhaust mass over the cycle
m_f	mg	Particulate sampling filter mass
m_{gas}	g	Mass of gaseous emissions over the test cycle
m_p	mg	Particulate sample mass collected
m_{PM}	g	Mass of particulate emissions over the test cycle
m_{se}	kg	Exhaust sample mass over the test cycle

Symbol	Unit	Term
m_{sed}	kg	Mass of diluted exhaust gas passing the dilution tunnel
m_{sep}	kg	Mass of diluted exhaust gas passing the particulate collection filters
m_{ssd}	kg	Mass of secondary diluent
M_a	g/mol	Molar mass of the intake air
M_d	g/mol	Molar mass of the diluent
M_e	g/mol	Molar mass of the exhaust
M_{gas}	g/mol	Molar mass of gaseous components
M	Nm	Torque
M_f	Nm	Torque absorbed by auxiliaries/equipment to be fitted
M_r	Nm	Torque absorbed by auxiliaries/equipment to be removed
n	-	Number of measurements
n_r	-	Number of measurements with regeneration
n	min ⁻¹	Engine rotational speed
n_{hi}	min ⁻¹	High engine speed
n_{lo}	min ⁻¹	Low engine speed
n_{pref}	min ⁻¹	Preferred engine speed
n_p	r/s	PDP pump speed
p_a	kPa	Saturation vapour pressure of engine intake air
p_b	kPa	Total atmospheric pressure
p_d	kPa	Saturation vapour pressure of the diluent
p_p	kPa	Absolute pressure
p_r	kPa	Water vapour pressure after cooling bath
p_s	kPa	Dry atmospheric pressure
P	kW	Power
P_f	kW	Power absorbed by auxiliaries/equipment to be fitted
P_r	kW	Power absorbed by auxiliaries/equipment to be removed
q_{mad}	kg/s	Intake air mass flow rate on dry basis
q_{maw}	kg/s	Intake air mass flow rate on wet basis
q_{mCe}	kg/s	Carbon mass flow rate in the raw exhaust gas
q_{mCf}	kg/s	Carbon mass flow rate into the engine
q_{mCp}	kg/s	Carbon mass flow rate in the partial flow dilution system
q_{mdew}	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mdw}	kg/s	Diluent mass flow rate on wet basis
q_{medf}	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
q_{mew}	kg/s	Exhaust gas mass flow rate on wet basis
q_{mex}	kg/s	Sample mass flow rate extracted from dilution tunnel
q_{mf}	kg/s	Fuel mass flow rate
q_{mp}	kg/s	Sample flow of exhaust gas into partial flow dilution system
q_{vCVS}	m ³ /s	CVS volume rate
q_{vs}	dm ³ /min	System flow rate of exhaust analyzer system
q_{vt}	cm ³ /min	Tracer gas flow rate
r_d	-	Dilution ratio

Symbol	Unit	Term
r_D	-	Diameter ratio of SSV
r_h	-	Hydrocarbon response factor of the FID
r_m	-	Methanol response factor of the FID
r_p	-	Pressure ratio of SSV
r_s	-	Average sample ratio
r^2	-	Coefficient of determination
ρ	kg/m ³	Density
ρ_e	kg/m ³	Exhaust gas density
s	-	Standard deviation
T	K	Absolute temperature
T_a	K	Absolute temperature of the intake air
t	s	Time
t_{10}	s	Time between step input and 10 per cent of final reading
t_{50}	s	Time between step input and 50 per cent of final reading
t_{90}	s	Time between step input and 90 per cent of final reading
u	-	Ratio between densities of gas component and exhaust gas
V_0	m ³ /r	PDP gas volume pumped per revolution
V_s	dm ³	System volume of exhaust analyzer bench
W_{act}	kWh	Actual cycle work of the test cycle
W_{ref}	kWh	Reference cycle work of the test cycle
X_0	m ³ /r	PDP calibration function

3.3. Symbols and abbreviations for the fuel composition

w_{ALF}	hydrogen content of fuel, per cent mass
w_{BET}	carbon content of fuel, per cent mass
w_{GAM}	sulphur content of fuel, per cent mass
w_{DEL}	nitrogen content of fuel, per cent mass
w_{EPS}	oxygen content of fuel, per cent mass
α	molar hydrogen ratio (H/C)
γ	molar sulphur ratio (S/C)
δ	molar nitrogen ratio (N/C)
ε	molar oxygen ratio (O/C)
referring to a fuel $CH_\alpha O_\varepsilon N_\delta S_\gamma$	

3.4. Symbols and abbreviations for the chemical components

C1	Carbon 1 equivalent hydrocarbon
CH ₄	Methane
C ₂ H ₆	Ethane
C ₃ H ₈	Propane
CO	Carbon monoxide
CO ₂	Carbon dioxide
DOP	Di-octylphtalate

HC	Hydrocarbons
H ₂ O	Water
NMHC	Non-methane hydrocarbons
NO _x	Oxides of nitrogen
NO	Nitric oxide
NO ₂	Nitrogen dioxide
PM	Particulate matter

3.5. Abbreviations

CFV	Critical Flow Venturi
CLD	Chemiluminescent Detector
CVS	Constant Volume Sampling
deNO _x	NO _x after-treatment system
EGR	Exhaust gas recirculation
FID	Flame Ionization Detector
GC	Gas Chromatograph
HCLD	Heated Chemiluminescent Detector
HFID	Heated Flame Ionization Detector
LPG	Liquefied Petroleum Gas
NDIR	Non-Dispersive Infrared (Analyzer)
NG	Natural Gas
NMC	Non-Methane Cutter
PDP	Positive Displacement Pump
Per cent FS	Per cent of full scale
PFS	Partial Flow System
SSV	Subsonic Venturi
VGT	Variable Geometry Turbine
HEC	Hybrid engine cycle
HPC	Hybrid powertrain cycle
WHSC	World harmonized steady state cycle
WHTC	World harmonized transient cycle
WHVC	World harmonized vehicle cycle

4. GENERAL REQUIREMENTS

The engine system shall be so designed, constructed and assembled as to enable the engine in normal use to comply with the provisions of this gtr during its useful life, as defined by the Contracting Party, including when installed in the vehicle.

5. PERFORMANCE REQUIREMENTS

When implementing the test procedure contained in this gtr as part of their national legislation, Contracting Parties to the 1998 Agreement are encouraged to use limit values which represent at least the same level of severity as their existing regulations;

pending the development of harmonized limit values, by the Executive Committee (AC.3) of the 1998 Agreement, for inclusion in the gtr at a later date.

5.1. Emission of gaseous and particulate pollutants

The emissions of gaseous and particulate pollutants by the engine shall be determined on the WHTC and WHSC test cycles, as described in paragraph 7.

For hybrid vehicles, the emissions of gaseous and particulate pollutants shall be determined on the cycles derived in accordance with Annex 8 for the HEC or Annex 9 for the HPC.

The measurement systems shall meet the linearity requirements in paragraph 9.2. and the specifications in paragraph 9.3. (gaseous emissions measurement), paragraph 9.4. (particulate measurement) and in Annex 3.

Other systems or analyzers may be approved by the type approval or certification authority, if it is found that they yield equivalent results in accordance with paragraph 5.1.1.

5.1.1. Equivalency

The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the system under consideration and one of the systems of this gtr.

"Results" refer to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, test cell, and on the same engine, and is preferred to be run concurrently. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics as described in Annex 4, paragraph A.4.3., obtained under the laboratory test cell and the engine conditions described above. Outliers shall be determined in accordance with ISO 5725 and excluded from the database. The systems to be used for correlation testing shall be subject to the approval by the type approval or certification authority.

5.2. Engine family

5.2.1. General

An engine family is characterized by design parameters. These shall be common to all engines within the family. The engine manufacturer may decide which engines belong to an engine family, as long as the membership criteria listed in paragraph 5.2.3. are respected. The engine family shall be approved by the type approval or certification authority. The manufacturer shall provide to the type approval or certification authority the appropriate information relating to the emission levels of the members of the engine family.

5.2.2. Special cases

In some cases there may be interaction between parameters. This shall be taken into consideration to ensure that only engines with similar exhaust emission characteristics are included within the same engine family. These cases shall be identified by the manufacturer and notified to the type approval or certification authority. It shall then be taken into account as a criterion for creating a new engine family.

In case of devices or features, which are not listed in paragraph 5.2.3. and which have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer on the basis of good engineering practice, and shall be notified to the type approval or certification authority. It shall then be taken into account as a criterion for creating a new engine family.

In addition to the parameters listed in paragraph 5.2.3., the manufacturer may introduce additional criteria allowing the definition of families of more restricted size. These parameters are not necessarily parameters that have an influence on the level of emissions.

5.2.3. Parameters defining the engine family

5.2.3.1. Combustion cycle

- (a) 2-stroke cycle
- (b) 4-stroke cycle
- (c) Rotary engine
- (d) Others

5.2.3.2. Configuration of the cylinders

5.2.3.2.1. Position of the cylinders in the block

- (a) V
- (b) In line
- (c) Radial
- (d) Others (F, W, etc.)

5.2.3.2.2. Relative position of the cylinders

Engines with the same block may belong to the same family as long as their bore center-to-center dimensions are the same.

5.2.3.3. Main cooling medium

- (a) air
- (b) water

(c) oil

5.2.3.4. Individual cylinder displacement

5.2.3.4.1. Engine with a unit cylinder displacement $\geq 0.75 \text{ dm}^3$

In order for engines with a unit cylinder displacement of $\geq 0.75 \text{ dm}^3$ to be considered to belong to the same engine family, the spread of their individual cylinder displacements shall not exceed 15 per cent of the largest individual cylinder displacement within the family.

5.2.3.4.2. Engine with a unit cylinder displacement $< 0.75 \text{ dm}^3$

In order for engines with a unit cylinder displacement of $< 0.75 \text{ dm}^3$ to be considered to belong to the same engine family, the spread of their individual cylinder displacements shall not exceed 30 per cent of the largest individual cylinder displacement within the family.

5.2.3.4.3. Engine with other unit cylinder displacement limits

Engines with an individual cylinder displacement that exceeds the limits defined in paragraphs 5.2.3.4.1. and 5.2.3.4.2. may be considered to belong to the same family with the approval of the type approval or certification authority. The approval shall be based on technical elements (calculations, simulations, experimental results etc.) showing that exceeding the limits does not have a significant influence on the exhaust emissions.

5.2.3.5. Method of air aspiration

- (a) naturally aspirated
- (b) pressure charged
- (c) pressure charged with charge cooler

5.2.3.6. Fuel type

- (a) Diesel
- (b) Natural gas (NG)
- (c) Liquefied petroleum gas (LPG)
- (d) Ethanol

5.2.3.7. Combustion chamber type

- (a) Open chamber
- (b) Divided chamber
- (c) Other types

5.2.3.8. Ignition Type

- (a) Positive ignition
- (b) Compression ignition

- 5.2.3.9. Valves and porting
 - (a) Configuration
 - (b) Number of valves per cylinder

- 5.2.3.10. Fuel supply type
 - (a) Liquid fuel supply type
 - (i) Pump and (high pressure) line and injector
 - (ii) In-line or distributor pump
 - (iii) Unit pump or unit injector
 - (iv) Common rail
 - (v) Carburettor(s)
 - (vi) Others
 - (b) Gas fuel supply type
 - (i) Gaseous
 - (ii) Liquid
 - (iii) Mixing units
 - (iv) Others
 - (c) Other types

- 5.2.3.11. Miscellaneous devices
 - (a) Exhaust gas recirculation (EGR)
 - (b) Water injection
 - (c) Air injection
 - (d) Others

- 5.2.3.12. Electronic control strategy

The presence or absence of an electronic control unit (ECU) on the engine is regarded as a basic parameter of the family.

In the case of electronically controlled engines, the manufacturer shall present the technical elements explaining the grouping of these engines in the same family, i.e. the reasons why these engines can be expected to satisfy the same emission requirements.

These elements can be calculations, simulations, estimations, description of injection parameters, experimental results, etc.

Examples of controlled features are:

- (a) Timing
- (b) Injection pressure
- (c) Multiple injections
- (d) Boost pressure
- (e) VGT
- (f) EGR

5.2.3.13. Exhaust after-treatment systems

The function and combination of the following devices are regarded as membership criteria for an engine family:

- (a) Oxidation catalyst
- (b) Three-way catalyst
- (c) DeNO_x system with selective reduction of NO_x (addition of reducing agent)
- (d) Other DeNO_x systems
- (e) Particulate trap with passive regeneration
- (f) Particulate trap with active regeneration
- (g) Other particulate traps
- (h) Other devices

When an engine has been certified without after-treatment system, whether as parent engine or as member of the family, then this engine, when equipped with an oxidation catalyst, may be included in the same engine family, if it does not require different fuel characteristics.

If it requires specific fuel characteristics (e.g. particulate traps requiring special additives in the fuel to ensure the regeneration process), the decision to include it in the same family shall be based on technical elements provided by the manufacturer. These elements shall indicate that the expected emission level of the equipped engine complies with the same limit value as the non-equipped engine.

When an engine has been certified with after-treatment system, whether as parent engine or as member of a family, whose parent engine is equipped with the same after-treatment system, then this engine, when equipped without after-treatment system, shall not be added to the same engine family.

5.2.4. Choice of the parent engine

5.2.4.1. Compression ignition engines

Once the engine family has been agreed by the type approval or certification authority, the parent engine of the family shall be selected using the primary criterion of the highest fuel delivery per stroke at the declared maximum torque speed. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criterion of highest fuel delivery per stroke at rated speed.

5.2.4.2. Positive ignition engines

Once the engine family has been agreed by the type approval or certification authority, the parent engine of the family shall be selected using the primary criterion of the largest displacement. In the event that two or more engines share this primary criterion, the parent engine shall be selected using the secondary criterion in the following order of priority:

- (a) the highest fuel delivery per stroke at the speed of declared rated power;
- (b) the most advanced spark timing;
- (c) the lowest EGR rate.

5.2.4.3. Remarks on the choice of the parent engine

The type approval or certification authority may conclude that the worst-case emission of the family can best be characterized by testing additional engines. In this case, the engine manufacturer shall submit the appropriate information to determine the engines within the family likely to have the highest emissions level.

If engines within the family incorporate other features which may be considered to affect exhaust emissions, these features shall also be identified and taken into account in the selection of the parent engine.

If engines within the family meet the same emission values over different useful life periods, this shall be taken into account in the selection of the parent engine.

5.3. Hybrid powertrain family

5.3.1. The general hybrid powertrain family is characterised by design parameters. These shall be common to all hybrid powertrains within the family. The manufacturer may decide, which hybrid powertrain belongs to the family, as long as the membership criteria listed in 5.3.3. are respected. The hybrid powertrain family shall be approved by the type approval or certification authority, all appropriate information relating to the emission levels of the members of the hybrid powertrain family.^

5.3.2. Special cases

In some cases there may be interaction between parameters. This shall be taken into consideration to ensure that only hybrid powertrains with similar exhaust emission characteristics are included within the same hybrid powertrain family. These cases shall be identified by the manufacturer and notified to the type approval or certification authority. It shall then be taken into account as a criterion for creating a new hybrid powertrain family.

In case of devices or features, which are not listed in paragraph 5.3.3. and which have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer on the basis of good engineering practice, and shall be notified to the type approval or certification authority. It shall then be taken into account as a criterion for creating a new hybrid powertrain family.

In addition to the parameters listed in paragraph 5.3.3., the manufacturer may introduce additional criteria allowing the definition of families of more restricted size. These parameters are not necessarily parameters that have an influence on the level of emissions.

5.3.3. Parameters defining the hybrid powertrain family

5.3.3.1. Internal combustion engine

- (a)
- (b)

5.3.3.2. Energy converter

- (a) Electric
- (b) Hydraulic
- (c) Other

5.3.3.3 ReESS

- (a) Electric
- (b) Hydraulic
- (c) Other

5.3.3.4. Transmission

- (a) Manual
- (b) Automatic
- (c) Dual clutch
- (d) Other

5.3.3.5. Hybrid control strategy

The manufacturer shall present the technical elements explaining the grouping of hybrid powertrains in the same family, i.e. the reasons why these powertrains can be expected to satisfy the same emission requirements.

These elements can be calculations, simulations, estimations, description of the hybrid ECU, experimental results, etc.

Examples of controlled features are:

- (a)
- (b)
- (c)
- (d)

5.3.3.6 Other

Reserved.

5.3.4. Choice of the parent hybrid powertrain

Reserved.

6. TEST CONDITIONS

6.1. Laboratory test conditions

The absolute temperature (T_a) of the engine intake air expressed in Kelvin, and the dry atmospheric pressure (p_s), expressed in kPa shall be measured and the parameter f_a shall be determined according to the following provisions. In multi-cylinder engines having distinct groups of intake manifolds, such as in a "Vee" engine configuration, the average temperature of the distinct groups shall be taken. The parameter f_a shall be reported with the test results. For better repeatability and reproducibility of the test results, it is recommended that the parameter f_a be such that: $0.93 \leq f_a \leq 1.07$. Contracting Parties can make the parameter f_a compulsory.

(a) Compression-ignition engines:

Naturally aspirated and mechanically supercharged engines:

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T_a}{298}\right)^{0.7} \quad (1)$$

Turbocharged engines with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} \times \left(\frac{T_a}{298}\right)^{1.5} \quad (2)$$

(b) Positive ignition engines:

$$f_a = \left(\frac{99}{p_s}\right)^{1.2} \times \left(\frac{T_a}{298}\right)^{0.6} \quad (3)$$

6.2. Engines with charge air-cooling

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

If a test laboratory system or external blower is used, the coolant flow rate shall be set to achieve a charge air temperature within ± 5 K of the maximum charge air temperature specified by the manufacturer at the rated speed and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall

not be changed for the whole test cycle, unless this results in unrepresentative overcooling of the charge air. The charge air cooler volume shall be based upon good engineering practice and shall be representative of the production engine's in-use installation. The laboratory system shall be designed to minimize accumulation of condensate. Any accumulated condensate shall be drained and all drains shall be completely closed before emission testing.

If the engine manufacturer specifies pressure-drop limits across the charge-air cooling system, it shall be ensured that the pressure drop across the charge-air cooling system at engine conditions specified by the manufacturer is within the manufacturer's specified limit(s). The pressure drop shall be measured at the manufacturer's specified locations.

6.3. Engine power

The basis of specific emissions measurement is engine power and cycle work as determined in accordance with paragraphs 6.3.1. to 6.3.5.

6.3.1. General engine installation

The engine shall be tested with the auxiliaries/equipment listed in Annex 7.

If auxiliaries/equipment are not installed as required, their power shall be taken into account in accordance with paragraphs 6.3.2. to 6.3.5.

6.3.2. Auxiliaries/equipment to be fitted for the emissions test

If it is inappropriate to install the auxiliaries/equipment required according to Annex 7 on the test bench, the power absorbed by them shall be determined and subtracted from the measured engine power (reference and actual) over the whole engine speed range of the WHTC and over the test speeds of the WHSC.

6.3.3. Auxiliaries/equipment to be removed for the test

Where the auxiliaries/equipment not required according to Annex 7 cannot be removed, the power absorbed by them may be determined and added to the measured engine power (reference and actual) over the whole engine speed range of the WHTC and over the test speeds of the WHSC. If this value is greater than 3 per cent of the maximum power at the test speed it shall be demonstrated to the type approval or certification authority.

6.3.4. Determination of auxiliary power

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

- (a) auxiliaries/equipment required according to Annex 7, are not fitted to the engine; and/or

- (b) auxiliaries/equipment not required according to Annex 7, are fitted to the engine.

The values of auxiliary power and the measurement/calculation method for determining auxiliary power shall be submitted by the engine manufacturer for the whole operating area of the test cycles, and approved by the certification or type approval authority.

6.3.5. Engine cycle work

The calculation of reference and actual cycle work (see paragraphs 7.4.8. and 7.8.6.) shall be based upon engine power according to paragraph 6.3.1. In this case, P_f and P_r of equation 4 are zero, and P equals P_m .

If auxiliaries/equipment are installed according to paragraphs 6.3.2. and/or 6.3.3., the power absorbed by them shall be used to correct each instantaneous cycle power value $P_{m,i}$, as follows:

$$P_i = P_{m,i} - P_{f,i} + P_{r,i} \quad (4)$$

where:

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

$P_{f,i}$ is the power absorbed by auxiliaries/equipment to be fitted, kW

$P_{r,i}$ is the power absorbed by auxiliaries/equipment to be removed, kW

6.3.5.1. For a hybrid powertrain, the cycle work is defined in accordance with annex 8, paragraph A.8.5.11.

6.4. Engine air intake system

An engine air intake system or a test laboratory system shall be used presenting an air intake restriction within ± 300 Pa of the maximum value specified by the manufacturer for a clean air cleaner at the rated speed and full load. The static differential pressure of the restriction shall be measured at the location specified by the manufacturer.

6.5. Engine exhaust system

An engine exhaust system or a test laboratory system shall be used presenting an exhaust backpressure within 80 to 100 per cent of the maximum value specified by the manufacturer at the rated speed and full load. If the maximum restriction is 5 kPa or less, the set point shall be no less than 1.0 kPa from the maximum. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in paragraphs 9.3.10. and 9.3.11.

6.6. Engine with exhaust after-treatment system

If the engine is equipped with an exhaust after-treatment system, the exhaust pipe shall have the same diameter as found in-use, or as specified by the manufacturer, for at least four pipe diameters upstream of the expansion section containing the after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment system shall be the same as in the 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. For variable-restriction aftertreatment devices, the maximum exhaust restriction is defined at the aftertreatment condition (degreening/aging and regeneration/loading level) specified by the manufacturer. If the maximum restriction is 5 kPa or less, the set point shall be no less than 1.0 kPa from the maximum. The after-treatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

The emissions measured on the test cycle shall be representative of the emissions in the field. In the case of an engine equipped with a exhaust after-treatment system that requires the consumption of a reagent, the reagent used for all tests shall be declared by the manufacturer.

For engines equipped with exhaust after-treatment systems that are regenerated on a periodic basis, as described in paragraph 6.6.2., emission results shall be adjusted to account for regeneration events. In this case, the average emission depends on the frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs.

After-treatment systems with continuous regeneration according to paragraph 6.6.1. do not require a special test procedure.

6.6.1. Continuous regeneration

For an exhaust after-treatment system based on a continuous regeneration process the emissions shall be measured on an after-treatment system that has been stabilized so as to result in repeatable emissions behaviour.

The regeneration process shall occur at least once during the WHTC **hot start** test and the manufacturer shall declare the normal conditions under which regeneration occurs (soot load, temperature, exhaust back-pressure, etc.).

In order to demonstrate that the regeneration process is continuous, at least three WHTC hot start tests shall be conducted. For the purpose of this demonstration, the engine shall be warmed up in accordance with paragraph 7.4.1., the engine be soaked according to paragraph 7.6.3. and the first WHTC hot start test be run. The subsequent hot start tests shall be started after soaking according to paragraph 7.6.3. During the tests, exhaust temperatures and pressures shall be recorded (temperature before and after the after-treatment system, exhaust back pressure, etc.).

The after-treatment system is considered to be of the continuous regeneration type if the conditions declared by the manufacturer occur during the test during a sufficient time and the emission results do not scatter by more than ± 25 per cent or 0.005 g/kWh, whichever is greater.

If the exhaust after-treatment system has a security mode that shifts to a periodic regeneration mode, it shall be checked according to paragraph 6.6.2. For that specific case, the applicable emission limits may be exceeded and would not be weighted.

6.6.2. Periodic regeneration

For an exhaust after-treatment based on a periodic regeneration process, the emissions shall be measured on at least three WHTC hot start tests, one with and two without a regeneration event on a stabilized after-treatment system, and the results be weighted in accordance with equation 5.

The regeneration process shall occur at least once during the WHTC hot start test. The engine may be equipped with a switch capable of preventing or permitting the regeneration process provided this operation has no effect on the original engine calibration.

The manufacturer shall declare the normal parameter conditions under which the regeneration process occurs (soot load, temperature, exhaust back-pressure, etc.) and its duration. The manufacturer shall also provide the frequency of the regeneration event in terms of number of tests during which the regeneration occurs compared to number of tests without regeneration. The exact procedure to determine this frequency shall be based upon in use data using good engineering judgement, and shall be agreed by the type approval or certification authority.

The manufacturer shall provide an after-treatment system that has been loaded in order to achieve regeneration during a WHTC test. Regeneration shall not occur during this engine-conditioning phase.

For the purpose of this testing, the engine shall be warmed up in accordance with paragraph 7.4.1., the engine be soaked according to paragraph 7.6.3. and the WHTC hot start test be started.

Average brake specific emissions between regeneration phases shall be determined from the arithmetic mean of several approximately equidistant WHTC hot start test results (g/kWh). As a minimum, at least one WHTC hot start test as close as possible prior to a regeneration test and one WHTC hot start test immediately after a regeneration test shall be conducted. As an alternative, the manufacturer may provide data to show that the emissions remain constant (± 25 per cent or 0.005 g/kWh, whichever is greater) between regeneration phases. In this case, the emissions of only one WHTC hot start test may be used.

During the regeneration test, all the data needed to detect regeneration shall be recorded (CO or NO_x emissions, temperature before and after the after-treatment system, exhaust back pressure, etc.).

During the regeneration test, the applicable emission limits may be exceeded.

The test procedure is schematically shown in figure 2.

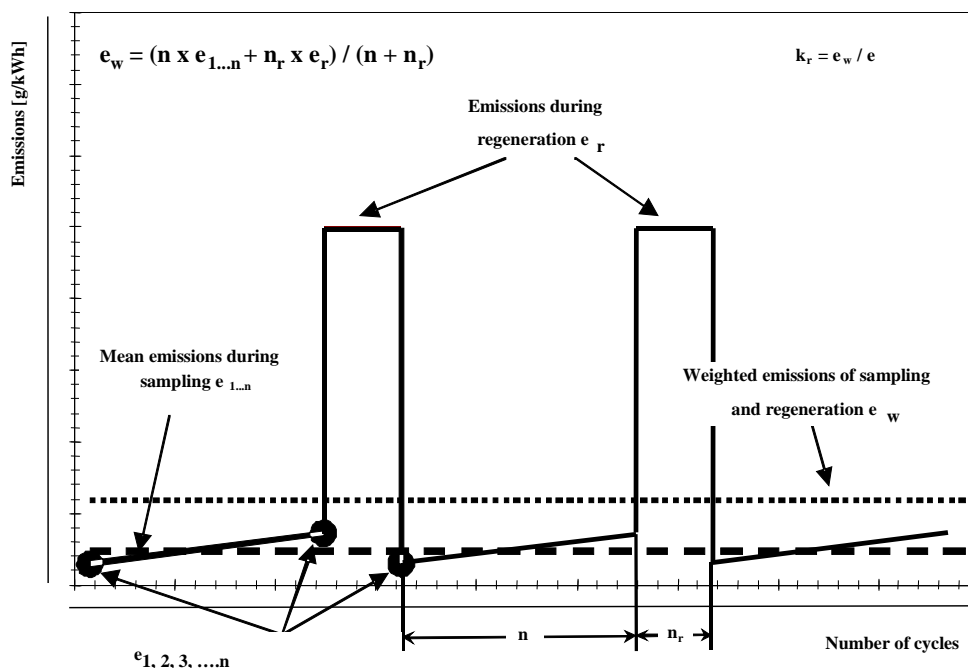


Figure 2:
Scheme of periodic regeneration

The WHTC hot start emissions shall be weighted as follows:

$$e_w = \frac{n \times \bar{e} + n_r \times \bar{e}_r}{n + n_r} \quad (5)$$

where:

- n is the number of WHTC hot start tests without regeneration,
- n_r is the number of WHTC hot start tests with regeneration (minimum one test),
- \bar{e} is the average specific emission without regeneration, g/kWh,
- \bar{e}_r is the average specific emission with regeneration, g/kWh.

For the determination of \bar{e}_r , the following provisions apply:

- (a) If regeneration takes more than one hot start WHTC, consecutive full hot start WHTC tests shall be conducted and emissions continued to be measured without soaking and without shutting the engine off, until regeneration is completed, and the average of the hot start WHTC tests be calculated.

- (b) If regeneration is completed during any hot start WHTC, the test shall be continued over its entire length.

In agreement with the type approval or certification authority, the regeneration adjustment factors may be applied either multiplicative (c) or additive (d) based upon good engineering analysis.

- (c) The multiplicative adjustment factors shall be calculated as follows:

$$k_{r,u} = \frac{e_w}{e} \text{ (upward)} \quad (6)$$

$$k_{r,d} = \frac{e_w}{e_r} \text{ (downward)} \quad (6a)$$

- (d) The additive adjustment factors shall be calculated as follows:

$$k_{r,u} = e_w - e \text{ (upward)} \quad (7)$$

$$k_{r,d} = e_w - e_r \text{ (downward)} \quad (8)$$

With reference to the specific emission calculations in paragraph 8.6.3., the regeneration adjustment factors shall be applied, as follows:

- (e) for a test without regeneration, $k_{r,u}$ shall be multiplied with or be added to, respectively, the specific emission e in equations 69 or 70,
 (f) for a test with regeneration, $k_{r,d}$ shall be multiplied with or be subtracted from, respectively, the specific emission e in equations 69 or 70.

At the request of the manufacturer, the regeneration adjustment factors

- (g) may be extended to other members of the same engine family,
 (h) may be extended to other engine families using the same aftertreatment system with the prior approval of the type approval or certification authority based on technical evidence to be supplied by the manufacturer, that the emissions are similar.

6.7. Cooling system

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

6.8. Lubricating oil

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

6.9. Specification of the reference fuel

The use of one standardized reference fuel has always been considered as an ideal condition for ensuring the reproducibility of regulatory emission testing, and Contracting Parties are encouraged to use such fuel in their compliance testing. However, until performance requirements (i.e. limit values) have been introduced into this gtr, Contracting Parties to the 1998 Agreement are allowed to define their own reference fuel for their national legislation, to address the actual situation of market fuel for vehicles in use.

The appropriate diesel reference fuels of the European Union, the United States of America and Japan listed in Annex 2 are recommended to be used for testing. Since fuel characteristics influence the engine exhaust gas emission, the characteristics of the fuel used for the test shall be determined, recorded and declared with the results of the test.

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

6.10. Crankcase emissions

No crankcase emissions shall be discharged directly into the ambient atmosphere, with the following exception: engines equipped with turbochargers, pumps, blowers, or superchargers for air induction may discharge crankcase emissions to the ambient atmosphere if the emissions are added to the exhaust emissions (either physically or mathematically) during all emission testing. Manufacturers taking advantage of this exception shall install the engines so that all crankcase emission can be routed into the emissions sampling system.

For the purpose of this paragraph, crankcase emissions that are routed into the exhaust upstream of exhaust aftertreatment during all operation are not considered to be discharged directly into the ambient atmosphere.

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

- (a) The tubing materials shall be smooth-walled, electrically conductive, and not reactive with crankcase emissions. Tube lengths shall be minimized as far as possible.
- (b) The number of bends in the laboratory crankcase tubing shall be minimized, and the radius of any unavoidable bend shall be maximized.
- (c) The laboratory crankcase exhaust tubing shall be heated, thin-walled or insulated and shall meet the engine manufacturer's specifications for crankcase back pressure.
- (b) The crankcase exhaust tubing shall connect into the raw exhaust downstream of any aftertreatment system, downstream of any installed exhaust restriction, and sufficiently upstream of any sample probes to ensure complete mixing with the engine's exhaust before sampling. The crankcase exhaust tube shall extend

into the free stream of exhaust to avoid boundary-layer effects and to promote mixing. The crankcase exhaust tube's outlet may orient in any direction relative to the raw exhaust flow.

7. TEST PROCEDURES

7.1. Principles of emissions measurement

To measure the brake-specific emissions, the engine shall be operated over the test cycles defined in paragraphs 7.2.1., 7.2.2. **and 7.2.3.** The measurement of brake-specific emissions requires the determination of the mass of components in the exhaust and the corresponding engine cycle work. The components are determined by the sampling methods described in paragraphs 7.1.1. and 7.1.2.

For hybrid vehicles, the derivation of the individual engine or powertrain test cycles is described in Annex 8 or Annex 9, respectively.

7.1.1. Continuous sampling

In continuous sampling, the component's concentration is measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or dilute) exhaust flow rate at the emission sampling location to determine the component's mass flow rate. The component's emission is continuously summed over the test cycle. This sum is the total mass of the emitted component.

7.1.2. Batch sampling

In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous components in a bag and collecting particulate matter (PM) on a filter. The batch sampled concentrations are multiplied by the total exhaust mass or mass flow (raw or dilute) from which it was extracted during the test cycle. This product is the total mass or mass flow of the emitted component. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.

7.1.3. Measurement procedures

This gtr applies two measurement procedures that are functionally equivalent. Both procedures may be used for the WHTC, WHSC, **HEC and HPC** test cycles:

- (a) the gaseous components are sampled continuously in the raw exhaust gas, and the particulates are determined using a partial flow dilution system,
- (b) the gaseous components and the particulates are determined using a full flow dilution system (CVS system).

Any combination of the two principles (e.g. raw gaseous measurement and full flow particulate measurement) is permitted.

7.2. Test cycles

7.2.1. Transient test cycle WHTC

The transient test cycle WHTC is listed in Annex 1a as a second-by-second sequence of normalized speed and torque values. In order to perform the test on an engine test cell, the normalized values shall be converted to the actual values for the individual engine under test based on the engine-mapping curve. The conversion is referred to as denormalization, and the test cycle so developed as the reference cycle of the engine to be tested. With those reference speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.

For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle. For cycle validation, the actual cycle work shall be within prescribed limits of the reference cycle work.

For the gaseous pollutants, continuous sampling (raw or dilute exhaust gas) or batch sampling (dilute exhaust gas) may be used. The particulate sample shall be diluted with a conditioned diluent (such as ambient air), and collected on a single suitable filter. The WHTC is shown schematically in figure 3.

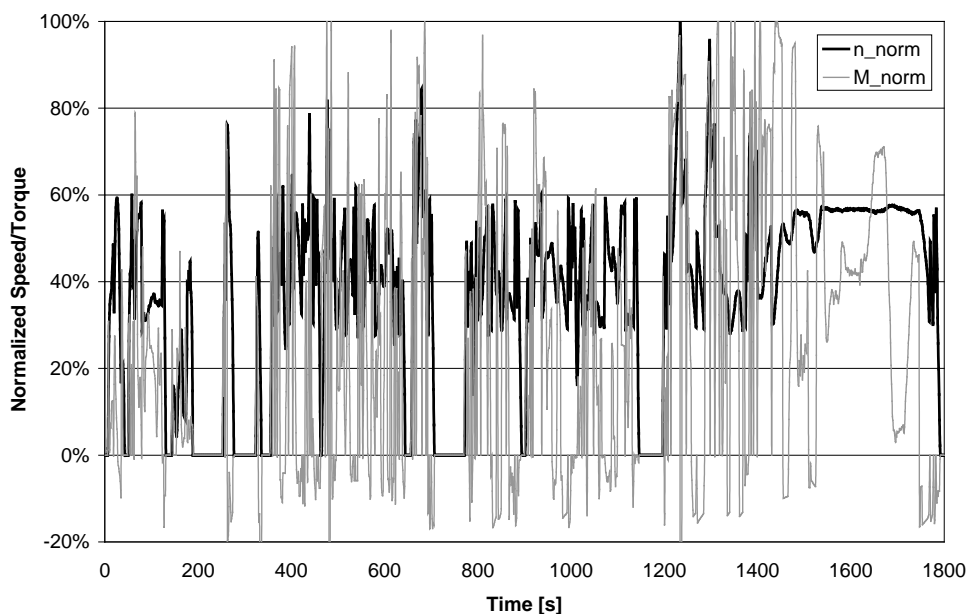


Figure 3:
WHTC test cycle

7.2.2. Ramped steady state test cycle WHSC

The ramped steady state test cycle WHSC consists of a number of normalized speed and load modes which shall be converted to the reference values for the individual engine under test based on the engine-mapping curve. The engine shall be operated for the prescribed time in each mode, whereby engine speed and load shall be changed linearly within 20 ± 1 seconds. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.

The concentration of each gaseous pollutant, exhaust flow and power output shall be determined over the test cycle. The gaseous pollutants may be recorded continuously or sampled into a sampling bag. The particulate sample shall be diluted with a conditioned diluent (such as ambient air). One sample over the complete test procedure shall be taken, and collected on a single suitable filter.

For calculation of the brake specific emissions, the actual cycle work shall be calculated by integrating actual engine power over the cycle.

The WHSC is shown in table 1. Except for mode 1, the start of each mode is defined as the beginning of the ramp from the previous mode.

Mode	Normalized Speed (per cent)	Normalized Torque (per cent)	Mode length (s) incl. 20 s ramp
1	0	0	210
2	55	100	50
3	55	25	250
4	55	70	75
5	35	100	50
6	25	25	200
7	45	70	75
8	45	25	150
9	55	50	125
10	75	100	50
11	35	50	200
12	35	25	250
13	0	0	210
Sum			1895

Table 1:
WHSC test cycle

7.2.3. Transient test cycle WHVC (hybrid powertrains only)

The transient test cycle WHVC is listed in Appendix 1b as a second-by-second sequence of vehicle speed and road gradients. In order to perform the test on an engine or powertrain test cell, the cycle values need to be converted to the reference values for rotational speed and torque for the individual engine under test in accordance with either method in sections 7.2.3.1. or 7.2.3.2.

It should be noted that the test cycles referred to as HEC and HPC in this gtr are not standardized cycles like the WHTC and WHSC, but test cycles developed individually for each hybrid powertrain from the WHVC.

7.2.3.1. HILS method

The conversion is carried out according to annex 8, and the test cycle so developed is the reference cycle of the engine to be tested (HEC). With those reference speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.

7.2.3.2. Powertrain method

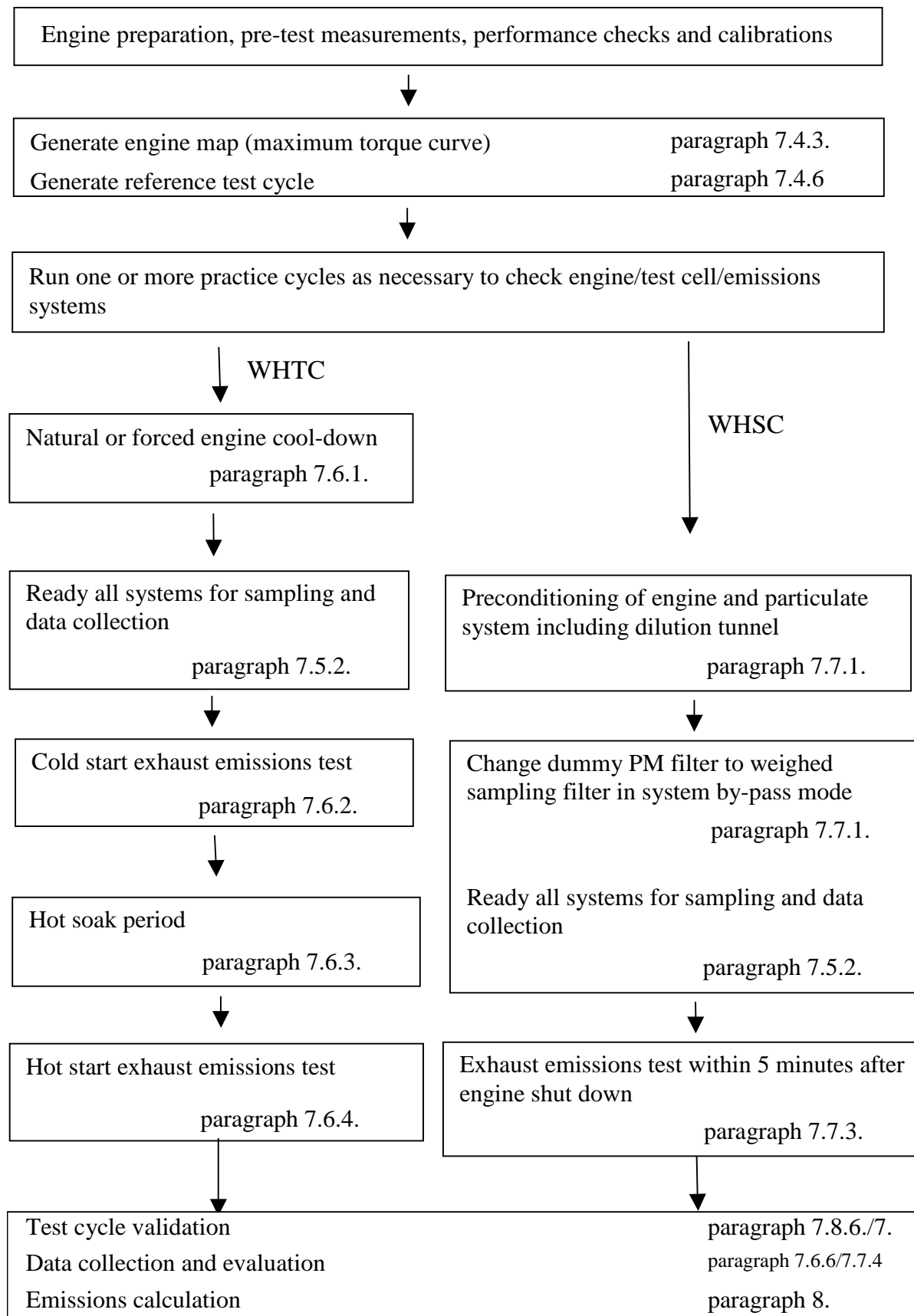
The conversion is carried out according to annex 9, and the test cycle so developed is the reference cycle of the engine to be tested (HPC). With those reference speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.

7.3. General test sequence

The following flow chart outlines the general guidance that should be followed during testing. The details of each step are described in the relevant paragraphs. Deviations from the guidance are permitted where appropriate, but the specific requirements of the relevant paragraphs are mandatory.

For the WHTC, the test procedure consists of a cold start test following either natural or forced cool-down of the engine, a hot soak period and a hot start test. Selection of the hot soak period and the weighting factor between cold start test and hot start test shall be decided by the Contracting Parties.

For the WHSC, the test procedure consists of a hot start test following engine preconditioning at WHSC mode 9.



7.4. Engine mapping and reference cycle

Pre-test engine measurements, pre-test engine performance checks and pre-test system calibrations shall be made prior to the engine mapping procedure in line with the general test sequence shown in paragraph 7.3.

As basis for WHTC and WHSC reference cycle generation, the engine shall be mapped under full load operation for determining the speed vs. maximum torque and speed vs. maximum power curves. The mapping curve shall be used for denormalizing engine speed (paragraph 7.4.6.) and engine torque (paragraph 7.4.7.).

For hybrid vehicle powertrains, the mapping procedure in paragraph A.9.4.1 shall be used. Paragraphs 7.4.1. to 7.4.8. do not apply.

7.4.1. Engine warm-up

The engine shall be warmed up between 75 per cent and 100 per cent of its maximum power or according to the recommendation of the manufacturer and good engineering judgment. Towards the end of the warm up it shall be operated in order to stabilize the engine coolant and lube oil temperatures to within ± 2 per cent of its mean values for at least 2 minutes or until the engine thermostat controls engine temperature.

7.4.2. Determination of the mapping speed range

The minimum and maximum mapping speeds are defined as follows:

Minimum mapping speed = idle speed
Maximum mapping speed = $n_{hi} \times 1.02$ or speed where full load torque drops off to zero, whichever is smaller.

7.4.3. Engine mapping curve

When the engine is stabilized according to paragraph 7.4.1., the engine mapping shall be performed according to the following procedure.

- (a) The engine shall be unloaded and operated at idle speed.
- (b) The engine shall be operated with maximum operator demand at minimum mapping speed.
- (c) The engine speed shall be increased at an average rate of $8 \pm 1 \text{ min}^{-1}/\text{s}$ from minimum to maximum mapping speed, or at a constant rate such that it takes 4 to 6 min to sweep from minimum to maximum mapping speed. Engine speed and torque points shall be recorded at a sample rate of at least one point per second.

When selecting option (b) in paragraph 7.4.7. for determining negative reference torque, the mapping curve may directly continue with minimum operator demand from maximum to minimum mapping speed.

7.4.4. 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 shall satisfy the intent of the specified mapping procedures to determine the maximum available torque at all engine speeds achieved during the test cycles. Deviations from the mapping techniques specified in this paragraph for reasons of safety or representativeness shall be approved by the type approval or certification authority along with the justification for their use. In no case, however, the torque curve shall be run by descending engine speeds for governed or turbocharged engines.

7.4.5. 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:

- (a) an unreasonable amount of time has transpired since the last map, as determined by engineering judgement, or
- (b) physical changes or recalibrations have been made to the engine which potentially affect engine performance.

7.4.6. Denormalization of engine speed

For generating the reference cycles, the normalized speeds of Annex 1 (WHTC) and table 1 (WHSC) shall be denormalized using the following equation:

$$n_{ref} = n_{norm} \times (0.45 \times n_{lo} + 0.45 \times n_{pref} + 0.1 \times n_{hi} - n_{idle}) \times 2.0327 + n_{idle} \quad (9)$$

For determination of n_{pref} , the integral of the maximum torque shall be calculated from n_{idle} to n_{95h} from the engine mapping curve, as determined in accordance with paragraph 7.4.3.

The engine speeds in figures 4 and 5 are defined, as follows:

- n_{lo} is the lowest speed where the power is 55 per cent of maximum power
- n_{pref} is the engine speed where the integral of maximum mapped torque is 51 per cent of the whole integral between n_{idle} and n_{95h}
- n_{hi} is the highest speed where the power is 70 per cent of maximum power
- n_{idle} is the idle speed
- n_{95h} is the highest speed where the power is 95 per cent of maximum power

For engines (mainly positive ignition engines) with a steep governor droop curve, where fuel cut off does not permit to operate the engine up to n_{hi} or n_{95h} , the following provisions apply:

- n_{hi} in equation 9 is replaced with $n_{P_{max}} \times 1.02$
- n_{95h} is replaced with $n_{P_{max}} \times 1.02$

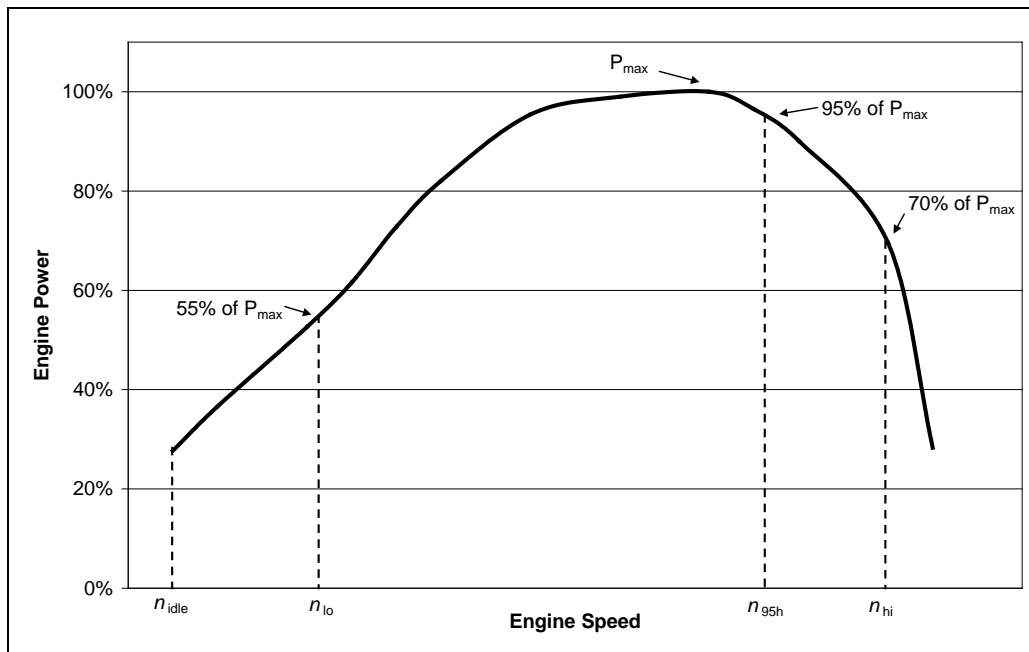


Figure 4:
Definition of test speeds

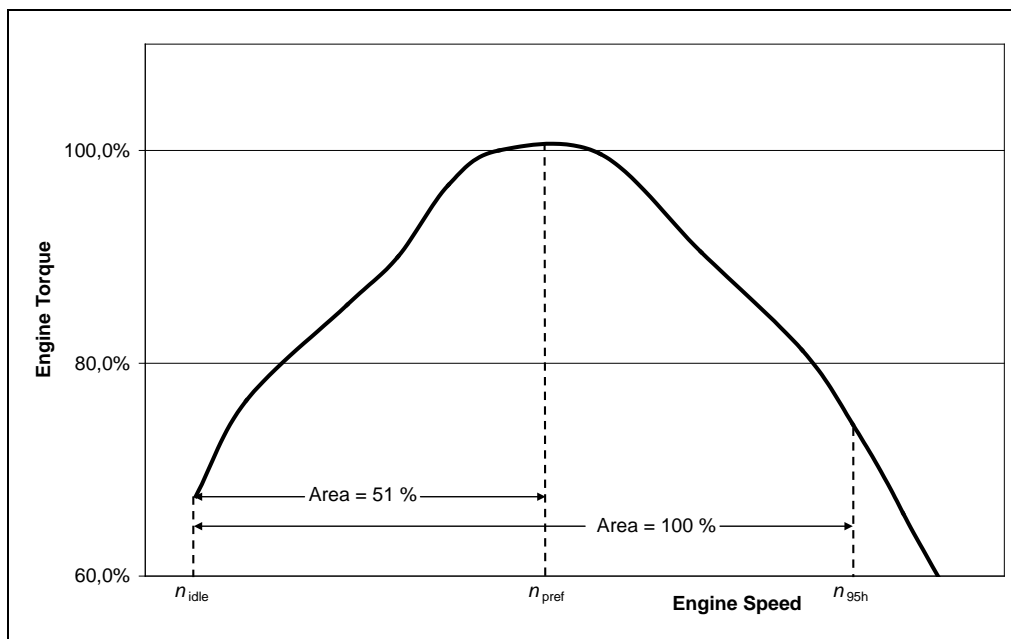


Figure 5:
Definition of n_{pref}

7.4.7. Denormalization of engine torque

The torque values in the engine dynamometer schedule of Annex 1 (WHTC) and in table 1 (WHSC) are normalized to the maximum torque at the respective speed. For

generating the reference cycles, the torque values for each individual reference speed value as determined in paragraph 7.4.6. shall be denormalized, using the mapping curve determined according to paragraph 7.4.3., as follows:

$$M_{\text{ref},i} = \frac{M_{\text{norm},i}}{100} \times M_{\text{max},i} + M_{\text{f},i} - M_{\text{r},i} \quad (10)$$

where:

$M_{\text{norm},i}$ is the normalized torque, per cent

$M_{\text{max},i}$ is the maximum torque from the mapping curve, Nm

$M_{\text{f},i}$ is the torque absorbed by auxiliaries/equipment to be fitted, Nm

$M_{\text{r},i}$ is the torque absorbed by auxiliaries/equipment to be removed, Nm

If auxiliaries/equipment are fitted in accordance with paragraph 6.3.1. and Annex 7, M_{f} and M_{r} are zero.

The negative torque values of the motoring points (m in Annex 1) shall take on, for purposes of reference cycle generation, reference values determined in either of the following ways:

- (a) negative 40 per cent of the positive torque available at the associated speed point,
- (b) mapping of the negative torque required to motor the engine from maximum to minimum mapping speed,
- (c) determination of the negative torque required to motor the engine at idle and at n_{hi} and linear interpolation between these two points.

7.4.8. Calculation of reference cycle work

Reference cycle work shall be determined over the test cycle by synchronously calculating instantaneous values for engine power from reference speed and reference torque, as determined in paragraphs 7.4.6. and 7.4.7. Instantaneous engine power values shall be integrated over the test cycle to calculate the reference cycle work W_{ref} (kWh). If auxiliaries are not fitted in accordance with paragraph 6.3.1., the instantaneous power values shall be corrected using equation (4) in paragraph 6.3.5.

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 actual cycle work, any negative torque values shall be set equal to zero and included. If integration is performed at a frequency of less than 5 Hz, 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.

7.5. Pre-test procedures

7.5.1. Installation of the measurement equipment

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

7.5.2. Preparation of measurement equipment for sampling

The following steps shall be taken before emission sampling begins:

- (a) Leak checks shall be performed within 8 hours prior to emission sampling according to paragraph 9.3.4.
- (b) For batch sampling, clean storage media shall be connected, such as evacuated bags.
- (c) All measurement instruments shall be started according to the instrument manufacturer's instructions and good engineering judgment.
- (d) Dilution systems, sample pumps, cooling fans, and the data-collection system shall be started.
- (e) The sample flow rates shall be adjusted to desired levels, using bypass flow, if desired.
- (f) Heat exchangers in the sampling system shall be pre-heated or pre-cooled to within their operating temperature ranges for a test.
- (g) Heated or cooled components such as sample lines, filters, coolers, and pumps shall be allowed to stabilize at their operating temperatures.
- (h) Exhaust dilution system flow shall be switched on at least 10 minutes before a test sequence.
- (i) Any electronic integrating devices shall be zeroed or re-zeroed, before the start of any test interval.

7.5.3. Checking the gas analyzers

Gas analyzer ranges shall be selected. Emission analyzers with automatic or manual range switching are permitted. During the test cycle, the range of the emission analyzers shall not be switched. At the same time the gains of an analyzer's analogue operational amplifier(s) may not be switched during the test cycle.

Zero and span response shall be determined for all analyzers using internationally-traceable gases that meet the specifications of paragraph 9.3.3. FID analyzers shall be spanned on a carbon number basis of one (C1).

7.5.4. Preparation of the particulate sampling filter

At least one hour before the test, the filter shall be placed in a petri dish, which is protected against dust contamination and allows air exchange, and placed in a weighing chamber for stabilization. At the end of the stabilization period, the filter shall be weighed and the tare weight shall be recorded. The filter shall then be stored

in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within eight hours of its removal from the weighing chamber.

7.5.5. Adjustment of the dilution system

The total diluted exhaust gas flow of a full flow dilution system or the diluted exhaust gas flow through a partial flow dilution system shall be set to eliminate water condensation in the system, and to obtain a filter face temperature between 315 K (42 °C) and 325 K (52 °C).

7.5.6. Starting the particulate sampling system

The particulate sampling system shall be started and operated on by-pass. The particulate background level of the diluent may be determined by sampling the diluent prior to the entrance of the exhaust gas into the dilution tunnel. The measurement may be done prior to or after the test. If the measurement is done both at the beginning and at the end of the cycle, the values may be averaged. If a different sampling system is used for background measurement, the measurement shall be done in parallel to the test run.

7.6. WHTC cycle run

This paragraph also applies to the HEC and HPC test cycles of hybrid vehicles. Different cycles for the cold start and hot start are permitted, if it is the result of the conversion procedure in annex 8 or annex 9.

7.6.1. Engine cool-down

A natural or forced cool-down procedure may be applied. For forced cool-down, good engineering judgment shall be used to set up systems to send cooling air across the engine, to send cool oil through the engine lubrication system, to remove heat from the coolant through the engine cooling system, and to remove heat from an exhaust after-treatment system. In the case of a forced after-treatment system cool down, cooling air shall not be applied until the after-treatment system has cooled below its catalytic activation temperature. Any cooling procedure that results in unrepresentative emissions is not permitted.

7.6.2. Cold start test

The cold-start test shall be started when the temperatures of the engine's lubricant, coolant, and after-treatment systems are all between 293 and 303 K (20 and 30 °C). The engine shall be started using one of the following methods:

- (a) the engine shall be started as recommended in the owners manual using a production starter motor and adequately charged battery or a suitable power supply; or
- (b) the engine shall be started by using the dynamometer. The engine shall be motored within ± 25 per cent of its typical in-use cranking speed. Cranking

shall be stopped within 1 second after the engine is running. If the engine does not start after 15 seconds of cranking, cranking shall be stopped and the reason for the failure to start determined, unless the owners manual or the service-repair manual describes the longer cranking time as normal.

7.6.3. Hot soak period

Immediately upon completion of the cold start test, the engine shall be conditioned for the hot start test using a 10 ± 1 minutes hot soak period.

7.6.4. Hot start test

The engine shall be started at the end of the hot soak period as defined in paragraph 7.6.3. using the starting methods given in paragraph 7.6.2.

7.6.5. Test sequence

The test sequence of both cold start and hot start test shall commence at the start of the engine. After the engine is running, cycle control shall be initiated so that engine operation matches the first set point of the cycle.

The WHTC shall be performed according to the reference cycle as set out in paragraph 7.4. Engine speed and torque command set points shall be issued at 5 Hz (10 Hz recommended) or greater. The set points shall be calculated by linear interpolation between the 1 Hz set points of the reference cycle. Actual engine speed and torque shall be recorded at least once every second during the test cycle (1 Hz), and the signals may be electronically filtered.

7.6.5.1. Stop/start system

If a stop/start system is used or if the hybrid engine cycle requires an engine stop, the engine shall be turned off at idle and/or motoring points, as commanded by the engine ECU. Emissions measurement and data collection shall continue until the end of test cycle.

7.6.6. Collection of emission relevant data

At the start of the test sequence, the measuring equipment shall be started, simultaneously:

- (a) start collecting or analyzing diluent, if a full flow dilution system is used;
- (b) start collecting or analyzing raw or diluted exhaust gas, depending on the method used;
- (c) start measuring the amount of diluted exhaust gas and the required temperatures and pressures;
- (d) start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used;
- (e) start recording the feedback data of speed and torque of the dynamometer.

If raw exhaust measurement is used, the emission concentrations ((NM)HC, CO and NO_x) and the exhaust gas mass flow rate shall be measured continuously and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

If a full flow dilution system is used, HC and NO_x shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyzer 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, CO₂, and NMHC may be determined by integration of continuous measurement signals or by analyzing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the diluent shall be determined prior to the point where the exhaust enters into the dilution tunnel by integration or by collecting into the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).

7.6.7. Particulate sampling

At the start of the test sequence, the particulate sampling system shall be switched from by-pass to collecting particulates.

If a partial flow dilution system is used, the sample pump(s) shall be controlled, so that the flow rate through the particulate sample probe or transfer tube is maintained proportional to the exhaust mass flow rate as determined in accordance with paragraph 9.4.6.1.

If a full flow dilution system 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 ± 2.5 per cent of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it shall be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ± 2.5 per cent of its set value (except for the first 10 seconds of sampling). 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 ± 2.5 per cent because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower sample flow rate.

7.6.8. Engine stalling and equipment malfunction

If the engine stalls anywhere during the cold start test, **except in case of an engine stop commanded by the ECU**, the test shall be voided. The engine shall be preconditioned and restarted according to the requirements of paragraph 7.6.2., and the test repeated.

If the engine stalls anywhere during the hot start test, **except in case of an engine stop commanded by the ECU**, the hot start test shall be voided. The engine shall be soaked according to paragraph 7.6.3., and the hot start test repeated. In this case, the cold start test need not be repeated.

If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided and repeated in line with the above provisions.

7.7. WHSC cycle run

This paragraph does not apply to hybrid vehicles.

7.7.1. Preconditioning the dilution system and the engine

The dilution system and the engine shall be started and warmed up in accordance with paragraph 7.4.1. After warm-up, the engine and sampling system shall be preconditioned by operating the engine at mode 9 (see paragraph 7.2.2., table 1) for a minimum of 10 minutes while simultaneously operating the dilution system. Dummy particulate emissions samples may be collected. Those sample filters need not be stabilized or weighed, and may be discarded. Flow rates shall be set at the approximate flow rates selected for testing. The engine shall be shut off after preconditioning.

7.7.2. Engine starting

5 ± 1 minutes after completion of preconditioning at mode 9 as described in paragraph 7.7.1., the 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 in accordance with paragraph 7.6.2.

7.7.3. Test sequence

The test sequence shall commence after the engine is running and within one minute after engine operation is controlled to match the first mode of the cycle (idle).

The WHSC shall be performed according to the order of test modes listed in table 1 of paragraph 7.2.2.

7.7.4. Collection of emission relevant data

At the start of the test sequence, the measuring equipment shall be started, simultaneously:

- (a) start collecting or analyzing diluent, if a full flow dilution system is used;
- (b) start collecting or analyzing raw or diluted exhaust gas, depending on the method used;
- (c) start measuring the amount of diluted exhaust gas and the required temperatures and pressures;

- (d) start recording the exhaust gas mass flow rate, if raw exhaust gas analysis is used;
- (e) start recording the feedback data of speed and torque of the dynamometer.

If raw exhaust measurement is used, the emission concentrations ((NM)HC, CO and NO_x) and the exhaust gas mass flow rate shall be measured continuously and stored with at least 2 Hz on a computer system. All other data may be recorded with a sample rate of at least 1 Hz. For analogue analyzers the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

If a full flow dilution system is used, HC and NO_x shall be measured continuously in the dilution tunnel with a frequency of at least 2 Hz. The average concentrations shall be determined by integrating the analyzer 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, CO₂, and NMHC may be determined by integration of continuous measurement signals or by analyzing the concentrations in the sample bag, collected over the cycle. The concentrations of the gaseous pollutants in the diluent shall be determined by integration or by collecting into the background bag. All other parameters that need to be measured shall be recorded with a minimum of one measurement per second (1 Hz).

7.7.5. Particulate sampling

At the start of the test sequence, the particulate sampling system shall be switched from by-pass to collecting particulates. If a partial flow dilution system is used, the sample pump(s) shall be controlled, so that the flow rate through the particulate sample probe or transfer tube is maintained proportional to the exhaust mass flow rate as determined in accordance with paragraph 9.4.6.1.

If a full flow dilution system 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 ± 2.5 per cent of the set flow rate. If flow compensation (i.e., proportional control of sample flow) is used, it shall be demonstrated that the ratio of main tunnel flow to particulate sample flow does not change by more than ± 2.5 per cent of its set value (except for the first 10 seconds of sampling). 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 ± 2.5 per cent because of high particulate loading on the filter, the test shall be voided. The test shall be rerun using a lower sample flow rate.

7.7.6. Engine stalling and equipment malfunction

If the engine stalls anywhere during the cycle, the test shall be voided. The engine shall be preconditioned according to paragraph 7.7.1. and restarted according to paragraph 7.7.2., and the test repeated.

If a malfunction occurs in any of the required test equipment during the test cycle, the test shall be voided and repeated in line with the above provisions.

7.8. Post-test procedures

7.8.1. Operations after test

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

7.8.2. Verification of proportional sampling

For any proportional batch sample, such as a bag sample or PM sample, it shall be verified that proportional sampling was maintained according to paragraphs 7.6.7. and 7.7.5. Any sample that does not fulfil the requirements shall be voided.

7.8.3. PM conditioning and weighing

The particulate filter shall be placed into covered or sealed containers or the filter holders shall be closed, in order to protect the sample filters against ambient contamination. Thus protected, the filter shall be returned to the weighing chamber. The filter shall be conditioned for at least one hour, and then weighed according to paragraph 9.4.5. The gross weight of the filter shall be recorded.

7.8.4. Drift verification

As soon as practical but no later than 30 minutes after the test cycle is complete or during the soak period, the zero and span responses of the gaseous analyzer ranges used shall be determined. For the purpose of this paragraph, test cycle is defined as follows:

- (a) for the WHTC: the complete sequence cold - soak – hot,
- (b) for the WHTC hot start test (paragraph 6.6.): the sequence soak – hot,
- (c) for the multiple regeneration WHTC hot start test (paragraph 6.6.): the total number of hot start tests,
- (d) for the WHSC: the test cycle.

The following provisions apply for analyzer drift:

- (e) The pre-test zero and span and post-test zero and span responses may be directly directly inserted into equation 66 of paragraph 8.6.1. without determining drift;
- (f) If the drift difference between the pre-test and post-test results is less than 1 per cent of full scale, the measured concentrations may be used uncorrected or may be corrected for drift according to paragraph 8.6.1.;

- (g) If the drift difference between the pre-test and post-test results is equal to or greater than 1 per cent of full scale, the test shall be voided or the measured concentrations shall be corrected for drift according to paragraph 8.6.1.

7.8.5. Analysis of gaseous bag sampling

As soon as practical, the following shall be performed:

- (a) Gaseous bag samples shall be analyzed no later than 30 minutes after the hot start test is complete or during the soak period for the cold start test.
- (b) Background samples shall be analyzed no later than 60 minutes after the hot start test is complete.

7.8.6. Calculation of cycle work

Before calculating actual cycle work, any points recorded during engine starting shall be omitted. Actual cycle work shall be determined over the test cycle by synchronously using actual speed and actual torque values to calculate instantaneous values for engine power. Instantaneous engine power values shall be integrated over the test cycle to calculate the actual cycle work W_{act} (kWh). If auxiliaries/equipment are not fitted in accordance with paragraph 6.3.1., the instantaneous power values shall be corrected using equation (4) in paragraph 6.3.5.

The same methodology as described in paragraph 7.4.8. shall be used for integrating actual engine power.

7.8.7. Validation of cycle work

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 paragraph 8.6.3.).

W_{act} shall be between 85 per cent and 105 per cent of W_{ref} .

This section does not apply to engines used in hybrid vehicles.

7.8.8. Validation statistics of the test cycle

Linear regressions of the actual values (n_{act} , M_{act} , P_{act}) on the reference values (n_{ref} , M_{ref} , P_{ref}) shall be performed for both the WHTC and the WHSC.

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

The method of least squares shall be used, with the best-fit equation having the form:

$$y = a_1x + a_0 \tag{11}$$

where:

- y = actual value of speed (min^{-1}), torque (Nm), or power (kW)
- a_1 = slope of the regression line
- x = reference value of speed (min^{-1}), torque (Nm), or power (kW)
- a_0 = y intercept of the regression line

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

This analysis shall be performed at 1 Hz or greater. For a test to be considered valid, the criteria of table 2 (WHTC) or table 3 (WHSC) shall be met.

	Speed	Torque	Power
Standard error of estimate (SEE) of y on x	maximum 5 per cent of maximum test speed	maximum 10 per cent of maximum engine torque	maximum 10 per cent of maximum engine power
Slope of the regression line, a_1	0.95 to 1.03	0.83 - 1.03	0.89 - 1.03
Coefficient of determination, r^2	minimum 0.970	minimum 0.850	minimum 0.910
y intercept of the regression line, a_0	maximum 10 per cent of idle speed	± 20 Nm or ± 2 per cent of maximum torque whichever is greater	± 4 kW or ± 2 per cent of maximum power whichever is greater

Table 2:
Regression line tolerances for the WHTC

	Speed	Torque	Power
Standard error of estimate (SEE) of y on x	maximum 1 per cent of maximum test speed	maximum 2 per cent of maximum engine torque	maximum 2 per cent of maximum engine power
Slope of the regression line, a_1	0.99 to 1.01	0.98 - 1.02	0.98 - 1.02
Coefficient of determination, r^2	minimum 0.990	minimum 0.950	minimum 0.950
y intercept of the regression line, a_0	maximum 1 per cent of maximum test speed	± 20 Nm or ± 2 per cent of maximum torque whichever is greater	± 4 kW or ± 2 per cent of maximum power whichever is greater

Table 3
Regression line tolerances for the WHSC

For regression purposes only, point omissions are permitted where noted in table 4 before doing the regression calculation. However, those points shall not be omitted for the calculation of cycle work and emissions. Point omission may be applied to the whole or to any part of the cycle.

Event	Conditions	Permitted point omissions
Minimum operator demand (idle point)	$n_{ref} = 0$ per cent and $M_{ref} = 0$ per cent and $M_{act} > (M_{ref} - 0.02 M_{max. mapped torque})$ and $M_{act} < (M_{ref} + 0.02 M_{max. mapped torque})$	speed and power
Minimum operator demand (motoring point)	$M_{ref} < 0$ per cent	power and torque
Minimum operator demand	$n_{act} \leq 1.02 n_{ref}$ and $M_{act} > M_{ref}$ and $n_{act} > n_{ref}$ and $M_{act} \leq M_{ref}$ and $n_{act} > 1.02 n_{ref}$ and $M_{ref} < M_{act} \leq (M_{ref} + 0.02 M_{max. mapped torque})$	power and either torque or speed
Maximum operator demand	$n_{act} < n_{ref}$ and $M_{act} \geq M_{ref}$ and $n_{act} \geq 0.98 n_{ref}$ and $M_{act} < M_{ref}$ and $n_{act} < 0.98 n_{ref}$ and $M_{ref} > M_{act} \geq (M_{ref} - 0.02 M_{max. mapped torque})$	power and either torque or speed

Table 4:
Permitted point omissions from regression analysis

8. EMISSION CALCULATION

The final test result shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure, in accordance with ASTM E 29-06B. No rounding of intermediate values leading to the final break-specific emission result is permitted.

Examples of the calculation procedures are given in Annex 6.

Emissions calculation on a molar basis in accordance with Annex 7 of gtr No. 11 (NRMM), is permitted with the prior agreement of the type approval or certification authority.

8.1. Dry/wet correction

If the emissions are measured on a dry basis, the measured concentration shall be converted to a wet basis according to the following equation:

$$c_w = k_w \cdot c_d \quad (12)$$

where:

c_d is the dry concentration in ppm or per cent volume

k_w is the dry/wet correction factor

8.1.1. Raw exhaust gas

$$k_{w,a} = \left(1 - \frac{1.2442 \times H_a + 111.19 \times w_{ALF} \times \frac{q_{mf,i}}{q_{mad,i}}}{773.4 + 1.2442 \times H_a + \frac{q_{mf,i}}{q_{mad,i}} \times k_f \times 1,000} \right) \times 1.008 \quad (13)$$

or

$$k_{w,a} = \left(1 - \frac{1.2442 \times H_a + 111.19 \times w_{ALF} \times \frac{q_{mf,i}}{q_{mad,i}}}{773.4 + 1.2442 \times H_a + \frac{q_{mf,i}}{q_{mad,i}} \times k_f \times 1,000} \right) / \left(1 - \frac{p_f}{p_b} \right) \quad (14)$$

or

$$k_{w,a} = \left(\frac{1}{1 + \alpha \times 0.005 \times (c_{CO_2} + c_{CO})} - k_{w1} \right) \times 1.008 \quad (15)$$

with

$$k_{fw} = 0.055594 \times w_{ALF} + 0.0080021 \times w_{DEL} + 0.0070046 \times w_{EPS} \quad (16)$$

and

$$k_{w1} = \frac{1.608 \times H_a}{1,000 + (1.608 \times H_a)} \quad (17)$$

where:

H_a is the intake air humidity, g water per kg dry air

w_{ALF} is the hydrogen content of the fuel, per cent mass

$q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s

$q_{mad,i}$ is the instantaneous dry intake air mass flow rate, kg/s

p_r	is the water vapour pressure after cooling bath, kPa
p_b	is the total atmospheric pressure, kPa
w_{DEL}	is the nitrogen content of the fuel, per cent mass
w_{EPS}	is the oxygen content of the fuel, per cent mass
α	is the molar hydrogen ratio of the fuel
c_{CO_2}	is the dry CO ₂ concentration, per cent
c_{CO}	is the dry CO concentration, per cent

Equations (13) and (14) are principally identical with the factor 1.008 in equations (13) and (15) being an approximation for the more accurate denominator in equation (14).

8.1.2. Diluted exhaust gas

$$k_{w,e} = \left[\left(1 - \frac{\alpha \times c_{CO_2w}}{200} \right) - k_{w2} \right] \times 1.008 \quad (18)$$

or

$$k_{w,e} = \left[\left(\frac{(1 - k_{w2})}{1 + \frac{\alpha \times c_{CO_2d}}{200}} \right) \right] \times 1.008 \quad (19)$$

with

$$k_{w2} = \frac{1.608 \times \left[H_d \times \left(1 - \frac{1}{D} \right) + H_a \times \left(\frac{1}{D} \right) \right]}{1,000 + \left\{ 1.608 \times \left[H_d \times \left(1 - \frac{1}{D} \right) + H_a \times \left(\frac{1}{D} \right) \right] \right\}} \quad (20)$$

where:

α	is the molar hydrogen ratio of the fuel
c_{CO_2w}	is the wet CO ₂ concentration, per cent
c_{CO_2d}	is the dry CO ₂ concentration, per cent
H_d	is the diluent humidity, g water per kg dry air
H_a	is the intake air humidity, g water per kg dry air
D	is the dilution factor (see paragraph 8.5.2.3.2.)

8.1.3. Diluent

$$k_{w,d} = (1 - k_{w3}) \times 1.008 \quad (21)$$

with

$$k_{w3} = \frac{1.608 \times H_d}{1,000 + (1.608 \times H_d)} \quad (22)$$

where:

H_d is the diluent humidity, g water per kg dry air

8.2. NOx correction for humidity

As the NOx emission depends on ambient air conditions, the NOx concentration shall be corrected for humidity with the factors given in paragraph 8.2.1. or 8.2.2. The intake air humidity H_a may be derived from relative humidity measurement, dew point measurement, vapour pressure measurement or dry/wet bulb measurement using generally accepted equations.

8.2.1. Compression-ignition engines

$$k_{h,D} = \frac{15.698 \times H_a}{1,000} + 0.832 \quad (23)$$

where:

H_a is the intake air humidity, g water per kg dry air

8.2.2. Positive ignition engines

$$k_{h,G} = 0.6272 + 44.030 \times 10^{-3} \times H_a - 0.862 \times 10^{-3} \times H_a^2 \quad (24)$$

where:

H_a is the intake air humidity, g water per kg dry air

8.3. Particulate filter buoyancy correction

The sampling filter mass shall be corrected for its buoyancy in air. The buoyancy correction depends on sampling filter density, air density and the density of the balance calibration weight, and does not account for the buoyancy of the PM itself. The buoyancy correction shall be applied to both tare filter mass and gross filter mass.

If the density of the filter material is not known, the following densities shall be used:

- (a) teflon coated glass fiber filter: 2,300 kg/m³
- (b) teflon membrane filter: 2,144 kg/m³
- (c) teflon membrane filter with polymethylpentene support ring: 920 kg/m³

For stainless steel calibration weights, a density of 8,000 kg/m³ shall be used. If the material of the calibration weight is different, its density shall be known.

The following equation shall be used:

$$m_f = m_{\text{uncor}} \times \left(\frac{1 - \frac{\rho_a}{\rho_w}}{1 - \frac{\rho_a}{\rho_f}} \right) \quad (25)$$

with

$$\rho_a = \frac{p_b \times 28.836}{8.3144 \times T_a} \quad (26)$$

where:

m_{uncor}	is the uncorrected particulate filter mass, mg
ρ_a	is the density of the air, kg/m ³
ρ_w	is the density of balance calibration weight, kg/m ³
ρ_f	is the density of the particulate sampling filter, kg/m ³
p_b	is the total atmospheric pressure, kPa
T_a	is the air temperature in the balance environment, K
28.836	is the molar mass of the air at reference humidity (282.5 K), g/mol
8.3144	is the molar gas constant

The particulate sample mass m_p used in paragraphs 8.4.3. and 8.5.3. shall be calculated as follows:

$$m_p = m_{f,G} - m_{f,T} \quad (27)$$

where:

$m_{f,G}$	is the buoyancy corrected gross particulate filter mass, mg
$m_{f,T}$	is the buoyancy corrected tare particulate filter mass, mg

8.4. Partial flow dilution (PFS) and raw gaseous measurement

The instantaneous concentration signals of the gaseous components are used for the calculation of the mass emissions by multiplication with the instantaneous exhaust mass flow rate. The exhaust mass flow rate may be measured directly, or calculated using the methods of intake air and fuel flow measurement, tracer method or intake air and air/fuel ratio measurement. Special attention shall be paid to the response times of the different instruments. These differences shall be accounted for by time aligning the signals. For particulates, the exhaust mass flow rate signals are used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality shall be checked by applying a regression analysis between sample and exhaust flow in accordance with paragraph 9.4.6.1. The complete test set up is schematically shown in figure 6.

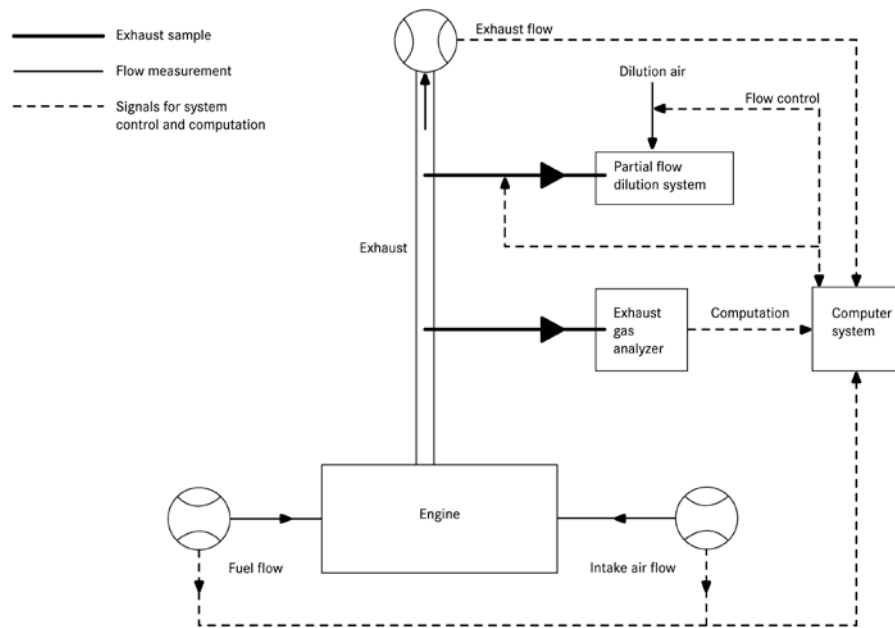


Figure 6:
Scheme of raw/partial flow measurement system

8.4.1. Determination of exhaust gas mass flow

8.4.1.1. Introduction

For calculation of the emissions in the raw exhaust gas and for controlling of a partial flow dilution system, it is necessary to know the exhaust gas mass flow rate. For the determination of the exhaust mass flow rate, either of the methods described in paragraphs 8.4.1.3 to 8.4.1.7 may be used.

8.4.1.2. Response time

For the purpose of emissions calculation, the response time of either method described in paragraphs 8.4.1.3. to 8.4.1.7. shall be equal to or less than the analyzer response time of ≤ 10 s, as required in paragraph 9.3.5.

For the purpose of controlling of a partial flow dilution system, a faster response is required. For partial flow dilution systems with online control, the response time shall be ≤ 0.3 s. For partial flow dilution systems with look ahead control based on a pre-recorded test run, the response time of the exhaust flow measurement system shall be ≤ 5 s with a rise time of ≤ 1 s. The system response time shall be specified by the instrument manufacturer. The combined response time requirements for the exhaust gas flow and partial flow dilution system are indicated in paragraph 9.4.6.1.

8.4.1.3. Direct measurement method

Direct measurement of the instantaneous exhaust flow shall be done by systems, such as:

- (a) pressure differential devices, like flow nozzle, (details see ISO 5167)
- (b) ultrasonic flowmeter
- (c) vortex flowmeter

Precautions shall be taken to avoid measurement errors which will impact emission value errors. Such precautions include the careful installation of the device in the engine exhaust system according to the instrument manufacturers' recommendations and to good engineering practice. Especially, engine performance and emissions shall not be affected by the installation of the device.

The flowmeters shall meet the linearity requirements of paragraph 9.2.

8.4.1.4. Air and fuel measurement method

This involves measurement of the airflow and the fuel flow with suitable flowmeters. The calculation of the instantaneous exhaust gas flow shall be as follows:

$$q_{mew,i} = q_{maw,i} + q_{mf,i} \quad (28)$$

where:

$q_{mew,i}$ is the instantaneous exhaust mass flow rate, kg/s

$q_{maw,i}$ is the instantaneous intake air mass flow rate, kg/s

$q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s

The flowmeters shall meet the linearity requirements of paragraph 9.2., but shall be accurate enough to also meet the linearity requirements for the exhaust gas flow.

8.4.1.5. Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust.

A known amount of an inert gas (e.g. pure helium) shall be injected into the exhaust gas flow as a tracer. The gas is mixed and diluted by the exhaust gas, but shall not react in the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

In order to ensure complete mixing of the tracer gas, the exhaust gas sampling probe shall be located at least 1 m or 30 times the diameter of the exhaust pipe, whichever is larger, downstream of the tracer gas injection point. The sampling probe may be located closer to the injection point if complete mixing is verified by comparing the tracer gas concentration with the reference concentration when the tracer gas is injected upstream of the engine.

The tracer gas flow rate shall be set so that the tracer gas concentration at engine idle speed after mixing becomes lower than the full scale of the trace gas analyzer.

The calculation of the exhaust gas flow shall be as follows:

$$q_{mew,i} = \frac{q_{vt} \times \rho_e}{60 \times (c_{mix,i} - c_b)} \quad (29)$$

where:

- $q_{mew,i}$ is the instantaneous exhaust mass flow rate, kg/s
- q_{vt} is tracer gas flow rate, cm³/min
- $c_{mix,i}$ is the instantaneous concentration of the tracer gas after mixing, ppm
- ρ_e is the density of the exhaust gas, kg/m³ (cf. table 4)
- c_b is the background concentration of the tracer gas in the intake air, ppm

The background concentration of the tracer gas (c_b) may be determined by averaging the background concentration measured immediately before the test run and after the test run.

When the background concentration is less than 1 per cent of the concentration of the tracer gas after mixing ($c_{mix,i}$) at maximum exhaust flow, the background concentration may be neglected.

The total system shall meet the linearity requirements for the exhaust gas flow of paragraph 9.2.

8.4.1.6. Airflow and air to fuel ratio measurement method

This involves exhaust mass calculation from the air flow and the air to fuel ratio. The calculation of the instantaneous exhaust gas mass flow is as follows:

$$q_{mew,i} = q_{maw,i} \times \left(1 + \frac{1}{A/F_{st} \times \lambda_i} \right) \quad (30)$$

with

$$A / F_{st} = \frac{138.0 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma \right)}{12.011 + 1.00794 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.065 \times \gamma} \quad (31)$$

$$\lambda_i = \frac{\left(100 - \frac{c_{COd} \times 10^{-4}}{2} - c_{HCw} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{COd} \times 10^{-4}}{3.5 \times c_{CO2d}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{CO} \times 10^{-4}}{3.5 \times c_{CO2d}}}\right) \times (c_{CO2d} + c_{COd} \times 10^{-4})}{4.764 \times \left(1 + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times (c_{CO2d} + c_{COd} \times 10^{-4} + c_{HCw} \times 10^{-4})} \quad (32)$$

where:

$q_{maw,i}$ is the instantaneous intake air mass flow rate, kg/s

A/F_{st} is the stoichiometric air to fuel ratio, kg/kg

λ_i is the instantaneous excess air ratio

c_{CO2d} is the dry CO₂ concentration, per cent

c_{COd} is the dry CO concentration, ppm

c_{HCw} is the wet HC concentration, ppm

Airflowmeter and analyzers shall meet the linearity requirements of paragraph 9.2., and the total system shall meet the linearity requirements for the exhaust gas flow of paragraph 9.2.

If an air to fuel ratio measurement equipment such as a zirconia type sensor is used for the measurement of the excess air ratio, it shall meet the specifications of paragraph 9.3.2.7.

8.4.1.7. Carbon balance method

This involves exhaust mass calculation from the fuel flow and the gaseous exhaust components that include carbon. The calculation of the instantaneous exhaust gas mass flow is as follows:

$$q_{mew,i} = q_{mf,i} \times \left(\frac{w_{BET}^2 \times 1.4}{(1.0828 \times w_{BET} + k_{fd} \times k_c) \times k_c} \left(1 + \frac{H_a}{1000}\right) + 1 \right) \quad (33)$$

with

$$k_c = (c_{CO2d} - c_{CO2d,a}) \times 0.5441 + \frac{c_{COd}}{18.522} + \frac{c_{HCw}}{17.355} \quad (34)$$

and

$$k_{fd} = -0.055594 \times w_{ALF} + 0.0080021 \times w_{DEL} + 0.0070046 \times w_{EPS} \quad (35)$$

where:

$q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s

H_a is the intake air humidity, g water per kg dry air

w_{BET} is the carbon content of the fuel, per cent mass

w_{ALF}	is the hydrogen content of the fuel, per cent mass
w_{DEL}	is the nitrogen content of the fuel, per cent mass
w_{EPS}	is the oxygen content of the fuel, per cent mass
$c_{\text{CO}_2\text{d}}$	is the dry CO_2 concentration, per cent
$c_{\text{CO}_2\text{d,a}}$	is the dry CO_2 concentration of the intake air, per cent
c_{CO}	is the dry CO concentration, ppm
c_{HCw}	is the wet HC concentration, ppm

8.4.2. Determination of the gaseous components

8.4.2.1. Introduction

The gaseous components in the raw exhaust gas emitted by the engine submitted for testing shall be measured with the measurement and sampling systems described in paragraph 9.3. and Annex 3. The data evaluation is described in paragraph 8.4.2.2.

Two calculation procedures are described in paragraphs 8.4.2.3. and 8.4.2.4., which are equivalent for the reference fuels of Annex 2. The procedure in paragraph 8.4.2.3. is more straightforward, since it uses tabulated u values for the ratio between component and exhaust gas density. The procedure in paragraph 8.4.2.4. is more accurate for fuel qualities that deviate from the specifications in Annex 2, but requires elementary analysis of the fuel composition.

8.4.2.2. Data evaluation

For the evaluation of the gaseous emissions, the raw emission concentrations (HC, CO and NO_x) and the exhaust gas mass flow rate shall be recorded and stored with at least 2 Hz on a computer system. All other data shall be recorded with a sample rate of at least 1 Hz. For analogue analyzers, the response shall be recorded, and the calibration data may be applied online or offline during the data evaluation.

For calculation of the mass emission of the gaseous components, the traces of the recorded concentrations and the trace of the exhaust gas mass flow rate shall be time aligned by the transformation time as defined in paragraph 3.1.30. Therefore, the response time of each gaseous emissions analyzer and of the exhaust gas mass flow system shall be determined according to paragraphs 8.4.1.2. and 9.3.5., respectively, and recorded.

8.4.2.3. Calculation of mass emission based on tabulated values

The mass of the pollutants (g/test) shall be determined by calculating the instantaneous mass emissions from the raw concentrations of the pollutants and the exhaust gas mass flow, aligned for the transformation time as determined in accordance with paragraph 8.4.2.2., integrating the instantaneous values over the cycle, and multiplying the integrated values with the u values from table 5. If measured on a dry basis, the dry/wet correction according to paragraph 8.1. shall be

applied to the instantaneous concentration values before any further calculation is done.

For the calculation of NO_x, the mass emission shall be multiplied, where applicable, with the humidity correction factor $k_{h,D}$, or $k_{h,G}$, as determined according to paragraph 8.2.

The following equation shall be applied:

$$m_{\text{gas}} = u_{\text{gas}} \times \sum_{i=1}^{i=n} c_{\text{gas},i} \times q_{\text{mew},i} \times \frac{1}{f} \quad (\text{in g/test}) \quad (36)$$

where:

u_{gas} is the ratio between density of exhaust component and density of exhaust gas

$c_{\text{gas},i}$ is the instantaneous concentration of the component in the exhaust gas, ppm

$q_{\text{mew},i}$ is the instantaneous exhaust mass flow, kg/s

f is the data sampling rate, Hz

n is the number of measurements

Fuel	ρ_e	Gas					
		NO _x	CO	HC	CO ₂	O ₂	CH ₄
		$\rho_{\text{gas}} [\text{kg/m}^3]$					
		2.053	1.250	^{a)}	1.9636	1.4277	0.716
		$u_{\text{gas}}^{\text{b)}$					
Diesel	1.2943	0.001586	0.000966	0.000479	0.001517	0.001103	0.000553
Ethanol	1.2757	0.001609	0.000980	0.000805	0.001539	0.001119	0.000561
CNG ^{c)}	1.2661	0.001621	0.000987	0.000558 ^{d)}	0.001551	0.001128	0.000565
Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	0.000559
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	0.000558
LPG ^{e)}	1.2811	0.001602	0.000976	0.000510	0.001533	0.001115	0.000559

a) depending on fuel
 b) at $\lambda = 2$, dry air, 273 K, 101.3 kPa
 c) u accurate within 0.2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 %
 d) NMHC on the basis of CH_{2.93} (for total HC the u_{gas} coefficient of CH₄ shall be used)
 e) u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %

Table 5:

Raw exhaust gas u values and component densities

8.4.2.4. Calculation of mass emission based on exact equations

The mass of the pollutants (g/test) shall be determined by calculating the instantaneous mass emissions from the raw concentrations of the pollutants, the u values and the exhaust gas mass flow, aligned for the transformation time as determined in accordance with paragraph 8.4.2.2. and integrating the instantaneous values over the cycle. If measured on a dry basis, the dry/wet correction according to paragraph 8.1. shall be applied to the instantaneous concentration values before any further calculation is done.

For the calculation of NO_x, the mass emission shall be multiplied with the humidity correction factor $k_{h,D}$, or $k_{h,G}$, as determined according to paragraph 8.2.

The following equation shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^{i=n} u_{\text{gas},i} \times c_{\text{gas},i} \times q_{\text{mew},i} \times \frac{1}{f} \quad (\text{in g/test}) \quad (37)$$

where:

- $u_{\text{gas},i}$ is the instantaneous density ratio of exhaust component and exhaust gas
- $c_{\text{gas},i}$ is the instantaneous concentration of the component in the exhaust gas, ppm
- $q_{\text{mew},i}$ is the instantaneous exhaust mass flow, kg/s
- f is the data sampling rate, Hz
- n is the number of measurements

The instantaneous u values shall be calculated as follows:

$$u_{\text{gas},i} = M_{\text{gas}} / (M_{e,i} \times 1,000) \quad (38)$$

or

$$u_{\text{gas},i} = \rho_{\text{gas}} / (\rho_{e,i} \times 1,000) \quad (39)$$

with

$$\rho_{\text{gas}} = M_{\text{gas}} / 22.414 \quad (40)$$

where:

- M_{gas} is the molar mass of the gas component, g/mol (cf. Annex 6)
- $M_{e,i}$ is the instantaneous molar mass of the exhaust gas, g/mol
- ρ_{gas} is the density of the gas component, kg/m³
- $\rho_{e,i}$ is the instantaneous density of the exhaust gas, kg/m³

The molar mass of the exhaust, M_e , shall be derived for a general fuel composition CH _{α} O _{ε} N _{δ} S _{γ} under the assumption of complete combustion, as follows:

$$M_{e,i} = \frac{1 + \frac{q_{mf,i}}{q_{maw,i}}}{\frac{q_{mf,i}}{q_{maw,i}} \times \frac{\frac{\alpha}{4} + \frac{\varepsilon}{2} + \frac{\delta}{2}}{12.011 + 1.00794 \times \alpha + 15.9994 \times \varepsilon + 14.0067 \times \delta + 32.065 \times \gamma} + \frac{\frac{H_a \times 10^{-3}}{2 \times 1.00794 + 15.9994} + \frac{1}{M_a}}{1 + H_a \times 10^{-3}}} \quad (41)$$

where:

- $q_{maw,i}$ is the instantaneous intake air mass flow rate on wet basis, kg/s
- $q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s
- H_a is the intake air humidity, g water per kg dry air

M_a is the molar mass of the dry intake air = 28.965 g/mol

The exhaust density ρ_e shall be derived, as follows:

$$\rho_{e,i} = \frac{1,000 + H_a + 1,000 \times (q_{mf,i}/q_{mad,i})}{773.4 + 1.2434 \times H_a + k_{fw} \times 1,000 \times (q_{mf,i}/q_{mad,i})} \quad (42)$$

where:

$q_{mad,i}$ is the instantaneous intake air mass flow rate on dry basis, kg/s

$q_{mf,i}$ is the instantaneous fuel mass flow rate, kg/s

H_a is the intake air humidity, g water per kg dry air

k_{fw} is the fuel specific factor of wet exhaust (equation 16) in paragraph 8.1.1.

8.4.3. Particulate determination

8.4.3.1. Data evaluation

The particulate mass shall be calculated according to equation 27 of paragraph 8.3. For the evaluation of the particulate concentration, the total sample mass (m_{sep}) through the filter over the test cycle shall be recorded.

With the prior approval of the type approval or certification authority, the particulate mass may be corrected for the particulate level of the diluent, as determined in paragraph 7.5.6., in line with good engineering practice and the specific design features of the particulate measurement system used.

8.4.3.2. Calculation of mass emission

Depending on system design, the mass of particulates (g/test) shall be calculated by either of the methods in paragraphs 8.4.3.2.1. or 8.4.3.2.2. after buoyancy correction of the particulate sample filter according to paragraph 8.3.

8.4.3.2.1. Calculation based on sample ratio

$$m_{PM} = m_p / (r_s \times 1,000) \quad (43)$$

where:

m_p is the particulate mass sampled over the cycle, mg

r_s is the average sample ratio over the test cycle

with

$$r_s = \frac{m_{se}}{m_{ew}} \times \frac{m_{sep}}{m_{sed}} \quad (44)$$

where:

- m_{se} is the sample mass over the cycle, kg
- m_{ew} is the total exhaust mass flow over the cycle, kg
- m_{sep} is the mass of diluted exhaust gas passing the particulate collection filters, kg
- m_{sed} is the mass of diluted exhaust gas passing the dilution tunnel, kg

In case of the total sampling type system, m_{sep} and m_{sed} are identical.

8.4.3.2.2. Calculation based on dilution ratio

$$m_{PM} = \frac{m_p}{m_{sep}} \times \frac{m_{edf}}{1,000} \quad (45)$$

where:

- m_p is the particulate mass sampled over the cycle, mg
- m_{sep} is the mass of diluted exhaust gas passing the particulate collection filters, kg
- m_{edf} is the mass of equivalent diluted exhaust gas over the cycle, kg

The total mass of equivalent diluted exhaust gas mass over the cycle shall be determined as follows:

$$m_{edf} = \sum_{i=1}^{i=n} q_{medf,i} \times \frac{1}{f} \quad (46)$$

$$q_{medf,i} = q_{mew,i} \times r_{d,i} \quad (47)$$

$$r_{d,i} = \frac{q_{mdew,i}}{(q_{mdew,i} - q_{mdw,i})} \quad (48)$$

where:

- $q_{medf,i}$ is the instantaneous equivalent diluted exhaust mass flow rate, kg/s
- $q_{mew,i}$ is the instantaneous exhaust mass flow rate, kg/s
- $r_{d,i}$ is the instantaneous dilution ratio
- $q_{mdew,i}$ is the instantaneous diluted exhaust mass flow rate, kg/s
- $q_{mdw,i}$ is the instantaneous diluent mass flow rate, kg/s
- f is the data sampling rate, Hz
- n is the number of measurements

8.5. Full flow dilution measurement (CVS)

The concentration signals, either by integration over the cycle or by bag sampling, of the gaseous components shall be used for the calculation of the mass emissions by multiplication with the diluted exhaust mass flow rate. The exhaust mass flow rate shall be measured with a constant volume sampling (CVS) system, which may use a

positive displacement pump (PDP), a critical flow venturi (CFV) or a subsonic venturi (SSV) with or without flow compensation.

For bag sampling and particulate sampling, a proportional sample shall be taken from the diluted exhaust gas of the CVS system. For a system without flow compensation, the ratio of sample flow to CVS flow shall not vary by more than ± 2.5 per cent from the set point of the test. For a system with flow compensation, each individual flow rate shall be constant within ± 2.5 per cent of its respective target flow rate.

The complete test set up is schematically shown in figure 7.

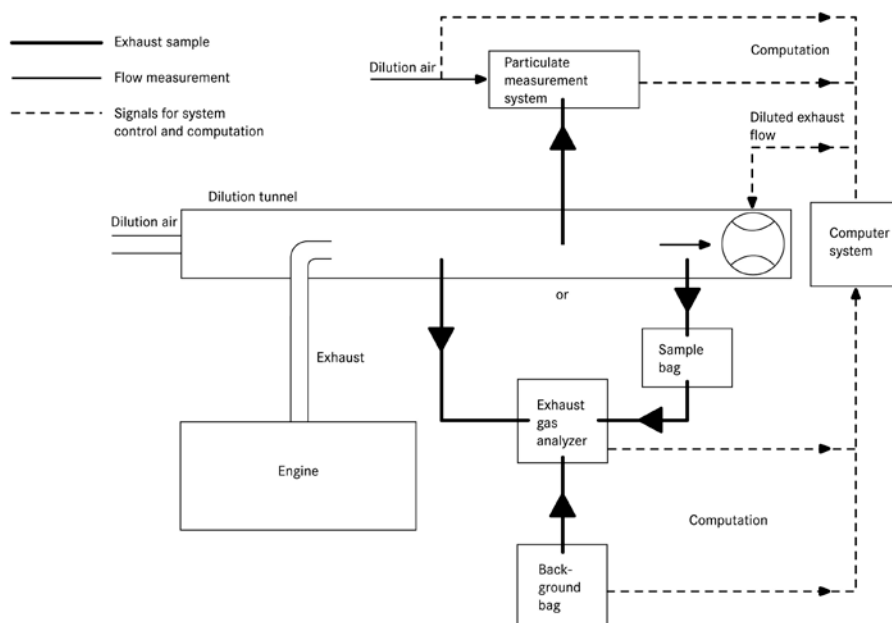


Figure 7:
Scheme of full flow measurement system

8.5.1. Determination of the diluted exhaust gas flow

8.5.1.1. Introduction

For calculation of the emissions in the diluted exhaust gas, it is necessary to know the diluted exhaust gas mass flow rate. 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 (V_0 for PDP, K_V for CFV, C_d for SSV) by either of the methods described in paragraphs 8.5.1.2. to 8.5.1.4. If the total sample flow of particulates (m_{sep}) exceeds 0.5 per cent of the total CVS flow (m_{ed}), the CVS flow shall be corrected for m_{sep} or the particulate sample flow shall be returned to the CVS prior to the flow measuring device.

8.5.1.2. PDP-CVS system

The calculation of the mass flow over the cycle is as follows, if the temperature of the diluted exhaust is kept within ± 6 K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \times V_0 \times n_p \times p_p \times 273 / (101.3 \times T) \quad (49)$$

where:

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

n_p is the total revolutions of pump per test

p_p is the absolute pressure at pump inlet, kPa

T is the average temperature of the diluted exhaust gas at pump 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:

$$m_{ed,i} = 1.293 \times V_0 \times n_{p,i} \times p_p \times 273 / (101.3 \times T) \quad (50)$$

where:

$n_{p,i}$ is the total revolutions of pump per time interval

8.5.1.3. CFV-CVS system

The calculation of the mass flow over the cycle is as follows, if the temperature of the diluted exhaust is kept within ± 11 K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \times t \times K_v \times p_p / T^{0.5} \quad (51)$$

where:

t is the cycle time, s

K_v is the calibration coefficient of the critical flow venturi for standard conditions,

p_p is the absolute pressure at venturi inlet, kPa

T is the 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:

$$m_{ed,i} = 1.293 \times \Delta t_i \times K_v \times p_p / T^{0.5} \quad (52)$$

where:

Δt_i is the time interval, s

8.5.1.4. SSV-CVS system

The calculation of the mass flow over the cycle shall be as follows, if the temperature of the diluted exhaust is kept within ± 11 K over the cycle by using a heat exchanger:

$$m_{ed} = 1.293 \times Q_{SSV} \quad (53)$$

with

$$Q_{SSV} = A_0 d_v^2 C_d p_p \sqrt{\left[\frac{1}{T} \left(r_p^{1.4286} - r_p^{1.7143} \right) \cdot \left(\frac{1}{1 - r_D^4 r_p^{1.4286}} \right) \right]} \quad (54)$$

where:

$$A_0 \text{ is } 0.006111 \text{ in SI units of } \left(\frac{m^3}{\text{min}} \right) \left(\frac{K^{\frac{1}{2}}}{kPa} \right) \left(\frac{1}{mm^2} \right)$$

d_v is the diameter of the SSV throat, m

C_d is the discharge coefficient of the SSV

p_p is the absolute pressure at venturi inlet, kPa

T is the temperature at the venturi inlet, K

r_p is the ratio of the SSV throat to inlet absolute static pressure, $1 - \frac{\Delta p}{p_a}$

r_D is the ratio of the SSV throat diameter, d , to the inlet pipe inner diameter D

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:

$$m_{ed} = 1.293 \times Q_{SSV} \times \Delta t_i \quad (55)$$

where:

Δt_i is the time interval, s

The real time calculation shall be initialized with either a reasonable value for C_d , such as 0.98, or a reasonable value of Q_{SSV} . If the calculation is initialized with Q_{SSV} , the initial value of Q_{SSV} shall be used to evaluate the Reynolds number.

During all emissions tests, the Reynolds number at the SSV throat shall be in the range of Reynolds numbers used to derive the calibration curve developed in paragraph 9.5.4.

8.5.2. Determination of the gaseous components

8.5.2.1. Introduction

The gaseous components in the diluted exhaust gas emitted by the engine submitted for testing shall be measured by the methods described in Annex 3. Dilution of the exhaust shall be done with filtered ambient air, synthetic air or nitrogen. The flow capacity of the full flow system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. Data evaluation and calculation procedures are described in paragraphs 8.5.2.2. and 8.5.2.3.

8.5.2.2. Data evaluation

For continuous sampling, the emission concentrations (HC, CO and NO_x) shall be recorded and stored with at least 1 Hz on a computer system, for bag sampling one mean value per test is required. The diluted exhaust gas mass flow rate and all other data shall be recorded with a sample rate of at least 1 Hz. For analogue analyzers the response will be recorded, and the calibration data may be applied online or offline during the data evaluation.

8.5.2.3. Calculation of mass emission

8.5.2.3.1. Systems with constant mass flow

For systems with heat exchanger, the mass of the pollutants shall be determined from the following equation:

$$m_{\text{gas}} = u_{\text{gas}} \times c_{\text{gas}} \times m_{\text{ed}} \quad (\text{in g/test}) \quad (56)$$

where:

u_{gas} is the ratio between density of exhaust component and density of air

c_{gas} is the average background corrected concentration of the component, ppm

m_{ed} is the total diluted exhaust mass over the cycle, kg

If measured on a dry basis, the dry/wet correction according to paragraph 8.1. shall be applied.

For the calculation of NO_x, the mass emission shall be multiplied, if applicable, with the humidity correction factor $k_{\text{h,D}}$, or $k_{\text{h,G}}$, as determined according to paragraph 8.2.

The u values are given in table 6. For calculating the u_{gas} values, the density of the diluted exhaust gas has been assumed to be equal to air density. Therefore, the u_{gas} values are identical for single gas components, but different for HC.

Fuel	ρ_{de}	Gas					
		NO _x	CO	HC	CO ₂	O ₂	CH ₄
		ρ_{gas} [kg/m ³]					
		2.053	1.250	a)	1.9636	1.4277	0.716
u_{gas} ^{b)}							
Diesel	1.293	0.001588	0.000967	0.000480	0.001519	0.001104	0.000553
Ethanol	1.293	0.001588	0.000967	0.000795	0.001519	0.001104	0.000553
CNG ^{c)}	1.293	0.001588	0.000967	0.000584 ^{d)}	0.001519	0.001104	0.000553
Propane	1.293	0.001588	0.000967	0.000507	0.001519	0.001104	0.000553
Butane	1.293	0.001588	0.000967	0.000501	0.001519	0.001104	0.000553
LPG ^{e)}	1.293	0.001588	0.000967	0.000505	0.001519	0.001104	0.000553
a) depending on fuel b) at $\lambda = 2$, dry air, 273 K, 101.3 kPa c) u accurate within 0.2 % for mass composition of: C = 66 - 76 %; H = 22 - 25 %; N = 0 - 12 % d) NMHC on the basis of CH _{2.93} (for total HC the u_{gas} coefficient of CH ₄ shall be used) e) u accurate within 0.2 % for mass composition of: C3 = 70 - 90 %; C4 = 10 - 30 %							

Table 6:
Diluted exhaust gas u values and component densities

Alternatively, the u values may be calculated using the exact calculation method generally described in paragraph 8.4.2.4., as follows:

$$u_{gas} = \frac{M_{gas}}{M_d \times \left(1 - \frac{1}{D}\right) + M_e \times \left(\frac{1}{D}\right)} \tag{57}$$

where:

M_{gas} is the molar mass of the gas component, g/mol (cf. Annex 6)

M_e is the molar mass of the exhaust gas, g/mol

M_d is the molar mass of the diluent = 28.965 g/mol

D is the dilution factor (see paragraph 8.5.2.3.2.)

8.5.2.3.2. Determination of the background corrected concentrations

The average background concentration of the gaseous pollutants in the diluent shall be subtracted from the 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 equation shall be used:

$$c_{gas} = c_{gas,e} - c_d \times (1 - (1/D)) \tag{58}$$

where:

$c_{gas,e}$ is the concentration of the component measured in the diluted exhaust gas, ppm

c_d is the concentration of the component measured in the diluent, ppm

D is the dilution factor

The dilution factor shall be calculated as follows:

a) for diesel and LPG fuelled gas engines

$$D = \frac{F_S}{c_{\text{CO}_2,e} + (c_{\text{HC},e} + c_{\text{CO},e}) \times 10^{-4}} \quad (59)$$

b) for NG fuelled gas engines

$$D = \frac{F_S}{c_{\text{CO}_2,e} + (c_{\text{NMHC},e} + c_{\text{CO},e}) \times 10^{-4}} \quad (60)$$

where:

- $c_{\text{CO}_2,e}$ is the wet concentration of CO₂ in the diluted exhaust gas, per cent vol
- $c_{\text{HC},e}$ is the wet concentration of HC in the diluted exhaust gas, ppm C1
- $c_{\text{NMHC},e}$ is the wet concentration of NMHC in the diluted exhaust gas, ppm C1
- $c_{\text{CO},e}$ is the wet concentration of CO in the diluted exhaust gas, ppm
- F_S is the stoichiometric factor

The stoichiometric factor shall be calculated as follows:

$$F_S = 100 \times \frac{1}{1 + \frac{\alpha}{2} + 3.76 \times \left(1 + \frac{\alpha}{4}\right)} \quad (61)$$

where:

- α is the molar hydrogen ratio of the fuel (H/C)

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

$$\begin{aligned} F_S \text{ (diesel)} &= 13.4 \\ F_S \text{ (LPG)} &= 11.6 \\ F_S \text{ (NG)} &= 9.5 \end{aligned}$$

8.5.2.3.3. 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 equation shall be applied:

$$m_{\text{gas}} = \sum_{i=1}^n [(m_{\text{ed},i} \times c_{\text{gas},e} \times u_{\text{gas}})] - [(m_{\text{ed}} \times c_d \times (1 - 1/D) \times u_{\text{gas}})] \quad (62)$$

where:

$c_{\text{gas,e}}$ is the concentration of the component measured in the diluted exhaust gas, ppm

c_d is the concentration of the component measured in the diluent, ppm

$m_{\text{ed,i}}$ is the instantaneous mass of the diluted exhaust gas, kg

m_{ed} is the total mass of diluted exhaust gas over the cycle, kg

u_{gas} is the tabulated value from table 6

D is the dilution factor

8.5.3. Particulate determination

8.5.3.1. Calculation of mass emission

The particulate mass (g/test) shall be calculated after buoyancy correction of the particulate sample filter according to paragraph 8.3., as follows:

$$m_{\text{PM}} = \frac{m_p}{m_{\text{sep}}} \times \frac{m_{\text{ed}}}{1,000} \quad (63)$$

where:

m_p is the particulate mass sampled over the cycle, mg

m_{sep} is the mass of diluted exhaust gas passing the particulate collection filters, kg

m_{ed} is the mass of diluted exhaust gas over the cycle, kg

with

$$m_{\text{sep}} = m_{\text{set}} - m_{\text{ssd}} \quad (64)$$

where:

m_{set} is the mass of double diluted exhaust gas through particulate filter, kg

m_{ssd} is the mass of secondary diluent, kg

If the particulate background level of the diluent is determined in accordance with paragraph 7.5.6., the particulate mass may be background corrected. In this case, the particulate mass (g/test) shall be calculated as follows:

$$m_{\text{PM}} = \left[\frac{m_p}{m_{\text{sep}}} - \left(\frac{m_b}{m_{\text{sd}}} \times \left(1 - \frac{1}{D} \right) \right) \right] \times \frac{m_{\text{ed}}}{1,000} \quad (65)$$

where:

m_{sep} is the mass of diluted exhaust gas passing the particulate collection filters, kg

m_{ed} is the mass of diluted exhaust gas over the cycle, kg

m_{sd} is the mass of diluent sampled by background particulate sampler, kg

m_b is the mass of the collected background particulates of the diluent, mg

D is the dilution factor as determined in paragraph 8.5.2.3.2.

8.6. General calculations

8.6.1. Drift correction

With respect to drift verification in paragraph 7.8.4., the corrected concentration value shall be calculated as follows:

$$c_{\text{cor}} = c_{\text{ref},z} + (c_{\text{ref},s} - c_{\text{ref},z}) \left(\frac{2 \cdot c_{\text{gas}} - (c_{\text{pre},z} + c_{\text{post},z})}{(c_{\text{pre},s} + c_{\text{post},s}) - (c_{\text{pre},z} + c_{\text{post},z})} \right) \quad (66)$$

where:

- $c_{\text{ref},z}$ is the reference concentration of the zero gas (usually zero), ppm
- $c_{\text{ref},s}$ is the reference concentration of the span gas, ppm
- $c_{\text{pre},z}$ is the pre-test analyzer concentration of the zero gas, ppm
- $c_{\text{pre},s}$ is the pre-test analyzer concentration of the span gas, ppm
- $c_{\text{post},z}$ is the post-test analyzer concentration of the zero gas, ppm
- $c_{\text{post},s}$ is the post-test analyzer concentration of the span gas, ppm
- c_{gas} is the sample gas concentration, ppm

Two sets of brake-specific emission results shall be calculated for each component in accordance with paragraphs 8.3. and/or 8.4., after any other corrections have been applied. One set shall be calculated using uncorrected concentrations and another set shall be calculated using the concentrations corrected for drift according to equation 59.

Depending on the measurement system and calculation method used, the uncorrected emissions results shall be calculated with equations 30, 31 50, 51 or 55, respectively. For calculation of the corrected emissions, c_{gas} in equations 30, 31 50, 51 or 55, respectively, shall be replaced with c_{cor} of equation 59. If instantaneous concentration values $c_{\text{gas},i}$ are used in the respective equation, the corrected value shall also be applied as instantaneous value $c_{\text{cor},i}$. In equation 51, the correction shall be applied to both the measured and the background concentration.

The comparison shall be made as a percentage of the uncorrected results. The difference between the uncorrected and the corrected brake-specific emission values shall be within ± 4 per cent of the uncorrected brake-specific emission values or within ± 4 per cent of the respective limit value, whichever is greater. If the drift is greater than 4 per cent, the test shall be voided.

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

8.6.2. Calculation of NMHC and CH₄ with the non-methane cutter

The calculation of NMHC and CH₄ depends on the calibration method used. The FID for the measurement without NMC (lower path of Annex 3, figure 11), shall be

calibrated with propane. For the calibration of the FID in series with NMC (upper path of Annex 3, figure 11), the following methods are permitted.

(a) calibration gas – propane; propane bypasses NMC,

(b) calibration gas – methane; methane passes through NMC

The concentration of NMHC and CH₄ shall be calculated as follows for (a):

$$: \quad c_{NMHC} = \frac{c_{HC(w/oNMC)} \times (1 - E_M) - c_{HC(w/NMC)}}{E_E - E_M} \quad (67)$$

$$c_{CH_4} = \frac{c_{HC(w/NMC)} - c_{HC(w/oNMC)} \times (1 - E_E)}{r_h \times (E_E - E_M)} \quad (68)$$

The concentration of NMHC and CH₄ shall be calculated as follows for (b):

$$c_{NMHC} = \frac{c_{HC(w/oNMC)} \times (1 - E_M) - c_{HC(w/NMC)} \times r_h \times (1 - E_M)}{E_E - E_M} \quad (67a)$$

$$c_{CH_4} = \frac{c_{HC(w/NMC)} \times r_h \times (1 - E_M) - c_{HC(w/oNMC)} \times (1 - E_E)}{r_h \times (E_E - E_M)} \quad (68a)$$

where:

$c_{HC(w/NMC)}$ is the HC concentration with sample gas flowing through the NMC, ppm

$c_{HC(w/oNMC)}$ is the HC concentration with sample gas bypassing the NMC, ppm

r_h is the methane response factor as determined per paragraph 9.3.7.2.

E_M is the methane efficiency as determined per paragraph 9.3.8.1.

E_E is the ethane efficiency as determined per paragraph 9.3.8.2.

If $r_h < 1.05$, it may be omitted in equations 67, 67a and 68a.

8.6.3. Calculation of the specific emissions

The specific emissions e_{gas} or e_{PM} (g/kWh) shall be calculated for each individual component in the following ways depending on the type of test cycle.

The following formula shall be applied:

- (a) for the WHSC, hot WHTC, or cold WHTC

$$e = \frac{m}{W_{\text{act}}} \quad (69)$$

- (b) for HEC and HPC (hybrid vehicles)

$$e = \frac{m}{W_{\text{sys}}} \quad (69a)$$

where:

m is the mass emission of the component, g/test

W_{act} is the actual cycle work as determined according to paragraph 7.8.6., kWh

W_{sys} is the shaft output work as determined according to annex 8, paragraph 5.3, kWh (for HEC, HPC)

The final test result shall be a weighted average from cold start test and hot start test in accordance with the following equations.

- (a) for the WHTC,

$$e = \frac{(0.14 \times m_{\text{cold}}) + (0.86 \times m_{\text{hot}})}{(0.14 \times W_{\text{act,cold}}) + (0.86 \times W_{\text{act,hot}})} \quad (70)$$

- (b) for HEC and HPC (hybrid vehicles)

$$e = \frac{(0.14 \times m_{\text{cold}}) + (0.86 \times m_{\text{hot}})}{(0.14 \times W_{\text{sys,cold}}) + (0.86 \times W_{\text{sys,hot}})} \quad (70a)$$

where:

m_{cold} is the mass emission of the component on the cold start test, g/test

m_{hot} is the mass emission of the component on the hot start test, g/test

$W_{\text{act,cold}}$ is the actual cycle work on the cold start test, kWh

$W_{\text{act,hot}}$ is the actual cycle work on the hot start test, kWh

$W_{\text{sys,cold}}$ is the shaft output work on the cold start test, kWh

$W_{\text{sys,hot}}$ is the shaft output work on the hot start test, kWh

If periodic regeneration in accordance with paragraph 6.6.2 applies, the regeneration adjustment factors $k_{r,u}$ or $k_{r,d}$ shall be multiplied with or be added to, respectively, the specific emissions result e as determined in equations 69 and 70.”

9. EQUIPMENT SPECIFICATION AND VERIFICATION

This gtr does not contain details of flow, pressure, and temperature measuring equipment or systems. Instead, only the linearity requirements of such equipment or systems necessary for conducting an emissions test are given in paragraph 9.2.

9.1. Dynamometer specification

An engine dynamometer with adequate characteristics to perform the appropriate test cycle described in paragraphs 7.2.1. and 7.2.2. shall be used.

The instrumentation for torque and speed measurement shall allow the measurement accuracy of the shaft power as needed to comply with the cycle validation criteria. Additional calculations may be necessary. The accuracy of the measuring equipment shall be such that the linearity requirements given in paragraph 9.2., table 7 are not exceeded.

9.2. Linearity requirements

The calibration of all measuring instruments and systems shall be traceable to national (international) standards. The measuring instruments and systems shall comply with the linearity requirements given in table 7. The linearity verification according to paragraph 9.2.1. shall be performed for the gas analyzers at least every 3 months or whenever a system repair or change is made that could influence calibration. For the other instruments and systems, the linearity verification shall be done as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements.

Measurement system	$ x_{\min} \cdot (a_1 - 1) + a_0 $	Slope a_1	Standard error SEE	Coefficient of determination r^2
Engine speed	$\leq 0.05\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Engine torque	$\leq 1\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Fuel flow	$\leq 1\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Airflow	$\leq 1\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Exhaust gas flow	$\leq 1\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Diluent flow	$\leq 1\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Diluted exhaust gas flow	$\leq 1\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Sample flow	$\leq 1\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Gas analyzers	$\leq 0.5\% \text{ max}$	0.99 - 1.01	$\leq 1\% \text{ max}$	≥ 0.998
Gas dividers	$\leq 0.5\% \text{ max}$	0.98 - 1.02	$\leq 2\% \text{ max}$	≥ 0.990
Temperatures	$\leq 1\% \text{ max}$	0.99 - 1.01	$\leq 1\% \text{ max}$	≥ 0.998
Pressures	$\leq 1\% \text{ max}$	0.99 - 1.01	$\leq 1\% \text{ max}$	≥ 0.998
PM balance	$\leq 1\% \text{ max}$	0.99 - 1.01	$\leq 1\% \text{ max}$	≥ 0.998

Table 7:
Linearity requirements of instruments and measurement systems

9.2.1. Linearity verification

9.2.1.1. Introduction

A linearity verification shall be performed for each measurement system listed in table 7. At least 10 reference values, or as specified otherwise, shall be introduced to the measurement system, and the measured values shall be compared to the reference values by using a least squares linear regression in accordance with equation 11. The maximum limits in table 6 refer to the maximum values expected during testing.

9.2.1.2. General requirements

The measurement systems shall be warmed up according to the recommendations of the instrument manufacturer. The measurement systems shall be operated at their specified temperatures, pressures and flows.

9.2.1.3. Procedure

The linearity verification shall be run for each normally used operating range with the following steps.

- (a) The instrument shall be set at zero by introducing a zero signal. For gas analyzers, purified synthetic air (or nitrogen) shall be introduced directly to the analyzer port.

- (b) The instrument shall be spanned by introducing a span signal. For gas analyzers, an appropriate span gas shall be introduced directly to the analyzer port.
- (c) The zero procedure of (a) shall be repeated.
- (d) The verification shall be established by introducing at least 10 reference values (including zero) that are within the range from zero to the highest values expected during emission testing. For gas analyzers, known gas concentrations shall be introduced directly to the analyzer port.
- (e) At a recording frequency of at least 1 Hz, the reference values shall be measured and the measured values recorded for 30 s.
- (f) The arithmetic mean values over the 30 s period shall be used to calculate the least squares linear regression parameters according to equation 11 in paragraph 7.8.7.
- (g) The linear regression parameters shall meet the requirements of paragraph 9.2., table 7.
- (h) The zero setting shall be rechecked and the verification procedure repeated, if necessary.

9.3. Gaseous emissions measurement and sampling system

9.3.1. Analyzer specifications

9.3.1.1. General

The analyzers shall have a measuring range and response time appropriate for the accuracy required to measure the concentrations of the exhaust gas components under transient and steady state conditions.

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

9.3.1.2. Accuracy

The accuracy, defined as the deviation of the analyzer reading from the reference value, shall not exceed ± 2 per cent of the reading or ± 0.3 per cent of full scale whichever is larger.

9.3.1.3. Precision

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1 per cent of full scale concentration for each range used above 155 ppm (or ppm C) or 2 per cent of each range used below 155 ppm (or ppm C).

9.3.1.4. Noise

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

9.3.1.5. Zero drift

The drift of the zero response shall be specified by the instrument manufacturer.

9.3.1.6. Span drift

The drift of the span response shall be specified by the instrument manufacturer.

9.3.1.7. Rise time

The rise time of the analyzer installed in the measurement system shall not exceed 2.5 s.

9.3.1.8. Gas drying

Exhaust gases may be measured wet or dry. A gas-drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

9.3.2. Gas analyzers

9.3.2.1. Introduction

Paragraphs 9.3.2.2 to 9.2.3.7 describe the measurement principles to be used. A detailed description of the measurement systems is given in Annex 3. The gases to be measured shall be analyzed with the following instruments. For non-linear analyzers, the use of linearizing circuits is permitted.

9.3.2.2. Carbon monoxide (CO) analysis

The carbon monoxide analyzer shall be of the non-dispersive infrared (NDIR) absorption type.

9.3.2.3. Carbon dioxide (CO₂) analysis

The carbon dioxide analyzer shall be of the non-dispersive infrared (NDIR) absorption type.

9.3.2.4. Hydrocarbon (HC) analysis

The hydrocarbon analyzer shall be of the heated flame ionization detector (HFID) type with detector, valves, pipework, etc. heated so as to maintain a gas temperature of $463\text{ K} \pm 10\text{ K}$ ($190 \pm 10\text{ }^\circ\text{C}$). Optionally, for NG fuelled and PI engines, the

hydrocarbon analyzer may be of the non-heated flame ionization detector (FID) type depending upon the method used (see Annex 3, paragraph A.3.1.3.).

9.3.2.5. Non-methane hydrocarbon (NMHC) analysis

The determination of the non-methane hydrocarbon fraction shall be performed with a heated non-methane cutter (NMC) operated in line with an FID as per Annex 3, paragraph A.3.1.4. by subtraction of the methane from the hydrocarbons. For determination of NMHC and CH₄, the FID may be calibrated and spanned with CH₄ calibration gas.

9.3.2.6. Oxides of nitrogen (NO_x) analysis

Two measurement instruments are specified for NO_x measurement and either instrument may be used provided it meets the criteria specified in paragraph 9.3.2.6.1. or 9.3.2.6.2., respectively. For the determination of system equivalency of an alternate measurement procedure in accordance with paragraph 5.1.1., only the CLD is permitted.

9.3.2.6.1. Chemiluminescent detector (CLD)

If measured on a dry basis, the oxides of nitrogen analyzer shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with a NO₂/NO converter. 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 paragraph 9.3.9.2.2.) is satisfied. For both CLD and HCLD, the sampling path shall be maintained at a wall temperature of 328 K to 473 K (55 °C to 200 °C) up to the converter for dry measurement, and up to the analyzer for wet measurement.

9.3.2.6.2. Non-dispersive ultraviolet detector (NDUV)

A non-dispersive ultraviolet (NDUV) analyzer shall be used to measure NO_x concentration. If the NDUV analyzer measures only NO, a NO₂/NO converter shall be placed upstream of the NDUV analyzer. The NDUV temperature shall be maintained to prevent aqueous condensation, unless a sample dryer is installed upstream of the NO₂/NO converter, if used, or upstream of the analyzer.

9.3.2.7. Air to fuel measurement

The air to fuel measurement equipment used to determine the exhaust gas flow as specified in paragraph 8.4.1.6. shall be a wide range air to fuel ratio sensor or lambda sensor of Zirconia type. The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

The accuracy of the sensor with incorporated electronics shall be within:

± 3 per cent of reading	for	$\lambda < 2$
± 5 per cent of reading	for	$2 \leq \lambda < 5$

± 10 per cent of reading for $5 \leq \lambda$

To fulfill the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

9.3.3. Gases

The shelf life of all gases shall be respected.

9.3.3.1. Pure gases

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

a) For raw exhaust gas

Purified nitrogen

(Contamination ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO₂, ≤ 0.1 ppm NO)

Purified oxygen

(Purity > 99.5 per cent vol O₂)

Hydrogen-helium mixture (FID burner fuel)

(40 ± 1 per cent hydrogen, balance helium)

(Contamination ≤ 1 ppm C1, ≤ 400 ppm CO₂)

Purified synthetic air

(Contamination ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO₂, ≤ 0.1 ppm NO)

(Oxygen content between 18-21 per cent vol.)

b) For dilute exhaust gas (optionally for raw exhaust gas)

Purified nitrogen

(Contamination ≤ 0.05 ppm C1, ≤ 1 ppm CO, ≤ 10 ppm CO₂, ≤ 0.02 ppm NO)

Purified oxygen

(Purity > 99.5 per cent vol O₂)

Hydrogen-helium mixture (FID burner fuel)

(40 ± 1 per cent hydrogen, balance helium)

(Contamination ≤ 0.05 ppm C1, ≤ 10 ppm CO₂)

Purified synthetic air

(Contamination ≤ 0.05 ppm C1, ≤ 1 ppm CO, ≤ 10 ppm CO₂, ≤ 0.02 ppm NO)

(Oxygen content between 20.5 - 21.5 per cent vol.)

If gas bottles are not available, a gas purifier may be used, if contamination levels can be demonstrated.

9.3.3.2. Calibration and span gases

Mixtures of gases having the following chemical compositions shall be available, if applicable. Other gas combinations are allowed provided the gases do not react with one another. The expiration date of the calibration gases stated by the manufacturer shall be recorded.

C₃H₈ and purified synthetic air (see paragraph 9.3.3.1.);

CO and purified nitrogen;

NO and purified nitrogen;

NO₂ and purified synthetic air;

CO₂ and purified nitrogen;

CH₄ and purified synthetic air;

C₂H₆ and purified synthetic air

The true concentration of a calibration and span gas shall be within ± 1 per cent of the nominal value, and shall be traceable to national or international standards. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

9.3.3.3. *Gas dividers*

The gases used for calibration and span may also be obtained by means of gas dividers (precision blending devices), diluting with purified N₂ or with purified synthetic air. The accuracy of the gas divider shall be such that the concentration of the blended calibration gases is accurate to within ± 2 per cent. This accuracy implies that primary gases used for blending shall be known to an accuracy of at least ± 1 per cent, traceable to national or international gas standards. The verification shall be performed at between 15 and 50 per cent of full scale for each calibration incorporating a gas divider. An additional verification may be performed using another calibration gas, if the first verification has failed.

Optionally, the blending device may be checked with an instrument which by nature is linear, e.g. using NO gas with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The gas divider shall be checked at the settings used and the nominal value shall be compared to the measured concentration of the instrument. This difference shall in each point be within ± 1 per cent of the nominal value.

For conducting the linearity verification according to paragraph 9.2.1., the gas divider shall be accurate to within ± 1 per cent.

9.3.3.4. Oxygen interference check gases

Oxygen interference check gases are a blend of propane, oxygen and nitrogen. They shall contain propane with $350 \text{ ppm C} \pm 75 \text{ ppm C}$ hydrocarbon. The concentration value shall be determined to calibration gas tolerances by chromatographic analysis of total hydrocarbons plus impurities or by dynamic blending. The oxygen concentrations required for positive ignition and compression ignition engine testing are listed in table 8 with the remainder being purified nitrogen.

Type of engine	O ₂ concentration (per cent)
Compression ignition	21 (20 to 22)
Compression and positive ignition	10 (9 to 11)
Compression and positive ignition	5 (4 to 6)
Positive ignition	0 (0 to 1)

Table 8:
Oxygen interference check gases

9.3.4. *Leak check*

A system leak check shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyzer pump shall be switched on. After an initial stabilization period all flowmeters will read approximately zero in the absence of a leak. 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 per cent of the in-use flow rate for the portion of the system being checked. The analyzer flows and bypass flows may be used to estimate the in-use flow rates.

Alternatively, the system may be evacuated to a pressure of at least 20 kPa vacuum (80 kPa absolute). After an initial stabilization period the pressure increase Δp (kPa/min) in the system shall not exceed:

$$\Delta p = p / V_s \times 0.005 \times q_{vs} \tag{71}$$

where:

V_s is the system volume, l
 q_{vs} is the system flow rate, l/min

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 for a correctly calibrated analyzer after an adequate period of time the reading is ≤ 99 per cent compared to the introduced concentration, this points to a leakage problem that shall be corrected.

9.3.5. Response time check of the analytical system

The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analyzers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 s. The gases used for the test shall cause a concentration change of at least 60 per cent full scale (FS).

The concentration trace of each single gas component shall be recorded. The response time is defined to be the difference in time between the gas switching and the appropriate change of the recorded concentration. The system response time (t_{90}) consists of the delay time to the measuring detector and the rise time of the detector. The delay time is defined as the time from the change (t_0) until the response is 10 per cent of the final reading (t_{10}). The rise time is defined as the time between 10 per cent and 90 per cent response of the final reading ($t_{90} - t_{10}$).

For time alignment of the analyzer and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 per cent of the final reading (t_{50}).

The system response time shall be ≤ 10 s with a rise time of ≤ 2.5 s in accordance with paragraph 9.3.1.7. for all limited components (CO, NO_x, HC or NMHC) and all ranges used. When using a NMC for the measurement of NMHC, the system response time may exceed 10 s.

9.3.6. Efficiency test of NO_x converter

The efficiency of the converter used for the conversion of NO₂ into NO is tested as given in paragraphs 9.3.6.1 to 9.3.6.8 (see figure 8).

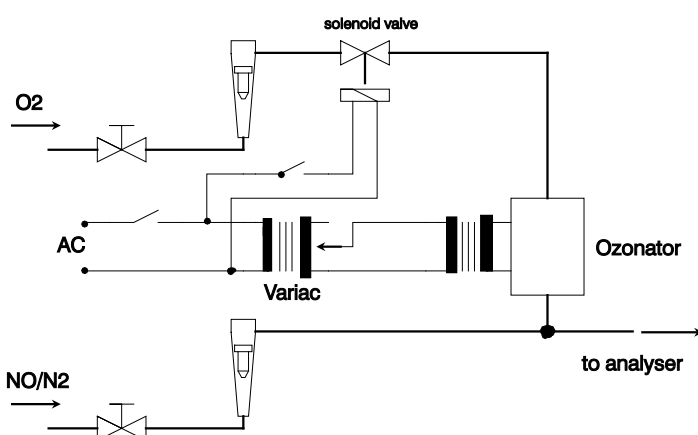


Figure 8:
Scheme of NO₂ converter efficiency device

9.3.6.1. Test setup

Using the test setup as schematically shown in figure 8 and the procedure below, the efficiency of the converter shall be tested by means of an ozonator.

9.3.6.2. 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 shall amount to about 80 per cent of the operating range and the NO₂ concentration of the gas mixture to less than 5 per cent of the NO concentration). The NO_x analyzer shall be in the NO mode so that the span gas does not pass through the converter. The indicated concentration has to be recorded.

9.3.6.3. Calculation

The per cent efficiency of the converter shall be calculated as follows:

$$E_{\text{NO}_x} = \left(1 + \frac{a-b}{c-d} \right) \times 100 \quad (72)$$

where:

- a* is the NO_x concentration according to paragraph 9.3.6.6.
- b* is the NO_x concentration according to paragraph 9.3.6.7.
- c* is the NO concentration according to paragraph 9.3.6.4.
- d* is the NO concentration according to paragraph 9.3.6.5.

9.3.6.4. Adding of oxygen

Via a T-fitting, oxygen or zero air shall be added continuously to the gas flow until the concentration indicated is about 20 per cent less than the indicated calibration concentration given in paragraph 9.3.6.2. (the analyzer is in the NO mode).

The indicated concentration (*c*) shall be recorded. The ozonator is kept deactivated throughout the process.

9.3.6.5. Activation of the ozonator

The ozonator shall be activated to generate enough ozone to bring the NO concentration down to about 20 per cent (minimum 10 per cent) of the calibration concentration given in paragraph 9.3.6.2. The indicated concentration (*d*) shall be recorded (the analyzer is in the NO mode).

9.3.6.6. NO_x mode

The NO analyzer shall be switched to the NO_x mode so that the gas mixture (consisting of NO, NO₂, O₂ and N₂) now passes through the converter. The indicated concentration (*a*) shall be recorded (the analyzer is in the NO_x mode).

9.3.6.7. Deactivation of the ozonator

The ozonator is now deactivated. The mixture of gases described in paragraph 9.3.6.6. passes through the converter into the detector. The indicated concentration (*b*) shall be recorded (the analyzer is in the NO_x mode).

9.3.6.8. NO mode

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air shall be shut off. The NO_x reading of the analyzer shall not deviate by more than ± 5 per cent from the value measured according to paragraph 9.3.6.2. (the analyzer is in the NO mode).

9.3.6.9. Test interval

The efficiency of the converter shall be tested at least once per month.

9.3.6.10. Efficiency requirement

The efficiency of the converter E_{NO_x} shall not be less than 95 per cent.

If, with the analyzer in the most common range, the ozonator cannot give a reduction from 80 per cent to 20 per cent according to paragraph 9.3.6.5., the highest range which will give the reduction shall be used.

9.3.7. Adjustment of the FID

9.3.7.1. Optimization of the detector response

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

With the fuel and airflow rates set at the manufacturer's recommendations, a 350 ± 75 ppm C span gas shall be introduced to the analyzer. 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. This is the initial flow rate setting which may need further optimization depending on the results of the hydrocarbon response factors and the oxygen interference check according to paragraphs 9.3.7.2. and 9.3.7.3. If the oxygen interference or the

hydrocarbon response factors do not meet the following specifications, the airflow shall be incrementally adjusted above and below the manufacturer's specifications, repeating paragraphs 9.3.7.2. and 9.3.7.3. for each flow.

The optimization may optionally be conducted using the procedures outlined in SAE paper No. 770141.

9.3.7.2. Hydrocarbon response factors

A linearity verification of the analyzer shall be performed using propane in air and purified synthetic air according to paragraph 9.2.1.3.

Response factors shall be determined when introducing an analyzer into service and after major service intervals. The response factor (r_h) 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 shall be at a level to give a response of approximately 80 per cent of full scale. The concentration shall be known to an accuracy of ± 2 per cent in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be preconditioned for 24 hours at a temperature of $298 \text{ K} \pm 5 \text{ K}$ ($25 \text{ }^\circ\text{C} \pm 5 \text{ }^\circ\text{C}$).

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

- | | |
|--|---------------------------|
| (a) methane and purified synthetic air | $1.00 \leq r_h \leq 1.15$ |
| (b) propylene and purified synthetic air | $0.90 \leq r_h \leq 1.1$ |
| (c) toluene and purified synthetic air | $0.90 \leq r_h \leq 1.1$ |

These values are relative to a r_h of 1 for propane and purified synthetic air.

9.3.7.3. Oxygen interference check

For raw exhaust gas analyzers only, the oxygen interference check shall be performed when introducing an analyzer into service and after major service intervals.

A measuring range shall be chosen where the oxygen interference check gases will fall in the upper 50 per cent. The test shall be conducted with the oven temperature set as required. Oxygen interference check gas specifications are found in paragraph 9.3.3.4.

- the analyzer shall be set at zero,
- the analyzer shall be spanned with the 0 per cent oxygen blend for positive ignition engines. Compression ignition engine instruments shall be spanned with the 21 per cent oxygen blend.
- the zero response shall be rechecked. If it has changed by more than 0.5 per cent of full scale, steps (a) and (b) of this paragraph shall be repeated.

- (d) the 5 per cent and 10 per cent oxygen interference check gases shall be introduced.
- (e) the zero response shall be rechecked. If it has changed by more than ± 1 per cent of full scale, the test shall be repeated.
- (f) the oxygen interference E_{O_2} shall be calculated for each mixture in step (d) as follows:

$$E_{O_2} = (c_{ref,d} - c) \times 100 / c_{ref,d} \quad (73)$$

with the analyzer response being

$$c = \frac{c_{ref,b} \times c_{FS,b}}{c_{m,b}} \times \frac{c_{m,d}}{c_{FS,d}} \quad (74)$$

where:

$c_{ref,b}$ is the reference HC concentration in step (b), ppm C

$c_{ref,d}$ is the reference HC concentration in step (d), ppm C

$c_{FS,b}$ is the full scale HC concentration in step (b), ppm C

$c_{FS,d}$ is the full scale HC concentration in step (d), ppm C

$c_{m,b}$ is the measured HC concentration in step (b), ppm C

$c_{m,d}$ is the measured HC concentration in step (d), ppm C

- (g) The oxygen interference E_{O_2} shall be less than ± 1.5 per cent for all required oxygen interference check gases prior to testing.
- (h) If the oxygen interference E_{O_2} is greater than ± 1.5 per cent, corrective action may be taken by incrementally adjusting the airflow above and below the manufacturer's specifications, the fuel flow and the sample flow.
- (i) The oxygen interference shall be repeated for each new setting.

9.3.8. *Efficiency of the non-methane cutter (NMC)*

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 per cent, and for the other hydrocarbons represented by ethane is 100 per cent. 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 paragraph 8.6.2.).

9.3.8.1. 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:

$$E_M = 1 - \frac{c_{HC(w/NMC)}}{c_{HC(w/o NMC)}} \quad (75)$$

where:

$c_{\text{HC(w/NMC)}}$ is the HC concentration with CH_4 flowing through the NMC, ppm C
 $c_{\text{HC(w/o NMC)}}$ is the HC concentration with CH_4 bypassing the NMC, ppm C

9.3.8.2. 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:

$$E_E = 1 - \frac{c_{\text{HC(w/NMC)}}}{c_{\text{HC(w/o NMC)}}} \quad (76)$$

where:

$c_{\text{HC(w/NMC)}}$ is the HC concentration with C_2H_6 flowing through the NMC, ppm C
 $c_{\text{HC(w/o NMC)}}$ is the HC concentration with C_2H_6 bypassing the NMC, ppm C

9.3.9. *Interference effects*

Other gases than the one being analyzed 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 reaction. The interference checks in paragraphs 9.3.9.1. and 9.3.9.3. shall be performed prior to an analyzer's initial use and after major service intervals.

9.3.9.1. CO analyzer interference check

Water and CO_2 can interfere with the CO analyzer performance. Therefore, a CO_2 span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyzer response recorded. The analyzer response shall not be more than 2 per cent of the mean CO concentration expected during testing.

Interference procedures for CO_2 and H_2O may also be run separately. If the CO_2 and H_2O levels used are higher than the maximum levels expected during testing, each observed interference value shall be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference procedures concentrations of H_2O that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the two scaled interference values shall meet the tolerance specified in this paragraph.

9.3.9.2. NO_x analyzer quench checks for CLD analyzer

The two gases of concern for CLD (and HCLD) analyzers are CO₂ 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. If the CLD analyzer uses quench compensation algorithms that utilize H₂O and/or CO₂ measurement instruments, quench shall be evaluated with these instruments active and with the compensation algorithms applied.

9.3.9.2.1. CO₂ quench check

A CO₂ span gas having a concentration of 80 to 100 per cent of full scale of the maximum operating range shall be passed through the NDIR analyzer and the CO₂ value recorded as *A*. It shall then be diluted approximately 50 per cent with NO span gas and passed through the NDIR and CLD, with the CO₂ and NO values recorded as *B* and *C*, respectively. The CO₂ 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 per cent quench shall be calculated as follows:

$$E_{\text{CO}_2} = \left[1 - \left(\frac{C \times A}{(D \times A) - (D \times B)} \right) \right] \times 100 \quad (77)$$

where:

- A* is the undiluted CO₂ concentration measured with NDIR, per cent
- B* is the diluted CO₂ concentration measured with NDIR, per cent
- C* is the diluted NO concentration measured with (H)CLD, ppm
- D* is the undiluted NO concentration measured with (H)CLD, ppm

Alternative methods of diluting and quantifying of CO₂ and NO span gas values such as dynamic mixing/blending are permitted with the approval of the type approval or certification authority.

9.3.9.2.2. Water quench check

This check applies to wet gas concentration measurements only. Calculation of water quench shall 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 per cent to 100 per cent 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 water temperature shall be determined and recorded as *F*. 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 (in per cent) of the mixture shall be calculated as follows:

$$H = 100 \times (G / p_b) \quad (78)$$

and recorded as H . The expected diluted NO span gas (in water vapour) concentration shall be calculated as follows:

$$D_e = D \times (1 - H / 100) \quad (79)$$

and recorded as D_e . For diesel exhaust, the maximum exhaust water vapour concentration (in per cent) expected during testing shall be estimated, under the assumption of a fuel H/C ratio of 1.8/1, from the maximum CO₂ concentration in the exhaust gas A as follows:

$$H_m = 0.9 \times A \quad (80)$$

and recorded as H_m

The per cent water quench shall be calculated as follows:

$$E_{H_2O} = 100 \times ((D_e - C) / D_e) \times (H_m / H) \quad (81)$$

where:

D_e is the expected diluted NO concentration, ppm

C is the measured diluted NO concentration, ppm

H_m is the maximum water vapour concentration, per cent

H is the actual water vapour concentration, per cent

9.3.9.2.3. Maximum allowable quench

The combined CO₂ and water quench shall not exceed 2 per cent of full scale.

9.3.9.3. NO_x analyzer quench check for NDUV analyzer

Hydrocarbons and H₂O can positively interfere with a NDUV analyzer by causing a response similar to NO_x. If the NDUV analyzer uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously such measurements shall be conducted to test the algorithms during the analyzer interference verification.

9.3.9.3.1. Procedure

The NDUV analyzer shall be started, operated, zeroed, and spanned according to the instrument manufacturer's instructions. It is recommended to extract engine exhaust to perform this verification. A CLD shall be used to quantify NO_x in the exhaust. The CLD response shall be used as the reference value. Also HC shall be measured

in the exhaust with a FID analyzer. The FID response shall be used as the reference hydrocarbon value.

Upstream of any sample dryer, if used during testing, the engine exhaust shall be introduced into the NDUV analyzer. Time shall be allowed for the analyzer response to stabilize. Stabilization time may include time to purge the transfer line and to account for analyzer response. While all analyzers measure the sample's concentration, 30 s of sampled data shall be recorded, and the arithmetic means for the three analyzers calculated.

The CLD mean value shall be subtracted from the NDUV mean value. This difference shall be multiplied by the ratio of the expected mean HC concentration to the HC concentration measured during the verification, as follows:

$$E_{\text{HC/H}_2\text{O}} = (c_{\text{NO}_x,\text{CLD}} - c_{\text{NO}_x,\text{NDUV}}) \times \left(\frac{c_{\text{HC},e}}{c_{\text{HC},m}} \right) \quad (82)$$

where

$c_{\text{NO}_x,\text{CLD}}$ is the measured NO_x concentration with CLD, ppm
 $c_{\text{NO}_x,\text{NDUV}}$ is the measured NO_x concentration with NDUV, ppm
 $c_{\text{HC},e}$ is the expected max. HC concentration, ppm
 $c_{\text{HC},m}$ is the measured HC concentration, ppm

9.3.9.3.2. Maximum allowable quench

The combined HC and water quench shall not exceed 2 per cent of the NO_x concentration expected during testing.

9.3.9.4. *Sample dryer (to be aligned with gtr No 11)*

A sample dryer removes water, which can otherwise interfere with a NO_x measurement.

9.3.9.4.1. Sample dryer efficiency

For dry CLD analyzers, it shall be demonstrated that for the highest expected water vapour concentration H_m (see paragraph 9.3.9.2.2.), the sample dryer maintains CLD humidity at ≤ 5 g water/kg dry air (or about 0.008 per cent H_2O), which is 100 per cent relative humidity at 3.9 °C and 101.3 kPa. This humidity specification is also equivalent to about 25 per cent relative humidity at 25 °C and 101.3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD. Humidity of the CLD exhaust might also be measured as long as the only flow into the CLD is the flow from the dehumidifier.

9.3.9.4.2. Sample dryer NO_2 penetration

Liquid water remaining in an improperly designed sample dryer can remove NO₂ from the sample. If a sample dryer is used in combination with an NDUV analyzer without an NO₂/NO converter upstream, it could therefore remove NO₂ from the sample prior to NO_x measurement.

The sample dryer shall allow for measuring at least 95 per cent of the total NO₂ at the maximum expected concentration of NO₂.

9.3.10. Sampling for raw gaseous emissions, if applicable

The gaseous emissions sampling probes shall 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 but 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 recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest CO₂ emission. For exhaust emission calculation the total exhaust mass flow shall be used.

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

9.3.11. Sampling for dilute gaseous emissions, if applicable

The exhaust pipe between the engine and the full flow dilution system shall conform to the requirements laid down in Annex 3. The gaseous emissions sample probe(s) shall be installed in the dilution tunnel at a point where the diluent and exhaust gas are well mixed, and in close proximity to the particulates sampling probe.

Sampling can generally be done in two ways:

- (a) the emissions are sampled into a sampling bag over the cycle and measured after completion of the test; for HC, the sample bag shall be heated to 464 ± 11 K (191 ± 11 °C), for NO_x, the sample bag temperature shall be above the dew point temperature;
- (b) the emissions are sampled continuously and integrated over the cycle.

The background concentrations shall be sampled upstream of the dilution tunnel into a sampling bag, and shall be subtracted from the emissions concentration according to paragraph 8.5.2.3.2.

9.4. Particulate measurement and sampling system

9.4.1. General specifications

To determine the mass of the particulates, a particulate dilution and sampling system, a particulate sampling filter, a microgram balance, and a temperature and humidity controlled weighing chamber, are required. The particulate sampling system shall be designed to ensure a representative sample of the particulates proportional to the exhaust flow.

9.4.2. General requirements of the dilution system

The determination of the particulates requires dilution of the sample with filtered ambient air, synthetic air or nitrogen (the diluent). The dilution system shall be set as follows:

- (a) completely eliminate water condensation in the dilution and sampling systems,
- (b) maintain the temperature of the diluted exhaust gas between 315 K (42 °C) and 325 K (52 °C) within 20 cm upstream or downstream of the filter holder(s),
- (c) the diluent temperature shall be between 293 K and 325 K (20 °C to 42 °C) in close proximity to the entrance into the dilution tunnel; [within the specified range, Contracting Parties may require tighter specifications for engines to be type approved or certified in their territory],
- (d) the minimum dilution ratio shall be within the range of 5:1 to 7:1 and at least 2:1 for the primary dilution stage based on the maximum engine exhaust flow rate,
- (e) for a partial flow dilution system, the residence time in the system from the point of diluent introduction to the filter holder(s) shall be between 0.5 and 5 seconds,
- (f) for a full flow dilution system, the overall residence time in the system from the point of diluent introduction to the filter holder(s) shall be between 1 and 5 seconds, and the residence time in the secondary dilution system, if used, from the point of secondary diluent introduction to the filter holder(s) shall be at least 0.5 seconds.

Dehumidifying the diluent before entering the dilution system is permitted, and especially useful if diluent humidity is high.

9.4.3. Particulate sampling

9.4.3.1. Partial flow dilution system

The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference. Therefore, the installation provisions of paragraph 9.3.10. also apply to particulate sampling. The sampling line shall conform to the requirements laid down in Annex 3.

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 recommended to combine the manifolds upstream of the sampling probe. If this is not practical, it is permissible to acquire a sample from the group with the highest particulate emission. For exhaust emission calculation the total exhaust mass flow of the manifold shall be used.

9.4.3.2. Full flow dilution system

The particulate sampling probe shall be installed in close proximity to the gaseous emissions sampling probe, but sufficiently distant as to not cause interference, in the dilution tunnel. Therefore, the installation provisions of paragraph 9.3.11. also apply to particulate sampling. The sampling line shall conform to the requirements laid down in Annex 3.

9.4.4. Particulate sampling filters

The diluted exhaust shall be sampled by a filter that meets the requirements of paragraphs 9.4.4.1. to 9.4.4.3. during the test sequence.

9.4.4.1. Filter specification

All filter types shall have a 0.3 μm DOP (di-octylphthalate) collection efficiency of at least 99 per cent. The filter material shall be either:

- (a) fluorocarbon (PTFE) coated glass fiber, or
- (b) fluorocarbon (PTFE) membrane.

9.4.4.2. Filter size

The filter shall be circular with a nominal diameter of 47 mm (tolerance of 46.50 ± 0.6 mm) and an exposed diameter (filter stain diameter) of at least 38 mm.

9.4.4.3. Filter face velocity

The face velocity through the filter shall be between 0.90 and 1.00 m/s with less than 5 per cent of the recorded flow values exceeding this range. If the total PM mass on the filter exceeds 400 μg , the filter face velocity may be reduced to 0.50 m/s. The face velocity shall be calculated as the volumetric flow rate of the sample at the pressure upstream of the filter and temperature of the filter face, divided by the filter's exposed area.

9.4.5. Weighing chamber and analytical balance specifications

The chamber (or room) environment shall be free of any ambient contaminants (such as dust, aerosol, or semi-volatile material) that could contaminate the particulate filters. The weighing room shall meet the required specifications for at least 60 min before weighing filters.

9.4.5.1. Weighing chamber conditions

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within $295\text{ K} \pm 1\text{ K}$ ($22\text{ °C} \pm 1\text{ °C}$) during all filter conditioning and weighing. The humidity shall be maintained to a dew point of $282.5\text{ K} \pm 1\text{ K}$ ($9.5\text{ °C} \pm 1\text{ °C}$).

If the stabilization and weighing environments are separate, the temperature of the stabilization environment shall be maintained at a tolerance of $295\text{ K} \pm 3\text{ K}$ ($22\text{ °C} \pm 3\text{ °C}$), but the dew point requirement remains at $282.5\text{ K} \pm 1\text{ K}$ ($9.5\text{ °C} \pm 1\text{ °C}$).

Humidity and ambient temperature shall be recorded.

9.4.5.2. *Reference filter weighing*

At least two unused reference filters shall be weighed within 12 hours of, but preferably at the same time as the sample filter weighing. They shall be the same material as the sample filters. Buoyancy correction shall be applied to the weighings.

If the weight of any of the reference filters changes between sample filter weighings by more than $10\text{ }\mu\text{g}$, all sample filters shall be discarded and the emissions test repeated.

The reference filters shall be periodically replaced based on good engineering judgement, but at least once per year.

9.4.5.3. *Analytical balance*

The analytical balance used to determine the filter weight shall meet the linearity verification criterion of paragraph 9.2., table 7. This implies a precision (standard deviation) of at least $2\text{ }\mu\text{g}$ and a resolution of at least $1\text{ }\mu\text{g}$ (1 digit = $1\text{ }\mu\text{g}$).

In order to ensure accurate filter weighing, it is recommended that the balance be installed as follows:

- (a) installed on a vibration-isolation platform to isolate it from external noise and vibration,
- (b) shielded from convective airflow with a static-dissipating draft shield that is electrically grounded.

9.4.5.4. Elimination of static electricity effects

The filter shall be neutralized prior to weighing, e.g. by a Polonium neutralizer or a device of similar effect. If a PTFE membrane filter is used, the static electricity shall be measured and is recommended to be within ± 2.0 V of neutral.

Static electric charge shall be minimized in the balance environment. Possible methods are as follows:

- (a) the balance shall be electrically grounded,
- (b) stainless steel tweezers shall be used if PM samples are handled manually,
- (c) tweezers shall be grounded with a grounding strap, or a grounding strap shall be provided for the operator such that the grounding strap shares a common ground with the balance. Grounding straps shall have an appropriate resistor to protect operators from accidental shock.

9.4.5.5. Additional specifications

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, shall be designed to minimize deposition or alteration of the particulates. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

9.4.5.6. Calibration of the flow measurement instrumentation

Each flowmeter used in a particulate sampling and partial flow dilution system shall be subjected to the linearity verification, as described in paragraph 9.2.1., as often as necessary to fulfil the accuracy requirements of this gtr. For the flow reference values, an accurate flowmeter traceable to international and/or national standards shall be used. For differential flow measurement calibration see paragraph 9.4.6.2.

9.4.6. Special requirements for the partial flow dilution system

The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate. For this it is essential that the dilution ratio or the sampling ratio r_d or r_s be determined such that the accuracy requirements of paragraph 9.4.6.2. are fulfilled.

9.4.6.1. System response time

For the control of a partial flow dilution system, a fast system response is required. The transformation time for the system shall be determined by the procedure in paragraph 9.4.6.6. If the combined transformation time of the exhaust flow measurement (see paragraph 8.4.1.2.) and the partial flow system is ≤ 0.3 s, online control shall be used. If the transformation time exceeds 0.3 s, look ahead control

based on a pre-recorded test run shall be used. In this case, the combined rise time shall be ≤ 1 s and the combined delay time ≤ 10 s.

The total system response shall be designed as to ensure a representative sample of the particulates, $q_{mp,i}$, proportional to the exhaust mass flow. To determine the proportionality, a regression analysis of $q_{mp,i}$ versus $q_{mew,i}$ shall be conducted on a minimum 5 Hz data acquisition rate, and the following criteria shall be met:

- (a) the coefficient of determination r^2 of the linear regression between $q_{mp,i}$ and $q_{mew,i}$ shall not be less than 0.95,
- (b) the standard error of estimate of $q_{mp,i}$ on $q_{mew,i}$ shall not exceed 5 per cent of q_{mp} maximum,
- (c) q_{mp} intercept of the regression line shall not exceed ± 2 per cent of q_{mp} maximum.

Look-ahead control is required if the combined transformation times of the particulate system, $t_{50,P}$ and of the exhaust mass flow signal, $t_{50,F}$ are > 0.3 s. In this case, a pre-test shall be run, and the exhaust mass flow signal of the pre-test be used for controlling the sample flow into the particulate system. A correct control of the partial dilution system is obtained, if the time trace of $q_{mew,pre}$ of the pre-test, which controls q_{mp} , is shifted by a "look-ahead" time of $t_{50,P} + t_{50,F}$.

For establishing the correlation between $q_{mp,i}$ and $q_{mew,i}$ the data taken during the actual test shall be used, with $q_{mew,i}$ time aligned by $t_{50,F}$ relative to $q_{mp,i}$ (no contribution from $t_{50,P}$ to the time alignment). That is, the time shift between q_{mew} and q_{mp} is the difference in their transformation times that were determined in paragraph 9.4.6.6.

9.4.6.2. Specifications for differential flow measurement

For partial flow dilution systems, the accuracy of the sample flow q_{mp} is of special concern, if not measured directly, but determined by differential flow measurement:

$$q_{mp} = q_{mdew} - q_{mdw} \quad (83)$$

In this case, the maximum error of the difference shall be such that the accuracy of q_{mp} is within ± 5 per cent when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

Acceptable accuracies of q_{mp} can be obtained by either of the following methods:

- (a) The absolute accuracies of q_{mdew} and q_{mdw} are ± 0.2 per cent which guarantees an accuracy of q_{mp} of ≤ 5 per cent at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios.
- (b) Calibration of q_{mdw} relative to q_{mdew} is carried out such that the same accuracies for q_{mp} as in (a) are obtained. For details see paragraph 9.4.6.2.
- (c) The accuracy of q_{mp} is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO₂. Accuracies equivalent to method (a) for q_{mp} are required.

- (d) The absolute accuracy of q_{mdew} and q_{mdw} is within ± 2 per cent of full scale, the maximum error of the difference between q_{mdew} and q_{mdw} is within 0.2 per cent, and the linearity error is within ± 0.2 per cent of the highest q_{mdew} observed during the test.

9.4.6.3. Calibration of differential flow measurement

The flowmeter or the flow measurement instrumentation shall be calibrated in one of the following procedures, such that the probe flow q_{mp} into the tunnel shall fulfil the accuracy requirements of paragraph 9.4.6.2.:

- (a) The flowmeter for q_{mdw} shall be connected in series to the flowmeter for q_{mdew} , the difference between the two flowmeters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest q_{mdw} value used during the test and the value of q_{mdew} used during the test. The dilution tunnel may be bypassed.
- (b) A calibrated flow device shall be connected in series to the flowmeter for q_{mdew} and the accuracy shall be checked for the value used for the test. The calibrated flow device shall be connected in series to the flowmeter for q_{mdw} , and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 50, relative to q_{mdew} used during the test.
- (c) The transfer tube (TT) shall be disconnected from the exhaust, and a calibrated flow-measuring device with a suitable range to measure q_{mp} shall be connected to the transfer tube. q_{mdew} shall be set to the value used during the test, and q_{mdw} shall be sequentially set to at least 5 values corresponding to dilution ratios between 3 and 50. Alternatively, a special calibration flow path may be provided, in which the tunnel is bypassed, but the total and diluent flow through the corresponding meters as in the actual test.
- (d) A tracer gas shall be fed into the exhaust transfer tube TT. This tracer gas may be a component of the exhaust gas, like CO_2 or NO_x . After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 50. The accuracy of the sample flow shall be determined from the dilution ratio r_d :

$$q_{mp} = q_{mdew} / r_d \quad (84)$$

The accuracies of the gas analyzers shall be taken into account to guarantee the accuracy of q_{mp} .

9.4.6.4. Carbon flow check

A carbon flow check using actual exhaust is strongly recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new engine is installed, or something significant is changed in the test cell configuration.

The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 per cent or more of CO₂. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

If a carbon flow check is conducted, the procedure given in Annex 5 shall be applied. The carbon flow rates shall be calculated according to equations 80 to 82 in Annex 5. All carbon flow rates should agree to within 3 per cent.

9.4.6.5. Pre-test check

A pre-test check shall be performed within 2 hours before the test run in the following way.

The accuracy of the flowmeters shall be checked by the same method as used for calibration (see paragraph 9.4.6.2.) for at least two points, including flow values of q_{mdw} that correspond to dilution ratios between 5 and 15 for the q_{mdew} value used during the test.

If it can be demonstrated by records of the calibration procedure under paragraph 9.4.6.2. that the flowmeter calibration is stable over a longer period of time, the pre-test check may be omitted.

9.4.6.6. Determination of the transformation time

The system settings for the transformation time evaluation shall be exactly the same as during measurement of the test run. The transformation time shall be determined by the following method.

An independent reference flowmeter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flowmeter shall have a transformation time of less than 100 ms for the flow step size used in the response time measurement, with flow restriction sufficiently low as to not affect the dynamic performance of the partial flow dilution system, and consistent with good engineering practice.

A step change shall be introduced to the exhaust flow (or airflow if exhaust flow is calculated) input of the partial flow dilution system, from a low flow to at least 90 per cent of maximum exhaust flow. The trigger for the step change shall be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flowmeter response shall be recorded at a sample rate of at least 10 Hz.

From this data, the transformation time shall be determined for the partial flow dilution system, which is the time from the initiation of the step stimulus to the 50 per cent point of the flowmeter response. In a similar manner, the transformation times of the q_{mp} signal of the partial flow dilution system and of the $q_{mew,i}$ signal of

the exhaust flowmeter shall be determined. These signals are used in the regression checks performed after each test (see paragraph 9.4.6.1.)

The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (< 100 ms) of the reference flowmeter shall be subtracted from this value. This is the "look-ahead" value of the partial flow dilution system, which shall be applied in accordance with paragraph 9.4.6.1.

9.5. Calibration of the CVS system

9.5.1. General

The CVS system shall be calibrated by using an accurate flowmeter 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 flowmeters may be used, e.g. calibrated venturi, calibrated laminar flowmeter, calibrated turbine meter.

9.5.2. Calibration of the positive displacement pump (PDP)

All the parameters related to the pump shall be simultaneously measured along with the parameters related to a calibration venturi which is connected in series with the pump. The calculated flow rate (in m³/s 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 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.

Leaks in all the connections and ducting between the calibration venturi and the CVS pump shall be maintained lower than 0.3 per cent of the lowest flow point (highest restriction and lowest PDP speed point).

9.5.2.1. Data analysis

The airflow rate (q_{vCVS}) at each restriction setting (minimum 6 settings) shall be calculated in standard m³/s from the flowmeter data using the manufacturer's prescribed method. The airflow rate shall then be converted to pump flow (V_0) in m³/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{q_{vCVS}}{n} \times \frac{T}{273} \times \frac{101.3}{p_p} \quad (85)$$

where:

$q_{v, CVS}$ is the airflow rate at standard conditions (101.3 kPa, 273 K), m^3/s

T is the temperature at pump inlet, K

p_p is the absolute pressure at pump inlet, kPa

n is the pump speed, rev/s

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function (X_0) between pump speed, pressure differential from pump inlet to pump outlet and absolute pump outlet pressure shall be calculated as follows:

$$X_0 = \frac{1}{n} \times \sqrt{\frac{\Delta p_p}{p_p}} \quad (86)$$

where:

Δp_p is the pressure differential from pump inlet to pump outlet, kPa

p_p is the absolute outlet pressure at pump outlet, kPa

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

$$V_0 = D_0 - m \times X_0 \quad (87)$$

D_0 and m are the intercept and slope, 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 (D_0) shall increase as the pump flow range decreases.

The calculated values from the equation shall be within ± 0.5 per cent of the measured value of V_0 . 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 indicates a change of the slip rate.

9.5.3. 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 venturi inlet pressure and temperature.

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

9.5.3.1. Data analysis

The airflow rate (q_{vCVS}) at each restriction setting (minimum 8 settings) shall be calculated in standard m^3/s 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:

$$K_v = \frac{q_{vCVS} \times \sqrt{T}}{p_p} \quad (88)$$

where:

q_{vCVS} is the airflow rate at standard conditions (101.3 kPa, 273 K), m^3/s
 T is the temperature at the venturi inlet, K
 p_p is the absolute pressure at venturi inlet, kPa

The average K_v and the standard deviation shall be calculated. The standard deviation shall not exceed ± 0.3 per cent of the average K_v .

9.5.4. Calibration of the subsonic venturi (SSV)

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat, as shown in equation 43 (see paragraph 8.5.1.4.).

9.5.4.1. Data analysis

The airflow rate (Q_{SSV}) at each restriction setting (minimum 16 settings) shall be calculated in standard m^3/s from the flowmeter data using the manufacturer's prescribed method. The discharge coefficient shall be calculated from the calibration data for each setting as follows:

$$C_d = \frac{Q_{SSV}}{d_v^2 \times p_p \times \sqrt{\left[\frac{I}{T} \times (r_p^{1.4286} - r_p^{1.7143}) \times \left(\frac{I}{1 - r_D^4 \times r_p^{1.4286}} \right) \right]}} \quad (89)$$

where:

Q_{SSV} is the airflow rate at standard conditions (101.3 kPa, 273 K), m^3/s

T is the temperature at the venturi inlet, K

d_v is the diameter of the SSV throat, m

r_p is the ratio of the SSV throat to inlet absolute static pressure = $1 - \frac{\Delta p}{p_p}$

r_D is the ratio of the SSV throat diameter, d_v , to the inlet pipe inner diameter D

To determine the range of subsonic flow, C_d shall be plotted as a function of Reynolds number Re , at the SSV throat. The Re at the SSV throat shall be calculated with the following equation:

$$Re = A_1 \times \frac{Q_{SSV}}{d_v \times \mu} \quad (90)$$

with

$$\mu = \frac{b \times T^{1.5}}{S + T} \quad (91)$$

where:

A_1 is 25.55152 in SI units of $\left(\frac{1}{m^3}\right)\left(\frac{\text{min}}{s}\right)\left(\frac{\text{mm}}{m}\right)$

Q_{SSV} is the airflow rate at standard conditions (101.3 kPa, 273 K), m^3/s

d_v is the diameter of the SSV throat, m

μ is the absolute or dynamic viscosity of the gas, kg/ms

b is 1.458×10^6 (empirical constant), $\text{kg/ms K}^{0.5}$

S is 110.4 (empirical constant), K

Because Q_{SSV} is an input to the Re equation, the calculations shall be started with an initial guess for Q_{SSV} or C_d of the calibration venturi, and repeated until Q_{SSV} converges. The convergence method shall be accurate to 0.1 per cent of point or better.

For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation shall be within ± 0.5 per cent of the measured C_d for each calibration point.

9.5.5. 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 analyzed, and the mass calculated according to paragraph 8.5.2.3. except in the case of propane where a u factor of 0.000507 is used in place of 0.000480 for HC. Either of the following two techniques shall be used.

9.5.5.1. 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 (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

analyzed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated.

The mass so determined shall be within ± 3 per cent of the known mass of the gas injected.

9.5.5.2. Metering by means of a gravimetric technique

The mass of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ± 0.01 g. 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 analyzed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated.

The mass so determined shall be within ± 3 per cent of the known mass of the gas injected.

Annex 1

a) WHTC ENGINE DYNAMOMETER SCHEDULE

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	per cent	per cent	s	per cent	per cent	s	per cent	per cent
1	0.0	0.0	47	0.0	0.0	93	32.8	32.7
2	0.0	0.0	48	0.0	0.0	94	33.7	32.5
3	0.0	0.0	49	0.0	0.0	95	34.4	29.5
4	0.0	0.0	50	0.0	13.1	96	34.3	26.5
5	0.0	0.0	51	13.1	30.1	97	34.4	24.7
6	0.0	0.0	52	26.3	25.5	98	35.0	24.9
7	1.5	8.9	53	35.0	32.2	99	35.6	25.2
8	15.8	30.9	54	41.7	14.3	100	36.1	24.8
9	27.4	1.3	55	42.2	0.0	101	36.3	24.0
10	32.6	0.7	56	42.8	11.6	102	36.2	23.6
11	34.8	1.2	57	51.0	20.9	103	36.2	23.5
12	36.2	7.4	58	60.0	9.6	104	36.8	22.7
13	37.1	6.2	59	49.4	0.0	105	37.2	20.9
14	37.9	10.2	60	38.9	16.6	106	37.0	19.2
15	39.6	12.3	61	43.4	30.8	107	36.3	18.4
16	42.3	12.5	62	49.4	14.2	108	35.4	17.6
17	45.3	12.6	63	40.5	0.0	109	35.2	14.9
18	48.6	6.0	64	31.5	43.5	110	35.4	9.9
19	40.8	0.0	65	36.6	78.2	111	35.5	4.3
20	33.0	16.3	66	40.8	67.6	112	35.2	6.6
21	42.5	27.4	67	44.7	59.1	113	34.9	10.0
22	49.3	26.7	68	48.3	52.0	114	34.7	25.1
23	54.0	18.0	69	51.9	63.8	115	34.4	29.3
24	57.1	12.9	70	54.7	27.9	116	34.5	20.7
25	58.9	8.6	71	55.3	18.3	117	35.2	16.6
26	59.3	6.0	72	55.1	16.3	118	35.8	16.2
27	59.0	4.9	73	54.8	11.1	119	35.6	20.3
28	57.9	m	74	54.7	11.5	120	35.3	22.5
29	55.7	m	75	54.8	17.5	121	35.3	23.4
30	52.1	m	76	55.6	18.0	122	34.7	11.9
31	46.4	m	77	57.0	14.1	123	45.5	0.0
32	38.6	m	78	58.1	7.0	124	56.3	m
33	29.0	m	79	43.3	0.0	125	46.2	m
34	20.8	m	80	28.5	25.0	126	50.1	0.0
35	16.9	m	81	30.4	47.8	127	54.0	m
36	16.9	42.5	82	32.1	39.2	128	40.5	m
37	18.8	38.4	83	32.7	39.3	129	27.0	m
38	20.7	32.9	84	32.4	17.3	130	13.5	m
39	21.0	0.0	85	31.6	11.4	131	0.0	0.0
40	19.1	0.0	86	31.1	10.2	132	0.0	0.0
41	13.7	0.0	87	31.1	19.5	133	0.0	0.0
42	2.2	0.0	88	31.4	22.5	134	0.0	0.0
43	0.0	0.0	89	31.6	22.9	135	0.0	0.0
44	0.0	0.0	90	31.6	24.3	136	0.0	0.0
45	0.0	0.0	91	31.9	26.9	137	0.0	0.0
46	0.0	0.0	92	32.4	30.6	138	0.0	0.0

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
139	0.0	0.0	189	0.0	5.9	239	0.0	0.0
140	0.0	0.0	190	0.0	0.0	240	0.0	0.0
141	0.0	0.0	191	0.0	0.0	241	0.0	0.0
142	0.0	4.9	192	0.0	0.0	242	0.0	0.0
143	0.0	7.3	193	0.0	0.0	243	0.0	0.0
144	4.4	28.7	194	0.0	0.0	244	0.0	0.0
145	11.1	26.4	195	0.0	0.0	245	0.0	0.0
146	15.0	9.4	196	0.0	0.0	246	0.0	0.0
147	15.9	0.0	197	0.0	0.0	247	0.0	0.0
148	15.3	0.0	198	0.0	0.0	248	0.0	0.0
149	14.2	0.0	199	0.0	0.0	249	0.0	0.0
150	13.2	0.0	200	0.0	0.0	250	0.0	0.0
151	11.6	0.0	201	0.0	0.0	251	0.0	0.0
152	8.4	0.0	202	0.0	0.0	252	0.0	0.0
153	5.4	0.0	203	0.0	0.0	253	0.0	31.6
154	4.3	5.6	204	0.0	0.0	254	9.4	13.6
155	5.8	24.4	205	0.0	0.0	255	22.2	16.9
156	9.7	20.7	206	0.0	0.0	256	33.0	53.5
157	13.6	21.1	207	0.0	0.0	257	43.7	22.1
158	15.6	21.5	208	0.0	0.0	258	39.8	0.0
159	16.5	21.9	209	0.0	0.0	259	36.0	45.7
160	18.0	22.3	210	0.0	0.0	260	47.6	75.9
161	21.1	46.9	211	0.0	0.0	261	61.2	70.4
162	25.2	33.6	212	0.0	0.0	262	72.3	70.4
163	28.1	16.6	213	0.0	0.0	263	76.0	m
164	28.8	7.0	214	0.0	0.0	264	74.3	m
165	27.5	5.0	215	0.0	0.0	265	68.5	m
166	23.1	3.0	216	0.0	0.0	266	61.0	m
167	16.9	1.9	217	0.0	0.0	267	56.0	m
168	12.2	2.6	218	0.0	0.0	268	54.0	m
169	9.9	3.2	219	0.0	0.0	269	53.0	m
170	9.1	4.0	220	0.0	0.0	270	50.8	m
171	8.8	3.8	221	0.0	0.0	271	46.8	m
172	8.5	12.2	222	0.0	0.0	272	41.7	m
173	8.2	29.4	223	0.0	0.0	273	35.9	m
174	9.6	20.1	224	0.0	0.0	274	29.2	m
175	14.7	16.3	225	0.0	0.0	275	20.7	m
176	24.5	8.7	226	0.0	0.0	276	10.1	m
177	39.4	3.3	227	0.0	0.0	277	0.0	m
178	39.0	2.9	228	0.0	0.0	278	0.0	0.0
179	38.5	5.9	229	0.0	0.0	279	0.0	0.0
180	42.4	8.0	230	0.0	0.0	280	0.0	0.0
181	38.2	6.0	231	0.0	0.0	281	0.0	0.0
182	41.4	3.8	232	0.0	0.0	282	0.0	0.0
183	44.6	5.4	233	0.0	0.0	283	0.0	0.0
184	38.8	8.2	234	0.0	0.0	284	0.0	0.0
185	37.5	8.9	235	0.0	0.0	285	0.0	0.0
186	35.4	7.3	236	0.0	0.0	286	0.0	0.0
187	28.4	7.0	237	0.0	0.0	287	0.0	0.0
188	14.8	7.0	238	0.0	0.0	288	0.0	0.0

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
289	0.0	0.0	339	0.0	0.0	389	25.2	14.7
290	0.0	0.0	340	0.0	0.0	390	28.6	28.4
291	0.0	0.0	341	0.0	0.0	391	35.5	65.0
292	0.0	0.0	342	0.0	0.0	392	43.8	75.3
293	0.0	0.0	343	0.0	0.0	393	51.2	34.2
294	0.0	0.0	344	0.0	0.0	394	40.7	0.0
295	0.0	0.0	345	0.0	0.0	395	30.3	45.4
296	0.0	0.0	346	0.0	0.0	396	34.2	83.1
297	0.0	0.0	347	0.0	0.0	397	37.6	85.3
298	0.0	0.0	348	0.0	0.0	398	40.8	87.5
299	0.0	0.0	349	0.0	0.0	399	44.8	89.7
300	0.0	0.0	350	0.0	0.0	400	50.6	91.9
301	0.0	0.0	351	0.0	0.0	401	57.6	94.1
302	0.0	0.0	352	0.0	0.0	402	64.6	44.6
303	0.0	0.0	353	0.0	0.0	403	51.6	0.0
304	0.0	0.0	354	0.0	0.5	404	38.7	37.4
305	0.0	0.0	355	0.0	4.9	405	42.4	70.3
306	0.0	0.0	356	9.2	61.3	406	46.5	89.1
307	0.0	0.0	357	22.4	40.4	407	50.6	93.9
308	0.0	0.0	358	36.5	50.1	408	53.8	33.0
309	0.0	0.0	359	47.7	21.0	409	55.5	20.3
310	0.0	0.0	360	38.8	0.0	410	55.8	5.2
311	0.0	0.0	361	30.0	37.0	411	55.4	m
312	0.0	0.0	362	37.0	63.6	412	54.4	m
313	0.0	0.0	363	45.5	90.8	413	53.1	m
314	0.0	0.0	364	54.5	40.9	414	51.8	m
315	0.0	0.0	365	45.9	0.0	415	50.3	m
316	0.0	0.0	366	37.2	47.5	416	48.4	m
317	0.0	0.0	367	44.5	84.4	417	45.9	m
318	0.0	0.0	368	51.7	32.4	418	43.1	m
319	0.0	0.0	369	58.1	15.2	419	40.1	m
320	0.0	0.0	370	45.9	0.0	420	37.4	m
321	0.0	0.0	371	33.6	35.8	421	35.1	m
322	0.0	0.0	372	36.9	67.0	422	32.8	m
323	0.0	0.0	373	40.2	84.7	423	45.3	0.0
324	4.5	41.0	374	43.4	84.3	424	57.8	m
325	17.2	38.9	375	45.7	84.3	425	50.6	m
326	30.1	36.8	376	46.5	m	426	41.6	m
327	41.0	34.7	377	46.1	m	427	47.9	0.0
328	50.0	32.6	378	43.9	m	428	54.2	m
329	51.4	0.1	379	39.3	m	429	48.1	m
330	47.8	m	380	47.0	m	430	47.0	31.3
331	40.2	m	381	54.6	m	431	49.0	38.3
332	32.0	m	382	62.0	m	432	52.0	40.1
333	24.4	m	383	52.0	m	433	53.3	14.5
334	16.8	m	384	43.0	m	434	52.6	0.8
335	8.1	m	385	33.9	m	435	49.8	m
336	0.0	m	386	28.4	m	436	51.0	18.6
337	0.0	0.0	387	25.5	m	437	56.9	38.9
338	0.0	0.0	388	24.6	11.0	438	67.2	45.0

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
439	78.6	21.5	489	45.5	m	539	56.7	m
440	65.5	0.0	490	40.4	m	540	46.9	m
441	52.4	31.3	491	49.7	0.0	541	37.5	m
442	56.4	60.1	492	59.0	m	542	30.3	m
443	59.7	29.2	493	48.9	m	543	27.3	32.3
444	45.1	0.0	494	40.0	m	544	30.8	60.3
445	30.6	4.2	495	33.5	m	545	41.2	62.3
446	30.9	8.4	496	30.0	m	546	36.0	0.0
447	30.5	4.3	497	29.1	12.0	547	30.8	32.3
448	44.6	0.0	498	29.3	40.4	548	33.9	60.3
449	58.8	m	499	30.4	29.3	549	34.6	38.4
450	55.1	m	500	32.2	15.4	550	37.0	16.6
451	50.6	m	501	33.9	15.8	551	42.7	62.3
452	45.3	m	502	35.3	14.9	552	50.4	28.1
453	39.3	m	503	36.4	15.1	553	40.1	0.0
454	49.1	0.0	504	38.0	15.3	554	29.9	8.0
455	58.8	m	505	40.3	50.9	555	32.5	15.0
456	50.7	m	506	43.0	39.7	556	34.6	63.1
457	42.4	m	507	45.5	20.6	557	36.7	58.0
458	44.1	0.0	508	47.3	20.6	558	39.4	52.9
459	45.7	m	509	48.8	22.1	559	42.8	47.8
460	32.5	m	510	50.1	22.1	560	46.8	42.7
461	20.7	m	511	51.4	42.4	561	50.7	27.5
462	10.0	m	512	52.5	31.9	562	53.4	20.7
463	0.0	0.0	513	53.7	21.6	563	54.2	13.1
464	0.0	1.5	514	55.1	11.6	564	54.2	0.4
465	0.9	41.1	515	56.8	5.7	565	53.4	0.0
466	7.0	46.3	516	42.4	0.0	566	51.4	m
467	12.8	48.5	517	27.9	8.2	567	48.7	m
468	17.0	50.7	518	29.0	15.9	568	45.6	m
469	20.9	52.9	519	30.4	25.1	569	42.4	m
470	26.7	55.0	520	32.6	60.5	570	40.4	m
471	35.5	57.2	521	35.4	72.7	571	39.8	5.8
472	46.9	23.8	522	38.4	88.2	572	40.7	39.7
473	44.5	0.0	523	41.0	65.1	573	43.8	37.1
474	42.1	45.7	524	42.9	25.6	574	48.1	39.1
475	55.6	77.4	525	44.2	15.8	575	52.0	22.0
476	68.8	100.0	526	44.9	2.9	576	54.7	13.2
477	81.7	47.9	527	45.1	m	577	56.4	13.2
478	71.2	0.0	528	44.8	m	578	57.5	6.6
479	60.7	38.3	529	43.9	m	579	42.6	0.0
480	68.8	72.7	530	42.4	m	580	27.7	10.9
481	75.0	m	531	40.2	m	581	28.5	21.3
482	61.3	m	532	37.1	m	582	29.2	23.9
483	53.5	m	533	47.0	0.0	583	29.5	15.2
484	45.9	58.0	534	57.0	m	584	29.7	8.8
485	48.1	80.0	535	45.1	m	585	30.4	20.8
486	49.4	97.9	536	32.6	m	586	31.9	22.9
487	49.7	m	537	46.8	0.0	587	34.3	61.4
488	48.7	m	538	61.5	m	588	37.2	76.6

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
589	40.1	27.5	639	39.8	m	689	46.6	0.0
590	42.3	25.4	640	36.0	m	690	32.3	34.6
591	43.5	32.0	641	29.7	m	691	32.7	68.6
592	43.8	6.0	642	21.5	m	692	32.6	67.0
593	43.5	m	643	14.1	m	693	31.3	m
594	42.8	m	644	0.0	0.0	694	28.1	m
595	41.7	m	645	0.0	0.0	695	43.0	0.0
596	40.4	m	646	0.0	0.0	696	58.0	m
597	39.3	m	647	0.0	0.0	697	58.9	m
598	38.9	12.9	648	0.0	0.0	698	49.4	m
599	39.0	18.4	649	0.0	0.0	699	41.5	m
600	39.7	39.2	650	0.0	0.0	700	48.4	0.0
601	41.4	60.0	651	0.0	0.0	701	55.3	m
602	43.7	54.5	652	0.0	0.0	702	41.8	m
603	46.2	64.2	653	0.0	0.0	703	31.6	m
604	48.8	73.3	654	0.0	0.0	704	24.6	m
605	51.0	82.3	655	0.0	0.0	705	15.2	m
606	52.1	0.0	656	0.0	3.4	706	7.0	m
607	52.0	m	657	1.4	22.0	707	0.0	0.0
608	50.9	m	658	10.1	45.3	708	0.0	0.0
609	49.4	m	659	21.5	10.0	709	0.0	0.0
610	47.8	m	660	32.2	0.0	710	0.0	0.0
611	46.6	m	661	42.3	46.0	711	0.0	0.0
612	47.3	35.3	662	57.1	74.1	712	0.0	0.0
613	49.2	74.1	663	72.1	34.2	713	0.0	0.0
614	51.1	95.2	664	66.9	0.0	714	0.0	0.0
615	51.7	m	665	60.4	41.8	715	0.0	0.0
616	50.8	m	666	69.1	79.0	716	0.0	0.0
617	47.3	m	667	77.1	38.3	717	0.0	0.0
618	41.8	m	668	63.1	0.0	718	0.0	0.0
619	36.4	m	669	49.1	47.9	719	0.0	0.0
620	30.9	m	670	53.4	91.3	720	0.0	0.0
621	25.5	37.1	671	57.5	85.7	721	0.0	0.0
622	33.8	38.4	672	61.5	89.2	722	0.0	0.0
623	42.1	m	673	65.5	85.9	723	0.0	0.0
624	34.1	m	674	69.5	89.5	724	0.0	0.0
625	33.0	37.1	675	73.1	75.5	725	0.0	0.0
626	36.4	38.4	676	76.2	73.6	726	0.0	0.0
627	43.3	17.1	677	79.1	75.6	727	0.0	0.0
628	35.7	0.0	678	81.8	78.2	728	0.0	0.0
629	28.1	11.6	679	84.1	39.0	729	0.0	0.0
630	36.5	19.2	680	69.6	0.0	730	0.0	0.0
631	45.2	8.3	681	55.0	25.2	731	0.0	0.0
632	36.5	0.0	682	55.8	49.9	732	0.0	0.0
633	27.9	32.6	683	56.7	46.4	733	0.0	0.0
634	31.5	59.6	684	57.6	76.3	734	0.0	0.0
635	34.4	65.2	685	58.4	92.7	735	0.0	0.0
636	37.0	59.6	686	59.3	99.9	736	0.0	0.0
637	39.0	49.0	687	60.1	95.0	737	0.0	0.0
638	40.2	m	688	61.0	46.7	738	0.0	0.0

Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque	Time	Norm. Speed	Norm. Torque
s	per cent	per cent	s	per cent	per cent	s	per cent	per cent
739	0.0	0.0	789	17.2	m	839	38.1	m
740	0.0	0.0	790	14.0	37.6	840	37.2	42.7
741	0.0	0.0	791	18.4	25.0	841	37.5	70.8
742	0.0	0.0	792	27.6	17.7	842	39.1	48.6
743	0.0	0.0	793	39.8	6.8	843	41.3	0.1
744	0.0	0.0	794	34.3	0.0	844	42.3	m
745	0.0	0.0	795	28.7	26.5	845	42.0	m
746	0.0	0.0	796	41.5	40.9	846	40.8	m
747	0.0	0.0	797	53.7	17.5	847	38.6	m
748	0.0	0.0	798	42.4	0.0	848	35.5	m
749	0.0	0.0	799	31.2	27.3	849	32.1	m
750	0.0	0.0	800	32.3	53.2	850	29.6	m
751	0.0	0.0	801	34.5	60.6	851	28.8	39.9
752	0.0	0.0	802	37.6	68.0	852	29.2	52.9
753	0.0	0.0	803	41.2	75.4	853	30.9	76.1
754	0.0	0.0	804	45.8	82.8	854	34.3	76.5
755	0.0	0.0	805	52.3	38.2	855	38.3	75.5
756	0.0	0.0	806	42.5	0.0	856	42.5	74.8
757	0.0	0.0	807	32.6	30.5	857	46.6	74.2
758	0.0	0.0	808	35.0	57.9	858	50.7	76.2
759	0.0	0.0	809	36.0	77.3	859	54.8	75.1
760	0.0	0.0	810	37.1	96.8	860	58.7	36.3
761	0.0	0.0	811	39.6	80.8	861	45.2	0.0
762	0.0	0.0	812	43.4	78.3	862	31.8	37.2
763	0.0	0.0	813	47.2	73.4	863	33.8	71.2
764	0.0	0.0	814	49.6	66.9	864	35.5	46.4
765	0.0	0.0	815	50.2	62.0	865	36.6	33.6
766	0.0	0.0	816	50.2	57.7	866	37.2	20.0
767	0.0	0.0	817	50.6	62.1	867	37.2	m
768	0.0	0.0	818	52.3	62.9	868	37.0	m
769	0.0	0.0	819	54.8	37.5	869	36.6	m
770	0.0	0.0	820	57.0	18.3	870	36.0	m
771	0.0	22.0	821	42.3	0.0	871	35.4	m
772	4.5	25.8	822	27.6	29.1	872	34.7	m
773	15.5	42.8	823	28.4	57.0	873	34.1	m
774	30.5	46.8	824	29.1	51.8	874	33.6	m
775	45.5	29.3	825	29.6	35.3	875	33.3	m
776	49.2	13.6	826	29.7	33.3	876	33.1	m
777	39.5	0.0	827	29.8	17.7	877	32.7	m
778	29.7	15.1	828	29.5	m	878	31.4	m
779	34.8	26.9	829	28.9	m	879	45.0	0.0
780	40.0	13.6	830	43.0	0.0	880	58.5	m
781	42.2	m	831	57.1	m	881	53.7	m
782	42.1	m	832	57.7	m	882	47.5	m
783	40.8	m	833	56.0	m	883	40.6	m
784	37.7	37.6	834	53.8	m	884	34.1	m
785	47.0	35.0	835	51.2	m	885	45.3	0.0
786	48.8	33.4	836	48.1	m	886	56.4	m
787	41.7	m	837	44.5	m	887	51.0	m
788	27.7	m	838	40.9	m	888	44.5	m

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
889	36.4	m	939	32.7	56.5	989	32.6	m
890	26.6	m	940	33.4	62.8	990	30.9	m
891	20.0	m	941	34.6	68.2	991	29.9	m
892	13.3	m	942	35.8	68.6	992	29.2	m
893	6.7	m	943	38.6	65.0	993	44.1	0.0
894	0.0	0.0	944	42.3	61.9	994	59.1	m
895	0.0	0.0	945	44.1	65.3	995	56.8	m
896	0.0	0.0	946	45.3	63.2	996	53.5	m
897	0.0	0.0	947	46.5	30.6	997	47.8	m
898	0.0	0.0	948	46.7	11.1	998	41.9	m
899	0.0	0.0	949	45.9	16.1	999	35.9	m
900	0.0	0.0	950	45.6	21.8	1000	44.3	0.0
901	0.0	5.8	951	45.9	24.2	1001	52.6	m
902	2.5	27.9	952	46.5	24.7	1002	43.4	m
903	12.4	29.0	953	46.7	24.7	1003	50.6	0.0
904	19.4	30.1	954	46.8	28.2	1004	57.8	m
905	29.3	31.2	955	47.2	31.2	1005	51.6	m
906	37.1	10.4	956	47.6	29.6	1006	44.8	m
907	40.6	4.9	957	48.2	31.2	1007	48.6	0.0
908	35.8	0.0	958	48.6	33.5	1008	52.4	m
909	30.9	7.6	959	48.8	m	1009	45.4	m
910	35.4	13.8	960	47.6	m	1010	37.2	m
911	36.5	11.1	961	46.3	m	1011	26.3	m
912	40.8	48.5	962	45.2	m	1012	17.9	m
913	49.8	3.7	963	43.5	m	1013	16.2	1.9
914	41.2	0.0	964	41.4	m	1014	17.8	7.5
915	32.7	29.7	965	40.3	m	1015	25.2	18.0
916	39.4	52.1	966	39.4	m	1016	39.7	6.5
917	48.8	22.7	967	38.0	m	1017	38.6	0.0
918	41.6	0.0	968	36.3	m	1018	37.4	5.4
919	34.5	46.6	969	35.3	5.8	1019	43.4	9.7
920	39.7	84.4	970	35.4	30.2	1020	46.9	15.7
921	44.7	83.2	971	36.6	55.6	1021	52.5	13.1
922	49.5	78.9	972	38.6	48.5	1022	56.2	6.3
923	52.3	83.8	973	39.9	41.8	1023	44.0	0.0
924	53.4	77.7	974	40.3	38.2	1024	31.8	20.9
925	52.1	69.6	975	40.8	35.0	1025	38.7	36.3
926	47.9	63.6	976	41.9	32.4	1026	47.7	47.5
927	46.4	55.2	977	43.2	26.4	1027	54.5	22.0
928	46.5	53.6	978	43.5	m	1028	41.3	0.0
929	46.4	62.3	979	42.9	m	1029	28.1	26.8
930	46.1	58.2	980	41.5	m	1030	31.6	49.2
931	46.2	61.8	981	40.9	m	1031	34.5	39.5
932	47.3	62.3	982	40.5	m	1032	36.4	24.0
933	49.3	57.1	983	39.5	m	1033	36.7	m
934	52.6	58.1	984	38.3	m	1034	35.5	m
935	56.3	56.0	985	36.9	m	1035	33.8	m
936	59.9	27.2	986	35.4	m	1036	33.7	19.8
937	45.8	0.0	987	34.5	m	1037	35.3	35.1
938	31.8	28.8	988	33.9	m	1038	38.0	33.9

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
1039	40.1	34.5	1,089	46.3	24.0	1139	51.7	0.0
1040	42.2	40.4	1,090	47.8	20.6	1140	59.2	m
1041	45.2	44.0	1,091	47.2	3.8	1141	47.2	m
1042	48.3	35.9	1,092	45.6	4.4	1142	35.1	0.0
1043	50.1	29.6	1,093	44.6	4.1	1143	23.1	m
1044	52.3	38.5	1,094	44.1	m	1144	13.1	m
1045	55.3	57.7	1,095	42.9	m	1145	5.0	m
1046	57.0	50.7	1,096	40.9	m	1146	0.0	0.0
1047	57.7	25.2	1,097	39.2	m	1147	0.0	0.0
1048	42.9	0.0	1,098	37.0	m	1148	0.0	0.0
1049	28.2	15.7	1,099	35.1	2.0	1149	0.0	0.0
1050	29.2	30.5	1,100	35.6	43.3	1150	0.0	0.0
1051	31.1	52.6	1,101	38.7	47.6	1151	0.0	0.0
1052	33.4	60.7	1,102	41.3	40.4	1152	0.0	0.0
1053	35.0	61.4	1,103	42.6	45.7	1153	0.0	0.0
1054	35.3	18.2	1,104	43.9	43.3	1154	0.0	0.0
1055	35.2	14.9	1,105	46.9	41.2	1155	0.0	0.0
1056	34.9	11.7	1,106	52.4	40.1	1156	0.0	0.0
1057	34.5	12.9	1,107	56.3	39.3	1157	0.0	0.0
1058	34.1	15.5	1108	57.4	25.5	1158	0.0	0.0
1059	33.5	m	1109	57.2	25.4	1159	0.0	0.0
1060	31.8	m	1110	57.0	25.4	1160	0.0	0.0
1061	30.1	m	1111	56.8	25.3	1161	0.0	0.0
1062	29.6	10.3	1112	56.3	25.3	1162	0.0	0.0
1063	30.0	26.5	1113	55.6	25.2	1163	0.0	0.0
1064	31.0	18.8	1114	56.2	25.2	1164	0.0	0.0
1065	31.5	26.5	1115	58.0	12.4	1165	0.0	0.0
1066	31.7	m	1116	43.4	0.0	1166	0.0	0.0
1067	31.5	m	1117	28.8	26.2	1167	0.0	0.0
1068	30.6	m	1118	30.9	49.9	1168	0.0	0.0
1069	30.0	m	1119	32.3	40.5	1169	0.0	0.0
1070	30.0	m	1120	32.5	12.4	1170	0.0	0.0
1071	29.4	m	1121	32.4	12.2	1171	0.0	0.0
1072	44.3	0.0	1122	32.1	6.4	1172	0.0	0.0
1073	59.2	m	1123	31.0	12.4	1173	0.0	0.0
1074	58.3	m	1124	30.1	18.5	1174	0.0	0.0
1075	57.1	m	1125	30.4	35.6	1175	0.0	0.0
1076	55.4	m	1126	31.2	30.1	1176	0.0	0.0
1077	53.5	m	1127	31.5	30.8	1177	0.0	0.0
1078	51.5	m	1128	31.5	26.9	1178	0.0	0.0
1079	49.7	m	1129	31.7	33.9	1179	0.0	0.0
1080	47.9	m	1130	32.0	29.9	1180	0.0	0.0
1081	46.4	m	1131	32.1	m	1181	0.0	0.0
1082	45.5	m	1132	31.4	m	1182	0.0	0.0
1083	45.2	m	1133	30.3	m	1183	0.0	0.0
1084	44.3	m	1134	29.8	m	1184	0.0	0.0
1085	43.6	m	1135	44.3	0.0	1185	0.0	0.0
1086	43.1	m	1136	58.9	m	1186	0.0	0.0
1087	42.5	25.6	1137	52.1	m	1187	0.0	0.0
1088	43.3	25.7	1138	44.1	m	1188	0.0	0.0

Time	Norm.	Norm.	Time	Norm.	Norm.	Time	Norm.	Norm.
s	Speed	Torque	s	Speed	Torque	s	Speed	Torque
	per cent	per cent		per cent	per cent		per cent	per cent
1189	0.0	0.0	1239	58.5	85.4	1289	61.9	76.1
1190	0.0	0.0	1240	59.5	85.6	1290	65.6	73.7
1191	0.0	0.0	1241	61.0	86.6	1291	69.9	79.3
1192	0.0	0.0	1242	62.6	86.8	1292	74.1	81.3
1193	0.0	0.0	1243	64.1	87.6	1293	78.3	83.2
1194	0.0	0.0	1244	65.4	87.5	1294	82.6	86.0
1195	0.0	0.0	1245	66.7	87.8	1295	87.0	89.5
1196	0.0	20.4	1246	68.1	43.5	1296	91.2	90.8
1197	12.6	41.2	1247	55.2	0.0	1297	95.3	45.9
1198	27.3	20.4	1248	42.3	37.2	1298	81.0	0.0
1199	40.4	7.6	1249	43.0	73.6	1299	66.6	38.2
1200	46.1	m	1250	43.5	65.1	1300	67.9	75.5
1201	44.6	m	1251	43.8	53.1	1301	68.4	80.5
1202	42.7	14.7	1252	43.9	54.6	1302	69.0	85.5
1203	42.9	7.3	1253	43.9	41.2	1303	70.0	85.2
1204	36.1	0.0	1254	43.8	34.8	1304	71.6	85.9
1205	29.3	15.0	1255	43.6	30.3	1305	73.3	86.2
1206	43.8	22.6	1256	43.3	21.9	1306	74.8	86.5
1207	54.9	9.9	1257	42.8	19.9	1307	76.3	42.9
1208	44.9	0.0	1258	42.3	m	1308	63.3	0.0
1209	34.9	47.4	1259	41.4	m	1309	50.4	21.2
1210	42.7	82.7	1260	40.2	m	1310	50.6	42.3
1211	52.0	81.2	1261	38.7	m	1311	50.6	53.7
1212	61.8	82.7	1262	37.1	m	1312	50.4	90.1
1213	71.3	39.1	1263	35.6	m	1313	50.5	97.1
1214	58.1	0.0	1264	34.2	m	1314	51.0	100.0
1215	44.9	42.5	1265	32.9	m	1315	51.9	100.0
1216	46.3	83.3	1266	31.8	m	1316	52.6	100.0
1217	46.8	74.1	1267	30.7	m	1317	52.8	32.4
1218	48.1	75.7	1268	29.6	m	1318	47.7	0.0
1219	50.5	75.8	1269	40.4	0.0	1319	42.6	27.4
1220	53.6	76.7	1270	51.2	m	1320	42.1	53.5
1221	56.9	77.1	1271	49.6	m	1321	41.8	44.5
1222	60.2	78.7	1272	48.0	m	1322	41.4	41.1
1223	63.7	78.0	1273	46.4	m	1323	41.0	21.0
1224	67.2	79.6	1274	45.0	m	1324	40.3	0.0
1225	70.7	80.9	1275	43.6	m	1325	39.3	1.0
1226	74.1	81.1	1276	42.3	m	1326	38.3	15.2
1227	77.5	83.6	1277	41.0	m	1327	37.6	57.8
1228	80.8	85.6	1278	39.6	m	1328	37.3	73.2
1229	84.1	81.6	1279	38.3	m	1329	37.3	59.8
1230	87.4	88.3	1280	37.1	m	1330	37.4	52.2
1231	90.5	91.9	1281	35.9	m	1331	37.4	16.9
1232	93.5	94.1	1282	34.6	m	1332	37.1	34.3
1233	96.8	96.6	1283	33.0	m	1333	36.7	51.9
1234	100.0	m	1284	31.1	m	1334	36.2	25.3
1235	96.0	m	1285	29.2	m	1335	35.6	m
1236	81.9	m	1286	43.3	0.0	1336	34.6	m
1237	68.1	m	1287	57.4	32.8	1337	33.2	m
1238	58.1	84.7	1288	59.9	65.4	1338	31.6	m

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
1339	30.1	m	1389	50.4	50.2	1439	36.3	98.8
1340	28.8	m	1390	53.0	26.1	1440	37.7	100.0
1341	28.0	29.5	1391	59.5	0.0	1441	39.2	100.0
1342	28.6	100.0	1392	66.2	38.4	1442	40.9	100.0
1343	28.8	97.3	1393	66.4	76.7	1443	42.4	99.5
1344	28.8	73.4	1394	67.6	100.0	1444	43.8	98.7
1345	29.6	56.9	1395	68.4	76.6	1445	45.4	97.3
1346	30.3	91.7	1396	68.2	47.2	1446	47.0	96.6
1347	31.0	90.5	1397	69.0	81.4	1447	47.8	96.2
1348	31.8	81.7	1398	69.7	40.6	1448	48.8	96.3
1349	32.6	79.5	1399	54.7	0.0	1449	50.5	95.1
1350	33.5	86.9	1400	39.8	19.9	1450	51.0	95.9
1351	34.6	100.0	1401	36.3	40.0	1451	52.0	94.3
1352	35.6	78.7	1402	36.7	59.4	1452	52.6	94.6
1353	36.4	50.5	1403	36.6	77.5	1453	53.0	65.5
1354	37.0	57.0	1404	36.8	94.3	1454	53.2	0.0
1355	37.3	69.1	1405	36.8	100.0	1455	53.2	m
1356	37.6	49.5	1406	36.4	100.0	1456	52.6	m
1357	37.8	44.4	1407	36.3	79.7	1457	52.1	m
1358	37.8	43.4	1408	36.7	49.5	1458	51.8	m
1359	37.8	34.8	1409	36.6	39.3	1459	51.3	m
1360	37.6	24.0	1410	37.3	62.8	1460	50.7	m
1361	37.2	m	1411	38.1	73.4	1461	50.7	m
1362	36.3	m	1412	39.0	72.9	1462	49.8	m
1363	35.1	m	1413	40.2	72.0	1463	49.4	m
1364	33.7	m	1414	41.5	71.2	1464	49.3	m
1365	32.4	m	1415	42.9	77.3	1465	49.1	m
1366	31.1	m	1416	44.4	76.6	1466	49.1	m
1367	29.9	m	1417	45.4	43.1	1467	49.1	8.3
1368	28.7	m	1418	45.3	53.9	1468	48.9	16.8
1369	29.0	58.6	1419	45.1	64.8	1469	48.8	21.3
1370	29.7	88.5	1420	46.5	74.2	1470	49.1	22.1
1371	31.0	86.3	1421	47.7	75.2	1471	49.4	26.3
1372	31.8	43.4	1422	48.1	75.5	1472	49.8	39.2
1373	31.7	m	1423	48.6	75.8	1473	50.4	83.4
1374	29.9	m	1424	48.9	76.3	1474	51.4	90.6
1375	40.2	0.0	1425	49.9	75.5	1475	52.3	93.8
1376	50.4	m	1426	50.4	75.2	1476	53.3	94.0
1377	47.9	m	1427	51.1	74.6	1477	54.2	94.1
1378	45.0	m	1428	51.9	75.0	1478	54.9	94.3
1379	43.0	m	1429	52.7	37.2	1479	55.7	94.6
1380	40.6	m	1430	41.6	0.0	1480	56.1	94.9
1381	55.5	0.0	1431	30.4	36.6	1481	56.3	86.2
1382	70.4	41.7	1432	30.5	73.2	1482	56.2	64.1
1383	73.4	83.2	1433	30.3	81.6	1483	56.0	46.1
1384	74.0	83.7	1434	30.4	89.3	1484	56.2	33.4
1385	74.9	41.7	1435	31.5	90.4	1485	56.5	23.6
1386	60.0	0.0	1436	32.7	88.5	1486	56.3	18.6
1387	45.1	41.6	1437	33.7	97.2	1487	55.7	16.2
1388	47.7	84.2	1438	35.2	99.7	1488	56.0	15.9

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
1489	55.9	21.8	1539	57.0	59.5	1589	56.8	42.9
1490	55.8	20.9	1540	56.7	57.0	1590	56.5	42.8
1491	55.4	18.4	1541	56.7	69.8	1591	56.7	43.2
1492	55.7	25.1	1542	56.8	58.5	1592	56.5	42.8
1493	56.0	27.7	1543	56.8	47.2	1593	56.9	42.2
1494	55.8	22.4	1544	57.0	38.5	1594	56.5	43.1
1495	56.1	20.0	1545	57.0	32.8	1595	56.5	42.9
1496	55.7	17.4	1546	56.8	30.2	1596	56.7	42.7
1497	55.9	20.9	1547	57.0	27.0	1597	56.6	41.5
1498	56.0	22.9	1548	56.9	26.2	1598	56.9	41.8
1499	56.0	21.1	1549	56.7	26.2	1599	56.6	41.9
1500	55.1	19.2	1550	57.0	26.6	1600	56.7	42.6
1501	55.6	24.2	1551	56.7	27.8	1601	56.7	42.6
1502	55.4	25.6	1552	56.7	29.7	1602	56.7	41.5
1503	55.7	24.7	1553	56.8	32.1	1603	56.7	42.2
1504	55.9	24.0	1554	56.5	34.9	1604	56.5	42.2
1505	55.4	23.5	1555	56.6	34.9	1605	56.8	41.9
1506	55.7	30.9	1556	56.3	35.8	1606	56.5	42.0
1507	55.4	42.5	1557	56.6	36.6	1607	56.7	42.1
1508	55.3	25.8	1558	56.2	37.6	1608	56.4	41.9
1509	55.4	1.3	1559	56.6	38.2	1609	56.7	42.9
1510	55.0	m	1560	56.2	37.9	1610	56.7	41.8
1511	54.4	m	1561	56.6	37.5	1611	56.7	41.9
1512	54.2	m	1562	56.4	36.7	1612	56.8	42.0
1513	53.5	m	1563	56.5	34.8	1613	56.7	41.5
1514	52.4	m	1564	56.5	35.8	1614	56.6	41.9
1515	51.8	m	1565	56.5	36.2	1615	56.8	41.6
1516	50.7	m	1566	56.5	36.7	1616	56.6	41.6
1517	49.9	m	1567	56.7	37.8	1617	56.9	42.0
1518	49.1	m	1568	56.7	37.8	1618	56.7	40.7
1519	47.7	m	1569	56.6	36.6	1619	56.7	39.3
1520	47.3	m	1570	56.8	36.1	1620	56.5	41.4
1521	46.9	m	1571	56.5	36.8	1621	56.4	44.9
1522	46.9	m	1572	56.9	35.9	1622	56.8	45.2
1523	47.2	m	1573	56.7	35.0	1623	56.6	43.6
1524	47.8	m	1574	56.5	36.0	1624	56.8	42.2
1525	48.2	0.0	1575	56.4	36.5	1625	56.5	42.3
1526	48.8	23.0	1576	56.5	38.0	1626	56.5	44.4
1527	49.1	67.9	1577	56.5	39.9	1627	56.9	45.1
1528	49.4	73.7	1578	56.4	42.1	1628	56.4	45.0
1529	49.8	75.0	1579	56.5	47.0	1629	56.7	46.3
1530	50.4	75.8	1580	56.4	48.0	1630	56.7	45.5
1531	51.4	73.9	1581	56.1	49.1	1631	56.8	45.0
1532	52.3	72.2	1582	56.4	48.9	1632	56.7	44.9
1533	53.3	71.2	1583	56.4	48.2	1633	56.6	45.2
1534	54.6	71.2	1584	56.5	48.3	1634	56.8	46.0
1535	55.4	68.7	1585	56.5	47.9	1635	56.5	46.6
1536	56.7	67.0	1586	56.6	46.8	1636	56.6	48.3
1537	57.2	64.6	1587	56.6	46.2	1637	56.4	48.6
1538	57.3	61.9	1588	56.5	44.4	1638	56.6	50.3

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
1639	56.3	51.9	1689	57.6	8.9	1739	56.1	46.8
1640	56.5	54.1	1690	57.5	8.0	1740	56.1	45.8
1641	56.3	54.9	1691	57.5	5.8	1741	56.2	46.0
1642	56.4	55.0	1692	57.3	5.8	1742	56.3	45.9
1643	56.4	56.2	1693	57.6	5.5	1743	56.3	45.9
1644	56.2	58.6	1694	57.3	4.5	1744	56.2	44.6
1645	56.2	59.1	1695	57.2	3.2	1745	56.2	46.0
1646	56.2	62.5	1696	57.2	3.1	1746	56.4	46.2
1647	56.4	62.8	1697	57.3	4.9	1747	55.8	m
1648	56.0	64.7	1698	57.3	4.2	1748	55.5	m
1649	56.4	65.6	1699	56.9	5.5	1749	55.0	m
1650	56.2	67.7	1700	57.1	5.1	1750	54.1	m
1651	55.9	68.9	1701	57.0	5.2	1751	54.0	m
1652	56.1	68.9	1702	56.9	5.5	1752	53.3	m
1653	55.8	69.5	1703	56.6	5.4	1753	52.6	m
1654	56.0	69.8	1704	57.1	6.1	1754	51.8	m
1655	56.2	69.3	1705	56.7	5.7	1755	50.7	m
1656	56.2	69.8	1706	56.8	5.8	1756	49.9	m
1657	56.4	69.2	1707	57.0	6.1	1757	49.1	m
1658	56.3	68.7	1708	56.7	5.9	1758	47.7	m
1659	56.2	69.4	1709	57.0	6.6	1759	46.8	m
1660	56.2	69.5	1710	56.9	6.4	1760	45.7	m
1661	56.2	70.0	1711	56.7	6.7	1761	44.8	m
1662	56.4	69.7	1712	56.9	6.9	1762	43.9	m
1663	56.2	70.2	1713	56.8	5.6	1763	42.9	m
1664	56.4	70.5	1714	56.6	5.1	1764	41.5	m
1665	56.1	70.5	1715	56.6	6.5	1765	39.5	m
1666	56.5	69.7	1716	56.5	10.0	1766	36.7	m
1667	56.2	69.3	1717	56.6	12.4	1767	33.8	m
1668	56.5	70.9	1718	56.5	14.5	1768	31.0	m
1669	56.4	70.8	1719	56.6	16.3	1769	40.0	0.0
1670	56.3	71.1	1720	56.3	18.1	1770	49.1	m
1671	56.4	71.0	1721	56.6	20.7	1771	46.2	m
1672	56.7	68.6	1722	56.1	22.6	1772	43.1	m
1673	56.8	68.6	1723	56.3	25.8	1773	39.9	m
1674	56.6	68.0	1724	56.4	27.7	1774	36.6	m
1675	56.8	65.1	1725	56.0	29.7	1775	33.6	m
1676	56.9	60.9	1726	56.1	32.6	1776	30.5	m
1677	57.1	57.4	1727	55.9	34.9	1777	42.8	0.0
1678	57.1	54.3	1728	55.9	36.4	1778	55.2	m
1679	57.0	48.6	1729	56.0	39.2	1779	49.9	m
1680	57.4	44.1	1730	55.9	41.4	1780	44.0	m
1681	57.4	40.2	1731	55.5	44.2	1781	37.6	m
1682	57.6	36.9	1732	55.9	46.4	1782	47.2	0.0
1683	57.5	34.2	1733	55.8	48.3	1783	56.8	m
1684	57.4	31.1	1734	55.6	49.1	1784	47.5	m
1685	57.5	25.9	1735	55.8	49.3	1785	42.9	m
1686	57.5	20.7	1736	55.9	47.7	1786	31.6	m
1687	57.6	16.4	1737	55.9	47.4	1787	25.8	m
1688	57.6	12.4	1738	55.8	46.9	1788	19.9	m

Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent	Time s	Norm. Speed per cent	Norm. Torque per cent
1789	14.0	m						
1790	8.1	m						
1791	2.2	m						
1792	0.0	0.0						
1793	0.0	0.0						
1794	0.0	0.0						
1795	0.0	0.0						
1796	0.0	0.0						
1797	0.0	0.0						
1798	0.0	0.0						
1799	0.0	0.0						
1800	0.0	0.0						

m = motoring

Annex 2

REFERENCE FUELS

A.2.1. EUROPEAN DIESEL REFERENCE FUEL

Parameter	Unit	Limits <u>1/</u>		Test method	
		Minimum	Maximum		
Cetene number		52	54	ISO 5165	
Density at 15 °C	kg/m ³	833	837	ISO 3675	
Distillation:					
- 50 per cent vol.	°C	245		ISO 3405	
- 95 per cent vol	°C	345	350		
- final boiling point	°C		370		
Flash point	°C	55		ISO 2719	
Cold filter plugging point	°C		-5	EN 116	
Kinematic viscosity at 40 °C	mm ² /s	2.3	3.3	ISO 3104	
Polycyclic aromatic hydrocarbons	per cent m/m	2.0	6.0	EN 12916	
Conradson carbon residue (10 per cent DR)	per cent m/m		0.2	ISO 10370	
Ash content	per cent m/m		0.01	EN-ISO 6245	
Water content	per cent m/m		0.02	EN-ISO 12937	

Sulfur content	mg/kg		10	EN-ISO 14596	
Copper corrosion at 50 °C			1	EN-ISO 2160	
Lubricity (HFRR at 60 °C)	µm		400	CEC F-06-A-96	
Neutralisation number	mg KOH/g		0.02		
Oxidation stability @ 110°C <u>2/3/</u>	h	20		EN 14112	
FAME <u>4/</u>	per cent v/v	4.5	5.5	EN 14078	

1/ The values quoted in the specification are "true values". In establishing their limit values, the terms of ISO 4259 "Petroleum products - Determination and application of precision data in relation to methods of test have been applied and in determining a minimum value, a minimum difference of 2R above zero has been taken into account. In determining a maximum and minimum value, the minimum difference has been set at 4R (R = reproducibility).

Notwithstanding this measure, which is necessary for statistical reasons, the manufacturer of fuels should nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify the question as to whether a fuel meets the requirements of the specifications, the terms of ISO 4259 should be applied.

2/ Even though oxidation stability is controlled, it is likely that shelf life will be limited. Advice shall be sought from the supplier as to storage conditions and life.

3/ Oxidation stability can be demonstrated by EN-ISO 12205 or by EN 14112. This requirement shall be revised based on CEN/TC19 evaluations of oxidative stability performance and test limits.

4/ FAME quality according EN 14214 (ASTM D 6751).

5/ The latest version of the respective test method applies.

A.2.2. UNITED STATES OF AMERICA DIESEL REFERENCE FUEL 2-D

Parameter	Unit	Test method	Limits	
			min.	max.
Cetane number	1	ASTM D 613	40	50
Cetane index	1	ASTM D 976	40	50
Density at 15 °C	kg/m ³	ASTM D 1298	840	865
Distillation		ASTM D 86		
Initial boiling point	°C		171	204
10 per cent Vol.	°C		204	238
50 per cent Vol.	°C		243	282
90 per cent Vol.	°C		293	332
Final boiling point	°C		321	366
Flash point	°C	ASTM D 93	54	-
Kinematic viscosity at 37.9 °C	mm ² /s	ASTM D 445	2	3.2
Mass fraction of sulfur	ppm	ASTM D 2785	7	15
Volume fraction of aromatics	per cent v/v	ASTM D 1319	27	-

A.2.3. JAPAN DIESEL REFERENCE FUEL

Property	Unit	Test method	Grade 1		Grade 2		Cert. Diesel	
			min.	max.	min.	max.	min.	max.
Cetane index		ISO 4264	50	-	45	-	53	57
Density @ 15°C	kg/m ³		-	-	-	-	824	840
Distillation		ISO 3405						
50 per cent Vol.	°C		-	-	-	-	255	295
90 per cent Vol.	°C		-	360	-	350	300	345
End point	°C		-	-	-	-	-	370
Flash point	°C	ISO 3405	50	-	50	-	58	-
Cold filter plugging point	°C	ICS 75.160.20	-	-1	-	-5	-	-
Pour point	°C	ISO 3015	-	-2.5	-	-7.5	-	-
Kinematic viscosity @ 30 °C	mm ² /s	ISO 2909	2.7	-	2.5	-	3.0	4.5
Mass fraction of sulfur	per cent	ISO 4260	-	0.001	-	0.001	-	0.001
Volume fraction of total aromatics	per cent v/v	HPLC	-	-	-	-	-	25
Volume fraction of poly-aromatics	per cent v/v	HPLC	-	-	-	-	-	5.0
Mass fraction of carbon residue (10 per cent bottom)	mg	ISO 4260	-	0.1	-	0.1	-	-

Annex 3

MEASUREMENT EQUIPMENT

A.3.1. This annex contains the basic requirements and the general descriptions of the sampling and analyzing systems for gaseous and particulate emissions measurement. Since various configurations can produce equivalent results, exact conformance with the figures of this annex is not required. Components such as instruments, valves, solenoids, pumps, flow devices and switches may be used to provide additional information and coordinate the functions of the component systems. Other components, which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

A.3.1.1. Analytical system

A.3.1.2. Description of the analytical system

Analytical system for the determination of the gaseous emissions in the raw exhaust gas (figure 9) or in the diluted exhaust gas (figure 10) are described based on the use of:

- (a) HFID or FID analyzer for the measurement of hydrocarbons;
- (b) NDIR analyzers for the measurement of carbon monoxide and carbon dioxide;
- (c) HCLD or CLD analyzer for the measurement of the oxides of nitrogen.

The sample for all components should be taken with one sampling probe and internally split to the different analyzers. Optionally, two sampling probes located in close proximity may be used. Care shall be taken that no unintended condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

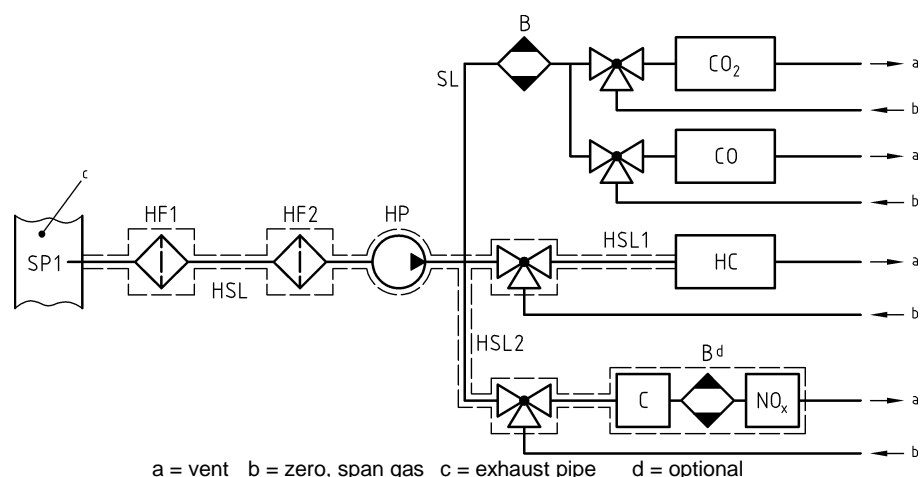


Figure 9

Schematic flow diagram of raw exhaust gas analysis system for CO, CO₂, NO_x, HC

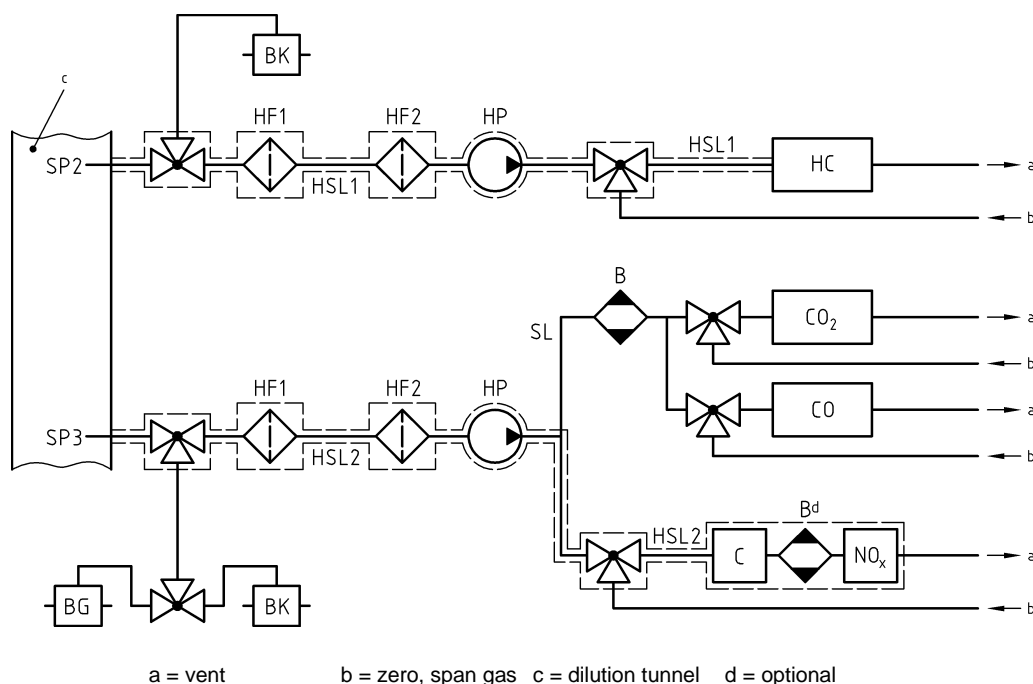


Figure 10

Schematic flow diagram of diluted exhaust gas analysis system for CO, CO₂, NO_x, HC

A.3.1.3. Components of figures 9 and 10

EP Exhaust pipe

SP Raw exhaust gas sampling probe (figure 9 only)

A stainless steel straight closed end multi-hole probe is recommended. The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1 mm. There shall be a minimum of 3 holes in 3 different radial planes sized to sample approximately the same flow. The probe shall extend across at least 80 per cent of the diameter of the exhaust pipe. One or two sampling probes may be used.

SP2 Dilute exhaust gas HC sampling probe (figure 10 only)

The probe shall:

- (a) be defined as the first 254 mm to 762 mm of the heated sampling line HSL1
- (b) have a 5 mm minimum inside diameter
- (c) be installed in the dilution tunnel DT (figure 15) at a point where the diluent and exhaust gas are well mixed (i.e. approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel)
- (d) be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies

- (e) be heated so as to increase the gas stream temperature to $463\text{ K} \pm 10\text{ K}$ ($190\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) at the exit of the probe, or to $385\text{ K} \pm 10\text{ K}$ ($112\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) for positive ignition engines
- (f) non-heated in case of FID measurement (cold)

SP3 Dilute exhaust gas CO, CO₂, NO_x sampling probe (figure 10 only)

The probe shall:

- (a) be in the same plane as SP2
- (b) be sufficiently distant (radially) from other probes and the tunnel wall so as to be free from the influence of any wakes or eddies
- (c) be heated and insulated over its entire length to a minimum temperature of 328 K ($55\text{ }^\circ\text{C}$) to prevent water condensation

HF1 Heated pre-filter (optional)

The temperature shall be the same as HSL1.

HF2 Heated filter

The filter shall extract any solid particles from the gas sample prior to the analyzer. The temperature shall be the same as HSL1. The filter shall be changed as needed.

HSL1 Heated sampling line

The sampling line provides a gas sample from a single probe to the split point(s) and the HC analyzer.

The sampling line shall:

- (a) have a 4 mm minimum and a 13.5 mm maximum inside diameter
- (b) be made of stainless steel or PTFE
- (c) maintain a wall temperature of $463\text{ K} \pm 10\text{ K}$ ($190\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) as measured at every separately controlled heated section, if the temperature of the exhaust gas at the sampling probe is equal to or below 463 K ($190\text{ }^\circ\text{C}$)
- (d) maintain a wall temperature greater than 453 K ($180\text{ }^\circ\text{C}$), if the temperature of the exhaust gas at the sampling probe is above 463 K ($190\text{ }^\circ\text{C}$)
- (e) maintain a gas temperature of $463\text{ K} \pm 10\text{ K}$ ($190\text{ }^\circ\text{C} \pm 10\text{ }^\circ\text{C}$) immediately before the heated filter HF2 and the HFID

HSL2 Heated NO_x sampling line

The sampling line shall:

- (a) maintain a wall temperature of 328 K to 473 K ($55\text{ }^\circ\text{C}$ to $200\text{ }^\circ\text{C}$), up to the converter for dry measurement, and up to the analyzer for wet measurement
- (b) be made of stainless steel or PTFE

HP Heated sampling pump

The pump shall be heated to the temperature of HSL.

SL Sampling line for CO and CO₂

The line shall be made of PTFE or stainless steel. It may be heated or unheated.

HC HFID analyzer

Heated flame ionization detector (HFID) or flame ionization detector (FID) for the determination of the hydrocarbons. The temperature of the HFID shall be kept at 453 K to 473 K (180 °C to 200 °C).

CO, CO₂ NDIR analyzer

NDIR analyzers for the determination of carbon monoxide and carbon dioxide (optional for the determination of the dilution ratio for PT measurement).

NO_x CLD analyzer or NDUV analyzer

CLD, HCLD or NDUV analyzer for the determination of the oxides of nitrogen. If a HCLD is used it shall be kept at a temperature of 328 K to 473 K (55 °C to 200 °C).

B Sample dryer (optional for NO measurement)

To cool and condense water from the exhaust sample. It is optional if the analyzer is free from water vapour interference as determined in paragraph 9.3.9.2.2. If water is removed by condensation, the sample gas temperature or dew point shall be monitored either within the water trap or downstream. The sample gas temperature or dew point shall not exceed 280 K (7 °C). Chemical dryers are not allowed for removing water from the sample.

BK Background bag (optional; figure 10 only)

For the measurement of the background concentrations.

BG Sample bag (optional; figure 10 only)

For the measurement of the sample concentrations.

A.3.1.4. Non-methane cutter method (NMC)

The cutter oxidizes all hydrocarbons except CH₄ to CO₂ and H₂O, so that by passing the sample through the NMC only CH₄ is detected by the HFID. In addition to the usual HC sampling train (see figures 9 and 10), a second HC sampling train shall be

installed equipped with a cutter as laid out in figure 11. This allows simultaneous measurement of total HC, CH₄ and NMHC.

The cutter shall be characterized at or above 600 K (327°C) prior to test work with respect to its catalytic effect on CH₄ and C₂H₆ at H₂O values representative of exhaust stream conditions. The dew point and O₂ level of the sampled exhaust stream shall be known. The relative response of the FID to CH₄ and C₂H₆ shall be determined in accordance with paragraph 9.3.8.

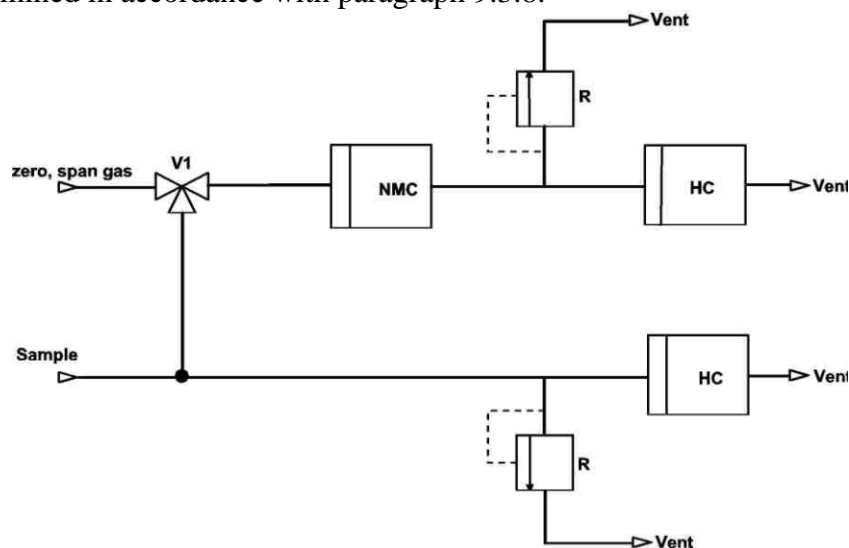


Figure 11

Schematic flow diagram of methane analysis with the NMC

A.3.1.5. Components of figure 11

NMC Non-methane cutter

To oxidize all hydrocarbons except methane

HC

Heated flame ionization detector (HFID) or flame ionization detector (FID) to measure the HC and CH₄ concentrations. The temperature of the HFID shall be kept at 453 K to 473 K (180 °C to 200 °C).

V1 Selector valve

To select zero and span gas

R Pressure regulator

To control the pressure in the sampling line and the flow to the HFID

A.3.2. Dilution and particulate sampling system

A.3.2.1. Description of partial flow system

A dilution system is described based upon the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas is passed to the particulate sampling system. The first method is referred to as total sampling type, the second method as fractional sampling type. The calculation of the dilution ratio depends upon the type of system used.

With the total sampling system as shown in figure 12, raw exhaust gas is transferred from the exhaust pipe (EP) to the dilution tunnel (DT) through the sampling probe (SP) and the transfer tube (TT). The total flow through the tunnel is adjusted with the flow controller FC2 and the sampling pump (P) of the particulate sampling system (see figure 16). The diluent flow is controlled by the flow controller FC1, which may use q_{mew} or q_{maw} and q_{mf} as command signals, for the desired exhaust split. The sample flow into DT is the difference of the total flow and the diluent flow. The diluent flow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device FM3 of the particulate sampling system (see figure 16). The dilution ratio is calculated from these two flow rates.

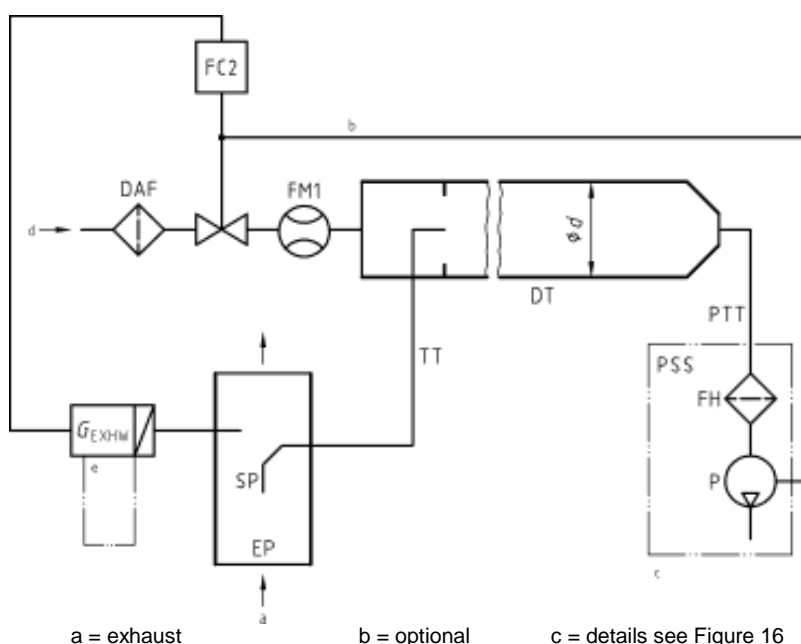


Figure 12

Scheme of partial flow dilution system (total sampling type)

With the fractional sampling system as shown in figure 13, raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling

probe SP and the transfer tube TT. The total flow through the tunnel is adjusted with the flow controller FC1 connected either to the diluentflow or to the suction blower for the total tunnel flow. The flow controller FC1 may use q_{mew} or q_{maw} and q_{mf} as command signals for the desired exhaust split. The sample flow into DT is the difference of the total flow and the diluentflow. The diluentflow rate is measured with the flow measurement device FM1, the total flow rate with the flow measurement device FM2. The dilution ratio is calculated from these two flow rates. From DT, a particulate sample is taken with the particulate sampling system (see figure 16).

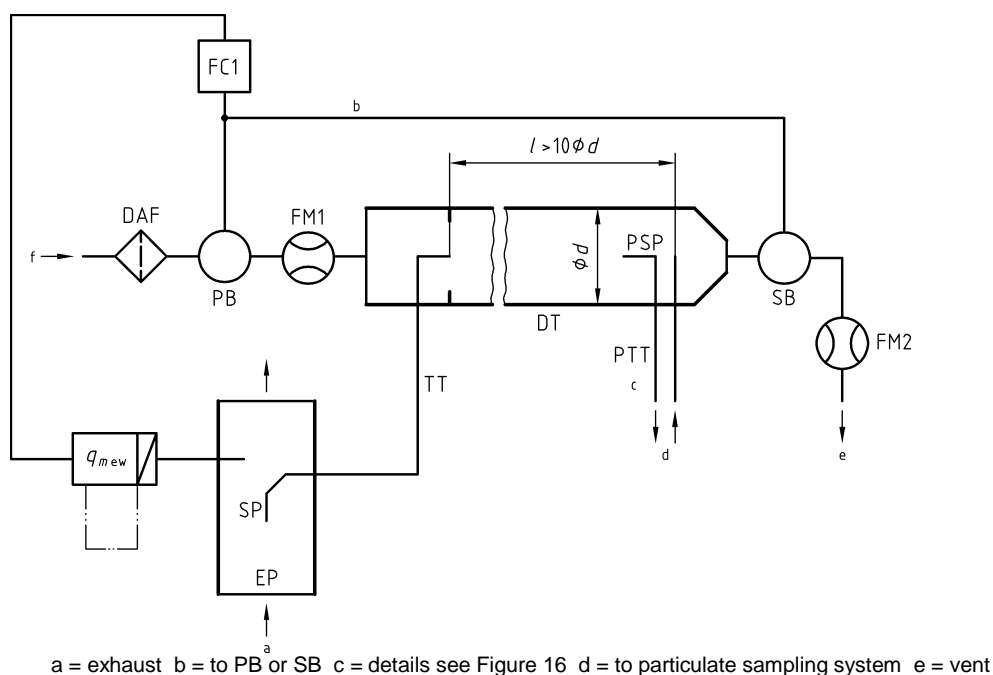


Figure 13

Scheme of partial flow dilution system (fractional sampling type)

A.3.2.2. Components of figures 12 and 13

EP Exhaust pipe

The exhaust pipe may be insulated. To reduce the thermal inertia of the exhaust pipe a thickness to diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length to diameter ratio of 12 or less. Bends shall be minimized to reduce inertial deposition. If the system includes a test bed silencer the silencer may also be insulated. It is recommended to have a straight pipe of 6 pipe diameters upstream and 3 pipe diameters downstream of the tip of the probe.

SP Sampling probe

The type of probe shall be either of the following

- (a) open tube facing upstream on the exhaust pipe centreline
- (b) open tube facing downstream on the exhaust pipe centreline
- (c) multiple hole probe as described under SP in paragraph A.3.1.3.
- (d) hatted probe facing upstream on the exhaust pipe centreline as shown in figure 14

The minimum inside diameter of the probe tip shall be 4 mm. The minimum diameter ratio between exhaust pipe and probe shall be 4.

When using probe type (a), an inertial pre-classifier (cyclone or impactor) with at 50 per cent cut point between 2.5 and 10 μm shall be installed immediately upstream of the filter holder.

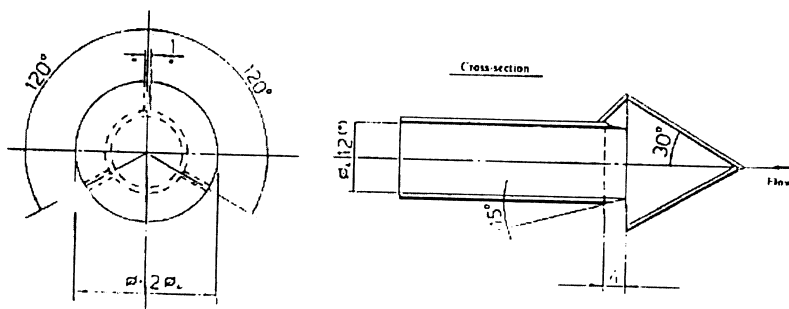


Figure 14
Scheme of hatted probe

TT Exhaust transfer tube

The transfer tube shall be as short as possible, but:

- (a) not more than 0.26 m in length, if insulated for 80 per cent of the total length, as measured between the end of the probe and the dilution stage;
- or
- (b) not more than 1 m in length, if heated above 150 °C for 90 per cent of the total length, as measured between the end of the probe and the dilution stage.

It shall be equal to or greater than the probe diameter, but not more than 25 mm in diameter, and exiting on the centreline of the dilution tunnel and pointing downstream.

With respect to (a), insulation shall be done with material with a maximum thermal conductivity of 0.05 W/mK with a radial insulation thickness corresponding to the diameter of the probe.

FC1 Flow controller

A flow controller shall be used to control the diluent flow through the pressure blower PB and/or the suction blower SB. It may be connected to the exhaust flow sensor signals specified in paragraph 8.4.1. The flow controller may be installed upstream or downstream of the respective blower. When using a pressurized air supply, FC1 directly controls the airflow.

FM1 Flow measurement device

Gas meter or other flow instrumentation to measure the diluent flow. FM1 is optional if the pressure blower PB is calibrated to measure the flow.

DAF Diluent filter

The diluent (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency (HEPA) filter that has an initial minimum collection efficiency of 99.97 per cent according to EN 1822-1 (filter class H14 or better), ASTM F 1471-93 or equivalent standard.

FM2 Flow measurement device (fractional sampling type, figure 13 only)

Gas meter or other flow instrumentation to measure the diluted exhaust gas flow. FM2 is optional if the suction blower SB is calibrated to measure the flow.

PB Pressure blower (fractional sampling type, figure 13 only)

To control the diluent flow rate, PB may be connected to the flow controllers FC1 or FC2. PB is not required when using a butterfly valve. PB may be used to measure the diluent flow, if calibrated.

SB Suction blower (fractional sampling type, figure 13 only)

SB may be used to measure the diluted exhaust gas flow, if calibrated.

DT Dilution tunnel (partial flow)

The dilution tunnel:

- (a) shall be of a sufficient length to cause complete mixing of the exhaust and diluent under turbulent flow conditions (Reynolds number, Re , greater than 4000, where Re is based on the inside diameter of the dilution tunnel) for a fractional sampling system, i.e. complete mixing is not required for a total sampling system;
- (b) shall be constructed of stainless steel;
- (c) may be heated to no greater than 325 K (52 °C) wall temperature;
- (d) may be insulated.

PSP Particulate sampling probe (fractional sampling type, figure 13 only)

The particulate sampling probe is the leading section of the particulate transfer tube PTT (see paragraph A.3.2.6.) and:

- (a) shall be installed facing upstream at a point where the diluent and exhaust gas are well mixed, i.e. on the dilution tunnel DT centreline approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- (b) shall be 8 mm in minimum inside diameter;
- (c) may be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by diluent pre-heating, provided the diluent temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust into the dilution tunnel;
- (d) may be insulated.

A.3.2.3. Description of full flow dilution system

A dilution system is described based upon the dilution of the total amount of raw exhaust gas in the dilution tunnel DT using the CVS (constant volume sampling) concept, and is shown in figure 15.

The diluted exhaust gas flow rate shall be measured either with a positive displacement pump (PDP), with a critical flow venturi (CFV) or with a subsonic venturi (SSV). A heat exchanger (HE) or electronic flow compensation (EFC) may be used for proportional particulate sampling and for flow determination. Since particulate mass determination is based on the total diluted exhaust gas flow, it is not necessary to calculate the dilution ratio.

For subsequent collection of the particulates, a sample of the dilute exhaust gas shall be passed to the double dilution particulate sampling system (see figure 17). Although partly a dilution system, the double dilution system is described as a modification of a particulate sampling system, since it shares most of the parts with a typical particulate sampling system.

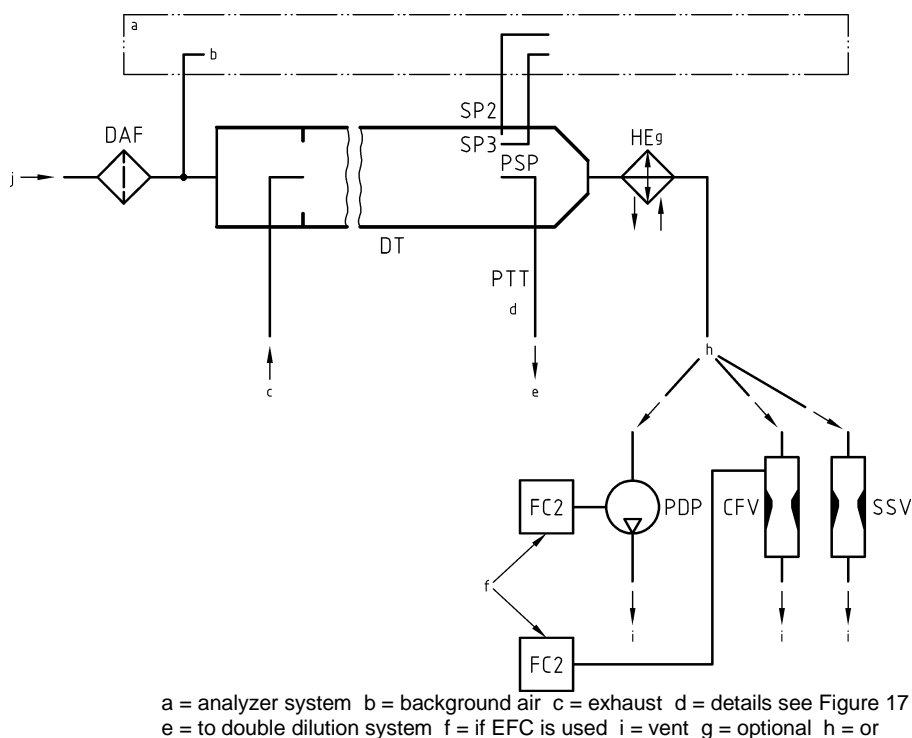


Figure 15

Scheme of full flow dilution system (CVS)

A.3.2.4. Components of figure 15

EP Exhaust pipe

The exhaust pipe length from the exit of the engine exhaust manifold, turbocharger outlet or after-treatment device to the dilution tunnel shall be not more than 10 m. If the system exceeds 4 m in length, then all tubing in excess of 4 m shall be insulated, except for an in-line smoke meter, if used. The radial thickness of the insulation shall be at least 25 mm. The thermal conductivity of the insulating material shall have a value no greater than 0.1 W/mK measured at 673 K. To reduce the thermal inertia of the exhaust pipe a thickness-to-diameter ratio of 0.015 or less is recommended. The use of flexible sections shall be limited to a length-to-diameter ratio of 12 or less.

PDP Positive displacement pump

The PDP meters total diluted exhaust flow from the number of the pump revolutions and the pump displacement. The exhaust system backpressure shall not be artificially lowered by the PDP or diluent inlet system. Static exhaust backpressure measured with the PDP system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the PDP at identical engine speed and load. The gas mixture temperature immediately ahead of the PDP shall be within ± 6 K of

the average operating temperature observed during the test, when no flow compensation (EFC) is used. Flow compensation is only permitted, if the temperature at the inlet to the PDP does not exceed 323 K (50 °C).

CFV Critical flow venturi

CFV measures total diluted exhaust flow by maintaining the flow at choked conditions (critical flow). Static exhaust backpressure measured with the CFV system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the CFV at identical engine speed and load. The gas mixture temperature immediately ahead of the CFV shall be within ± 11 K of the average operating temperature observed during the test, when no flow compensation (EFC) is used.

SSV Subsonic venturi

SSV measures total diluted exhaust flow by using the gas flow function of a subsonic venturi in dependence of inlet pressure and temperature and pressure drop between venturi inlet and throat. Static exhaust backpressure measured with the SSV system operating shall remain within ± 1.5 kPa of the static pressure measured without connection to the SSV at identical engine speed and load. The gas mixture temperature immediately ahead of the SSV shall be within ± 11 K of the average operating temperature observed during the test, when no flow compensation (EFC) is used.

HE Heat exchanger (optional)

The heat exchanger shall be of sufficient capacity to maintain the temperature within the limits required above. If EFC is used, the heat exchanger is not required.

EFC Electronic flow compensation (optional)

If the temperature at the inlet to the PDP, CFV or SSV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling into the double dilution system. For that purpose, the continuously measured flow rate signals are used to maintain the proportionality of the sample flow rate through the particulate filters of the double dilution system (see figure 17) within ± 2.5 per cent.

DT Dilution tunnel (full flow)

The dilution tunnel

- (a) shall be small enough in diameter to cause turbulent flow (Reynolds number, Re , greater than 4000, where Re is based on the inside diameter of the dilution tunnel) and of sufficient length to cause complete mixing of the exhaust and diluent;

- (b) may be insulated;
- (c) may be heated up to a wall temperature sufficient to eliminate aqueous condensation.

The engine exhaust shall be directed downstream at the point where it is introduced into the dilution tunnel, and thoroughly mixed. A mixing orifice may be used.

For the double dilution system, a sample from the dilution tunnel is transferred to the secondary dilution tunnel where it is further diluted, and then passed through the sampling filters (figure 17). The secondary dilution system shall provide sufficient secondary diluent to maintain the doubly diluted exhaust stream at a temperature between 315 K (42 °C) and 325 K (52 °C) immediately before the particulate filter.

DAF Diluent filter

The diluent (ambient air, synthetic air, or nitrogen) shall be filtered with a high-efficiency (HEPA) filter that has an initial minimum collection efficiency of 99.97 per cent according to EN 1822-1 (filter class H14 or better), ASTM F 1471-93 or equivalent standard.

PSP Particulate sampling probe

The probe is the leading section of PTT and

- (a) shall be installed facing upstream at a point where the diluent and exhaust gases are well mixed, i.e. on the dilution tunnel DT centreline of the dilution systems, approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- (b) shall be of 8 mm minimum inside diameter;
- (c) may be heated to no greater than 325 K (52 °C) wall temperature by direct heating or by diluent pre-heating, provided the air temperature does not exceed 325 K (52 °C) prior to the introduction of the exhaust in the dilution tunnel;
- (d) may be insulated.

A.3.2.5. Description of particulate sampling system

The particulate sampling system is required for collecting the particulates on the particulate filter and is shown in figures 16 and 17. In the case of total sampling partial flow dilution, which consists of passing the entire diluted exhaust sample through the filters, the dilution and sampling systems usually form an integral unit (see figure 12). In the case of fractional sampling partial flow dilution or full flow dilution, which consists of passing through the filters only a portion of the diluted exhaust, the dilution and sampling systems usually form different units.

For a partial flow dilution system, a sample of the diluted exhaust gas is taken from the dilution tunnel DT through the particulate sampling probe PSP and the particulate

transfer tube PTT by means of the sampling pump P, as shown in figure 16. The sample is passed through the filter holder(s) FH that contain the particulate sampling filters. The sample flow rate is controlled by the flow controller FC3.

For of full flow dilution system, a double dilution particulate sampling system shall be used, as shown in figure 17. A sample of the diluted exhaust gas is transferred from the dilution tunnel DT through the particulate sampling probe PSP and the particulate transfer tube PTT to the secondary dilution tunnel SDT, where it is diluted once more. The sample is then passed through the filter holder(s) FH that contain the particulate sampling filters. The diluent flow rate is usually constant whereas the sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (see figure 15) is used, the total diluted exhaust gas flow is used as command signal for FC3.

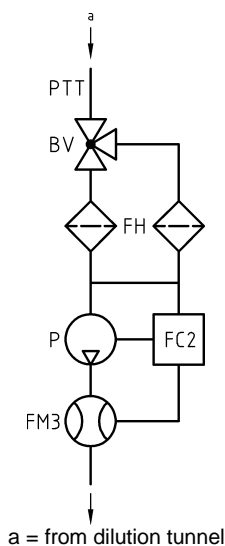
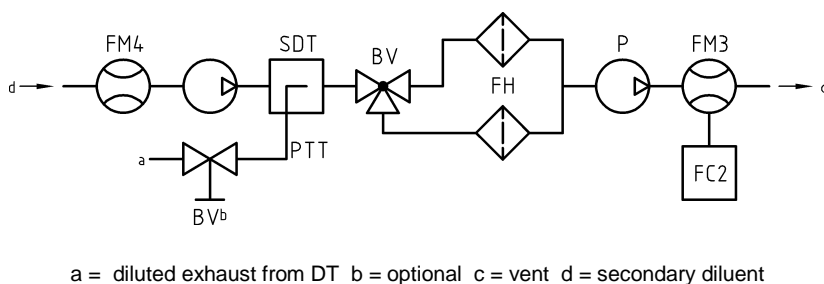


Figure 16
Scheme of particulate sampling system



a = diluted exhaust from DT b = optional c = vent d = secondary diluent

Figure 17
Scheme of double dilution particulate sampling system

A.3.2.6. Components of figures 16 (partial flow system only) and 17 (full flow system only)

PTT Particulate transfer tube

The transfer tube:

- (a) shall be inert with respect to PM;
- (b) may be heated to no greater than 325 K (52 °C) wall temperature;
- (c) may be insulated;

SDT Secondary dilution tunnel (figure 17 only)

The secondary dilution tunnel:

- (a) shall be of sufficient length and diameter so as to comply with the residence time requirements of paragraph 9.4.2.(f);
- (b) may be heated to no greater than 325 K (52 °C) wall temperature;
- (c) may be insulated.

FH Filter holder

The filter holder:

- (a) shall have a 12.5° (from center) divergent cone angle to transition from the transfer line diameter to the exposed diameter of the filter face;
- (b) may be heated to no greater than 325 K (52 °C) wall temperature;
- (c) may be insulated.

Multiple filter changers (auto changers) are acceptable, as long as there is no interaction between sampling filters.

PTFE membrane filters shall be placed in a specific cassette within the filter holder.

An inertial pre-classifier with a 50 per cent cut point between 2.5 µm and 10 µm shall be installed immediately upstream of the filter holder, if an open tube sampling probe facing upstream is used.

P Sampling pump

FC2 Flow controller

A flow controller shall be used for controlling the particulate sample flow rate.

FM3 Flow measurement device

Gas meter or flow instrumentation to determine the particulate sample flow through the particulate filter. It may be installed upstream or downstream of the sampling pump P.

FM4 Flow measurement device

Gas meter or flow instrumentation to determine the secondary diluent flow through the particulate filter.

BV Ball valve (optional)

The ball valve shall have an inside diameter not less than the inside diameter of the particulate transfer tube PTT, and a switching time of less than 0.5 s.

Annex 4

STATISTICS

A.4.1. Mean value and standard deviation

The arithmetic mean value shall be calculated as follows:

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \quad (92)$$

The standard deviation shall be calculated as follows:

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \quad (93)$$

A.4.2. Regression analysis

The slope of the regression shall be calculated as follows:

$$a_1 = \frac{\sum_{i=1}^n (y_i - \bar{y}) \times (x_i - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (94)$$

The y intercept of the regression shall be calculated as follows:

$$a_0 = \bar{y} - (a_1 \times \bar{x}) \quad (95)$$

The standard error of estimate (SEE) shall be calculated as follows:

$$SEE = \sqrt{\frac{\sum_{i=1}^n [y_i - a_0 - (a_1 \times x_i)]^2}{n-2}} \quad (96)$$

The coefficient of determination shall be calculated as follows:

$$r^2 = 1 - \frac{\sum_{i=1}^n [y_i - a_0 - (a_1 \times x_i)]^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (97)$$

A.4.3. Determination of system equivalency

The determination of system equivalency according to paragraph 5.1.1. shall be based on a 7 sample pair (or larger) correlation study between the candidate system and one of the accepted reference systems of this gtr using the appropriate test cycle(s). The equivalency criteria to be applied shall be the F-test and the two-sided Student t-test.

This statistical method examines the hypothesis that the sample standard deviation and sample mean value for an emission measured with the candidate system do not differ from the sample standard deviation and sample mean value for that emission measured with the reference system. The hypothesis shall be tested on the basis of a 10 per cent significance level of the F and t values. The critical F and t values for 7 to 10 sample pairs are given in table 9. If the F and t values calculated according to the equation below are greater than the critical F and t values, the candidate system is not equivalent.

The following procedure shall be followed. The subscripts R and C refer to the reference and candidate system, respectively:

- (a) Conduct at least 7 tests with the candidate and reference systems operated in parallel. The number of tests is referred to as n_R and n_C .
- (b) Calculate the mean values \bar{x}_R and \bar{x}_C and the standard deviations s_R and s_C .
- (c) Calculate the F value, as follows:

$$F = \frac{s_{\text{major}}^2}{s_{\text{minor}}^2} \quad (98)$$

(the greater of the two standard deviations s_R or s_C shall be in the numerator)

- (d) Calculate the t value, as follows:

$$t = \frac{|\bar{x}_C - \bar{x}_R|}{\sqrt{(n_C - 1) \times s_C^2 + (n_R - 1) \times s_R^2}} \times \sqrt{\frac{n_C \times n_R \times (n_C + n_R - 2)}{n_C + n_R}} \quad (99)$$

- (e) Compare the calculated F and t values with the critical F and t values corresponding to the respective number of tests indicated in table 9. If larger sample sizes are selected, consult statistical tables for 10 per cent significance (90 per cent confidence) level.

- (f) Determine the degrees of freedom (df), as follows:
- for the F -test: $df = n_R - 1 / n_C - 1$ (100)
- for the t -test: $df = n_C + n_R - 2$ (101)
- (g) Determine the equivalency, as follows:
- (i) if $F < F_{crit}$ and $t < t_{crit}$, then the candidate system is equivalent to the reference system of this gtr
- (ii) if $F \geq F_{crit}$ or $t \geq t_{crit}$, then the candidate system is different from the reference system of this gtr

Sample Size	F -test		t -test	
	df	F_{crit}	df	t_{crit}
7	6/6	3.055	12	1.782
8	7/7	2.785	14	1.761
9	8/8	2.589	16	1.746
10	9/9	2.440	18	1.734

Table 9
 t and F values for selected sample sizes

Annex 5

CARBON FLOW CHECK

A.5.1. Introduction

All but a tiny part of the carbon in the exhaust comes from the fuel, and all but a minimal part of this is manifest in the exhaust gas as CO₂. This is the basis for a system verification check based on CO₂ measurements.

The flow of carbon into the exhaust measurement systems is determined from the fuel flow rate. The flow of carbon at various sampling points in the emissions and particulate sampling systems is determined from the CO₂ concentrations and gas flow rates at those points.

In this sense, the engine provides a known source of carbon flow, and observing the same carbon flow in the exhaust pipe and at the outlet of the partial flow PM sampling system verifies leak integrity and flow measurement accuracy. This check has the advantage that the components are operating under actual engine test conditions of temperature and flow.

Figure 18 shows the sampling points at which the carbon flows shall be checked. The specific equations for the carbon flows at each of the sample points are given below.

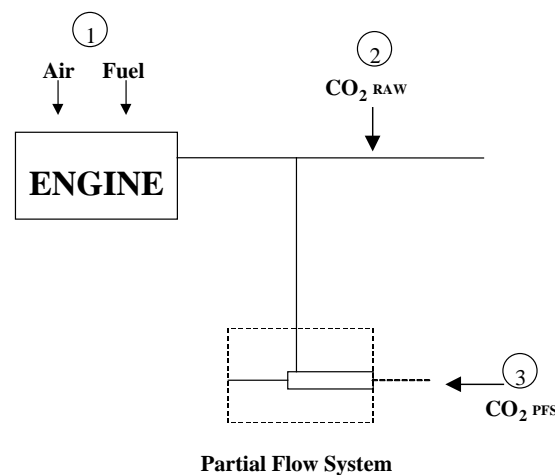


Figure 18
Measuring points for carbon flow check

A.5.2. Carbon flow rate into the engine (location 1)

The carbon mass flow rate into the engine for a fuel $\text{CH}_\alpha\text{O}_\varepsilon$ is given by:

$$q_{mCf} = \frac{12\beta}{12\beta + \alpha + 16\varepsilon} \times q_{mf} \quad (102)$$

where:

q_{mf} is the fuel mass flow rate, kg/s

A.5.3. Carbon flow rate in the raw exhaust (location 2)

The carbon mass flow rate in the exhaust pipe of the engine shall be determined from the raw CO_2 concentration and the exhaust gas mass flow rate:

$$q_{mCe} = \left(\frac{c_{\text{CO}_2,r} - c_{\text{CO}_2,a}}{100} \right) \times q_{mew} \times \frac{12.011}{M_{re}} \quad (103)$$

where:

$c_{\text{CO}_2,r}$ is the wet CO_2 concentration in the raw exhaust gas, per cent

$c_{\text{CO}_2,a}$ is the wet CO_2 concentration in the ambient air, per cent

q_{mew} is the exhaust gas mass flow rate on wet basis, kg/s

M_e is the molar mass of exhaust gas, g/mol

If CO_2 is measured on a dry basis it shall be converted to a wet basis according to paragraph 8.1.

A.5.4. Carbon flow rate in the dilution system (location 3)

For the partial flow dilution system, the splitting ratio also needs to be taken into account. The carbon flow rate shall be determined from the dilute CO_2 concentration, the exhaust gas mass flow rate and the sample flow rate:

$$q_{mCp} = \left(\frac{c_{\text{CO}_2,d} - c_{\text{CO}_2,a}}{100} \right) \times q_{mdew} \times \frac{12.011}{M_e} \times \frac{q_{mew}}{q_{mp}} \quad (104)$$

where:

$c_{\text{CO}_2,d}$ is the wet CO_2 concentration in the dilute exhaust gas at the outlet of the dilution tunnel, per cent

$c_{\text{CO}_2,a}$ is the wet CO_2 concentration in the ambient air, per cent

q_{mew} is the exhaust gas mass flow rate on wet basis, kg/s

q_{mp} is the sample flow of exhaust gas into partial flow dilution system, kg/s

M_e is the molar mass of exhaust gas, g/mol

If CO₂ is measured on a dry basis, it shall be converted to wet basis according to paragraph 8.1.

A.5.5. Calculation of the molar mass of the exhaust gas

The molar mass of the exhaust gas shall be calculated according to equation 41 (see paragraph 8.4.2.4.)

Alternatively, the following exhaust gas molar masses may be used:

$$M_e (\text{diesel}) = 28.9 \text{ g/mol}$$

$$M_e (\text{LPG}) = 28.6 \text{ g/mol}$$

$$M_e (\text{NG}) = 28.3 \text{ g/mol}$$

Annex 6

EXAMPLE OF CALCULATION PROCEDURE

A.6.1. Speed and torque denormalization procedure

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

$$\begin{aligned} \text{per cent speed} &= 43 \text{ per cent} \\ \text{per cent torque} &= 82 \text{ per cent} \end{aligned}$$

Given the following values:

$$\begin{aligned} n_{lo} &= 1,015 \text{ min}^{-1} \\ n_{hi} &= 2,200 \text{ min}^{-1} \\ n_{pref} &= 1,300 \text{ min}^{-1} \\ n_{idle} &= 600 \text{ min}^{-1} \end{aligned}$$

results in:

$$\begin{aligned} \text{actual speed} &= \frac{43 \times (0.45 \times 1,015 + 0.45 \times 1,300 + 0.1 \times 2,200 - 600) \times 2.0327}{100} + 600 \\ &= 1,178 \text{ min}^{-1} \end{aligned}$$

With the maximum torque of 700 Nm observed from the mapping curve at 1,178 min⁻¹

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

A.6.2. Basic data for stoichiometric calculations

Atomic mass of hydrogen	1.00794 g/atom
Atomic mass of carbon	12.011 g/atom
Atomic mass of sulphur	32.065 g/atom
Atomic mass of nitrogen	14.0067 g/atom
Atomic mass of oxygen	15.9994 g/atom
Atomic mass of argon	39.9 g/atom
Molar mass of water	18.01534 g/mol
Molar mass of carbon dioxide	44.01 g/mol
Molar mass of carbon monoxide	28.011 g/mol
Molar mass of oxygen	31.9988 g/mol
Molar mass of nitrogen	28.011 g/mol
Molar mass of nitric oxide	30.008 g/mol
Molar mass of nitrogen dioxide	46.01 g/mol
Molar mass of sulphur dioxide	64.066 g/mol

Molar mass of dry air 28.965 g/mol

Assuming no compressibility effects, all gases involved in the engine intake/combustion/exhaust process can be considered to be ideal and any volumetric calculations shall therefore be based on a molar volume of 22.414 l/mol according to Avogadro's hypothesis.

A.6.3. Gaseous emissions (diesel fuel)

The measurement data of an individual point of the test cycle (data sampling rate of 1 Hz) for the calculation of the instantaneous mass emission are shown below. In this example, CO and NO_x are measured on a dry basis, HC on a wet basis. The HC concentration is given in propane equivalent (C3) and has to be multiplied by 3 to result in the C1 equivalent. The calculation procedure is identical for the other points of the cycle.

The calculation example shows the rounded intermediate results of the different steps for better illustration. It should be noted that for actual calculation, rounding of intermediate results is not permitted (see paragraph 8.).

$T_{a,i}$ (K)	$H_{a,i}$ (g/kg)	W_{act} kWh	$q_{mew,i}$ (kg/s)	$q_{maw,i}$ (kg/s)	$q_{mf,i}$ (kg/s)	$c_{HC,i}$ (ppm)	$c_{CO,i}$ (ppm)	$c_{NOx,i}$ (ppm)
295	8.0	40	0.155	0.150	0.005	10	40	500

The following fuel composition is considered:

Component	Molar ratio	per cent mass
H	$\alpha = 1.8529$	$w_{ALF} = 13.45$
C	$\beta = 1.0000$	$w_{BET} = 86.50$
S	$\gamma = 0.0002$	$w_{GAM} = 0.050$
N	$\delta = 0.0000$	$w_{DEL} = 0.000$
O	$\epsilon = 0.0000$	$w_{EPS} = 0.000$

Step 1: Dry/wet correction (paragraph 8.1.):

Equation (16): $k_f = 0.055584 \times 13.45 - 0.0001083 \times 86.5 - 0.0001562 \times 0.05 = 0.7382$

$$\text{Equation (13): } k_{w,a} = \left(1 - \frac{1.2434 \times 8 + 111.12 \times 13.45 \times \frac{0.005}{0.148}}{773.4 + 1.2434 \times 8 + \frac{0.005}{0.148} \times 0.7382 \times 1,000} \right) \times 1.008 = 0.9331$$

Equation (12): $c_{CO,i} \text{ (wet)} = 40 \times 0.9331 = 37.3 \text{ ppm}$
 $c_{NOx,i} \text{ (wet)} = 500 \times 0.9331 = 466.6 \text{ ppm}$

Step 2: NO_x correction for temperature and humidity (paragraph 8.2.1.):

$$\text{Equation (23): } k_{h,D} = \frac{15.698 \times 8.00}{1,000} + 0.832 = 0.9576$$

Step 3: Calculation of the instantaneous emission of each individual point of the cycle (paragraph 8.4.2.3.):

$$\begin{aligned} \text{Equation (36): } m_{\text{HC},i} &= 10 \times 3 \times 0.155 &= 4.650 \\ m_{\text{CO},i} &= 37.3 \times 0.155 &= 5.782 \\ m_{\text{NOx},i} &= 466.6 \times 0.9576 \times 0.155 &= 69.26 \end{aligned}$$

Step 4: Calculation of the mass emission over the cycle by integration of the instantaneous emission values and the *u* values from table 5 (paragraph 8.4.2.3.):

The following calculation is assumed for the WHTC cycle (1,800 s) and the same emission in each point of the cycle.

$$\begin{aligned} \text{Equation (36): } m_{\text{HC}} &= 0.000479 \times \sum_{i=1}^{1800} 4.650 &= 4.01 \text{ g/test} \\ m_{\text{CO}} &= 0.000966 \times \sum_{i=1}^{1800} 5.782 &= 10.05 \text{ g/test} \\ m_{\text{NOx}} &= 0.001586 \times \sum_{i=1}^{1800} 69.26 &= 197.72 \text{ g/test} \end{aligned}$$

Step 5: Calculation of the specific emissions (paragraph 8.6.3.):

$$\begin{aligned} \text{Equation (69): } e_{\text{HC}} &= 4.01 / 40 &= 0.10 \text{ g/kWh} \\ e_{\text{CO}} &= 10.05 / 40 &= 0.25 \text{ g/kWh} \\ e_{\text{NOx}} &= 197.72 / 40 &= 4.94 \text{ g/kWh} \end{aligned}$$

A.6.4. Particulate Emission (diesel fuel)

<i>p_b</i> (kPa)	<i>W_{act}</i> (kWh)	<i>q_{mew,i}</i> (kg/s)	<i>q_{mf,i}</i> (kg/s)	<i>q_{mdw,i}</i> (kg/s)	<i>q_{mdew,i}</i> (kg/s)	<i>m_{uncor}</i> (mg)	<i>m_{sep}</i> (kg)
99	40	0.155	0.005	0.0015	0.0020	1.7000	1.515

Step 1: Calculation of *m_{edf}* (paragraph 8.4.3.5.2.):

$$\text{Equation (48): } r_{d,i} = \frac{0.002}{(0.002 - 0.0015)} = 4$$

$$\text{Equation (47): } q_{\text{medf},i} = 0.155 \times 4 = 0.620 \text{ kg/s}$$

$$\text{Equation (46): } m_{\text{edf}} = \sum_{i=1}^{1800} 0.620 = 1,116 \text{ kg/test}$$

Step 2: Buoyancy correction of the particulate mass (paragraph 8.3.)

$$\text{Equation (26): } \rho_a = \frac{99 \times 28.836}{8.3144 \times 295} = 1.164 \text{ kg/m}^3$$

$$[\text{Equation (25): } m_f = 1.7000 \times \frac{(1 - 1.164/8,000)}{(1 - 1.164/2,300)} = 1.7006 \text{ mg}]$$

Step 3: Calculation of the particulate mass emission (paragraph 8.4.3.5.2.):

$$\text{Equation (45): } m_{\text{PM}} = \frac{1.7006}{1.515} \times \frac{1,116}{1,000} = 1.253 \text{ g/test}$$

Step 4: Calculation of the specific emission (paragraph 8.6.3.):

$$\text{Equation (69): } e_{\text{PM}} = 1.253 / 40 = 0.031 \text{ g/kWh}$$

Annex 7

INSTALLATION OF AUXILIARIES AND EQUIPMENT FOR EMISSIONS TEST

Number	Auxiliaries	Fitted for emission test
1	Inlet system Inlet manifold Crankcase emission control system Control devices for dual induction inlet manifold system Air flow meter Air inlet duct work Air filter Inlet silencer Speed-limiting device	Yes Yes Yes Yes Yes, or test cell equipment Yes, or test cell equipment Yes, or test cell equipment Yes
2	Induction-heating device of inlet manifold	Yes, if possible to be set in the most favourable condition
3	Exhaust system Exhaust manifold Connecting pipes Silencer Tail pipe Exhaust brake Pressure charging device	Yes Yes Yes Yes No, or fully open Yes
4	Fuel supply pump	Yes
5	Equipment for gas engines Electronic control system, air flow meter, etc. Pressure reducer Evaporator Mixer	Yes Yes Yes Yes
6	Fuel injection equipment Prefilter Filter Pump High-pressure pipe Injector Air inlet valve Electronic control system, sensors, etc. Governor/control system Automatic full-load stop for the control rack depending on atmospheric conditions	Yes Yes Yes Yes Yes Yes Yes Yes Yes
7	Liquid-cooling equipment Radiator Fan Fan cowl Water pump Thermostat	No No No Yes Yes, may be fixed fully open

Number	Auxiliaries	Fitted for emission test
8	Air cooling Cowl Fan or Blower Temperature-regulating device	No No No No
9	Electrical equipment Alternator Coil or coils Wiring Electronic control system	No Yes Yes Yes
10	Intake air charging equipment Compressor driven either directly by the engine and/or by the exhaust gases Charge air cooler Coolant pump or fan (engine-driven) Coolant flow control device	Yes Yes, or test cell system No Yes
11	Anti-pollution device (exhaust after-treatment system)	Yes
12	Starting equipment	Yes, or test cell system
13	Lubricating oil pump	Yes

Annex 8

REQUIREMENTS FOR ENGINES INSTALLED IN HYBRID VEHICLES USING HILS METHOD

1. SCOPE

This annex shall apply to HVs, which are equipped with an internal combustion engine as one of their energy converters and for which the pollutant emissions shall be determined on the basis of an engine test.

2. TEST PROCEDURE

2.1 HILS method

The HILS method consists of running the internal combustion engine on the test bench (in accordance with the conventional engine test procedures) using the HV engine test cycle determined through following steps (and visualized in Figure X):

- 1) Confirmation of the object for approval**
- 2) Define the input parameters for the HV components in accordance with Paragraph A.8.3.8. and the Component Test Procedure of Paragraph A.8.4.**
- 3) Build the HILS system according to Paragraph A.8.3. and check its operation according to Paragraph A.8.7.**
- 4) Setup the HILS system with the HV model in accordance with Paragraph A.8.3.4.**
- 5) Verify the HV model operation in accordance with Paragraph A.8.6.**
- 6) Conduct the HILS simulated run in accordance with Paragraph A.8.5. and determine the engine test cycle.**
- 7) Conduct the exhaust emission test in accordance with Paragraph Y.Y.**

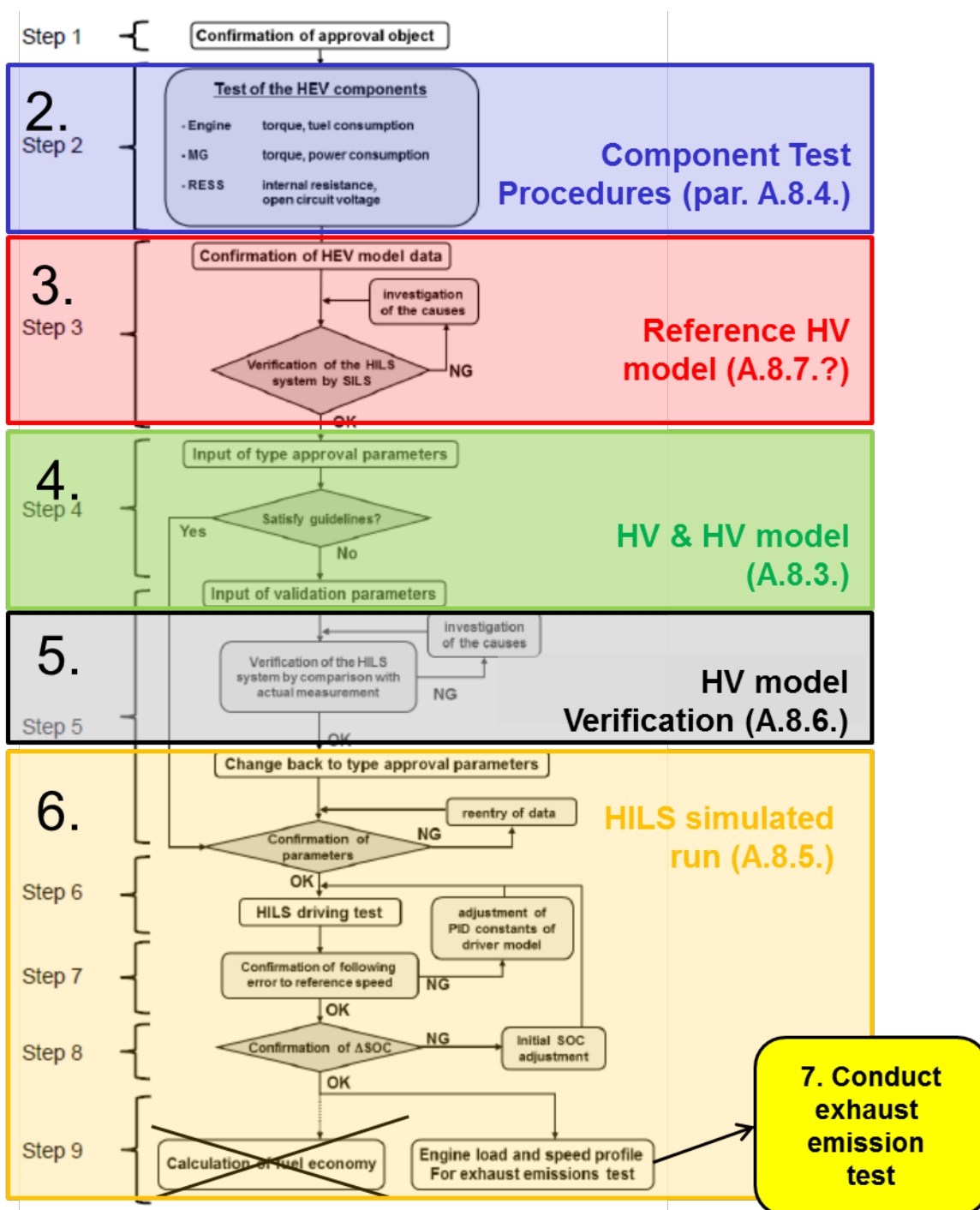


Figure X Flow chart HILS method [under review]

3. HILS system

The HILS system consist of, as shown in Figure X, the HILS hardware, the HV model and its input parameters, the driver model and the reference vehicle speed pattern as described in Annex 1.b., and the hybrid ECU(s) of the test

motor vehicle (hereinafter referred to as the “actual ECU”) and its power supply.

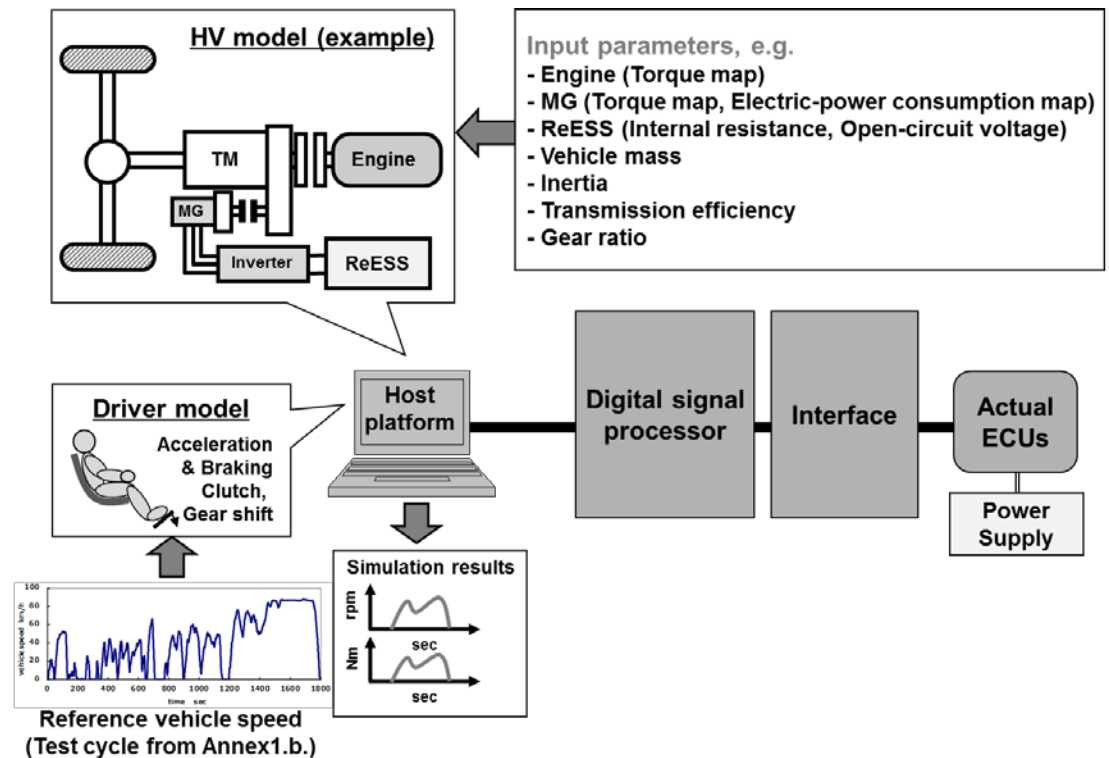


Figure X - Outline of HILS system for Heavy-Duty Hybrid Vehicles

The HV model shall be constructed from the available HV model components in the HILS library, which includes a driver model. For reference testing of the HILS system accuracy, a reference HV model is defined using the HILS library model components, defined input parameters and output values.

3.1. Models to be used

The models necessary for this test method are, in addition to an HV models for approval (including the reference ECU model for the Software-in-the-Loop Simulator (hereinafter referred to as the “SILS”) that is also used in the simulated running using the HILS system, as well as the defined Hermite interpolation procedure to be used when creating table data of the input parameters.

The software to be used is listed below:

- (a) HDH HILS library (Paragraph 3.4)
- (b) Reference HV model (Paragraph 6)
- (c) Hermite interpolation program (Appendix to be added)

3.2 Hardware

The HILS hardware shall have the signal types and number of channels that are required for constructing the interface between the HILS hardware and the actual ECU(s), and shall be checked and calibrated in accordance with Paragraph 6 (Reference HV model) and 7 (HV verification) to this Annex.

3.3. Actual ECU(s)

The hybrid system ECU(s) of the test vehicle shall be used for the HIL simulation. In case the functionalities of the hybrid system are performed by multiple controllers, those controllers may be integrated via interface or software emulation. However, the key hybrid functionalities shall be available in the hardware controller(s).

3.3.1. Key hybrid functionalities

Reserved.

3.4 HV Model

The HV model shall be created using the HILS library component models as specified in Paragraphs 3.4.1 through 3.4.7 to this Annex. A Matlab®/Simulink® library environment that contains models according to these specifications is available at [website reference](#).

After HV model build, the model parameters for the applied components shall be properly calibrated in accordance with Paragraph 3.8. to this Annex, and then the HV model performance shall be (verified) in accordance with Paragraph 7 to this Annex.

3.4.1 Auxiliary system model

3.4.1.1. Electric Auxiliary model

The electrical auxiliary system shall be modelled as a constant electrical power loss, $P_{el,aux}$. The current that is discharging the electrical energy storage, i_{aux} , is determined as:

$$i_{el,aux} = x P_{el,aux} / u \quad (\text{Eq. X})$$

Where:

$P_{el,aux}$: electric auxiliary power demand (W)

x : on/off control signal to toggle auxiliary load on or off (-)

u : electrical energy storage voltage (V)

$i_{el,aux}$: auxiliary current (A)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	$P_{el,aux}$	W	Auxiliary system load	dat.auxiliaryload.value
command signal	x	0/1	Off/On for auxiliary system	Aux_flgOnOff_B
sensor signal	i_{aux}	A	Auxiliary system current	Aux_iAct_A
elec in [V]	u	V	Voltage	phys_voltage_V
elec fb out [A]	i_{aux}	A	Current	phys_current_A

Table X Standard Electrical Auxiliary model parameters and interface

3.4.1.2. Mechanical Auxiliary model

The mechanical auxiliary system shall be modelled using a constant power loss, $P_{mech,aux}$. The power loss shall be implemented as a torque loss acting on the representative shaft.

$$M_{mech,aux} = x P_{mech,aux} / \omega \quad (\text{Eq. X})$$

Where:

$P_{mech,aux}$: mechanical auxiliary power demand (W)

x : on/off control signal to toggle auxiliary load on or off (-)

ω : shaft rotational speed (min^{-1})

$M_{mech,aux}$: auxiliary torque (Nm)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	$P_{\text{mech,aux}}$	W	Auxiliary system load	dat.auxiliaryload.value
	J_{aux}	kgm^2	Inertia	Dat.inertia.value
command signal	x	0/1	Off/On for auxiliary system	Aux_flgOnOff_B
sensor signal	M_{out}	Nm	Auxiliary system torque output	Aux_tqAct_A
mech in [Nm]	M_{out}	Nm	Torque	phys_torque_Nm
	J_{out}	kgm^2	Inertia	phys_inertia_kgm2
mech fb out [rad/s]	ω	rad/s	speed	phys_speed_radps

Table X Standard Mechanical Auxiliary model parameters and interface

3.4.2 Chassis model

A basic model of the chassis (the vehicle) shall be represented as an inertia. The model shall compute the vehicle speed from a propeller shaft torque and brake torque. The model shall consider rolling and aerodynamic drag resistances and take into account the road slope resistance. A schematic diagram is shown in Figure X.

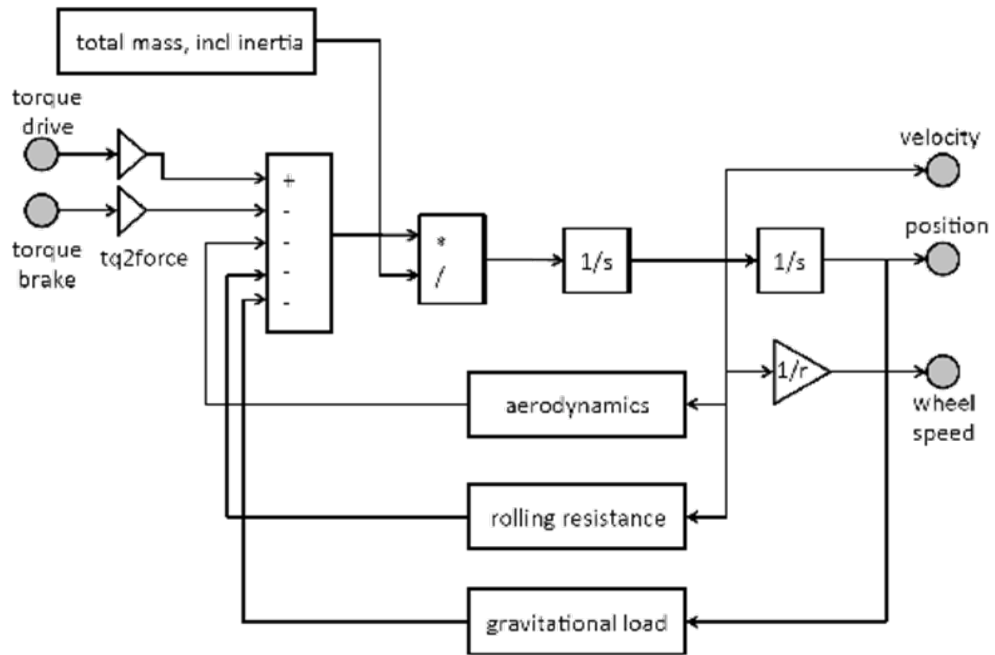


Figure X Chassis (vehicle) model diagram

The basic principle shall be input torque M_{in} to a gear reduction (final drive gear) with fixed ratio r_{fg} .

$$M_{drive} = \eta_{fg} M_{in} r_{fg} \quad (\text{Eq. X})$$

Where η_{fg} is the final gear efficiency.

The drive torque M_{drive} shall be counteracted by the brake torque M_{brake} . The resulting torque shall be converted to the drive force using the wheel radius r_{wheel} , according to equation X and acts on the road to drive the vehicle:

$$F_{drive} = \frac{M_{drive} - M_{brake}}{r_{wheel}} \quad (\text{Eq. X})$$

The force F_{drive} shall balance with forces for aerodynamic drag F_{aero} , rolling resistance F_{roll} and gravitation F_{grav} to find resulting acceleration force as follows:

$$m_{tot} \dot{v}_{vehicle} = F_{drive} - F_{aero} - F_{roll} - F_{grav} \quad (\text{Eq. X})$$

Where

m_{tot} : total mass of the vehicle (kg)

$\dot{v}_{vehicle}$: vehicle acceleration (m/s)

The total mass of the vehicle m_{tot} shall be calculated using the vehicle mass $m_{vehicle}$ and the inertia load from the powertrain components:

$$m_{tot} = m_{vehicle} + (J_{fg} + J_{powertrain})r_{fg}^2 + 2J_{wheel}r_{wheel}^2 \quad (\text{Eq. X})$$

Where

$m_{vehicle}$: Mass of the vehicle (kg)

J_{fg} : Inertia of the final gear (kgm²)

$J_{powertrain}$: Sum of all powertrain inertias (kgm²)

J_{wheel} : Inertia of the wheels (kg/m²)

The wheel speed shall be determined from the vehicle speed and wheel radius as:

$$\omega_{wheel} = v_{vehicle}/r_{wheel} \quad (\text{Eq. X})$$

The aerodynamic drag force shall be calculated as:

$$F_{aero} = 0.5\rho_{air}C_{drag}A_{front}v_{vehicle}^2 \quad (\text{Eq. X})$$

Where:

ρ : air density (kg/m³)

C_{drag} : air drag coefficient (-)

A_{front} : vehicle frontal area (m²)

$v_{vehicle}$: vehicle speed (m/s)

The rolling resistance shall be calculated using:

$$F_{roll} = f_{roll}m_{vehicle}g \cos(\alpha) \quad (\text{Eq. X})$$

Where:

f_{roll} : friction factor for wheel-road contact (-)

g : standard earth gravitation (m/s²)

α : road slope (rad)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	m_{vehicle}	kg	Vehicle mass	dat.vehicle.mass.value
	r_{fg}	-	Final gear ratio	dat.fg.ratio.value
	η_{fg}	-	Final gear efficiency	dat.fg.efficiency.value
	J_{fg}	kgm^2	Final gear inertia	dat.fg.inertia.value
	A_{front}	m^2	Vehicle frontal area	dat.aero.af.value
	C_d	-	Air drag coefficient	dat.aero.cd.value
	r_{wheel}	m	Wheel radius	dat.wheel.radius.value
	J_{wheel}	kgm^2	Wheel inertia	dat.wheel.inertia.value
	f	-	Rolling resistance coefficient	dat.wheel.rollingres.value
command signal	M_{brake}	Nm	Requested brake torque	Chassis_tqBrakeReq_Nm
sensor signal	v_{vehicle}	m/s	Actual vehicle speed	Chassis_vVehAct_mps
	ω_{wheel}	rad/s	Actual wheel speed	Chassis_nWheelAct_radps
	m_{tot}	kg	Vehicle mass	Chassis_massVehAct_kg
	α	rad	Road slope	Chassis_slopRoad_rad
mech in [Nm]	M_{drive}	Nm	torque	phys_torque_Nm
	$J_{\text{powertrain}}$	kgm^2	inertia	phys_inertia_kgm2
mech fb out	ω_{wheel}	rad/s	Rotational	phys_speed_radps

[rad/s]			speed	
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Table X Standard Chassis model parameters and interface

3.4.3 Driver model

The driver model shall actuate accelerator and brake pedal signals to realize the desired vehicle speed cycle and apply the shift control for manual transmissions through clutch and gear control.

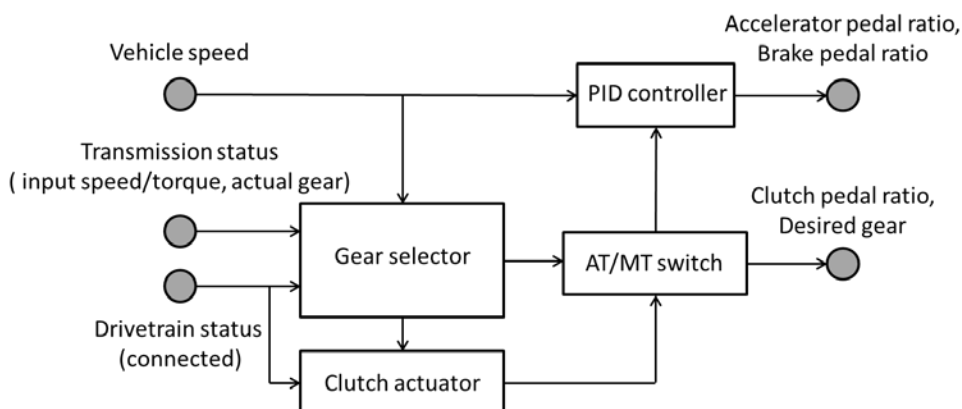


Figure X Driver model diagram

The driver model was prepared by following a modular approach and therefore contains different sub-modules. The model shown in Figure X is capable of running a vehicle equipped with either a manual gearbox with accelerator-, brake- and clutch pedal or a vehicle equipped with an automated gearbox where only accelerator- and brake pedal are used. For the manual transmission vehicle the decisions for gear shift manoeuvres are taken by the gear selector sub-module. For automated gearboxes this is bypassed but can be engaged also if needed.

The present driver model contains following:

- (a.) Sub-module controlling the vehicle speed (PID controller)
- (b.) Sub-module taking decisions of gear change
- (c.) Sub-module actuating the clutch pedal
- (d.) Sub-module switching signals when either a manual or an automated gearbox is used

For specific demands, single sub-modules can be easily removed or be planted in OEM specific driver models.

(a.) The sub-module controlling the vehicle speed is modelled using a simple PID-controller. It takes the reference speed from the driving cycle and compares it to the vehicles actual speed. If the vehicle's speed is too low it uses the accelerator pedal to demand acceleration, and vice versa if the vehicle's speed is too high, the driver uses the brake pedal to demand a deceleration of the vehicle. For vehicles not capable of running the desired speed (e.g. their design speed is lower than the demanded speed during the test run) the controller includes an anti-wind up function of the integral part, which can be also parameterized in the parameter file. If vehicles equipped with a manual transmission gearbox are driven it is considered that the accelerator pedal is not actuated during a gearshift manoeuvre.

(b.) The implemented gearshift strategy is based on the definition of shift polygons for up- and downshift manoeuvres. Together with a full load torque curve and a negative torque curve they describe the permitted operating range of the system. Crossing the upper shift polygon forces selection of a higher gear, crossing the lower one the selection of a lower gear (see figure X below).

The input signals needed for the gear selector sub-module to derive an actual gear request currently are:

- The actual gear engaged
- The input torque and rotational input speed (if this is transmission input torque or ICE output torque is still an open issue and has to be discussed in the HDH working group)
- Status of the drivetrain (next gear engaged and all clutches closed and synchronized again)

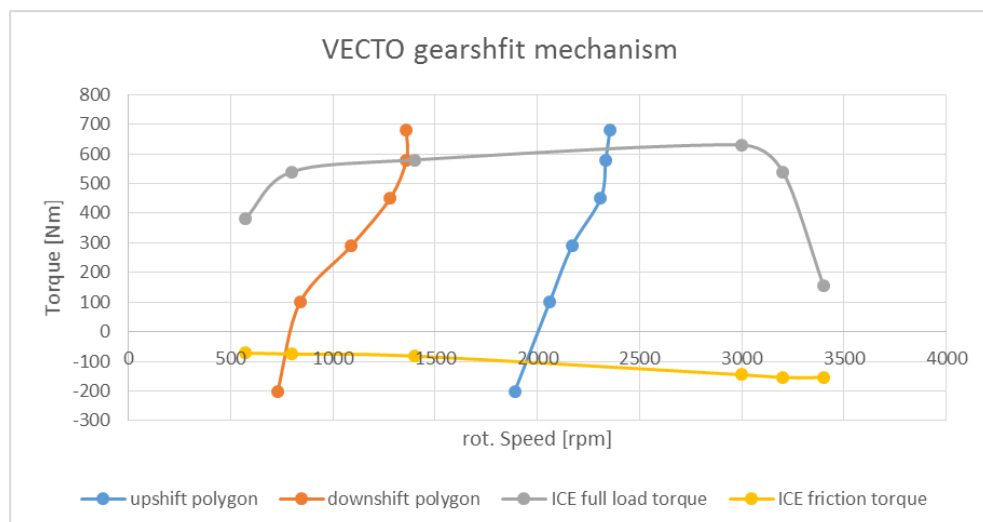


Figure X Gear shift model: polygons

Internally, also the test cycle and the time of clutch actuation during a shift manoeuvre are loaded in order to detect vehicle starts from standstill and engage the 1st gear on time before the desired speed is greater zero. This allows the vehicle to follow the desired speed within the given limits. The standard output value of the gearshift module when the vehicle stands still is the neutral gear. After a gear is changed a subsequent gear change is suppressed for a parameterized time and as long as the drivetrain is not connected to all propulsion engines and not fully synchronized again. The time limit is rejected and a next gear change is forced if rotational speed limits (lower than ICE idle speed or greater than ICE rated speed multiplied by 1.2) are exceeded.

(c.) The sub-module actuating the clutch pedal was designed to actuate the pedal if a vehicle equipped with a manual transmission gearbox is used. Excluding the function from the speed controller sub-module enables the driver model to be used in a wider field of applications. The clutch sub-module is triggered by the gear selector module and actuates the pedal as soon as a gearshift manoeuvre is requested. The clutch module simultaneously forces the speed controller to put the accelerator pedal to zero as long as the clutch is not closed and fully synchronized again after the gearshift manoeuvre. The time of clutch actuation has to be specified in the driver parameter file.

(d.) The AT/MT switch enables the driver model to be used either for a vehicle with a manual or an automated gearbox. The output signals for the MT mode are the requested gear and the accelerator-, brake-, and clutch pedal ratios. Using the AT mode the output signals are only accelerator- and brake pedal ratio. No gearshift manoeuvres are considered and therefore the accelerator pedal is also not set to zero even though a gear change is detected. The standard values for the clutch pedal ration and for a desired gear are zero in AT mode. Nevertheless, if the gear selection of the actual test vehicle should be overruled this can be done by enabling the desired gear output in the parameter file.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	?	-	Select gearbox mode MT(1) or AT(0)	dat.gearboxmode.value
	?	-	Gear selection model	dat.gearselectionmode.value
	?	s	Clutch time	dat.clutchtime.value

	?	m/s	Clutch is automatically acutated when speed is below this value	dat.clutchthershhold.value
	?	-	Driver PID controller	dat.controller
command signal	?	0-1	Accelerator pedal position	Drv_AccPedl_rat
	?	0-1	Brake pedal position	Drv_BrkPedl_rat
	?	0-1	Clutch pedal position	Drv_CluPedl_rat
	?	-	Gear request	Drv_nrGearReq
	?	m/s	Reference target speed	Drivecycle_RefSpeed_mps
sensor signal	?	m/s	Chassis speed	Chassis_vVehAct_mps
	?	rad/s	Transmission input speed	Transm_nInAct_radps
	?	Nm	Transmission input torque	Transm_tqInAct_Nm
	?	-	Actual gear ratio	Transm_grGearAct
	?	Boolean	Transmission status	Transm_flgConnected_B
	?	Boolean	Clutch status	Clu_flgConnected_B

Table X Standard Driver model parameters and interface

3.4.4. Electrical component models

3.4.4.1. DCDC converter model

The DC/DC converter is a device that changes the voltage level to desired voltage level. The converter model is general and captures the behaviour of several different converters such as Buck, Boost and Buck-Boost converters. As

DC/DC converters are dynamically fast compared to other dynamics in a powertrain a simple static model shall be used:

$$\mathbf{u}_{out} = x_{DCDC} \mathbf{u}_{in} \quad (\text{Eq. X})$$

Where

\mathbf{u}_{in} : input voltage level (V)

\mathbf{u}_{out} : output voltage level (V)

x_{DCDC} : conversion ratio, i.e. control signal (-)

The conversion ratio x_{DCDC} shall be determined by an open-loop controller to the desired voltage \mathbf{u}_{req} as:

$$x_{DCDC} = \mathbf{u}_{req} / \mathbf{u}_{in} \quad (\text{Eq. X})$$

The DC/DC converter losses shall be defined as current loss using a constant DC/DC converter efficiency according to:

$$i_{DCDCloss} = \begin{cases} i_{in}(1 - \eta_{DCDC})/x & \text{for } i_{in} \leq 0 \\ i_{in}/(x(1 - \eta_{DCDC})) & \text{for } i_{in} > 0 \end{cases} \quad (\text{Eq. X})$$

Where:

η_{DCDC} : DC/DC converter efficiency (-)

i_{in} : input current to DC/DC converter (A)

$i_{DCDCloss}$: DC/DC converter current loss (A)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	η_{DCDC}	-	efficiency	dat.efficiency.value
command signal	\mathbf{u}_{req}	V	Requested output voltage	dcdc_uReq_V
sensor signal	\mathbf{u}_{out}	V	Actual output voltage	dcdc_uAct_V
elec in [V]	\mathbf{u}_{in}	V	voltage	phys_voltage_V

elec out [V]	u_{out}	V	voltage	phys_voltage_V
elec fb in [A]	i_{out}	A	current	phys_current_A
elec fb out [A]	i_{in}	A	current	phys_current_A

Table X Standard DC/DC converter model parameters and interface

3.4.5. Energy converter models

3.4.5.1. Electric machine system model

An electric machine can generally be divided into two parts, the stator and the rotor. The rotor is the rotating part of the machine. The electric machine shall be modelled using maps, see Figure X.

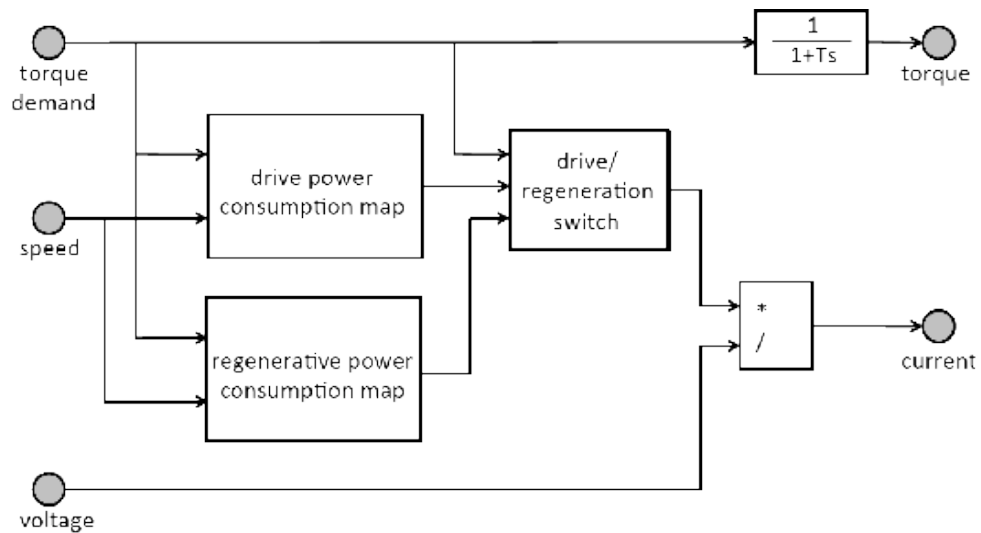


Figure X Electric machine model diagram

The electric machine dynamics shall be modelled as a first order system

$$\dot{M}_{em} = -\frac{1}{\tau_1}(M_{em} - M_{em,des}) \tag{Eq. X}$$

Where:

M_{em} : Electric machine torque (Nm)

$M_{em,des}$: Desired electric machine torque (Nm)

τ_1 : Electric machine time response constant (-)

The electric machine system power $P_{el,em}$ shall be mapped as function of the electric motor speed ω_{em} and torque M_{em} . Two separate maps shall be defined for the positive and negative torques.

$$P_{el,em} = f(M_{em}, \omega_{em}) \quad (\text{Eq. X})$$

The efficiency of the electric machine system shall be calculated as:

$$\eta_{em} = \frac{M_{em}\omega_{em}}{P_{el,em}} \quad (\text{Eq. X})$$

The electric machine system current shall be calculated as:

$$i_{em} = \frac{P_{el,em}}{u} \quad (\text{Eq. X})$$

Where:

i_{em} : electric machine system current (A)

u : battery voltage (V)

Based on its power loss $P_{loss,em}$, the electric machine model shall have a simple thermodynamics model to derive its temperature T_{em} according to:

$$P_{loss,em} = P_{el,em} - M_{em}\omega_{em} \quad (\text{Eq. X})$$

$$\dot{T}_{em} = \frac{1}{\tau_{em,heat}} (P_{loss,em} - (T_{em} - T_{em,cool})/R_{em,th}) \quad (\text{Eq. X})$$

Where:

T_{em} : Electric machine system temperature (K)

$\tau_{em,heat}$: Time constant for electric machine thermal mass ()

$T_{em,cool}$: Electric machine system cooling medium temperature (K)

$R_{em,th}$: Electric machine system thermal resistance ()

The electric machine system shall be torque or speed controlled using, respectively, an open-loop (feed-forward) control or PI-controller.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
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parameter	J_{em}	kgm^2	Inertia	dat.inertia.value
	τ_1	-	Time constant	dat.timeconstant.value
	?	Nm	Maximum torque =f(speed)	dat.maxtorque
	?	Nm	Minimum torque =f(speed)	dat.mintorque
	?	-	Speed controller (PI)	dat.ctrl
	$P_{el,em}$	W	Power map =f(speed,torque)	dat.elecpowmap
	?	kg/s	mass flow cooling fluid	dat.mflFluid
	$\tau_{em,heat}$	J/K	Thermal capacity	dat.cm.value
	R_{th}	K/W	Thermal resistance	dat.Rth.value
	?	-	Properties of the cooling fluid	dat.coolingFluid
command signal	?	rad/s	Requested speed	ElecMac_nReq_radps
	?	boolean	Switch speed/torque control	ElecMac_flgReqSwitch_B
	?	Nm	Requested torque	ElecMac_tqReq_Nm
sensor signal	M_{em}	Nm	Actual machine torque	ElecMac_tqAct_Nm
	ω_{em}	rad/s	Actual machine speed	ElecMac_nAct_radps
	i	A	Current	ElecMac_iAct_A
	T_{em}	K	Machine temperature	ElecMac_tAct_K
elec in [V]	u	V	voltage	phys_voltage_V

elec fb out [A]	i	A	current	phys_current_A
mech out [Nm]	M_{em}	Nm	torque	phys_torque_Nm
	J_{em}	kgm^2	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{em}	rad/s	rotational speed	phys_speed_radps

Table X Standard Electric Machine model parameters and interface

3.4.5.2. Hydraulic pump/motor model

A hydraulic pump/motor generally converts energy stored in a hydraulic accumulator to mechanical energy.

The pump/motor torque shall be modelled as:

$$M_{pm} = xD(p_{acc} - p_{res})\eta_{pm}^* \quad (\text{Eq. X})$$

Where:

M_{pm} : pump/motor torque (Nm)

x : pump/motor control signal between 0 and 1 (-)

D : pump/motor displacement (m^3)

p_{acc} : pressure in high pressure accumulator (Pa)

p_{res} : pressure in low pressure sump/reservoir (Pa)

η_{pm} : mechanical pump/motor efficiency (-)

The mechanical efficiency η_{pm} shall be determined using:

$$\eta_{pm}^* = \begin{cases} \eta_{pm} & \text{for } M_{pm} > 0 \\ 1/\eta_{pm} & \text{for } M_{pm} \leq 0 \end{cases} \quad (\text{Eq. X})$$

And be calculated as function of friction losses, hydrodynamic losses and viscous losses:

$$\eta_{pm} = f(x, p_{acc}, p_{res}, \omega_{pm}) \quad (\text{Eq. X})$$

Where:

ω_{pm} : pump/motor speed (rad/s)

The efficiency can be determined from experimental data.

The volumetric flow Q_{pm} through the pump/motor shall be calculated as:

$$Q_{pm} = xD\omega_{pm}\eta_{vpm}^* \quad (\text{Eq. X})$$

Where η_{vpm}^* is the pump/motor volumetric efficiency consisting of laminar, turbulent and compressibility losses, according to:

$$\eta_{vpm}^* = \begin{cases} 1/\eta_{vpm} & \text{for } M_{pm} > 0 \\ \eta_{vpm} & \text{for } M_{pm} \leq 0 \end{cases} \quad (\text{Eq. X})$$

The volumetric efficiency may be determined from measurements and mapped as function of the control command signal, the pressure difference of the pump/motor and its speed:

$$\eta_{vpm} = f(x, p_{acc}, p_{res}, \omega_{pm}) \quad (\text{Eq. X})$$

The pump/motor system shall be torque or speed controlled using, respectively, an open-loop (feed-forward) control or PI-controller.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	J_{pm}	kgm^2	Inertia	dat.inertia.value
	τ_1	-	Time constant	dat.timeconstant.value
	?	Nm	Maximum torque =f(speed)	dat.maxtorque
	D	m^3	Displacement volume	dat.displacement.value
	η_v	-	Volumetric efficiency	dat.volefficiency
	η_m	-	Mechanical efficiency	dat.mechefficiency
	?	-	PI controller	dat.ctrl

command signal	?	rad/s	Requested speed	Hpm_nReq_radps
	?	boolean	Switch speed/torque control	Hpm_flgReqSwitch_B
	?	Nm	Requested torque	Hpm_tqReq_Nm
sensor signal	M_{em}	Nm	Actual machine torque	Hpm_tqAct_Nm
	ω_{pm}	rad/s	Actual machine speed	Hpm_nAct_radps
	Q_{pm}	m^3/s	Actual volumetric flow	Hpm_flowAct_m3ps
	p_{acc}	Pa	Accumulator pressure	Hpm_pInAct_Pa
	p_{res}	Pa	Reservoir pressure	Hpm_pOutAct_Pa
fluid in 1 [Pa]	p_{acc}	Pa	pressure	phys_pressure_Pa
fluid in 2 [Pa]	p_{res}	Pa	pressure	phys_pressure_Pa
fluid out [m3/s]	Q_{pm}	m^3/s	Volume flow	phys_flow_m3ps
mech out [Nm]	M_{pm}	Nm	torque	phys_torque_Nm
	J_{pm}	kgm^2	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{pm}	rad/s	rotational speed	phys_speed_radps

Table X Standard Hydraulic Pump/Motor model parameters and interface

3.4.5.3. Internal Combustion Engine model

The internal combustion engine model shall be modelled using maps to represent the chemical to mechanical energy conversion and the applicable time response. The internal combustion engine model diagram is shown in Figure X.

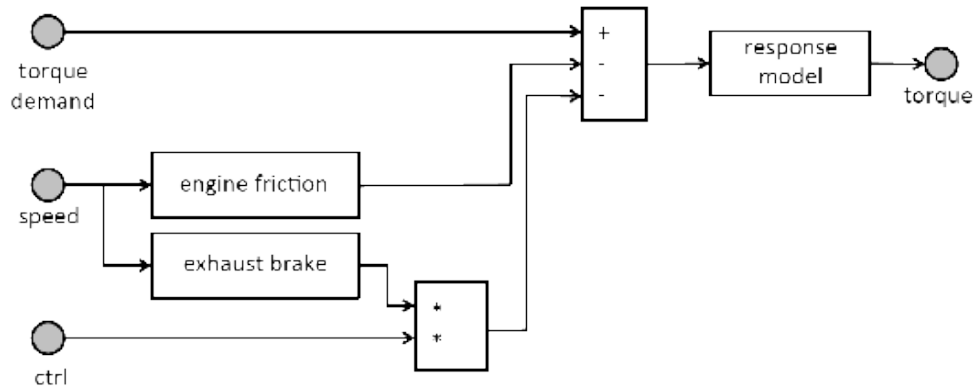


Figure X Internal combustion engine model diagram

The internal combustion engine shall include engine friction and exhaust braking, both as function of engine speed and modelled using maps. The exhaust brake can be controlled using e.g. an on/off control command signal.

The torque build-up response model shall use either of the following methods:

(a.) using a first-order model with fixed time constant (version 1) according to:

$$\dot{M}_{ice} = -\frac{1}{\tau_{ice}}(M_{ice} - M_{ice,des}) \quad (\text{Eq. X})$$

Where:

M_{ice} : ICE torque (Nm)

$M_{ice,des}$: ICE demand torque (Nm)

T_{ice} : time constant for ICE torque response model (s)

(b.) using a first-order model with speed dependent time constant (version 2) according to:

$$\dot{M}_{ice,1} = -\frac{1}{\tau_{ice}(\omega_{ice})}(M_{ice,1} - M_{ice,des1}(\omega_{ice})) \quad (\text{Eq. X})$$

$$M_{ice} = M_{ice,1} + M_{ice,des2}(\omega_{ice}) \quad (\text{Eq. X})$$

Where:

M_{ice} : ICE torque (Nm)

M_{ice1} : dynamic ICE torque (Nm)

$M_{ice,des1}$: dynamic ICE demand torque (Nm)

$M_{ice,des2}$: direct ICE demand torque (Nm)

τ_{ice} : speed dependent time constant for ICE torque response model (s)

ω_{ice} : engine speed (rad/s)

Both the speed dependent time constant and the dynamic and direct torque division are mapped as function of speed.

The internal combustion model shall have a thermodynamics model to represent the engine heat-up from cold start to its normal stabilized operating temperatures according to:

$$\theta_{ice,oil} = \max \left(\int_0^t \eta P_{ice,loss} dt + \theta_{ice,oil,cold}, \theta_{ice,oil,hot} \right) \quad (\text{Eq. X})$$

Where:

$\theta_{ice,oil}$: ICE oil temperature (K)

$P_{ice,loss}$: ICE power losses (W)

η : fraction of power loss that goes to heating (-)

$\theta_{ice,oil,cold}$: ICE oil temperature at (cold) start (K)

$\theta_{ice,oil,hot}$: ICE oil temperature at normal warm-up operating condition (K)

The internal combustion engine shall be torque or speed controlled using, respectively, an open-loop (feed-forward) control or PI-controller.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	J_{ice}	kgm ²	Inertia	dat.inertia.value
	τ_{ice}	-	Time constant	dat.timeconstant.value
	M_{fric}	Nm	Engine	dat.friction

			friction torque	
	M_{exh}	Nm	Exhaust brake torque	dat.exhaustbrake
	?	Nm	Maximum torque =f(speed)	dat.maxtorque
	?	-	PI controller	dat.ctrl
	?	kg/s	Fuel flow	dat.fuelmap
	?	kJ/kg	Net calorific value of fuel	dat.ncv.value
	?	kg/m ³	Fuel density	dat.rho.value
	?	-	Power loss to cooling and oil	dat.eta.value
	?	-	Properties of oil	dat.oil
	?	-	Properties of coolant	dat.cf
command signal	?	rad/s	Requested speed	Eng_nReq_radps
	?	boolean	Switch speed/torque control	Eng_flgReqSwitch_B
	?	Nm	Requested torque	Eng_tqReq_Nm
	?	boolean	Exhaust brake on/off	Eng_flgExhaustBrake_B
sensor signal	M_{ice}	Nm	Crankshaft torque	Eng_tqCrkSftAct_Nm
	$M_{ice}+M_{fric}+M_{exh}$	Nm	Indicated torque	Eng_tqIndAct_Nm
	ω_{ice}	rad/s	Actual engine speed	Eng_nAct_radps
	T_{ice}	K	Oil	Eng_tOilAct_K

			temperature	
chem fb out [kg/s]	?	kg/s	Fuel flow	phys_massflow_kgps
mech out [Nm]	M_{ice}	Nm	torque	phys_torque_Nm
	J_{ice}	kgm^2	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{ice}	rad/s	rotational speed	phys_speed_radps

Table X Standard Internal Combustion Engine model parameters and interface

3.4.6. Mechanical component models

3.4.6.1. Clutch model

The clutch model shall transfer the input torque on the primary clutch plate to the secondary output clutch plate according to three operating phases, i.e. opened, slipping and closed. Figure X shows the clutch model diagram.

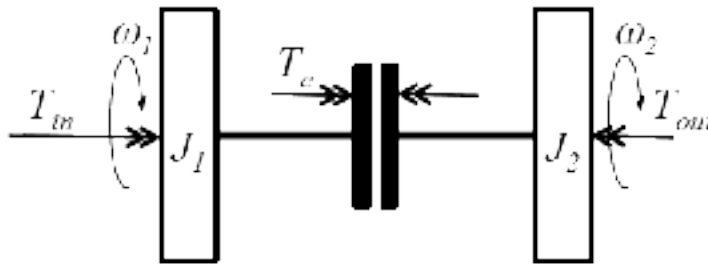


Figure X Clutch model diagram

The clutch model shall meet following equations of motion:

$$J_{cl,1}\dot{\omega}_{cl,1} = M_{cl1,in} - M_{cl} \tag{Eq. X}$$

$$J_{cl,2}\dot{\omega}_{cl,2} = M_{cl} - M_{cl2,out} \tag{Eq. X}$$

During clutch slip operation following relation is defined:

$$M_{cl} = uM_{cl,maxtorque}sign(\omega_1 - \omega_2) \tag{Eq. X}$$

$$\omega_1 = \omega_2|_{t=0} + \int_0^t (M_{cl1,in}(t) - M_{cl}(t)) dt \tag{Eq. X}$$

Where:

$M_{cl,maxtorque}$: maximum transferrable torque through clutch (Nm)

u_{cl} : clutch actuation control signal between 0 and 1 (-)

During clutch open and closed operation, the following relations shall apply:

$$M_{cl} = 0 \quad \text{for open} \quad (\text{Eq. X})$$

$$M_{cl2,out} = M_{cl1,in} \quad \text{for closed} \quad (\text{Eq. X})$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	J_1	kgm ²	Inertia	dat.in.inertia.value
	J_2	kgm ²	Inertia	dat.out.inertia.value
	$M_{maxtorque}$	Nm	Maximum clutch torque	dat.maxtorque.value
command signal	u	0-1	Requested clutch pedal position	Clu_ratReq_Rt
sensor signal	?	boolean	Clutch disengaged or not	Clu_flgConnected_B
mech in [Nm]	M_{in}	Nm	torque	phys_torque_Nm
	J_{in}	kgm ²	inertia	phys_inertia_kgm2
mech out [Nm]	M_{out}	Nm	torque	phys_torque_Nm
	J_{out}	kgm ²	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_1	rad/s	rotational speed	phys_speed_radps
mech fb out [rad/s]	ω_2	rad/s	rotational speed	phys_speed_radps

Table X Standard Clutch model parameters and interface

3.4.6.2. Continuously Variable Transmission model

The Continuously Variable Transmission (CVT) model shall represent a mechanical transmission that allows any gear ratio between a defined upper and lower limit. The CVT model shall be in accordance with:

$$M_{CVT,out} = r_{CVT} M_{CVT,in} \eta_{CVT} \quad (\text{Eq. X})$$

Where:

$M_{CVT,in}$: CVT input torque (Nm)

$M_{CVT,out}$: CVT output torque (Nm)

r_{CVT} : CVT ratio (-)

η_{CVT} : CVT efficiency (-)

The CVT efficiency shall be defined as function of input torque, output speed and gear ratio:

$$\eta_{CVT} = f(r_{CVT}, M_{CVT,in}, \omega_{CVT,out}) \quad (\text{Eq. X})$$

The CVT model shall assume zero speed slip so that following relation for speeds can be used:

$$\omega_{CVT,in} = r_{CVT} \omega_{CVT,out} \quad (\text{Eq. X})$$

The gear ratio of the CVT shall be controlled by a setpoint command and using a first-order representation for the CVT ratio change actuation according to:

$$\frac{d}{dt} r_{CVT} = \frac{1}{\tau_{CVT}} (-r_{CVT} + r_{CVT,des}) \quad (\text{Eq. X})$$

Where:

τ_{CVT} : CVT time constant (s)

$r_{CVT,des}$: CVT commanded gear ratio (-)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
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parameter	τ_{CVT}	-	Time constant	dat.timeconstant.value
	η_{CVT}	-	Efficiency	dat. efficiency
	$M_{maxtorque}$	Nm	Maximum clutch torque	dat.maxtorque.value
command signal	r_{des}	-	Requested CVT gear ratio	CVT_ratGearReq
sensor signal	r_{CVT}	-	Actual CVT gear ratio	CVT_ratGearAct_Rt
	ω_{out}	rad/s	Output speed	CVT_nOutAct_radps
	ω_{in}	rad/s	Input speed	CVT_nInAct_radps
mech in [Nm]	M_{in}	Nm	torque	phys_torque_Nm
	J_{in}	kgm ²	inertia	phys_inertia_kgm2
mech out [Nm]	M_{out}	Nm	torque	phys_torque_Nm
	J_{out}	kgm ²	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{out}	rad/s	rotational speed	phys_speed_radps
mech fb out [rad/s]	ω_{in}	rad/s	rotational speed	phys_speed_radps

Table X Standard CVT model parameters and interface

3.4.6.3. Flywheel model

The flywheel model shall represent a rotating mass that is used to store and release kinetic energy. The flywheel kinetic energy state is defined by:

$$E_{flywheel} = J_{flywheel} \omega_{flywheel}^2 \quad (\text{Eq. X})$$

Where:

$E_{flywheel}$: Kinetic energy of flywheel (J)

$J_{flywheel}$: Inertia of flywheel (kgm²)

$\omega_{flywheel}$: Flywheel speed (rad/s)

The basic flywheel model diagram is shown in Figure X.

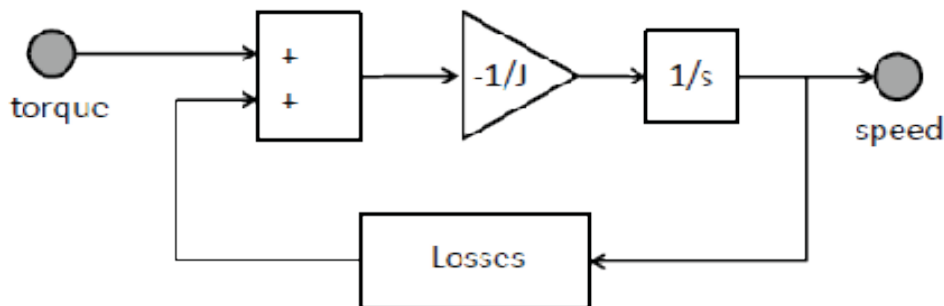


Figure X Flywheel model diagram

The flywheel model shall be defined according to:

$$J_{flywheel} \frac{d}{dt} \omega_{flywheel} = -M_{flywheel,in} - M_{flywheel,loss}(\omega_{flywheel}) \quad (\text{Eq. X})$$

Where:

$M_{flywheel,in}$: input torque to flywheel (Nm)

$M_{flywheel,loss}$: (speed dependent) flywheel losses (Nm)

The losses may be determined from measurements.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	J_{fly}	kgm^2	Inertia	dat.inertia.value
	M_{loss}	Nm	Torque loss map	dat.loss
command signal			no control signal	
sensor signal	ω_{fly}	rad/s	Flywheel speed	Flywheel_nAct_radps
mech in [Nm]	M_{in}	Nm	torque	phys_torque_Nm
	J_{in}	kgm^2	inertia	phys_inertia_kgm2

mech fb out [rad/s]	ω_{fly}	rad/s	rotational speed	phys_speed_radps
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Table X Standard Flywheel model parameters and interface

3.4.6.4. Mechanical connection model

A model for connection of two input shafts with a single output shaft, i.e. mechanical joint, can be modelled using gear ratios and efficiencies according to:

$$M_{out} = \eta_{out} r_{out} (\eta_{in,1} r_{in,1} M_{in,1} + \eta_{in,2} r_{in,2} M_{in,2}) \quad (\text{Eq. X})$$

Where:

- $M_{in,1}$: Input torque on shaft 1 (Nm)
- $M_{in,2}$: Input torque on shaft 2 (Nm)
- M_{out} : Output torque on shaft (Nm)
- $r_{in,1}$: Ratio of gear of shaft 1 (-)
- $r_{in,2}$: Ratio of gear of shaft 2 (-)
- $\eta_{in,1}$: Efficiency on gear of shaft 1 (-)
- $\eta_{in,2}$: Efficiency on gear of shaft 2 (-)
- r_{out} : Ratio of gear on output shaft (-)
- η_{out} : Efficiency of gear on output shaft (-)

The inertia of each shaft/gear combination is to be defined and added to the total powertrain inertia.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	J_1	kgm ²	Inertia	dat.in1.inertia.value
	$r_{in,1}$	-	Gear ratio	dat.in1.ratio.value
	$\eta_{in,1}$	-	Efficiency	dat.in1.eta.value

	J_2	kgm^2	Inertia	dat.in2.inertia.value
	$r_{in,2}$	-	Gear ratio	dat.in2.ratio.value
	$\eta_{in,2}$	-	Efficiency	dat.in2.eta.value
	J_{out}	kgm^2	Inertia	dat.out.inertia.value
	r_{out}	-	Gear ratio	dat.out.ratio.value
	η_{out}	-	Efficiency	dat.out.eta.value
command signal			no control signal	
sensor signal			no signal	
mech in 1 [Nm]	$M_{in,1}$	Nm	torque	phys_torque_Nm
	$J_{in,1}$	kgm^2	inertia	phys_inertia_kgm2
mech in 2 [Nm]	$M_{in,2}$	Nm	torque	phys_torque_Nm
	$J_{in,2}$	kgm^2	inertia	phys_inertia_kgm2
mech out [Nm]	M_{out}	Nm	torque	phys_torque_Nm
	J_{out}	kgm^2	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{in}	rad/s	rotational speed	phys_speed_radps
mech fb out 1 [rad/s]	$\omega_{out,1}$	rad/s	rotational speed	phys_speed_radps
mech fb out 2 [rad/s]	$\omega_{out,2}$	rad/s	rotational speed	phys_speed_radps

Table X Standard Mechanical Connection model parameters and interface

3.4.6.5. Retarder model

A retarder model shall be represented by a simple torque reduction according to:

$$M_{retarder,out} = M_{retarder,in} - uM_{retarder,max}(\omega_{retarder}) \quad (\text{Eq. X})$$

Where:

- u** : Retarder command signal between 0 and 1 (-)
- $M_{retarder,max}$** : (speed dependent) maximum retarder brake torque (Nm)
- $\omega_{retarder}$** : Retarder speed (rad/s)
- $M_{retarder,in}$** : Retarder input torque (Nm)
- $M_{retarder,out}$** : Retarder output torque (Nm)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	T_{loss}	Nm	Retarder brake torque map	dat.braketorque
command signal	u	-	Retarder on/off	Ret_flgOnOff_B
sensor signal	T_{loss}	Nm	Retarder brake torque	Ret_tqBrkAct_Nm
mech in [Nm]	M_{in}	Nm	torque	phys_torque_Nm
	J_{in}	kgm ²	inertia	phys_inertia_kgm2
mech out [Nm]	M_{out}	Nm	torque	phys_torque_Nm
	J_{out}	kgm ²	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{in}	rad/s	rotational speed	phys_speed_radps
mech fb out [rad/s]	ω_{out}	rad/s	rotational speed	phys_speed_radps

Table X Standard Retarder model parameters and interface

3.4.6.6. Spur gear model

The spur gear shall be represented by modelling two cogwheels in contact with a specified ratio according to:

$$\omega_{spur,out} = \omega_{spur,in}/r_{spur} \tag{Eq. X}$$

The spur gear losses shall be considered as torque losses and implemented through a spur efficiency as:

$$M_{out} = \begin{cases} M_{in}r_{spur}\eta_{spur}, & \text{for } M_{in} \leq 0 \\ M_{in}r_{spur}/\eta_{spur}, & \text{for } M_{in} > 0 \end{cases} \tag{Eq. X}$$

The spur gear inertia shall be included as:

$$J_{spur,out} = J_{spur,in}r_{spur}^2 + J_{spur} \tag{Eq. X}$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	J_{spur}	kgm ²	Inertia	dat.in.inertia.value
	r_{spur}	-	Gear ratio	dat.in.ratio.value
	η_{spur}	-	Efficiency	dat.in. efficiency.value
command signal			no signal	
sensor signal			no signal	
mech in [Nm]	M_{in}	Nm	torque	phys_torque_Nm
	J_{in}	kgm ²	inertia	phys_inertia_kgm2
mech out [Nm]	M_{out}	Nm	torque	phys_torque_Nm
	J_{out}	kgm ²	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{out}	rad/s	rotational speed	phys_speed_radps
mech fb out [rad/s]	ω_{in}	rad/s	rotational speed	phys_speed_radps

Table X Standard Spur Gear model parameters and interface

3.4.6.7. Torque Converter model

The torque converter is a fluid coupling device that transfers the input power from its impeller or pump wheel to its turbine wheel on the output shaft through its working fluid motion. The torque converter equipped with a stator will create torque multiplication in slipping mode.

The torque converter model shall be in accordance with following differential equations:

$$(J_{tc,in} + J_{impeller}) \frac{d}{dt} \omega_{in} = -M_{tc,in} - M_{tc,out} \tag{Eq. X}$$

The representation of the torque converter model is shown in Figure X.

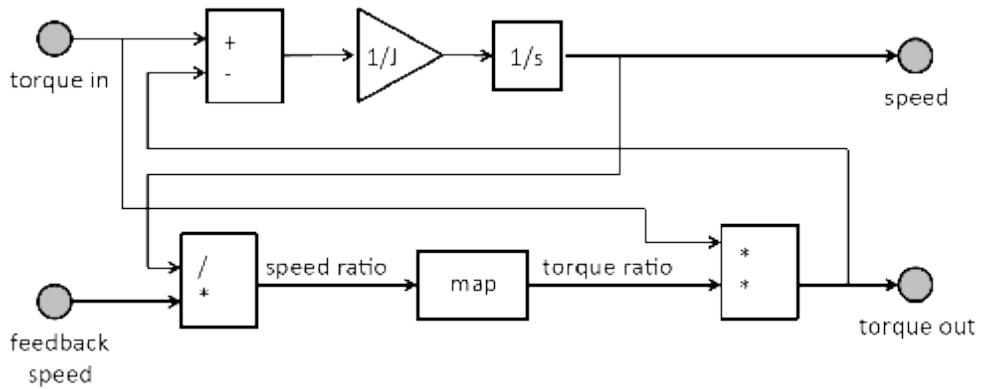


Figure X Torque converter model diagram

The torque converter model characteristics shall be mapped as function of (rotational) speeds using typical parameters like torque (multiplication) ratio and efficiency.

The speed and torque ratios for the torque converter model shall be in accordance with:

$$\omega_{tc,r} = \omega_{out} / \omega_{in} \tag{Eq. X}$$

$$M_{tc,r} = M_{out} / M_{in} \tag{Eq. X}$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	$J_{impeller}$	kgm ²	Inertia	dat.inertia.value

	?	-	Torque ratio map	dat.torqueratiomap
command signal	?	boolean	Torque converter lockup	TC_flgLockUp_B
sensor signal	ω_{out}	rad/s	Turbine speed	TC_nTurbineAct_radps
mech in [Nm]	M_{in}	Nm	torque	phys_torque_Nm
	J_{in}	kgm ²	inertia	phys_inertia_kgm2
mech out [Nm]	M_{out}	Nm	torque	phys_torque_Nm
	J_{out}	kgm ²	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{out}	rad/s	rotational speed	phys_speed_radps
mech fb out [rad/s]	ω_{in}	rad/s	rotational speed	phys_speed_radps

Table X Standard Torque Converter model parameters and interface

3.4.6.8. Shift transmission model

The shift transmission model shall be implemented as gears in contact, with a specific gear ratio r_{gear} in accordance with:

$$\omega_{tr,in} = \omega_{tr,out} r_{gear} \tag{Eq. X}$$

All losses in the transmission model shall be treated as torque losses and implemented through a fixed transmission efficiency for each individual gear. The transmission model shall then be in accordance with:

$$M_{out} = \begin{cases} M_{in} r_{gear} \eta_{gear}, & \text{for } M_{in} \leq 0 \\ M_{in} r_{gear} / \eta_{gear}, & \text{for } M_{in} > 0 \end{cases} \tag{Eq. X}$$

The total gearbox inertia shall depend on the active gear selection and is defined with following equation:

$$J_{gear,out} = J_{gear,in} r_{gear}^2 + J_{gear,out} \tag{Eq. X}$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	?	s	Shift time	dat.shifttime.value
	?	Nm	Maximum torque	dat.maxtorque.value
	?	-	Number of gears	dat.nofgear.value
	?	-	Gear numbers (vector)	dat.gear.number.value
	J_{gearbox}	kgm^2	Inertia (vector)	dat.gear.inertia.value
	r_{gear}	-	Gear ratio (vector)	dat.gear.ratio.value
	η_{gear}	-	Gear efficiency (vector)	dat.gear.efficiency.value
command signal	?	-	Requested gear number	Transm_nrGearReq
sensor signal	?	-	Actual gear number	Transm_nrGearAct
	?	boolean	Gear engaged	Transm_flgConnected_B
	ω_{out}	rad/s	Output speed	Transm_nOutAct_radps
	ω_{in}	rad/s	Input speed	Transm_nInAct_radps
mech in [Nm]	M_{in}	Nm	torque	phys_torque_Nm
	J_{in}	kgm^2	inertia	phys_inertia_kgm2
mech out [Nm]	M_{out}	Nm	torque	phys_torque_Nm
	J_{out}	kgm^2	inertia	phys_inertia_kgm2
mech fb in [rad/s]	ω_{out}	rad/s	rotational speed	phys_speed_radps

mech fb out [rad/s]	ω_{in}	rad/s	rotational speed	phys_speed_radps
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Table X Standard Shift Transmission model parameters and interface

3.4.7. Rechargeable energy storage systems

3.4.7.1. Battery (resistor) model

A resistor based battery model (Figure X) can be used and shall then satisfy:

$$u = e - R_i i \tag{Eq. X}$$

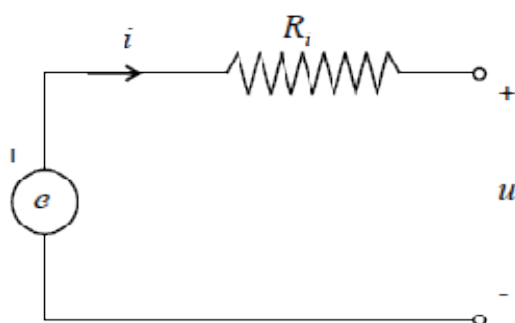


Figure X Representation diagram for battery

The open-circuit voltage e and the internal resistance R_i shall have dependency of the actual battery energy level. This battery state-of-charge SOC shall be defined as

$$SOC = SOC(0) - \int_0^t \frac{i}{3600C} dt \tag{Eq. X}$$

Using initial state $SOC(0)$ and battery capacity C .

A diagram for the resistor based model is shown in Figure X.

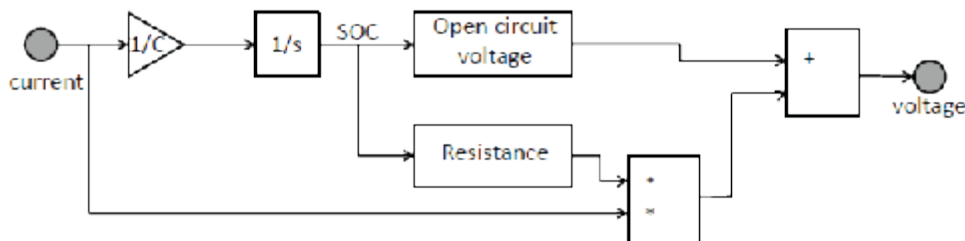


Figure X Resistor based battery model diagram

The battery can be scalable using a number of cells.

The battery model can include a thermodynamics model that applies similar modelling as for the electric machine system according to:

$$P_{loss} = R_i i^2 \quad (\text{Eq. X})$$

The power losses shall be converted to heat affecting the battery temperature that will be in accordance with:

$$\dot{T}_{bat} = \frac{1}{\tau_{bat,heat}} (P_{loss,bat} - (T_{bat} - T_{bat,cool})/R_{bat,th}) \quad (\text{Eq. X})$$

Where:

T_{bat} : Battery temperature (K)

$T_{bat,heat}$: Time constant for battery thermal mass ()

$T_{bat,cool}$: Battery cooling medium temperature (K)

$R_{bat,th}$: Battery thermal resistance ()

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	n_s	-	Number of cells connected in series	dat.ns.value
	n_p	-	Number of cells connected in parallel	dat.np.value
	C	Ah	Cell capacity	dat.capacity.value
	SOC(0)	%	Initial state of charge	dat.initialSOC.value
	e	V	Open circuit voltage =f(SOC)	dat.ocv.ocv
	R_i	Ω	Cell resistance	dat.resistance.R0

command signal			no signal	
sensor signal	i	A	Actual current	ReESS_iAct_A
	u	V	Actual output voltage	ReESS_uAct_V
	SOC	%	State of charge	ReESS_socAct_Rt
	T_{bat}	K	Battery temperature	ReESS_tAct_K
elec out [V]	u	V	Voltage	phys_voltage_V
elec fb in [A]	i	A	Current	phys_current_A

Table X Standard Resistor-based battery model parameters and interface

3.4.7.2. Battery (RC) model

A battery model that includes additional dynamics can be used and shall then be based on the representation using resistor and capacitor circuits as shown in Figure X.

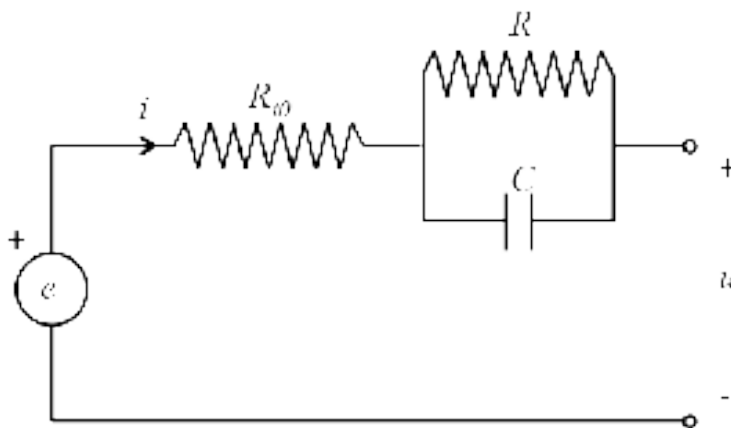


Figure X Representation diagram for RC-circuit battery model

The battery voltage shall satisfy:

$$u = e - R_{i0}i - u_{RC} \tag{Eq. X}$$

with:

$$\frac{d}{dt} u_{RC} = -\frac{1}{RC} u_{RC} + \frac{1}{C} i \quad (\text{Eq. X})$$

The open-circuit voltage e , the resistances R_{i0} and R and the capacitance C shall all have dependency of the actual energy state of the battery and be modelled using tabulated values in maps.

The battery can be scalable using a number of cells.

The battery model can include a thermodynamics model that applies similar modelling as for the electric machine system according to:

$$P_{loss} = R_i i^2 \quad (\text{Eq. X})$$

The power losses shall be converted to heat affecting the battery temperature that will be in accordance with:

$$\dot{T}_{bat} = \frac{1}{\tau_{bat,heat}} (P_{loss,bat} - (T_{bat} - T_{bat,cool})/R_{bat,th}) \quad (\text{Eq. X})$$

Where:

T_{bat} : Battery temperature (K)

$T_{bat,heat}$: Time constant for battery thermal mass ()

$T_{bat,cool}$: Battery cooling medium temperature (K)

$R_{bat,th}$: Battery thermal resistance ()

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	n_s	-	Number of cells connected in series	dat.ns.value
	n_p	-	Number of cells connected in parallel	dat.np.value
	C	Ah	Cell capacity	dat.capacity.value

	SOC(0)	%	Initial state of charge	dat.initialSOC.value
	e	V	Open circuit voltage =f(SOC)	dat.ocv.ocv
	R_{i0}	Ω	Cell resistance	dat.resistance.R0
	R	Ω	Cell resistance	dat.resistance.R
	C	F	Cell resistance	dat.resistance.C
command signal			no signal	
sensor signal	i	A	Actual current	ReESS_iAct_A
	u	V	Actual output voltage	ReESS_uAct_V
	SOC	%	State of charge	ReESS_socAct_Rt
	T_{bat}	K	Battery temperature	ReESS_tAct_K
elec out [V]	u	V	Voltage	phys_voltage_V
elec fb in [A]	i	A	Current	phys_current_A

Table X Standard RC-based battery model parameters and interface

3.4.7.3. Capacitor model

Reserved.

3.4.7.4. Accumulator model

A hydraulic accumulator is a pressure vessel to store and release a working medium (either fluid or gas). Commonly, a high pressure accumulator and a low pressure reservoir are part of the hydraulic system. Both the accumulator and reservoir shall be represented using the same modelling approach for which the basis is shown in Figure X.

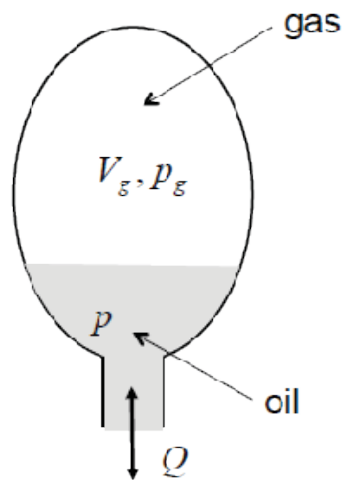


Figure X Accumulator representation

The accumulator shall be represented according to following equations, assuming ideal gas law, gas and fluid pressure to be equal and no losses in the accumulator:

$$\frac{d}{dt} V_{gas} = -Q \quad (\text{Eq. X})$$

$$p = \frac{m_g RT}{V_{gas}} \quad (\text{Eq. X})$$

Where:

m_g : charge gas mass (kg)

R : gas constant

T_g : charge gas temperature (K)

The model can contain a heat transfer model using following relation:

$$m_{gas} c_v \frac{d}{dt} T = - \frac{m_{gas} RT_g}{V_{gas}} Q - h A_w (T_{gas} - T_w) \quad (\text{Eq. X})$$

Where:

c_v : Charge gas specific volume ()

h : Accumulator heat transfer coefficient ()

A_w : Accumulator surface area (m²)

T_w : Accumulator surface temperature (K)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Type / Bus	Name	Unit	Description	Reference
parameter	T	K	Gas temperature	dat.gas.temperature.value
	m _g	kg	Mass of gas	dat.gas.mass.value
	R	J/kg	Gas constant	dat.gas.constant.value
	V _g	m ³	Tank volume	dat.capacity.volume.value
	V _f	m ³	Fluid volume	dat.capacity.fluid.value
	?	%	Initial fluid volume	dat.capacity.fluid.init.value
command signal			no signal	
sensor signal	p	Pa	Pressure	Acc_presAct_Pa
	T _g	K	Gas temperature	Acc_tGasAct_K
	V _g	-	Gas volume	Acc_volGas_Rt
fluid out [Pa]	p	Pa	Pressure	phys_pressure_Pa
fluid fb in [m3/s]	Q	m ³ /s	Volume flow	phys_flow_m3ps

Table X Standard Accumulator model parameters and interface

3.5 Provisions on OEM specific component models

However, if the verification of the HV model cannot be passed using a component model specified in Paragraph 3.4 to this Annex, the manufacturer may use an alternative model that is deemed to be at least equivalent to, though with better matching performance, as the prescribed model from Paragraph 3.4 to this Annex. An alternative model shall satisfy the intent of the specified procedure. Deviations from the models specified in Paragraph 3.4 to this Annex shall be approved by the type approval or certification authority. The manufacturer shall provide to the type approval or certification authority all

appropriate information relating to and including the alternative model along with the justification for its use.

3.6 Operation check of HILS system using the Reference HV Model

Reserved

3.7 Construction of the interface

3.7.1. The interface needs to be setup according to the HV model components as specified in paragraph 3.4. to this Annex and required for the operation of the HV model and actual ECU(s). In addition, specific signals can be defined in the interface model to allow proper operation of the actual ECU(s), e.g. ABS signals.

The interface shall not contain key hybrid control functionalities as specified in paragraph 3.3.1. to this Annex.

3.8. Input parameters

3.8.1. General introduction

Input parameters for the HV model HILS library components shall be obtained as outlined in Paragraphs 3.8.2. to 3.8.10 to this Annex.

3.8.2. Engine torque characteristics

The parameters for the engine torque characteristics shall be the table data obtained in accordance with paragraph 4.2 to this Annex. However, values equivalent to or lower than the minimum engine revolution speed may be added. In addition, the engine model accessory torque map shall not be used at the time of the approval test.

3.8.3. Electric motor torque – electric power consumption characteristics

The parameters for the electric motor torque and electric power consumption characteristics shall be the table data obtained in accordance with paragraph 4.3 to this Annex. However, characteristic values at a revolution speed of 0 rpm may be added.

3.8.4. Battery

3.8.4.1. Resistor based model

The parameter for the internal resistance – open voltage of the electric storage device shall be the table data obtained in accordance with paragraph 4.4.1. to this Annex.

3.8.4.2. RC-circuit based model

The parameters for the RC-circuit battery model shall be the data obtained in accordance with paragraph 4.4.2. to this Annex.

3.8.4.3. Capacitor model

Reserved.

3.8.5. Transmission efficiency

In case of a Parallel HV, the following shall be used:

(1) The efficiency of the transmission shall be 0.98 for a direct transmission, and 0.95 for all others.

(2) The efficiency of the final reduction gear shall be 0.95.

In case of a Series HV, the following shall be used:

(1) The efficiency of the transmission shall be 0.95 or can be a manufacturer specified value for fixed gear or 2-gear transmissions. The manufacturer shall then provide all relevant information and its justification to the type approval or certification authority.

(2) The efficiency of the final reduction gear shall be 0.95 or can be a manufacturer specified value. The manufacturer shall then provide all relevant information and its justification to the type approval or certification authority.

3.8.6. Test vehicle mass and curb weight

The vehicle test mass shall be calculated as function of the system rated power according to:

$$m_{vehicle} = 15.1 \times P_{rated}^{1.31} \quad (\text{Eq. X})$$

The vehicle kerb weight shall be calculated as function of the test vehicle mass according to:

$$m_{vehicle,0} = \begin{cases} -7.38 \times 10^{-6} m_{vehicle}^2 + 0.604 m_{vehicle}, & \text{for } m_{vehicle} \leq 35240 \text{ kg} \\ 12120 \text{ kg}, & \text{for } m_{vehicle} > 35240 \text{ kg} \end{cases} \quad (\text{Eq. X})$$

Under further review.

3.8.7. Rolling resistance coefficient

The rolling resistance coefficient shall be calculated by the following formula:

$$f_{roll} = 0.00513 + \frac{17.6}{m_{vehicle}} \quad (\text{Eq. X})$$

Where:

$m_{vehicle}$: test vehicle mass (kg) according to Paragraph 3.8.6. to this Annex.

3.8.8. Vehicle frontal area and air drag coefficient

The vehicle frontal area shall be calculated as function of test vehicle mass in accordance with following formula:

$$A_{front} = \begin{cases} -1.69 \cdot 10^{-8} m_{vehicle}^2 + 6.33 \cdot 10^{-4} m_{vehicle} + 1.67, & \text{for } m_{vehicle} \leq 18050 \\ 7.59 m^2, & \text{for } m_{vehicle} > 18050 \text{ kg} \end{cases} \quad (\text{Eq. X})$$

Under further review.

The vehicle air drag resistance coefficient shall be calculated in accordance with the following formula:

$$C_{drag} = \frac{3.6^2 \times (0.00299 \times A_{front} - 0.000832) \times g}{0.5 \times \rho_{air} \times A_{front}} \quad (\text{Eq. X})$$

Where:

g : gravitational acceleration, value defined as 9.80665 (m/s²)

ρ_{air} : air density at fixed value of 1.2 kg/m³

Under further review.

3.8.7. Inertia moment of rotating sections

Different inertia moment of the rotating sections shall be used for respective conditions as specified below:

(a) The inertia moment of the section from the gear on the driven (i.e. primary) side of the (shift) transmission up to and including the tyres shall be calculated that it matches 7% of the vehicle kerb mass.

(b) The inertia moment of the section from the engine to the gear on the driving side of the (shift) transmission shall be the manufacturer specified value(s).

(c) In case of Series HV, the inertia moment for the generator(s), wheel hub electric motor(s) or central electric motor(s) shall be the manufacturer specified value.

3.8.8. Maximum transmitted torque

For the maximum transmitted torque of the clutch and the synchronizer, the design value specified by the manufacturer shall be used.

3.8.9. Gear change period

The gear-change period for a manual transmission shall be set to one (1.0) second.

3.8.10. Gear change method

Gear positions at the start, acceleration and deceleration during the approval test shall be the respective gear positions in accordance with the specified methods for the types of HV listed below:

(1) Parallel HV fitted with a manual shift transmission: gear positions are defined by the shift strategy as part of the driver model.

(2) Parallel HV fitted with automated shift transmission (AMT) or automatic gear box (AT) with torque converter: gear positions according to the shift strategy of the actual transmission ECU control. Alternatively, the gear positions may be defined using the shift strategy as part of the driver model.

(3) Series HV: in case of a shift transmission being applied, the gear positions according to the shift strategy of the actual transmission ECU control shall be used.

3.8.11 Wheel radius

The wheel radius shall be defined as 0.40 m or a manufacturer specified value, whichever is the worst case with regard to the exhaust emissions.

3.8.12 Rear axle ratio

The rear axle ratio shall be defined in accordance with the provisions for the specified HV type:

(a) For Parallel HV when using the standardized wheel radius, the rear axle ratio shall be calculated in accordance with one of following options:

$$ratio_{axle} = \frac{60 \times 2 \times \pi}{1000 \times 87} \times \frac{0.566 \times 2.0327 \times (0.45 \times n_{lo} + 0.45 \times n_{pref} + 0.1 \times n_{hi} - n_{idle}) + n_{idle}}{ratio_{gear_high}} \quad (\text{Eq. X})$$

Or

$$ratio_{axle} = \frac{60 \times 2 \times \pi}{1000 \times 87} \times \frac{0.6241 \times n_{rated} + 143.21}{ratio_{gear_high}} \quad (\text{Eq. X})$$

(b) For Parallel HV when using a manufacturer specified wheel radius, the rear axle ratio shall be the manufacturer specified ratio representative for the worst case exhaust emissions.

(c) For Series HV, the rear axle ratio shall be the manufacturer specified ratio representative for the worst case exhaust emissions.

3.8.13 Other input parameters

All other input parameters shall have the manufacturer specified value representative for the worst case exhaust emissions.

4. Test procedures for Energy Converter(s) and Storage Device(s)

4.1. Scope

The procedures described in paragraphs 4.2. to 4.4. to this Annex shall be used for obtaining parameters for the HILS system components that is used for the calculation of the engine operating conditions using the HV model.

If a manufacturer believes that one of the above mentioned component test procedures is unsafe or unrepresentative for a specific component, an alternate component test procedure techniques may be used after approval of the type approval authority. These alternate techniques shall satisfy the intent of the specified component test procedure to generate representative data to model the component in the HILS system. Deviations from the component test procedure specified in this paragraph for reasons of safety or representativeness shall be approved by the type approval or certification authority along with the justification for their use.

4.2. Internal Combustion Engine

As the input parameters for the HILS system the engine torque characteristics, the engine friction loss and auxiliary brake shall be determined. The test method shall be as prescribed and schematically shown in Figure X.

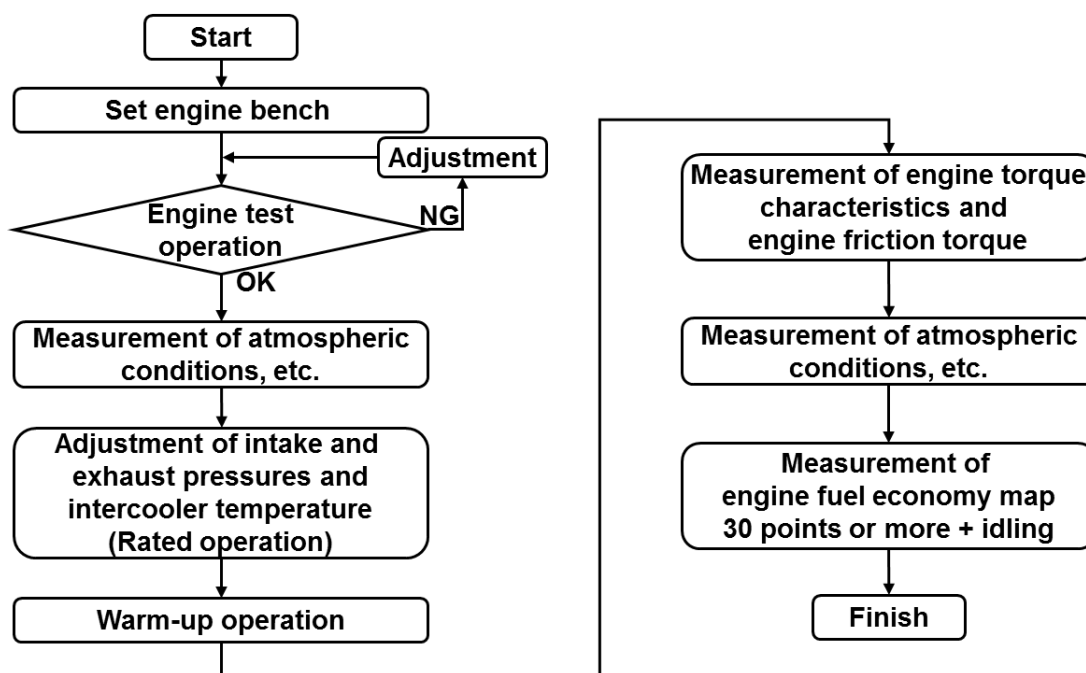


Figure X Engine component test procedure diagram

4.2.1. Test engine

The test engine shall be in accordance with the provision of paragraph 5.3.4. hybrid family.

4.2.2. Test Conditions

The test conditions shall be in accordance with paragraph 6.

4.2.5. Measurement of engine torque characteristics

The engine torque characteristics of the test engine shall be obtained by the method provided for in Paragraphs 4.2.5.1 and 4.2.5.2 to this Annex.

4.2.5.1. Range of engine speed for measurement

Reserved.

4.2.5.2. Measurement of engine torque characteristics

The engine torque characteristics in relation to the engine command values shall be measured after the test engine has been thoroughly warmed up until the coolant temperature, lubricant temperature and lubricant pressure stabilize. The measurement shall be carried out according to the following method:

- (1) The engine torque shall be measured, after confirming that the shaft torque and engine speed of the test engine are stabilized at a constant value for one

minute, by reading out the braking load or shaft torque of the engine dynamometer. If the test engine and the engine dynamometer are connected via a transmission, the read-out-value shall be divided by the transmission efficiency and gear ratio of the transmission.

(2) The engine speed shall be measured by reading the speed of the crank shaft or the revolution speed of the engine dynamometer. If the test engine and the engine dynamometer are connected via a transmission, the read-out-value shall be multiplied by the gear ratio.

(3) The engine torque shall be measured under at least 100 conditions in total, for the engine speed under 10 conditions within a range from the minimum engine speed to the maximum engine speed, and for the engine command values under 8 conditions within a range from 100% to 0% command value.

(4) In order to obtain the data of speed at the same command values, all recorded data shall undergo the piecewise cubic Hermite interpolation, and 100 or more table data shall be prepared in total, with 10 or more of the engine revolution speed and 10 or more of the engine command values. However, this provision shall not apply if Item (3) meets the condition of the said table data.

4.2.6. Measurement of engine friction torque

The friction torque of the test engine shall be measured by the method provided for in paragraphs 4.2.6.1. and 4.2.6.2. to this Annex. Furthermore, this may be omitted if the measurement of the engine torque characteristics can simultaneously measure the engine friction torque.

4.2.6.1. Range of engine speed for measurement

Reserved.

4.2.6.2. Measurement of friction torque of engine

The measurement of the friction torque of the engine shall be performed, after the test engine has been thoroughly warmed up until the coolant temperature, lubricant temperature and lubricant pressure stabilize. The measurement shall be carried out by driving the test engine from the engine dynamometer and performing the measurement under at least 6 conditions within a range from the minimum engine speed to the maximum engine speed. Moreover, the friction torque when the auxiliary brake system such as an exhaust brake is operative shall be measured if that brake is needed in the HILS system in addition to the engine brake.

4.3. Electric Motor / Generator

As the input parameters for the HILS system, the torque map and electric power consumption map of the electric storage device (including those with a

generator function. The same applies herein below.) shall be determined. The test method shall be as prescribed and schematically shown in Figure X.

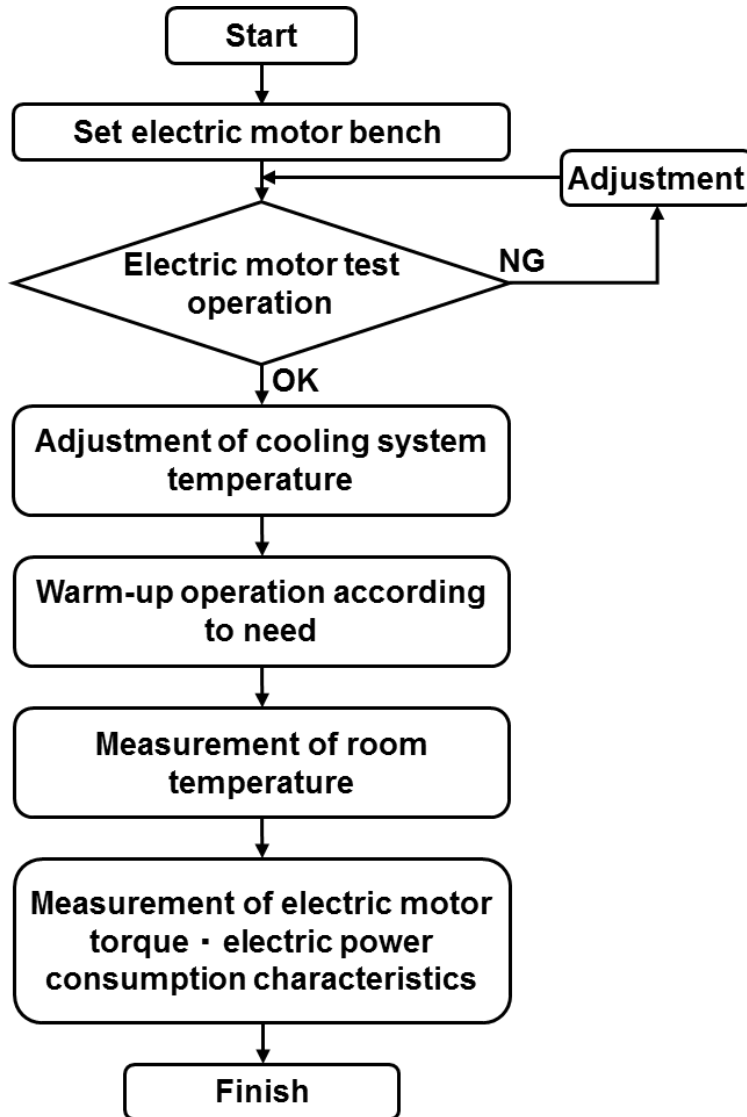


Figure X Electric motor test procedure diagram

4.3.1. Test electric motor and controller

The test motor and controller shall be in the condition described below:

(1) The test motor and controller shall be serviced in accordance with the inspection and maintenance procedure.

(2) The power supply shall be a direct-current constant-voltage power supply or battery, which is capable of supplying sufficient electric power for the necessary input power to the power electronics at the maximum output of the electric motor.

(3) The voltage applied to the power electronics shall be $\pm 5\%$ of the nominal voltage of the ReESS in the HV powertrain.

(4) If characteristics of the ReESS change due to a large voltage variation in the voltage applied to the power electronics, the test shall be conducted by setting 3 conditions for the applied voltage: the maximum, minimum and medium in its control.

(5) The wiring between the electric motor and its power electronics shall be according to their in-vehicle specifications. However, if its in-vehicle layout is not possible in the test cell, the wiring may be altered within a range not improving the electric motor performance. In addition, the wiring between the power electronics and the power supply need not be in accordance with their in-vehicle specifications.

(6) The cooling system shall be in accordance with its in-vehicle specifications. However, if its in-vehicle layout is not possible in the test cell, the setup may be modified, or alternatively a test cell cooling system may be used, within a range not improving its cooling performance.

(7) No transmission shall be installed. However, in the case of an electric motor that cannot be operated if it is separated from the transmission due to the vehicle configuration, or an electric motor that cannot be directly connected to the dynamometer, a transmission may be installed. In such a case, a transmission with a known fixed gear ratio and a known transmission efficiency shall be used and specified.

4.3.2. Accuracy, calibration, and so on, of measuring devices

Measuring devices that have the following accuracies and have been checked, serviced and calibrated according to the predetermined handling procedures shall be used:

(1) The accuracy of the measuring device for the drive torque shall be better than $\pm 1\%$ of the maximum torque of the test motor. The accuracy of the measuring device for the EM speed shall be better than $\pm 0.5\%$ of the maximum speed of the test motor.

(2) The measurement accuracy of the supplied electric power to the electric motor shall be better than $\pm 2\%$ of the maximum value of measured power.

(3) The accuracy of the device for measuring voltage shall be better than $\pm 1\%$ of the maximum value of measured voltage, and the accuracy of the device for measuring electrical current shall be better than $\pm 1\%$ of the maximum value of measured current.

(4) The accuracy of the temperature measuring device shall be $\pm 1\text{ K}$.

4.3.3. Test cell and preconditioning

Reserved.

4.3.4. Measurement of electric motor torque map

4.3.4.1. General introduction

The test motor shall be driven according to the method in paragraph 4.3.4.2. to this Annex, and the measurement shall be carried out in connection with the measurement items in paragraph 4.3.4.3. to this Annex.

4.3.4.2. Test procedure

The test motor shall be operated after it has been thoroughly warmed up under the warm-up operation conditions specified by the manufacturer.

(1) The torque output of the test motor shall be set under at least 6 conditions for the positive side and the negative side, respectively, within a range of the electric motor torque command values from the full-close (0 %) to the full-open (100 %).

(2) The test motor speed shall be set within a range of ± 1 % or ± 10 rpm, whichever is larger, of the target motor speeds that have been set under at least 6 conditions from the stopped state (0 rpm) to the maximum design revolution speed. Moreover, the torque may be measured at the minimum motor speed for a stable operation of the dynamometer if its measurement in the stopped state (0 rpm) is difficult.

The minimum stabilized running for each command value shall be at least 3 seconds up to rated power conditions.

(3) The measurement shall be performed with the internal electric machine temperature and power electronics temperature during the test kept within the manufacturer defined limit values. Furthermore, the motor may be temporarily operated with low-power or stopped for the purpose of cooling, as required to enable continuing the measurement procedure.

(4) The cooling system may be operated at its maximum cooling capacity.

4.3.4.3. Measurement items

(1) The shaft torque shall be recorded, after confirming that the shaft torque and speed of the test motor have been stabilized, by reading out the braking load or shaft torque of the dynamometer. If the test motor and the dynamometer are connected via a transmission, the read-out-value shall be divided by the known transmission efficiency and the known gear ratio of the transmission.

(2) The electric motor speed shall be recorded from the measured rotational speed of the test motor output shaft or the speed of the dynamometer. However, if the test motor and the dynamometer are connected via a transmission, the electric motor speed may be calculated from the recorded speed of the dynamometer by multiplying the value by the known transmission gear ratio.

(3) The input power to the power electronics shall be measured by a device measuring the electric power, voltage and current and all values shall be recorded. However, the input power may be calculated by multiplying the measured input voltage by the measured input current.

(4) In the operating condition prescribed in paragraph 4.3.4.1. to this Annex, the electric motor internal temperature and temperature of the power electronics (as specified by the manufacturer) shall be measured and recorded as reference values, simultaneously with the measurement of the shaft torque at each test rotational speed.

(5) The test cell temperature and coolant temperature (in the case of liquid-cooling) shall be measured and recorded during the test.

4.3.5. Calculation formulas

The shaft output of the electric motor shall be calculated by means of the following formula:

$$P_{em} = \frac{2\pi \times M_{em} \times N_{em}}{60 \times 1000} \quad (\text{Eq. X})$$

where:

P_{em} : Electric motor shaft output (kW)

M_{em} : Electric motor shaft torque (Nm)

N_{em} : Electric motor rotational speed (rpm)

4.4. Battery

4.4.1. Resistor based model test procedure for determining the internal resistance and open-circuit voltage

As the input parameters for the HILS system, the direct-current internal resistance – open voltage of the battery shall be obtained by the test method as prescribed and schematically shown below in Figure X:

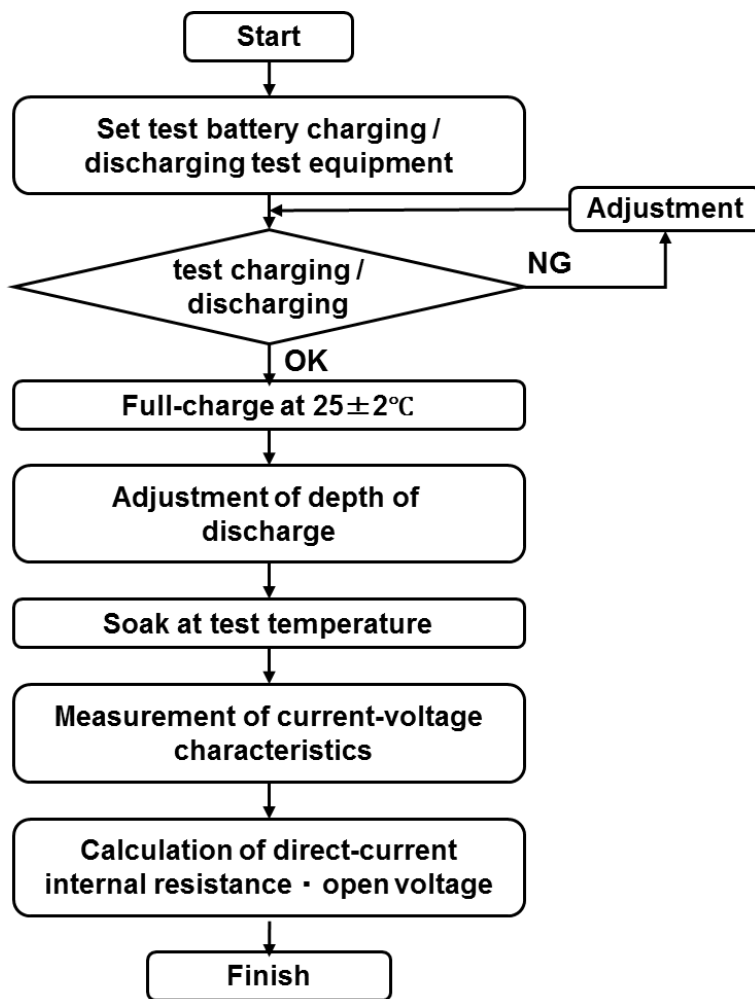


Figure X Battery test procedure diagram

4.4.1.1. Test battery

The test battery shall be in the condition described below:

(1) The test battery shall be either the complete battery system or a representative subsystem. If the manufacturer chooses to test with a representative subsystem, the manufacturer shall demonstrate that the test result can reasonably represent the performance of the complete battery under the same conditions.

(2) The test battery shall be one that has reached its rated capacity after a repeated charging / discharging cycle 5 times or less.

Rated capacity: The electric charge expressed in C_n (Ah) by the manufacturer. This is the electric quantity which can be released by the battery after fully charging it at an ambient temperature of 298 ± 2 K ($25 \text{ °C} \pm 2 \text{ °C}$) according to the charging method specified by the manufacturer, then soaking it for 1 hour

or more, but not more than 4 hours under the said condition, and letting it discharge until it reaches the discharge termination condition which is, at 298 K (25 °C) and with a constant current of I_n (A), 1.0 (V) per unit cell in the case of a nickel hydride battery, and a value specified by the manufacturer in the case of a lithium-ion battery.

$$I_n = C_n/n \quad (\text{Eq. X})$$

Where

I_n : Standard charging / discharging current (A)

C_n : n-hour rate of rated capacity published by manufacturer of battery (Ah)

n : n=3 (h) in case of nickel hydride battery, and

n=1 (h) or n=3 (h) in case of lithium-ion battery

4.4.1.2. Accuracy, calibration, etc. of measuring devices

Measuring devices that have the following accuracies and have been checked, serviced and calibrated according to the predetermined handling procedures shall be used:

(1) The accuracy of the thermometer shall be ± 1 K (1 °C) or less.

(2) The accuracy of the voltage measuring device shall be ± 1 % of the maximum value of measured voltage, and the accuracy of the current measurement device shall be ± 1 % of the maximum value of measured current.

4.4.1.3. Test conditions

(1) The test battery shall be placed in a temperature controlled test cell. The room temperature shall be 298 ± 2 K (25 ± 2 °C) or 318 ± 2 K (45 ± 2 °C), whatever is more appropriate according to the manufacturer.

(2) The voltage shall be measured at the terminals of the test battery.

(3) The temperature measurement shall follow the method specified by the manufacturer. Or it shall be performed, as shown in Figure X below, in the condition not affected by the outside temperature, with the thermometer attached to the central part of the battery and covered with insulation.

(4) The battery cooling system may be either activated or deactivated during the test.

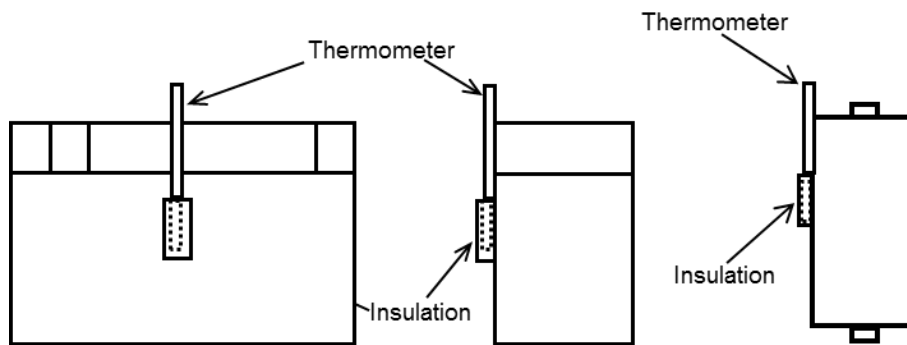


Figure X Battery temperature measurement locations (left: rectangular battery; right: cylindrical battery)

4.4.1.4 Current–voltage characteristic test

In this test, the voltage at the 10th second of discharging and charging with a constant current shall be measured according to the procedure given below:

(1) The test shall be conducted by changing the depth of discharge (100 % – state of charge %) within the range used for the test cycle as specified in Annex 1.b. The depth of discharge shall be level 3 or more, and shall be set in such a way as to allow for interpolation.

(2) As for the depth of discharge, after fully charging the battery at an ambient temperature of $298 \pm 2 \text{ K}$ ($25 \text{ °C} \pm 2 \text{ °C}$) according to the charging method specified by the manufacturer, it shall be soaked under the same condition. The adjustment shall be started 1 hour or more but not more than 4 hours thereafter. The adjustment shall be performed by changing the discharge time with a constant current I_n (A). The depth of discharge (a %) is the state after discharging the battery at I_n (A) for $(0.01 \times a \times n)$ hours. However, adjustment may be made by using the immediately preceding actually-measured battery capacity to calculate the discharge time for obtaining the targeted depth of discharge. Furthermore, if, after the completion of the current–voltage characteristic test at the first depth of discharge, an adjustment to the next depth of discharge is continuously performed, the adjustment may be made by calculating the discharge time from the present depth of discharge and the next depth of discharge.

(3) The battery temperature at the start of the test shall be $298 \pm 2 \text{ K}$ ($25 \text{ °C} \pm 2 \text{ °C}$). However, $318 \pm 2 \text{ K}$ ($45 \text{ °C} \pm 2 \text{ °C}$) may be selected by reporting in the application the actually-measured battery temperature at the time of the test cycle as specified in Annex 1.b. running equivalent to the in-vehicle condition.

(4) After adjusting the depth of discharge, soak the battery at the prescribed battery temperature at the start of the test. The test shall be started 1 hour or

more but not more than 4 hours thereafter, and 16 hours or more but not more than 24 hours thereafter in the case of 45°C.

(5) The test shall be conducted according to the sequence shown in Figure X:

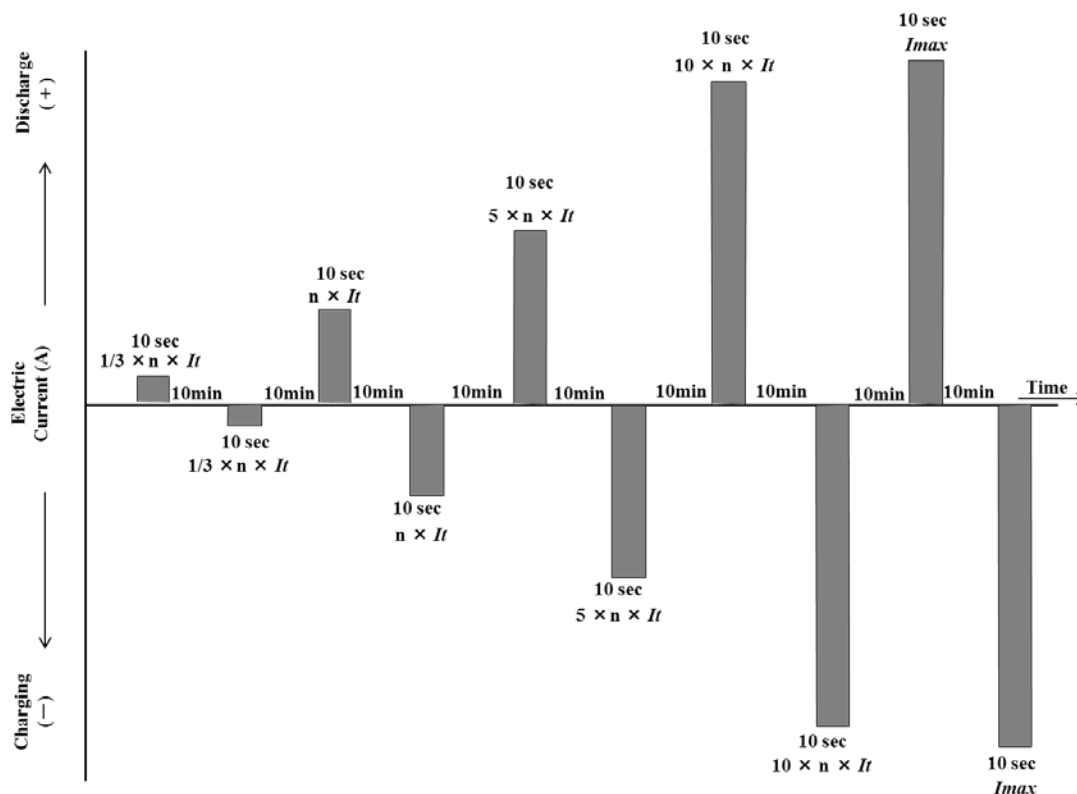


Figure X Test sequence of current-voltage characteristic test (example: when for rated capacity below 20Ah)

(6) The battery voltage at the 10th second shall be measured by discharging and charging at each current specified for each category of the rated capacity posted in Table 1 below. The upper limit of the charging – discharging current shall be 200 (A) or at least higher than the maximum value used in the HV as defined by the manufacturer. However, if the battery voltage at the 10th second exceeds the lower limit of discharging voltage or the upper limit of charging voltage, that measurement data shall be discarded.

Category of rated capacity	Charge / Discharge current				
	$\frac{1}{3} \cdot n \cdot I_n$	$n \cdot I_n$	$5 \cdot n \cdot I_n$	$10 \cdot n \cdot I_n$	I_{max}
Less than 20Ah	$\frac{1}{3} \cdot n \cdot I_n$	$n \cdot I_n$	$5 \cdot n \cdot I_n$	$10 \cdot n \cdot I_n$	I_{max}
20Ah or more	$\frac{1}{3} \cdot n \cdot I_n$	$n \cdot I_n$	$2 \cdot n \cdot I_n$	$5 \cdot n \cdot I_n$	I_{max}

Table X Charge/Discharge current values for test

(7) During the no-load period, the battery shall be cooled off for at least 10 minutes. It shall be confirmed that the change of temperature is kept within ± 2 °C before continuing with the next discharging or charging level.

4.4.1.5. Calculation of direct-current internal resistance and open-circuit voltage

Use the measurement data obtained according to Paragraph 4.4.1.4. to calculate the current–voltage characteristics from each charging, respectively, discharging currents and their corresponding voltages.

The method of the least-squares shall be used to determine the best-fit equation having the form:

$$y = a \times x + b \quad \text{(Eq. X)}$$

Where:

y = actual value of voltage (V)

x = actual value of current (A)

a = slope of the regression line

b = y-intercept value of the regression line

(1) For the discharge pulses, calculate the direct-current internal resistance R_d (i.e. absolute value of the slope) and the open-circuit voltage V_{d0} (i.e. the y-intercept) from the data (displayed in Figure X1).

(2) For the charge pulses, calculate the direct-current internal resistance R_c (i.e. absolute value of the slope) and the open-circuit voltage V_{c0} (i.e. the y-intercept) from the data (displayed in Figure X2).

(3) The open-circuit voltage V_0 as input parameter for the model shall be the calculated average of V_{d0} and V_{c0} .

(4) When a single internal resistance parameter is used as input parameter for the model, the direct-current internal resistance R_0 shall be the calculated average of R_d and R_c . Separate charge and discharge internal resistances may be used.

(5) In case a ReESS subsystem is used for the test, the representative system values shall be calculated.

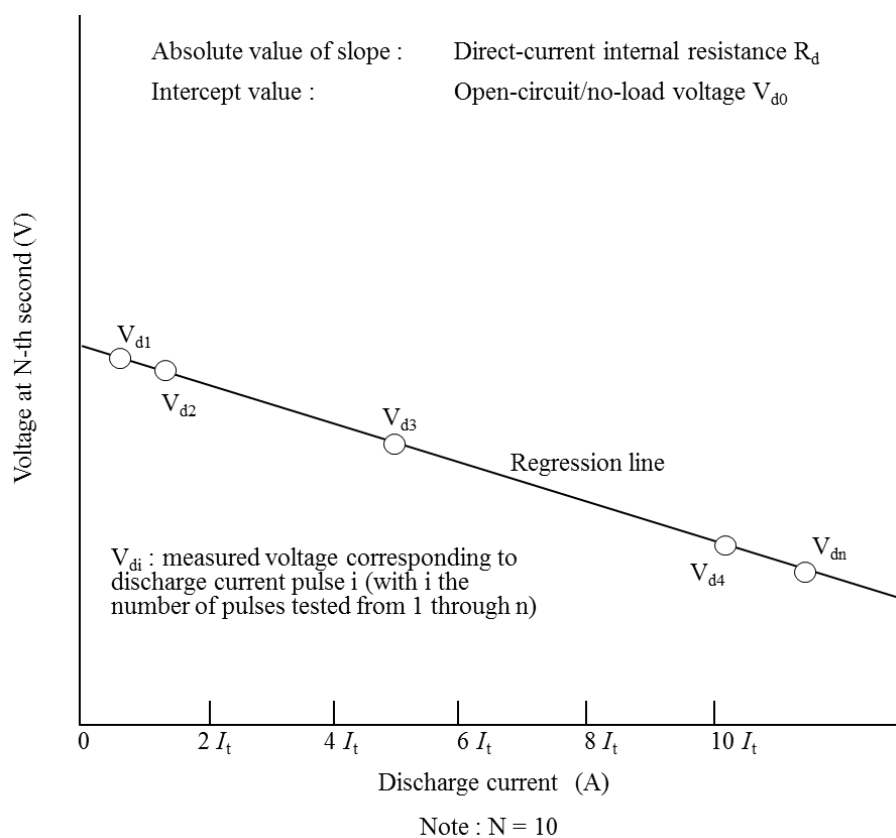


Figure X1 Determination of the Internal Resistance and Open-Circuit Voltage during Discharging

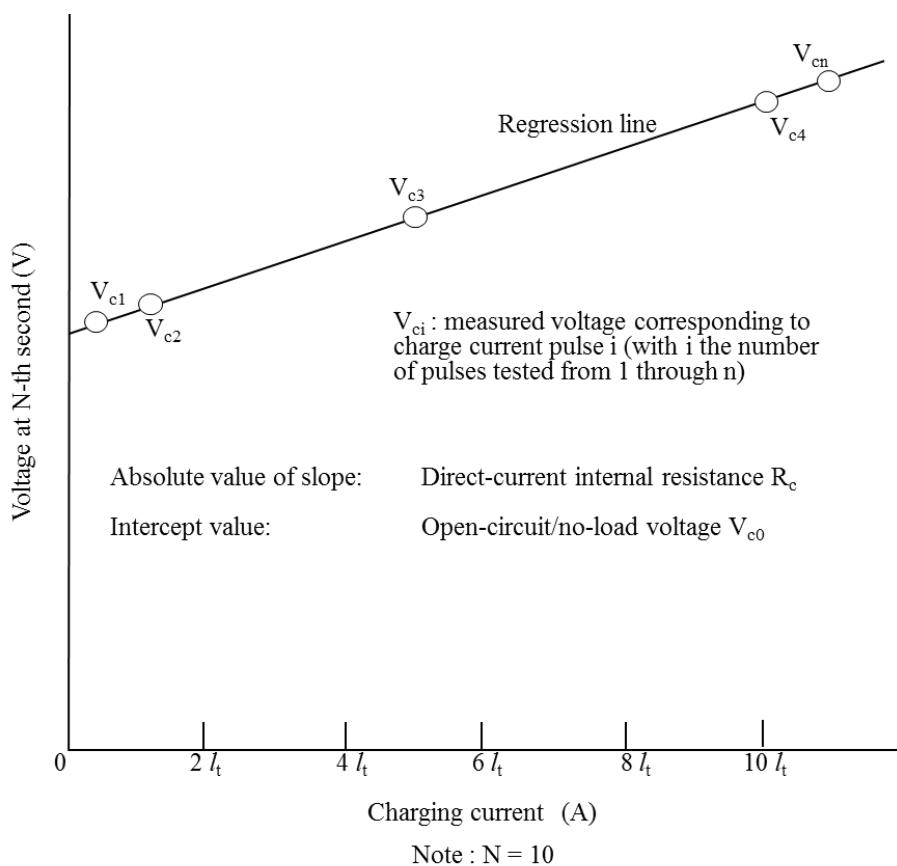


Figure X2 Determination of the Internal Resistance and Open-Circuit Voltage during Charging

4.4.2. RC-based battery model

Reserved

4.5. Capacitor model

Reserved

5. Creation of the engine cycle

5.1. Conversion method to obtain the engine cycle

5.1.1. Operation check of HILS system

Before calculating the engine cycle, the Reference HV model shall be run using the reference input parameters. It shall be confirm that the calculated output values of the HILS reference simulation run are within the tolerances. All Reference HV model, input parameters and output shall be in accordance with Paragraph 6. to this Annex.

5.1.2. HILS system and HV model verification of compatibility

Pursuant to the provisions of Paragraph 3. to this Annex, construct the HILS system by using the actual ECU, driver model, unique interface conversion model according to the system of the heavy-duty hybrid vehicle, HV model for approval, and so on, which are the objects of approval testing. In the HV model, input e.g. the engine torque characteristics and engine friction torque, the electric motor, electric power consumption - torque map, the battery internal resistance - open circuit voltage parameters that are measured pursuant to the provisions of Paragraph 4. to this Annex, as well as the vehicle specifications, rolling resistance coefficient and air resistance coefficients pursuant to the provision of Paragraph 3.8. to this Annex.

In accordance with Paragraph 6. to this Annex, confirm the operation of the HV model and the accuracy of the HILS simulated running.

5.1.3. Calculation of engine cycle by means of HILS system simulated running

Using the HILS system, perform the simulated running using the test cycle according to Annex 1.b. Record the HILS results in accordance with Paragraph 5.1.3.1. to this Annex at a measuring frequency of at least 5 Hz (10 Hz recommended), and use the engine speed and torque values as the command setpoints for the dynamometer.

5.1.3.1. HILS results signal specification

Reserved

5.1.4. Allowed tolerances for HILS system simulated running

Allowable errors in speed and time during the simulated running shall be, at any point during each running mode, within ± 2.0 km/h in speed and within ± 1.0 second in time, and shall be within the range of the coloured section in Figure X. Moreover, if deviations are within the tolerance corresponding to the setting items posted in the left column of Table X, they shall be deemed to be within the allowable errors. Time deviations at the times of start and gear change operation, however, shall not be included in the total cumulative time. In addition, this provision shall not apply to motor vehicles incapable of attaining the speeds of each running mode during the accelerations with their accelerator pedals fully depressed.

Setting item	Tolerance
1. Tolerable time range for one deviation	± 1.0 second
2. Tolerable time range for the total cumulative value of (absolute) deviations	2.0 seconds

3. Tolerable speed range for one deviation	± 2 km/h
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Table X Tolerances for cycle deviation

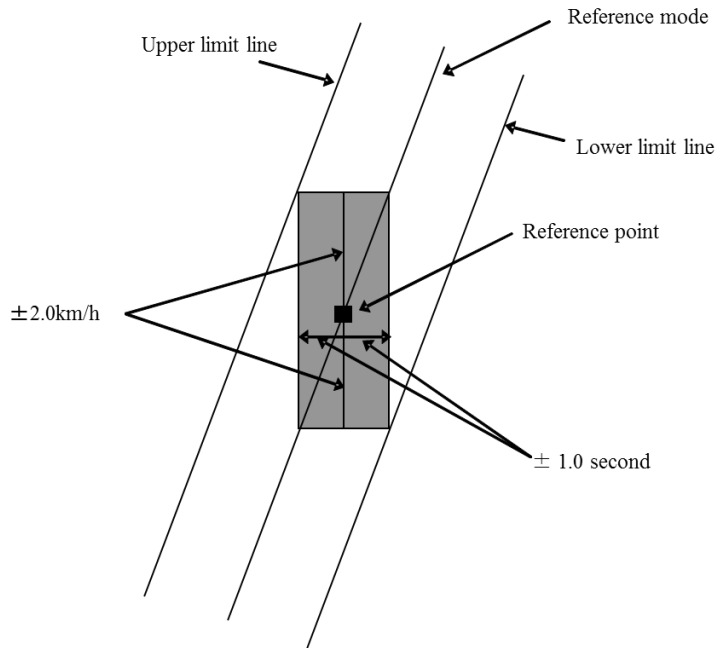


Figure X Allowed errors in speed and time during simulated running

5.1.5. Criteria for ReESS net energy change for HILS system simulated running

The initial state of charge shall be set so that the ratio of the energy conversion value of the energy balance to the integrated shaft output of the engine from the simulated running of the HILS system shall satisfy the following formulas:

$$|\Delta E / W_{eng_ref}| < 0.03 \quad \text{(Eq. X)}$$

Where:

ΔE : Net energy change of ReESS (kWh)

W_{eng_ref} : Integrated positive engine shaft power in HILS simulated run (kWh)

In case of battery:

$$\Delta E = \Delta Ah \times V_{nominal} \quad \text{(Eq. X)}$$

Where:

ΔAh : Electricity balance (Ah)

$V_{nominal}$: Rated voltage (V)

In case of capacitor:

$$\Delta E = 0.5 \times C_{cap} \times (V_{final}^2 - V_{init}^2) \quad (\text{Eq. X})$$

Where:

C_{cap} : Rated capacitance of the capacitor (F)

V_{init} : Initial voltage at start of test (V)

V_{final} : Final voltage at end of test (V)

In case of flywheels:

$$\Delta E = 0.5 \times J_{flywheel} \times (N_{final}^2 - N_{init}^2) \quad (\text{Eq. X})$$

Where:

C_{cap} : Rated capacitance of the capacitor (F)

N_{init} : Initial speed at start of test (min^{-1})

N_{final} : Final speed at end of test (min^{-1})

5.2. Replacement of test torque value at time of motoring

When the test torque becomes negative when the test cycle according Annex 1.b. is converted to the engine cycle by means of the HILS system according to this Annex, these negative torque values shall be replaced by a motoring request.

5.3. Calculation of integrated system shaft output

The integrated shaft output work (hereinafter referred to as “ W_{sys} ”) that is used to calculate the emission mass of the exhaust gas per unit work done shall be calculated using the integrated shaft output of the hybrid system from the HILS simulation run, as shown below:

(1) Cases where $W_{eng_act} < W_{eng_ref}$:

$$W_{sys} = W_{sys_ref} \times W_{eng_act} / W_{eng_ref} \quad (\text{Eq. X})$$

(2) Cases where $W_{eng_act} \geq W_{eng_ref}$:

$$W_{sys} = W_{sys_ref} \quad (\text{Eq. X})$$

where:

W_{sys} : Integrated positive shaft output of hybrid system (kWh)

W_{sys_ref} : Integrated positive shaft output of hybrid system from HILS simulation run (kWh)

W_{eng_act} : Integrated measured positive engine shaft output (kWh)

W_{eng_ref} : Integrated positive engine shaft output from HILS simulated run (kWh)

6. Reference HV model

6.1 Reference HV model description

Reserved.

6.2. Input parameters

Reserved.

6.3 Output parameters

Reserved.

7. Verification test procedure for HILS system for heavy-duty hybrid vehicles

7.1. Scope

This test procedure shall apply as the verification procedure for the HILS system used according to Paragraph 5. to this Annex.

7.2. Cases requiring verification of HILS system

The verification aims at checking the operation and the accuracy of the simulated running of the HV model. The verification shall be conducted when the equivalence of the HILS system to the test motor vehicle needs to be confirmed.

In case any of following conditions applies, the verification process according to Paragraph 7 to this Annex shall be required:

(a.) The HILS system is used for the first time

(b.) The HV system layout has changed

(c.) Changes are made to component models (e.g. structural change, larger or smaller number of model input parameters)

(d.) Different use of model component (e.g. manual to automated transmission)

(e.) Delay times or time constants of (internal combustion) engine or electric motor models are modified

Other cases may exist for which a verification is required.

The HILS system and HV model shall be approved by the type approval or certification authority. All deviations shall be provided to the type approval or certification authority along with the justification therefore and all appropriate information.

7.4. Vehicle test run

7.4.01 Test vehicle

Reserved.

7.4.1. Test procedure

The test using the test vehicle (hereinafter referred to as the “actual vehicle test”) which serves as the standard for the HILS system verification shall be conducted by either of the test methods described in Paragraph 7.4.1.1. through 7.4.1.3.

Provisions concerning measurement of exhaust emissions may be omitted according to need.

However, if the operation of the hybrid system cannot be reproduced with these test methods, the manufacturer may select an alternative test method that is deemed to be equivalent to these test methods may be used. This alternative method shall satisfy the intent of the specified procedure. Deviations from the method specified in this paragraph shall be approved by the type approval or certification authority. The manufacturer shall provide to the type approval or certification authority all appropriate information relating to the alternative method along with the justification for its use.

7.4.1.1. System bench test

Reserved.

7.4.1.2. Chassis dynamometer test

Reserved.

7.4.1.3. Road test

Reserved.

7.4.2. Test conditions

The test shall be conducted using both of the following two conditions:

(a.) Selected part of test cycle as defined in Annex 1.b. The selected part is defined as the 1st second to the 140st second.

(b.) The full test cycle as defined in Annex 1.b.

Figure X shows the flow diagram representing the verification test procedure for the HILS system and HV model.

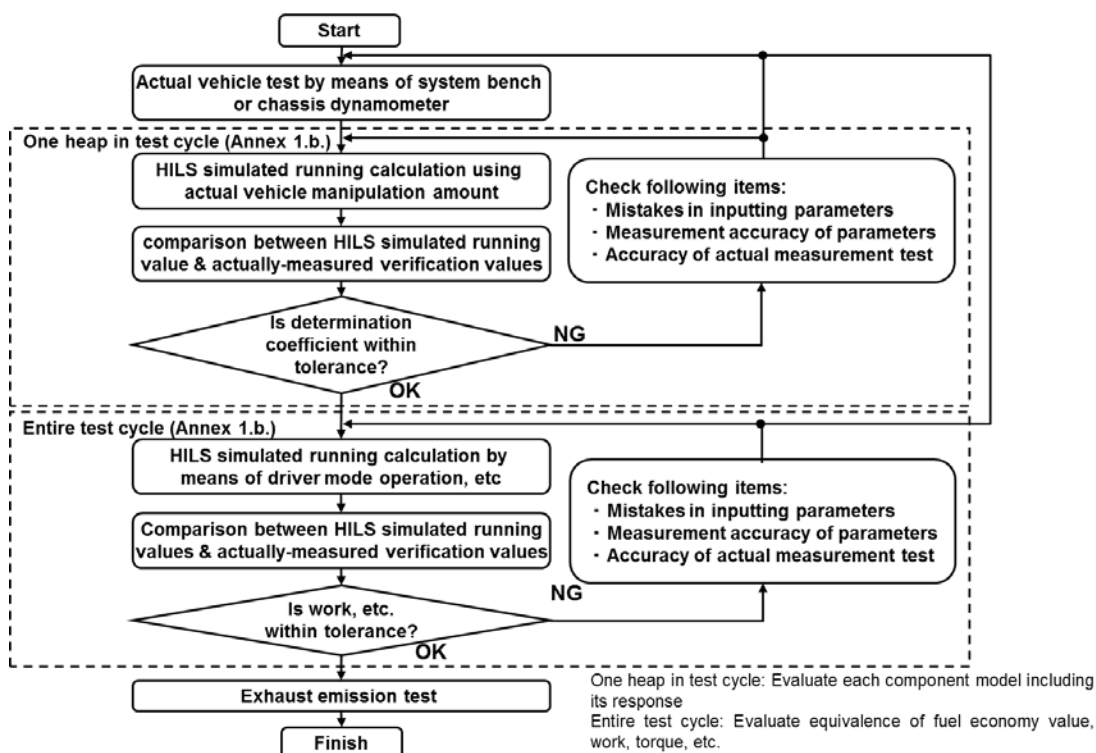


Figure X Flow diagram for Verification test procedure for HILS system and HV model

7.4.3. Measurement items

For all applicable components, at least the following shall be recorded from actual measurement (preferred) or ECU data (e.g. using CAN signals). The sampling frequency shall be 5Hz or higher. Data so obtained shall become the actually-measured data for the HILS system verification (hereinafter referred to as the “actually-measured verification values”).

(a.) System shaft speed (min⁻¹), system shaft torque (Nm), system shaft power (kW)

(b.) Vehicle speed (km/h)

(c.) Driver defined operation of the vehicle (accelerator, brake, clutch and shift operation signal, and so on) or quantity of manipulation on the engine dynamometer (throttle valve opening angle). All signals in units as applicable to the system and suitable for conversion towards use in conversion and interpolation routines.

(d.) Engine speed (min^{-1}), engine command values (-, %, Nm as applicable)

(e.) Electric motor speed (min^{-1}), torque command value (-, %, Nm as applicable)

(f.) Electric storage device power (kW), voltage (V), current (A)

Provisions for future components

(g.) *Hydraulic motor speed, torque command value*

(h.) *Hydraulic storage device power, mass flow, pressure*

7.5. HILS simulated running

7.5.1. Method for HILS simulated running

Use the HILS system constructed pursuant to the provisions of Paragraph 3. to this Annex to perform a simulated running pursuant to Paragraph 7.4.2. to this Annex and acquire the calculation data related to Paragraph 7.4.3. to this Annex. The data so obtained is the HILS simulated running data for HILS system verification (hereinafter referred to as the “HILS simulated running values”). In this case, the same parameters as those for the actual vehicle test shall be inputted in the HILS system, and the same gear positions (except the difference in gear positions involved in gear change operations) as those in the actual vehicle test shall be used for the simulated running. In addition, in cases where the load condition of the actual vehicle test is different from the bench engine characteristic test due to use of a (different) cooling fan, power steering or other auxiliaries, the engine model accessory torque map in the HV model may be used.

7.5.2. Test conditions

The HILS running test shall be conducted using both of the following two conditions:

(a.) Selected part of test cycle as defined in Annex 1.b. The selected part is defined as the 1st second to the 140st second. Input signals for the HV model are the relevant recorded values from the actual vehicle test (in accordance with Paragraph 7.4. to this Annex).

(b.) The full test cycle as defined in Annex 1.b. The driver model is to actuate all relevant signals as required for the HV model based on either the reference test cycle speed or the actual vehicle speed as recorded according to Paragraph 7.4. to this Annex.

7.6. Comparison of actually measured values with HILS simulated running

7.6.1. Confirmation of correlation

Correlation between the actually-measured verification values and the HILS simulated running values shall be verified for the selected test cycle part according to Paragraph 7.4.2.(a.) to this Annex. Table X shows the tolerances of the coefficient of determination between those values. Here, data during gear changes (from clutch disengagement to clutch engagement) and for one second before and after gear changes may be omitted.

	Vehicle speed	Engine			Electric/ Hydraulic Motor			Electric/ Hydraulic Storage Device		
		Speed	Torque	Power	Speed	Torque	Power	Voltage or Pressure	Current or Mass Flow	Power
SEE										
Slope, a_1										
R^2										
y-intercept, a_0										

Values are to be determined based on on-going validation test program

Table X

Tolerances (for selected part of the test cycle) for actually measured verification values and HILS simulated running values

7.6.2. Overall verification

7.6.2.1. Verification items and tolerances

Correlation between the actually-measured verification values and the HILS simulated running values shall be verified for the full test cycle (according to Paragraph 7.4.2.(b.) to this Annex).

Table X shows tolerances in the determination coefficient of the vehicle speed or engine revolution speed and of the engine torque and in the positive engine work.

In addition, in calculating the determination coefficient, data during gear change (from clutch disengagement to clutch engagement) and one second before and after gear change may be omitted.

	Vehicle speed	Engine			Positive engine work	Positive system work
		Speed	Torque	Power	$W_{eng_HILS} / W_{eng_vehicle}$	$W_{sys_HILS}/W_{sys_vehicle}$
SEE						
Slope, a_1						
R^2						
y-intercept, a_0						

Values are to be determined based on on-going validation test program

Table X

Tolerances (for full test cycle) for actually measured verification values and HILS simulated running values

Where:

W_{eng_HILS} : Integrated positive engine shaft output in HILS simulated running (kWh)

$W_{eng_vehicle}$: Integrated positive engine shaft output in actual vehicle test (kWh)

7.6.2.2. Calculation method for verification items

The engine torque and the positive engine work shall be acquired by the following methods, respectively, according to the test data enumerated below:

- (1) Actually-measured verification value:

Methods that are technically valid, such as a method where the value is calculated from the operating conditions of the hybrid system (system shaft revolution speed, system shaft torque) obtained by the actual vehicle test, using the input/output voltage and current to/from the electric motor controller, or a method where the value is calculated by using the data such as the engine torque characteristics acquired pursuant to Paragraph 4. to this Annex.

(2.) HILS simulated running value:

A method where the value is calculated from the engine operating conditions (speed, torque) obtained by the HILS simulated running.

7.6.2.3. Range of net energy change

The net energy changes in the actual test of the test vehicle and that during the HILS simulated running shall satisfy the following formula:

$$|\Delta E_{HILS} - \Delta E_{vehicle}|/C < 0.003 \quad (\text{Eq. X})$$

where:

ΔE_{HILS} : Energy conversion value of net energy change during HILS simulated running (kWh)

$\Delta E_{vehicle}$: Energy conversion value of net energy change during test vehicle running (kWh)

C : Energy conversion value of cumulative amount of ... (kWh)

7.6.2.4. Conditions for verification by means of determination coefficient of engine torque

Reserved.

Annex 9

**REQUIREMENTS FOR ENGINES INSTALLED IN HYBRID VEHICLES USING
POWETRAINS METHOD**

1. SCOPE

This annex shall apply to HVs, which are equipped with an internal combustion engine as one of their energy converters and for which the pollutant emissions are to be determined on the basis of a powertrain test.

2. TEST PROCEDURE

This Annex describes the procedure for simulating a chassis test for a pre-transmission or post-transmission hybrid system in a powertrain test cell. Following steps shall be carried out:

2.1 Powertrain method

Reserved.

3. Conduct the emission test

3.1. Set up the object for test in the test cell

Reserved.

3.2 Define interfacing between test object, model and dynamometer

3.2.1. Define all vehicle related parameters

Reserved.

3.2.2. Brake signal

Reserved.

3.2.3. Driver model

Reserved.

3.3 Collect and measure the pollutant emissions

Reserved.

3.4. Test statistics / validation

Reserved.

3.5. Net energy change correction

Reserved.

3.6. Calculation of test result

Reserved.

4. System power mapping procedure

4.1 Powertrain mapping

Engines that include electric hybrid systems shall be mapped as described in this paragraph. These provisions may be applied to other types of hybrid engines, consistent with good engineering judgment. The mapping procedure as given in paragraph 7.4 of this gtr shall be used except as noted in this paragraph. The powertrain map shall be generated with the hybrid system active as described in paragraph 4.1.2 or 4.1.3 of this section.

4.1.1. General

The purpose of the mapping procedure in this paragraph is to determine the maximum torque available at each speed with a charged ReESS. One of the following methods shall be used to generate a hybrid-active map.

4.1.2. Continuous sweep mapping

A powertrain map shall be performed by using a series of continuous sweeps to cover the powertrain's full range of operating speeds. The powertrain shall be prepared for hybrid-active mapping by ensuring that the ReESS state of charge is representative of normal operation. The sweep shall be performed as specified in paragraph 7.4 of this gtr, but the sweep shall be stopped to charge the ReESS when the power measured from the ReESS drops below the expected maximum power from the RESS by more than 2% of total system power (including engine and ReESS power). Unless good engineering judgment indicates otherwise, it may be assumed that the expected maximum power from the ReESS is equal to the measured ReESS power at the start of the sweep segment. For example, if the 3-second rolling average of total engine-ReESS power is 200 kW and the power from the ReESS at the beginning of the sweep segment is 50 kW, once the power from the ReESS reaches 46 kW, the sweep shall be stopped to charge the ReESS. Note that this assumption is not valid where the hybrid motor is torque-limited. Total system power shall be calculated as a 3-second rolling average of instantaneous total system power. After each charging event, the engine shall be stabilized for 15 seconds at the speed at which the previous segment ended with operator demand set to maximum before continuing the sweep from that speed. The cycle of charging, mapping, and recharging shall be repeated until the engine map is completed. The system may be shut down or other operation may

be included between segments to be consistent with the intent of this paragraph. For example, for systems in which continuous charging and discharging can overheat batteries to an extent that affects performance, the engine may be operated at zero power from the ReESS for enough time after the system is recharged to allow the batteries to cool. Good engineering judgment shall be used to smooth the torque curve to eliminate discontinuities between map intervals.

4.1.3. Discrete speed mapping

A powertrain map shall be performed by using discrete speeds. Map set points shall be selected at 13 equally spaced powertrain speeds. Mapping may be stopped at the highest speed above maximum power at which 50% of maximum power occurs. Powertrain speed shall be stabilized at each setpoint, targeting a torque value at 70% of peak torque at that speed without hybrid-assist. The engine shall be fully warmed up and the ReESS state of charge shall be within the normal operating range. The operator demand shall be moved to maximum, the powertrain shall be operated there for at least 10 seconds, and the 3-second rolling average feedback speed and torque shall be recorded at 1 Hz or higher. The peak 3-second average torque and 3-second average speed shall be recorded at that point. Linear interpolation shall be used to determine intermediate speeds and torques. §7.4.x. shall be followed to calculate the maximum test speed. The measured maximum test speed shall fall in the range from 92 to 108% of the estimated maximum test speed. If the measured maximum test speed does not fall in this range, the map shall be rerun using the measured value of maximum test speed.