Transmitted by the HDH Secretary

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Agenda items 4(a) and 4(c)

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 - document ECE-TRANS-WP29-GRPE-2014-11e

Amendments and complements to be taken into consideration

I. Background

Document ECE-TRANS-WP29-GRPE-2014-11e was prepared by the GRPE informal working group on heavy duty hybrids (HDH), to add the test procedure on heavy duty hybrids to gtr n° 4. In addition, minor changes of aligning gtr n° 4 with gtr n° 11 on nonroad mobile machinery are being introduced, as approved by WP.29 at its 162th session. With the agreement of GRPE, this document was due to be completed and when necessary amended in order to take into consideration the latest work progress of the HDH informal working group. This informal document presents these complements and amendments. The modifications to the original English text are marked using track changes. Non relevant editorial changes, such as section numbering and number of equations, tables and figures are not marked in all cases.

It should be noted that equations, tables and figures numbering and the corresponding references, and the symbols list in paragraph 3.2 have not yet been fully completed. This will be done during the final editing of document ECE-TRANS-WP29-GRPE-2014-11e.

II. Proposal

A. Statement of technical rationale and justification

Section 2., amend to read

2. Anticipated benefits

7. To enable manufacturers to develop new hybrid vehicle models more effectively and within a shorter time, it is desirable that gtr n°4 should be amended to cover the special requirements for hybrid vehicles. These savings will accrue not only to the manufacturer, but more importantly, to the consumer as well.~~Reserved.~~

However, amending a test procedure just to address the economic question does not address the mandate given when work on this amendment was first started. The test procedure must also better reflect how heavy-duty engines are are actually operated in hybrid vehicles. Compared to the measurement methods defined in this gtr, the new testing methods for hybrid vehicles are more representative of in-use driving behaviour of heavy-duty hybrid vehicles.

B. Text of Regulation

Section 2., amend to read

"2. Scope

2.1 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.

2.2. This regulation also applies to the measurement of the emission of gaseous and particulate pollutants from powertrains, used for propelling hybrid motor vehicles of categories 1-2 and 2, having a design speed exceeding 25 km/h and having a maximum mass exceeding 3.5 tonnes, being equipped with compression-ignition engines or positive-ignition engines fuelled with NG or LPG. It does not apply to plug-in hybrids.

Section 3.1.14., amend to read

3.1.14. "*Energy* converter" means the part of the powertrain converting one form of energy into a different one for the primary purpose of vehicle propulsion.

Section 3.1.16., amend to read

3.1.16. "*Energy storage system*" means the part of the powertrain that can store chemical, electrical or mechanical energy and that may also be able to internally convert those energies without being directly used for vehicle propulsion, and which can be refilled or recharged externally and/or internally.

Sections 3.1.37 and 3.1.52.,to be added

3.1.37. "*Parallel hybrid*" means a hybrid vehicle which is not a series hybrid; it includes power-split and series-parallel hybrids.

3.1.52. "*Series hybrid*" means a hybrid vehicle where the power delivered to the driven wheels is provided solely by energy converters other than the internal combustion engine.

New section 3.2.1., to be added

3.2.1 Symbols of Annexes 9 and 10

Symbol	*Unit*	*Term*
A, B, C	-	chassis dynamometer polynomial coefficients
A_{front}	m^2	vehicle frontal area
ASG_{flg}	-	automatic start gear detection flag
c	-	tuning constant for hyperbolic function
C	F	capacitance
CAP	Ah	battery coulomb capacity
C_{cap}	F	rated capacitance of capacitor
C_{drag}	-	vehicle air drag coefficient
D_{pm}	m^3	hydraulic pump/motor displacement
$Dt_{syncindi}$	s	clutch synchronization indication
$Dyno_{measured}$	-	chassis dynamometer A, B, C measured parameters
$Dyno_{settings}$	-	chassis dynamometer A, B, C parameter setting
$Dyno_{target}$	-	chassis dynamometer A, B, C target parameters
e	V	battery open-circuit voltage
$E_{flywheel}$	J	flywheel kinetic energy
f_{amp}	-	torque converter mapped torque amplification
f_{pump}	Nm	torque converter mapped pump torque
$F_{roadload}$	N	chassis dynamometer road load
f_{roll}	-	tyre rolling resistance coefficient
g	$\mathrm{m/s}^2$	gravitational coefficient
i_{aux}	A	electric auxiliary current
i_{em}	A	electric machine current
J	kgm^2	rotating inertia
J_{aux}	kgm^2	mechanical auxiliary load inertia

Symbol	Unit	Term
$J_{cl,1}$ / $J_{cl,2}$	kgm^2	clutch rotational inertias
J_{em}	kgm^2	electric machine rotational inertia
J_{fg}	kgm^2	final gear rotational inertia
$J_{flywheel}$	kgm^2	flywheel inertia
J_{gear}	kgm^2	transmission gear rotational inertia
J_p / J_t	kgm^2	torque converter pump / turbine rotational inertia
J_{pm}	kgm^2	hydraulic pump/motor rotational inertia
$J_{powertrain}$	kgm^2	total powertrain rotational inertia
$J_{retarder}$	kgm^2	retarder rotational inertia
J_{spur}	kgm^2	spur gear rotational inertia
J_{tot}	kgm^2	total vehicle powertrain inertia
J_{wheel}	kgm^2	wheel rotational inertia
K_K	-	PID anti-windup parameter
K_P, K_I, K_D	-	PID controller parameters
M_{aero}	Nm	aerodynamic drag torque
M_{cl}	Nm	clutch torque
$M_{cl,maxtorque}$	Nm	maximum clutch torque
M_{CVT}	Nm	CVT torque
M_{drive}	Nm	drive torque
M_{em}	Nm	electric machine torque
$M_{flywheel,loss}$	W	flywheel torque loss
M_{grav}	Nm	gravitational torque
M_{ice}	Nm	engine torque
$M_{mech,aux}$	Nm	mechanical auxiliary load torque
M_{mech_brake}	Nm	mechanical friction brake torque
M_p / M_t	Nm	torque converter pump / turbine torque
M_{pm}	Nm	hydraulic pump/motor torque
$M_{retarder}$	Nm	retarder torque
M_{roll}	Nm	rolling resistance torque
M_{start}	Nm	ICE starter motor torque
$M_{tc,loss}$	Nm	torque converter torque loss during lock-up
$m_{vehicle}$	kg	vehicle test mass
$m_{vehicle,0}$	kg	vehicle curb mass
n_{act}	min^{-1}	actual engine speed
n_{final}	min^{-1}	final speed at end of test
n_{init}	min^{-1}	initial speed at start of test
n_s / n_p	-	number of series / parallel cells
P	kW	(hybrid system) rated power
p_{acc}	Pa	hydraulic accumulator pressure
$pedal_{accelerator}$	-	accelerator pedal position

Symbol	*Unit*	*Term*
$pedal_{\mathrm{brake}}$	-	brake pedal position
$pedal_{\mathrm{clutch}}$	-	clutch pedal position
$pedal_{limit}$	-	clutch pedal threshold
$P_{\mathrm{el,aux}}$	kW	electric auxiliary power
$P_{\mathrm{el,em}}$	kW	electric machine electrical power
P_{em}	kW	electric machine mechanical power
p_{gas}	Pa	accumulator gas pressure
$P_{\mathrm{ice,loss}}$	W	ICE power loss
$P_{\mathrm{loss,bat}}$	W	battery power loss
$P_{\mathrm{loss,em}}$	kW	electric machine power loss
$P_{\mathrm{mech,aux}}$	kW	mechanical auxiliary load power
P_{rated}	kW	(hybrid system) rated power
p_{res}	Pa	hydraulic accumulator sump pressure
Q_{pm}	$\mathrm{m^3/s}$	hydraulic pump/motor volumetric flow
$R_{\mathrm{bat,th}}$	K/W	battery thermal resistance
r_{CVT}	-	CVT ratio
$R_{\mathrm{em,th}}$	K/W	thermal resistance for electric machine
r_{fg}	-	final gear ratio
r_{gear}	-	transmission gear ratio
R_{i}	Ω	capacitor internal resistance
R_{i0}, R	Ω	battery internal resistance
r_{spur}	-	spur gear ratio
r_{wheel}	m	wheel radius
SG_{flg}	-	skip gear flag
$slip_{\mathrm{limit}}$	rad/s	clutch speed threshold
SOC	-	state-of-charge
$T_{\mathrm{act}}(n_{\mathrm{act}})$	Nm	actual engine torque at actual engine speed
T_{bat}	K	battery temperature
$T_{\mathrm{bat,cool}}$	K	battery coolant temperature
$T_{\mathrm{capacitor}}$	K	capacitor temperature
T_{clutch}	s	clutch time
T_{em}	K	electric machine temperature
$T_{\mathrm{em,cool}}$	K	electric machine coolant temperature
$T_{\mathrm{ice,oil}}$	K	ICE oil temperature
$T_{\mathrm{max}}(n_{\mathrm{act}})$	Nm	maximum engine torque at actual engine speed
T_{norm}	-	normalized duty cycle torque value
$T_{\mathrm{startgear}}$	s	gear shift time prior to driveaway
u	V	voltage
u_{C}	V	capacitor voltage
u_{cl}	-	clutch pedal actuation
U_{final}	V	final voltage at end of test

Symbol	*Unit*	*Term*
u_{in} / u_{out}	V	input / output voltage
U_{init}	V	initial voltage at start of test
u_{req}	V	requested voltage
$V_{\mathrm{C,min/max}}$	V	capacitor minimum / maximum voltage
V_{gas}	m^3	accumulator gas volume
v_{max}	km/h	maximum vehicle speed
V_{nominal}	V	rated nominal voltage for REESS
v_{vehicle}	m/s	vehicle speed
W_{act}	kWh	actual engine work
$W_{\mathrm{eng\_HILS}}$	kWh	engine work in the HILS simulated run
$W_{\mathrm{eng\_test}}$	kWh	engine work in chassis dynamometer test
W_{sys}	kWh	hybrid system work
$W_{\mathrm{sys\_HILS}}$	kWh	hybrid system work in the HILS simulated run
$W_{\mathrm{sys\_test}}$	kWh	hybrid system work in powertrain test
x	-	control signal
x_{DCDC}	-	DC/DC converter control signal
α_{road}	rad	road gradient
γ	-	adiabatic index
ΔAh	Ah	net change of REESS coulombic charge
ΔE	kWh	net energy change of RESS
ΔE_{HILS}	kWh	net energy change of RESS in HILS simulated running
ΔE_{test}	kWh	net energy change of RESS in test
η_{CVT}	-	CVT efficiency
η_{DCDC}	-	DC/DC converter efficiency
η_{em}	-	electric machine efficiency
η_{fg}	-	final gear efficiency
η_{gear}	-	transmission gear efficiency
η_{pm}	-	hydraulic pump/motor mechanical efficiency
η_{spur}	-	spur gear efficiency
η_{vpm}	-	hydraulic pump/motor volumetric efficiency
ρ_{a}	$\mathrm{kg/m}^3$	air density
τ_1	-	first order time response constant
$\tau_{\mathrm{bat,heat}}$	J/K	battery thermal capacity
τ_{close}	s	clutch closing time constant
$\tau_{\mathrm{driveaway}}$	s	clutch closing time constant for driveaway
$\tau_{\mathrm{em,heat}}$	J/K	thermal capacity for electric machine mass
τ_{open}	s	clutch opening time constant
ω	rad/s	shaft rotational speed
ω_{p} / ω_{t}	rad/s	torque converter pump / turbine speed
$\dot{\omega}$	$\mathrm{rad/s}^2$	rotational acceleration

Section 5.1., amend to read

5.1. Emission of gaseous and particulate pollutants

5.1.1. Internal combustion engine

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. This paragraph also applies to vehicles with integrated starter/generator systems where the generator is not used for propelling the vehicle, for example stop/start systems.

~~For hybrid vehicles, the emissions of gaseous and particulate pollutants shall be determined on the cycles derived in accordance with Annex 9 for the HEC or Annex 10 for the HPC.~~

5.1.2. Hybrid powertrain

The emissions of gaseous and particulate pollutants by the hybrid powertrain shall be determined on the duty cycles derived in accordance with Annex 9 for the HEC or Annex 10 for the HPC.

Hybrid powertrains may be tested in accordance with paragraph 5.1.1., if the ratio between the propelling power of the electric motor, as measured in accordance with paragraph A.9.8.4. at speeds above idle speed, and the rated power of the engine is less than or equal to 5 per cent.

5.1.2.1. The Contracting Parties may decide to not make paragraph 5.1.2. and the related provisions for hybrid vehicles, specifically Annexes 9 and 10, compulsory in their regional transposition of this gtr.

In such case, the internal combustion engine used in the hybrid powertrain shall meet the applicable requirements of paragraph 5.1.1.

5.1.3. Measurement system

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~~4

5.1.~~1~~4. Equivalency

Section 5.3.2., amend to read

5.3.2. Special requirements

For a hybrid powertrain, interaction between design parameters shall be identified by the manufacturer in order to ensure that only hybrid powertrains with similar exhaust emission characteristics are included within the same hybrid powertrain family. These interactions shall be notified to the type approval or certification authority, and shall be taken into account as an additional criterion beyond the parameters listed in paragraph 5.3.3. for creating the hybrid powertrain family.

The individual test cycles HEC and HPC depend on the configuration of the hybrid powertrain. In order to determine if a hybrid powertrain belongs to the same family, or if a new hybrid powertrain configuration is to be added to an existing family, the manufacturer shall simulate a HILS test or run a powertrain test with this powertrain configuration and record the resulting duty cycle. ~~This duty cycle shall be compared to the duty cycle of the parent hybrid powertrain and meet the criteria in paragraph 5.3.2.1.~~

The duty cycle torque values shall be normalized as follows:

$$T_{norm} = \frac{T_{act}(n_{act})}{T_{max}(n_{act})} \qquad (1)$$

Where:

T_{norm}	are the normalized duty cycle torque values
n_{act}	is the actual engine speed, min^{-1}
$T_{\mathrm{act}}(n_{\mathrm{act}})$	is the actual engine torque at actual engine speed, Nm
$T_{\mathrm{max}}(n_{\mathrm{act}})$	is the maximum engine torque at actual engine speed, Nm

The normalized duty cycle shall be evaluated against the normalized duty cycle of the parent hybrid powertrain by means of a linear regression analysis. This analysis shall be performed at 1 Hz or greater. A hybrid powertrain shall be deemed to belong to the same family, if the criteria of table 2 in paragraph 7.8.8. are met.

~~5.3.2.1. Reserved~~

5.3.2.~~2~~1. 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.

Sections 5.3.3.1., 5.3.3.2. and 5.3.3.7., amend to read

5.3.3.1. Hybrid topology (architecture)

(a) Parallel

(b) Series

5.3.3.~~1~~2. Internal combustion engine

The engine family criteria of paragraph 5.2 shall be met when selecting the engine for the hybrid powertrain family.

~~Engines from different engine families with respect to paragraphs 5.2.3.2, 5.2.3.4, and 5.2.3.9 may be combined into a hybrid powertrain family based on their overall emission behavior.~~

~~5.3.3.2. Power of the internal combustion engine~~

~~Reserved~~

~~5.3.3.7. Other~~

~~Reserved.~~

Section 5.3.4., amend to read

5.3.4. Choice of the parent hybrid powertrain

Once the powertrain family has been agreed by the type approval or certification authority, the parent hybrid powertrain of the family shall be selected using the internal combustion engine with the highest power.

In case the engine with the highest power is used in multiple hybrid powertrains, the parent hybrid powertrain shall be the hybrid powertrain with the highest ratio of internal combustion engine to hybrid system work determined by HILS simulation or powertrain test.

Section 6., amend to read

6. TEST CONDITIONS

The general test conditions laid down in this paragraph shall apply to testing of the internal combustion engine (WHTC, WHSC, HEC) and of the powertrain (HPC) as specified in Annex 10.

Section 6.6.1., amend to read

...

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 for the gaseous components and by not more than ±25 per cent or 0.005 g/kWh, whichever is greater, for PM.

Section 6.6.2., amend to read

….

Average brake specific emissions between regeneration phases shall be determined from the arithmetic mean of several approximately equidistant hot start test results (g/kWh). As a minimum, at least one hot start test as close as possible prior to a regeneration test and one 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 for the gaseous components and ±25 per cent or 0.005 g/kWh, whichever is greater, for PM) between regeneration phases. In this case, the emissions of only one hot start test may be used.

Section 9., amend to read

9. Equipment specification and verification

This paragraph describes the required calibrations, verifications and interference checks of the measurement systems. Calibrations or verifications shall be generally performed over the complete measurement chain.

Internationally recognized-traceable standards shall be used to meet the tolerances specified for calibrations and verifications.

Instruments shall meet the specifications in table 7 for all ranges to be used for testing. Furthermore, any documentation received from instrument manufacturers showing that instruments meet the specifications in table 7 shall be kept.

Table 8 summarizes the calibrations and verifications described in paragraph 9 and indicates when these have to be performed.

Overall systems for measuring pressure, temperature, and dew point shall meet the requirements in table 8 and table 9. Pressure transducers shall be located in a temperature-controlled environment, or they shall compensate for temperature changes over their expected operating range. Transducer materials shall be compatible with the fluid being measured.~~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.~~

Table 7 (new)
Recommended performance specifications for measurement instruments

Measurement Instrument	Complete System Rise time	Recording frequency	Accuracy	Repeatability
Engine speed transducer	1 s	1 Hz means	2.0 % of pt. or 0.5 % of max	1.0 % of pt. or 0.25 % of max
Engine torque transducer	1 s	1 Hz means	2.0 % of pt. or 1.0 % of max	1.0 % of pt. or 0.5 % of max
Fuel flow meter	5 s	1 Hz	2.0 % of pt. or 1.5 % of max	1.0 % of pt. or 0.75 % of max
CVS flow (CVS with heat exchanger)	1 s (5 s)	1 Hz means (1 Hz)	2.0 % of pt. or 1.5 % of max	1.0 % of pt. or 0.75 % of max
Dilution air, inlet air, exhaust, and sample flow meters	1 s	1 Hz means of 5 Hz samples	2.5 % of pt. or 1.5 % of max	1.25 % of pt. or 0.75 % of max
Continuous gas analyzer raw	2.5 s	2 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.
Continuous gas analyzer dilute	5 s	1 Hz	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.
Batch gas analyzer	N/A	N/A	2.0 % of pt. or 2.0 % of meas.	1.0 % of pt. or 1.0 % of meas.
Analytical balance	N/A	N/A	1.0 µg	0.5 µg

Note: Accuracy and repeatability are based on absolute values. "pt." refers to the overall mean value expected at the respective emission limit ; "max." refers to the peak value expected at the respective emission limit over the duty cycle, not the maximum of the instrument's range; "meas." refers to the actual mean measured over the duty cycle.

Table 8 (new)
Summary of Calibration and Verifications

Type of calibration or verification	Minimum frequency [(a)]
9.2.: linearity	Speed: Upon initial installation, within 370 days before testing and after major maintenance. Torque: Upon initial installation, within 370 days before testing and after major maintenance. Clean air and diluted exhaust flows: Upon initial installation, within 370 days before testing and after major maintenance, unless flow is verified by propane check or by carbon oxygen balance. Raw exhaust flow: Upon initial installation, within 185 days before testing and after major maintenance. Gas analyzers: Upon initial installation, within 35 days before testing and after major maintenance. PM balance: Upon initial installation, within 370 days before testing and after major maintenance. Pressure and temperature: Upon initial installation, within 370 days before testing and after major maintenance.
9.3.1.2.: accuracy, repeatability and noise	Accuracy: Not required, but recommended for initial installation. Repeatability: Not required, but recommended for initial installation. Noise: Not required, but recommended for initial installation.
9.4.5.6.: flow instrument calibration	Upon initial installation and after major maintenance.
9.5.: CVS calibration	Upon initial installation and after major maintenance.
9.5.5: CVS verification [(b)]	Upon initial installation, within 35 days before testing, and after major maintenance. (propane check)
9.3.4.: vacuum-side leak check	Before each laboratory test according to paragraph 7.
9.3.9.1: CO analyzer interference check	Upon initial installation and after major maintenance.
9.3.7.1.: Adjustment of the FID	Upon initial installation and after major maintenance
9.3.7.2.: Hydrocarbon response factors	Upon initial installation, within 185 days before testing, and after major maintenance.
9.3.7.3.: Oxygen interference check	Upon initial installation, and after major maintenance and after FID optimization according to 9.3.7.1.
9.3.8.: Efficiency of the non-methane cutter (NMC)	Upon initial installation, within 185 days before testing, and after major maintenance.
9.3.9.2.: NOx analyzer quench check for CLD	Upon initial installation and after major maintenance.
9.3.9.3.: NOx analyzer quench check for NDUV	Upon initial installation and after major maintenance.
9.3.9.4.: Sampler dryer	Upon initial installation and after major maintenance.
9.3.6.: NO_x converter efficiency	Upon initial installation, within 35 days before testing, and after major maintenance.

Type of calibration or verification	Minimum frequency [(a)]
[(a)] Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment. [(b)] The CVS verification is not required for systems that agree within ± 2per cent based on a chemical balance of carbon or oxygen of the intake air, fuel, and diluted exhaust.	

Section 9.1., amend to read

9.1. Dynamometer specification

9.1.1. Shaft work

An engine dynamometer shall be used that has adequate characteristics to perform the applicable duty cycle including the ability to meet appropriate cycle validation criteria. The following dynamometers may be used:

(a) Eddy-current or water-brake dynamometers;

(b) Alternating-current or direct-current motoring dynamometers;

(c) One or more dynamometers.

~~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.~~

9.1.2. Torque measurement

Load cell or in-line torque meter may be used for torque measurements.

When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dynamometer shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.

Section 9.2., amend to read

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~~9. The linearity verification according to paragraph 9.2.1. shall be performed for the gas analyzers within 35 days before testing ~~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 within 370 days before testing~~as required by internal audit procedures, by the instrument manufacturer or in accordance with ISO 9000 requirements~~.

Table 7, re-number table 9

Section 9.3.1., amend to read

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.

Analyzers may be used, that have compensation algorithms that are functions of other measured gaseous components, and of the fuel properties for the specific engine test. Any compensation algorithm shall only provide offset compensation without affecting any gain (that is no bias).

9.3.1.2. Verifications for accuracy, repeatability, and noise~~Accuracy~~

The performance values for individual instruments specified in table 7 are the basis for the determination of the accuracy, repeatability, and noise of an instrument.

It is not required to verify instrument accuracy, repeatability, or noise. However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.~~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~~3. Rise time

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

9.3.1.~~8~~4. 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. It shall meet the requirements of section 9.3.9.4.

The following gas-drying devices are permitted:

(a) An osmotic-membrane dryer shall meet the temperature specifications in paragraph 9.3.2.2. The dew point, Tdew, and absolute pressure, ptotal, downstream of an osmotic-membrane dryer shall be monitored.

(b) A thermal chiller shall meet the NO_2 loss-performance check specified in paragraph 9.3.9.4.

Chemical dryers are not ~~an acceptable method of~~permitted for removing water from the sample.

Section 9.3.3.3., amend to read

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 N_2 or with purified synthetic air. Critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers may be used. Viscosity corrections shall be applied as necessary (if not done by gas divider internal software) to appropriately ensure correct gas division. 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.~~

The gas divider system shall meet the linearity verification in paragraph 9.2., table 7. 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.~~

Section 9.3.4., amend to read

9.3.4. Vacuum-side ~~L~~leak check

Upon initial sampling system installation, after major maintenance such as pre-filter changes, and within 8 hours prior to each test sequence, it shall be verified that there are no significant vacuum-side leaks using one of the leak tests described in this section. This verification does not apply to any full-flow portion of a CVS dilution system.

A leak may be detected either by measuring a small amount of flow when there shall be zero flow, by measuring the pressure increase of an evacuated system, or by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system. ~~A system leak check shall be performed~~.

9.3.4.1. Low-flow leak test

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.

9.3.4.2. Vacuum-decay leak test

~~Alternatively, the~~ The system ~~may~~ shall be evacuated to a pressure of at least 20 kPa vacuum (80 kPa absolute) and the leak rate of the system shall be observed as a decay in the applied vacuum. To perform this test the vacuum-side volume of the sampling system shall be known to within ±10 per cent of its true volume.

After an initial stabilization period the pressure increase Δp (kPa/min) in the system shall not exceed:

$$\Delta p = p / V_s \times 0.005 \times q_{vs} \qquad (74)$$

Where:

V_s is the system volume, l

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

9.3.4.3. Dilution-of-span-gas leak test

A gas analyzer shall be prepared as it would be for emission testing. Span gas shall be supplied to the analyzer port and it shall be verified that the span gas concentration is measured within its expected measurement accuracy and repeatability. Overflow span gas shall be routed to either the end of the sample probe, the open end of the transfer line with the sample probe disconnected, or a three-way valve installed in-line between a probe and its transfer line. ~~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~~.

It shall be verified that the measured overflow span gas concentration is within ±0.5 per cent of the span gas concentration. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the span gas or the analyzer itself. A measured value higher than expected does not indicate a leak.

Section 9.3.8., amend to read

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.).

It is recommended that a non-methane cutter is optimized by adjusting its temperature to achieve a $E_{CH4} < 0.15$ and a $E_{C2H6} > 0.98$ as determined by paragraph 9.3.8.1. and 9.9.8.2., as applicable. If adjusting NMC temperature does not result in achieving these specifications, it is recommended that the catalyst material is replaced.

Section 9.3.9.2.3., amend to read

9.3.9.2.3. Maximum allowable quench

The combined CO_2 and water quench shall not exceed 2 per cent ~~of full scale~~.

Section 9.3.9.4.2., amend to read

9.3.9.4.2. Sample dryer NO_2 penetration

Liquid water remaining in an improperly designed sample dryer can remove NO_2 from the sample. If a sample dryer is used ~~in combination with an NDUV analyzer~~ without an NO_2/NO converter upstream, it could therefore remove NO_2 from the sample prior to NO_x measurement.

The sample dryer shall allow for measuring at least 95 per cent of the total NO_2 at the maximum expected concentration of NO_2.

The following procedure shall be used to verify sample dryer performance:

NO_2 calibration gas that has an NO_2 concentration that is near the maximum expected during testing shall be overflowed at the gas sampling system's probe or overflow fitting. Time shall be allowed for stabilization of the total NOx response, accounting only for transport delays and instrument response. The mean of 30 s of recorded total NO_x data shall be calculated and this value recorded as x_{NOxref} and the NO_2 calibration gas be stopped

The sampling system shall be saturated by overflowing a dew point generator's output, set at a dew point of 50 °C, to the gas sampling system's probe or overflow fitting. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 minutes until the chiller is expected to be removing a constant rate of water.

The sampling system shall be immediately switched back to overflowing the NO_2 calibration gas used to establish x_{NOxref}. It shall be allowed for stabilization of the total NO_x response, accounting only for transport delays and instrument response. The mean of 30 s of recorded total NO_x data shall be calculated and this value recorded as $x_{NOxmeas}$.

$x_{NOxmeas}$ shall be corrected to x_{NOxdry} based upon the residual water vapour that passed through the chiller at the chiller's outlet temperature and pressure.

If x_{NOxdry} is less than 95 per cent of x_{NOxref}, the sample dryer shall be repaired or replaced .

Section 9.4.5.2., amend to read

9.4.5.2. Reference filter weighing

At least two unused reference filters shall be weighed within ~~12~~ 80 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 µg or ±10 per cent of the expected total PM mass, whichever is higher, 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.

Section 9.4.5.3., amend to read

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~~9. This implies a precision ~~(standard deviation)~~ of at least ~~2~~ 0.5 µg and a resolution of at least 1 µg (1 digit = 1 µg).

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

……….

Annex 1(b)., amend to read

(b) WHVC vehicle schedule

P = rated power of hybrid system as specified in Annex 9 or Annex 10, respectively

Road gradient from the previous time step shall be used where a placeholder (…) is set.

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*	*Time* *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
1	0	+5.02E-06*~~p~~P^2 -6.80E-03*~~p~~P +0.77	43	5~~,~~.96	…
2	0	…	44	2~~,~~.2	…
3	0	…	45	0	…
4	0	…	46	0	…
5	0	…	47	0	-1~~,~~.40E-06*~~p~~P^2 +2~~,~~.31E-03*~~p~~P -0~~,~~.81
6	0	…	48	0	+2~~,~~.22E-06*~~p~~P^2 -2~~,~~.19E-03*~~p~~P -0~~,~~.86
7	2~~,~~.35	…	49	0	+5~~,~~.84E-06*~~p~~P^2 -6~~,~~.68E-03*~~p~~P -0~~,~~.91
8	5~~,~~.57	…	50	1~~,~~.87	…
9	8~~,~~.18	…	51	4~~,~~.97	…
10	9~~,~~.37	…	52	8~~,~~.4	…
11	9~~,~~.86	…	53	9~~,~~.9	…
12	10~~,~~.18	…	54	11~~,~~.42	…
13	10~~,~~.38	…	55	15~~,~~.11	…
14	10~~,~~.57	…	56	18~~,~~.46	…
15	10~~,~~.95	…	57	20~~,~~.21	…
16	11~~,~~.56	…	58	22~~,~~.13	…
17	12~~,~~.22	…	59	24~~,~~.17	…
18	12~~,~~.97	…	60	25~~,~~.56	…
19	14~~,~~.33	…	61	26~~,~~.97	…
20	16~~,~~.38	…	62	28~~,~~.83	…
21	18~~,~~.4	…	63	31~~,~~.05	…
22	19~~,~~.86	…	64	33~~,~~.72	…
23	20~~,~~.85	…	65	36	…
24	21~~,~~.52	…	66	37~~,~~.91	…
25	21~~,~~.89	…	67	39~~,~~.65	…
26	21~~,~~.98	…	68	41~~,~~.23	…
27	21~~,~~.91	+1~~,~~.67E-06*~~p~~P^2 -2~~,~~.27E-03*~~p~~P +0~~,~~.26	69	42~~,~~.85	…
28	21~~,~~.68	-1~~,~~.67E-06*~~p~~P^2 +2~~,~~.27E-03*~~p~~P -0~~,~~.26	70	44~~,~~.1	…
29	21~~,~~.21	-5~~,~~.02E-06*~~p~~P^2 +6~~,~~.80E-03*~~p~~P -0~~,~~.77	71	44~~,~~.37	…
30	20~~,~~.44	…	72	44~~,~~.3	…
31	19~~,~~.24	…	73	44~~,~~.17	…
32	17~~,~~.57	…	74	44~~,~~.13	…
33	15~~,~~.53	…	75	44~~,~~.17	…
34	13~~,~~.77	…	76	44~~,~~.51	+3~~,~~.10E-06*~~p~~P^2 -3~~,~~.89E-03*~~p~~P -0~~,~~.76
35	12~~,~~.95	…	77	45~~,~~.16	+3~~,~~.54E-07*~~p~~P^2 -1~~,~~.10E-03*~~p~~P -0~~,~~.61
36	12~~,~~.95	…	78	45~~,~~.64	-2~~,~~.39E-06*~~p~~P^2 +1~~,~~.69E-03*~~p~~P -0~~,~~.47
37	13~~,~~.35	…	79	46~~,~~.16	…
38	13~~,~~.75	…	80	46~~,~~.99	…
39	13~~,~~.82	…	81	48~~,~~.19	…
40	13~~,~~.41	…	82	49~~,~~.32	…
41	12~~,~~.26	…	83	49~~,~~.7	…
42	9~~,~~.82	…	84	49~~,~~.5	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
85	48~~,~~.98	…
86	48~~,~~.65	…
87	48~~,~~.65	…
88	48~~,~~.87	…
89	48~~,~~.97	…
90	48~~,~~.96	…
91	49~~,~~.15	…
92	49~~,~~.51	…
93	49~~,~~.74	…
94	50~~,~~.31	…
95	50~~,~~.78	…
96	50~~,~~.75	…
97	50~~,~~.78	…
98	51~~,~~.21	…
99	51~~,~~.6	…
100	51~~,~~.89	…
101	52~~,~~.04	…
102	51~~,~~.99	…
103	51~~,~~.99	…
104	52~~,~~.36	…
105	52~~,~~.58	…
106	52~~,~~.47	…
107	52~~,~~.03	…
108	51~~,~~.46	…
109	51~~,~~.31	…
110	51~~,~~.45	…
111	51~~,~~.48	…
112	51~~,~~.29	…
113	51~~,~~.12	…
114	50~~,~~.96	…
115	50~~,~~.81	…
116	50~~,~~.86	…
117	51~~,~~.34	…
118	51~~,~~.68	…
119	51~~,~~.58	…
120	51~~,~~.36	…
121	51~~,~~.39	…
122	50~~,~~.98	-1~~,~~.91E-06*~~p~~P^{2} +1~~,~~.91E-03*~~p~~P -0~~,~~.06
123	48~~,~~.63	-1~~,~~.43E-06*~~p~~P^{2} +2~~,~~.13E-03*~~p~~P +0~~,~~.34
124	44~~,~~.83	-9~~,~~.50E-07*~~p~~P^{2} +2~~,~~.35E-03*~~p~~P +0~~,~~.74
125	40~~,~~.3	…
126	35~~,~~.65	…
127	30~~,~~.23	…
128	24~~,~~.08	…
129	18~~,~~.96	…
130	14~~,~~.19	…
131	8~~,~~.72	…
132	3~~,~~.41	…
133	0~~,~~.64	…
134	0	…
135	0	…
136	0	…
137	0	…
138	0	+2~~,~~.18E-06*~~p~~P^{2} -1~~,~~.58E-03*~~p~~P +1~~,~~.27
139	0	+5~~,~~.31E-06*~~p~~P^{2} -5~~,~~.52E-03*~~p~~P +1~~,~~.80
140	0	+8~~,~~.44E-06*~~p~~P^{2} -9~~,~~.46E-03*~~p~~P +2~~,~~.33
141	0	…
142	0~~,~~.63	…
143	1~~,~~.56	…
144	2~~,~~.99	…
145	4~~,~~.5	…
146	5~~,~~.39	…
147	5~~,~~.59	…
148	5~~,~~.45	…
149	5~~,~~.2	…
150	4~~,~~.98	…
151	4~~,~~.61	…
152	3~~,~~.89	…
153	3~~,~~.21	…
154	2~~,~~.98	…
155	3~~,~~.31	…
156	4~~,~~.18	…
157	5~~,~~.07	…
158	5~~,~~.52	…
159	5~~,~~.73	…
160	6~~,~~.06	…
161	6~~,~~.76	…
162	7~~,~~.7	…
163	8~~,~~.34	…
164	8~~,~~.51	…
165	8~~,~~.22	…
166	7~~,~~.22	…
167	5~~,~~.82	…
168	4~~,~~.75	…
169	4~~,~~.24	…
170	4~~,~~.05	…
171	3~~,~~.98	…
172	3~~,~~.91	…
173	3~~,~~.86	…
174	4~~,~~.17	…
175	5~~,~~.32	…
176	7~~,~~.53	…
177	10~~,~~.89	…
178	14~~,~~.81	…

Time s	Vehicle speed km/h	Road gradient per cent	Time s	Vehicle speed km/h	Road gradient per cent
179	17~~,~~.56	…	226	0~~,~~.73	…
180	18~~,~~.38	+2~~,~~.81E-06*~~p~~P^2 -3~~,~~.15E-03*~~p~~P +0~~,~~.78	227	0~~,~~.73	…
181	17~~,~~.49	-2~~,~~.81E-06*~~p~~P^2 +3~~,~~.15E-03*~~p~~P -0~~,~~.78	228	0	…
182	15~~,~~.18	-8~~,~~.44E-06*~~p~~P^2 +9~~,~~.46E-03*~~p~~P -2~~,~~.33	229	0	…
183	13~~,~~.08	…	230	0	…
184	12~~,~~.23	…	231	0	…
185	12~~,~~.03	…	232	0	…
186	11~~,~~.72	…	233	0	…
187	10~~,~~.69	…	234	0	…
188	8~~,~~.68	…	235	0	…
189	6~~,~~.2	…	236	0	…
190	4~~,~~.07	…	237	0	…
191	2~~,~~.65	…	238	0	…
192	1~~,~~.92	…	239	0	…
193	1~~,~~.69	…	240	0	…
194	1~~,~~.68	…	241	0	…
195	1~~,~~.66	…	242	0	+6~~,~~.51E-06*~~p~~P^2 -6~~,~~.76E-03*~~p~~P +1~~,~~.50
196	1~~,~~.53	…	243	0	+1~~,~~.30E-05*~~p~~P^2 -1~~,~~.35E-02*~~p~~P +3~~,~~.00
197	1~~,~~.3	…	244	0	+1~~,~~.95E-05*~~p~~P^2 -2~~,~~.03E-02*~~p~~P +4~~,~~.49
198	1	…	245	0	…
199	0~~,~~.77	…	246	0	…
200	0~~,~~.63	…	247	0	…
201	0~~,~~.59	…	248	0	…
202	0~~,~~.59	…	249	0	…
203	0~~,~~.57	…	250	0	…
204	0~~,~~.53	…	251	0	…
205	0~~,~~.5	…	252	0	…
206	0	…	253	1~~,~~.51	…
207	0	…	254	4~~,~~.12	…
208	0	…	255	7~~,~~.02	…
209	0	…	256	9~~,~~.45	…
210	0	…	257	11~~,~~.86	…
211	0	…	258	14~~,~~.52	…
212	0	…	259	17~~,~~.01	…
213	0	…	260	19~~,~~.48	…
214	0	…	261	22~~,~~.38	…
215	0	…	262	24~~,~~.75	…
216	0	…	263	25~~,~~.55	+6~~,~~.51E-06*~~p~~P^2 -6~~,~~.76E-03*~~p~~P +1~~,~~.50
217	0	-5~~,~~.63E-06*~~p~~P^2 +6~~,~~.31E-03*~~p~~P -1~~,~~.56	264	25~~,~~.18	-6~~,~~.51E-06*~~p~~P^2 +6~~,~~.76E-03*~~p~~P -1~~,~~.50
218	0	-2~~,~~.81E-06*~~p~~P^2 +3~~,~~.15E-03*~~p~~P -0~~,~~.78	265	23~~,~~.94	-1~~,~~.95E-05*~~p~~P^2 +2~~,~~.03E-02*~~p~~P -4~~,~~.49
219	0	+0~~,~~.00E+00*~~p~~P^2 +0~~,~~.00E+00*~~p~~P +0~~,~~.00	266	22~~,~~.35	…
220	0	…	267	21~~,~~.28	…
221	0	…	268	20~~,~~.86	…
222	0	…	269	20~~,~~.65	…
223	0	…	270	20~~,~~.18	…
224	0	…	271	19~~,~~.33	…
225	0	…	272	18~~,~~.23	…
			273	16~~,~~.99	…

Time s	*Vehicle speed km/h*	*Road gradient per cent*
274	15~~,~~.56	…
275	13~~,~~.76	…
276	11~~,~~.5	…
277	8~~,~~.68	…
278	5~~,~~.2	…
279	1~~,~~.99	…
280	0	…
281	0	-1~~,~~.30E-05*~~p~~P² +1~~,~~.35E-02*~~p~~P -3~~,~~.00
282	0	-6~~,~~.51E-06*~~p~~P² +6~~,~~.76E-03*~~p~~P -1~~,~~.50
283	0~~,~~.5	+0~~,~~.00E+00*~~p~~P² +0~~,~~.00E+00*~~p~~P +0~~,~~.00
284	0~~,~~.57	…
285	0~~,~~.6	…
286	0~~,~~.58	…
287	0	…
288	0	…
289	0	…
290	0	…
291	0	…
292	0	…
293	0	…
294	0	…
295	0	…
296	0	…
297	0	…
298	0	…
299	0	…
300	0	…
301	0	…
302	0	…
303	0	…
304	0	…
305	0	+5~~,~~.21E-06*~~p~~P² -5~~,~~.86E-03*~~p~~P -0~~,~~.21
306	0	+1~~,~~.04E-05*~~p~~P² -1~~,~~.17E-02*~~p~~P -0~~,~~.42
307	0	+1~~,~~.56E-05*~~p~~P² -1~~,~~.76E-02*~~p~~P -0~~,~~.62
308	0	…
309	0	…
310	0	…
311	0	…
312	0	…
313	0	…
314	0	…
315	0	…
316	0	…
317	0	…
318	0	…
319	0	…
320	0	…

Time s	*Vehicle speed km/h*	*Road gradient per cent*
321	0	…
322	0	…
323	0	…
324	3~~,~~.01	…
325	8~~,~~.14	…
326	13~~,~~.88	…
327	18~~,~~.08	…
328	20~~,~~.01	…
329	20~~,~~.3	+5~~,~~.21E-06*~~p~~P² -5~~,~~.86E-03*~~p~~P -0~~,~~.21
330	19~~,~~.53	-5~~,~~.21E-06*~~p~~P² +5~~,~~.86E-03*~~p~~P +0~~,~~.21
331	17~~,~~.92	-1~~,~~.56E-05*~~p~~P² +1~~,~~.76E-02*~~p~~P +0~~,~~.62
332	16~~,~~.17	…
333	14~~,~~.55	…
334	12~~,~~.92	…
335	11~~,~~.07	…
336	8~~,~~.54	…
337	5~~,~~.15	…
338	1~~,~~.96	…
339	0	…
340	0	…
341	0	…
342	0	…
343	0	…
344	0	…
345	0	…
346	0	-6~~,~~.53E-06*~~p~~P² +7~~,~~.62E-03*~~p~~P +1~~,~~.11
347	0	+2~~,~~.58E-06*~~p~~P² -2~~,~~.34E-03*~~p~~P +1~~,~~.60
348	0	+1~~,~~.17E-05*~~p~~P² -1~~,~~.23E-02*~~p~~P +2~~,~~.08
349	0	…
350	0	…
351	0	…
352	0	…
353	0	…
354	0~~,~~.9	…
355	2	…
356	4~~,~~.08	…
357	7~~,~~.07	…
358	10~~,~~.25	…
359	12~~,~~.77	…
360	14~~,~~.44	…
361	15~~,~~.73	…
362	17~~,~~.23	…
363	19~~,~~.04	…
364	20~~,~~.96	…
365	22~~,~~.94	…
366	25~~,~~.05	…
367	27~~,~~.31	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
368	29~~,~~.54	…
369	31~~,~~.52	…
370	33~~,~~.19	…
371	34~~,~~.67	…
372	36~~,~~.13	…
373	37~~,~~.63	…
374	39~~,~~.07	…
375	40~~,~~.08	…
376	40~~,~~.44	…
377	40~~,~~.26	+6~~,~~.91E-06*~~p~~P^2 -7~~,~~.10E-03*~~p~~P +0~~,~~.94
378	39~~,~~.29	+2~~,~~.13E-06*~~p~~P^2 -1~~,~~.91E-03*~~p~~P -0~~,~~.20
379	37~~,~~.23	-2~~,~~.65E-06*~~p~~P^2 +3~~,~~.28E-03*~~p~~P -1~~,~~.33
380	34~~,~~.14	…
381	30~~,~~.18	…
382	25~~,~~.71	…
383	21~~,~~.58	…
384	18~~,~~.5	…
385	16~~,~~.56	…
386	15~~,~~.39	…
387	14~~,~~.77	+2~~,~~.55E-06*~~p~~P^2 -2~~,~~.25E-03*~~p~~P +0~~,~~.26
388	14~~,~~.58	+7~~,~~.75E-06*~~p~~P^2 -7~~,~~.79E-03*~~p~~P +1~~,~~.86
389	14~~,~~.72	+1~~,~~.30E-05*~~p~~P^2 -1~~,~~.33E-02*~~p~~P +3~~,~~.46
390	15~~,~~.44	…
391	16~~,~~.92	…
392	18~~,~~.69	…
393	20~~,~~.26	…
394	21~~,~~.63	…
395	22~~,~~.91	…
396	24~~,~~.13	…
397	25~~,~~.18	…
398	26~~,~~.16	…
399	27~~,~~.41	…
400	29~~,~~.18	…
401	31~~,~~.36	…
402	33~~,~~.51	…
403	35~~,~~.33	…
404	36~~,~~.94	…
405	38~~,~~.6	…
406	40~~,~~.44	…
407	42~~,~~.29	…
408	43~~,~~.73	…
409	44~~,~~.47	…
410	44~~,~~.62	…
411	44~~,~~.41	+8~~,~~.17E-06*~~p~~P^2 -8~~,~~.13E-03*~~p~~P +2~~,~~.32
412	43~~,~~.96	+3~~,~~.39E-06*~~p~~P^2 -2~~,~~.94E-03*~~p~~P +1~~,~~.18
413	43~~,~~.41	-1~~,~~.39E-06*~~p~~P^2 +2~~,~~.25E-03*~~p~~P +0~~,~~.04
414	42~~,~~.83	…
415	42~~,~~.15	…
416	41~~,~~.28	…
417	40~~,~~.17	…
418	38~~,~~.9	…
419	37~~,~~.59	…
420	36~~,~~.39	…
421	35~~,~~.33	…
422	34~~,~~.3	…
423	33~~,~~.07	…
424	31~~,~~.41	…
425	29~~,~~.18	…
426	26~~,~~.41	…
427	23~~,~~.4	…
428	20~~,~~.9	…
429	19~~,~~.59	+8~~,~~.47E-07*~~p~~P^2 -6~~,~~.08E-04*~~p~~P +0~~,~~.36
430	19~~,~~.36	+3~~,~~.09E-06*~~p~~P^2 -3~~,~~.47E-03*~~p~~P +0~~,~~.69
431	19~~,~~.79	+5~~,~~.33E-06*~~p~~P^2 -6~~,~~.33E-03*~~p~~P +1~~,~~.01
432	20~~,~~.43	…
433	20~~,~~.71	…
434	20~~,~~.56	…
435	19~~,~~.96	…
436	20~~,~~.22	…
437	21~~,~~.48	…
438	23~~,~~.67	…
439	26~~,~~.09	…
440	28~~,~~.16	…
441	29~~,~~.75	…
442	30~~,~~.97	…
443	31~~,~~.99	…
444	32~~,~~.84	…
445	33~~,~~.33	…
446	33~~,~~.45	…
447	33~~,~~.27	+5~~,~~.50E-07*~~p~~P^2 -1~~,~~.13E-03*~~p~~P -0~~,~~.13
448	32~~,~~.66	-4~~,~~.23E-06*~~p~~P^2 +4~~,~~.06E-03*~~p~~P -1~~,~~.26
449	31~~,~~.73	-9~~,~~.01E-06*~~p~~P^2 +9~~,~~.25E-03*~~p~~P -2~~,~~.40
450	30~~,~~.58	…
451	29~~,~~.2	…
452	27~~,~~.56	…
453	25~~,~~.71	…
454	23~~,~~.76	…
455	21~~,~~.87	…
456	20~~,~~.15	…
457	18~~,~~.38	…
458	15~~,~~.93	…
459	12~~,~~.33	…
460	7~~,~~.99	…
461	4~~,~~.19	…
462	1~~,~~.77	…
463	0~~,~~.69	-1~~,~~.66E-06*~~p~~P^2 +1~~,~~.67E-03*~~p~~P -0~~,~~.86

Time *s*	*Vehicle speed km/h*	*Road gradient per cent*
464	1~~,~~.13	+5~~,~~.69E-06*~~p~~P^2 -5~~,~~.91E-03*~~p~~P +0~~,~~.68
465	2~~,~~.2	+1~~,~~.30E-05*~~p~~P^2 -1~~,~~.35E-02*~~p~~P +2~~,~~.23
466	3~~,~~.59	…
467	4~~,~~.88	…
468	5~~,~~.85	…
469	6~~,~~.72	…
470	8~~,~~.02	…
471	10~~,~~.02	…
472	12~~,~~.59	…
473	15~~,~~.43	…
474	18~~,~~.32	…
475	21~~,~~.19	…
476	24	…
477	26~~,~~.75	…
478	29~~,~~.53	…
479	32~~,~~.31	…
480	34~~,~~.8	…
481	36~~,~~.73	…
482	38~~,~~.08	…
483	39~~,~~.11	…
484	40~~,~~.16	…
485	41~~,~~.18	…
486	41~~,~~.75	…
487	41~~,~~.87	+8~~,~~.26E-06*~~p~~P^2 -8~~,~~.29E-03*~~p~~P +1~~,~~.09
488	41~~,~~.43	+3~~,~~.47E-06*~~p~~P^2 -3~~,~~.10E-03*~~p~~P -0~~,~~.05
489	39~~,~~.99	-1~~,~~.31E-06*~~p~~P^2 +2~~,~~.09E-03*~~p~~P -1~~,~~.19
490	37~~,~~.71	…
491	34~~,~~.93	…
492	31~~,~~.79	…
493	28~~,~~.65	…
494	25~~,~~.92	…
495	23~~,~~.91	…
496	22~~,~~.81	+6~~,~~.20E-07*~~p~~P^2 -2~~,~~.47E-04*~~p~~P -0~~,~~.38
497	22~~,~~.53	+2~~,~~.55E-06*~~p~~P^2 -2~~,~~.58E-03*~~p~~P +0~~,~~.43
498	22~~,~~.62	+4~~,~~.48E-06*~~p~~P^2 -4~~,~~.92E-03*~~p~~P +1~~,~~.23
499	22~~,~~.95	…
500	23~~,~~.51	…
501	24~~,~~.04	…
502	24~~,~~.45	…
503	24~~,~~.81	…
504	25~~,~~.29	…
505	25~~,~~.99	…
506	26~~,~~.83	…
507	27~~,~~.6	…
508	28~~,~~.17	…
509	28~~,~~.63	…
510	29~~,~~.04	…
511	29~~,~~.43	…
512	29~~,~~.78	…
513	30~~,~~.13	…
514	30~~,~~.57	…
515	31~~,~~.1	…
516	31~~,~~.65	…
517	32~~,~~.14	…
518	32~~,~~.62	…
519	33~~,~~.25	…
520	34~~,~~.2	…
521	35~~,~~.46	…
522	36~~,~~.81	…
523	37~~,~~.98	…
524	38~~,~~.84	…
525	39~~,~~.43	…
526	39~~,~~.73	…
527	39~~,~~.8	…
528	39~~,~~.69	-3~~,~~.04E-07*~~p~~P^2 +2~~,~~.73E-04*~~p~~P +0~~,~~.09
529	39~~,~~.29	-5~~,~~.09E-06*~~p~~P^2 +5~~,~~.46E-03*~~p~~P -1~~,~~.04
530	38~~,~~.59	-9~~,~~.87E-06*~~p~~P^2 +1~~,~~.07E-02*~~p~~P -2~~,~~.18
531	37~~,~~.63	…
532	36~~,~~.22	…
533	34~~,~~.11	…
534	31~~,~~.16	…
535	27~~,~~.49	…
536	23~~,~~.63	…
537	20~~,~~.16	…
538	17~~,~~.27	…
539	14~~,~~.81	…
540	12~~,~~.59	…
541	10~~,~~.47	…
542	8~~,~~.85	-5~~,~~.09E-06*~~p~~P^2 +5~~,~~.46E-03*~~p~~P -1~~,~~.04
543	8~~,~~.16	-1~~,~~.63E-07*~~p~~P^2 +4~~,~~.68E-05*~~p~~P +0~~,~~.17
544	8~~,~~.95	+4~~,~~.76E-06*~~p~~P^2 -5~~,~~.37E-03*~~p~~P +1~~,~~.39
545	11~~,~~.3	+4~~,~~.90E-06*~~p~~P^2 -5~~,~~.60E-03*~~p~~P +1~~,~~.47
546	14~~,~~.11	…
547	15~~,~~.91	…
548	16~~,~~.57	…
549	16~~,~~.73	…
550	17~~,~~.24	…
551	18~~,~~.45	…
552	20~~,~~.09	…
553	21~~,~~.63	…
554	22~~,~~.78	…
555	23~~,~~.59	…
556	24~~,~~.23	…
557	24~~,~~.9	…

Time *s*	*Vehicle speed km/h*	*Road gradient per cent*
558	25~~,~~.72	…
559	26~~,~~.77	…
560	28~~,~~.01	…
561	29~~,~~.23	…
562	30~~,~~.06	…
563	30~~,~~.31	…
564	30~~,~~.29	+1~~,~~.21E-07*~~p~~P^2 -4~~,~~.06E-04*~~p~~P +0~~,~~.33
565	30~~,~~.05	-4~~,~~.66E-06*~~p~~P^2 +4~~,~~.79E-03*~~p~~P -0~~,~~.81
566	29~~,~~.44	-9~~,~~.44E-06*~~p~~P^2 +9~~,~~.98E-03*~~p~~P -1~~,~~.95
567	28~~,~~.6	…
568	27~~,~~.63	…
569	26~~,~~.66	…
570	26~~,~~.03	-4~~,~~.66E-06*~~p~~P^2 +4~~,~~.79E-03*~~p~~P -0~~,~~.81
571	25~~,~~.85	+1~~,~~.21E-07*~~p~~P^2 -4~~,~~.06E-04*~~p~~P +0~~,~~.33
572	26~~,~~.14	+4~~,~~.90E-06*~~p~~P^2 -5~~,~~.60E-03*~~p~~P +1~~,~~.47
573	27~~,~~.08	…
574	28~~,~~.42	…
575	29~~,~~.61	…
576	30~~,~~.46	…
577	30~~,~~.99	…
578	31~~,~~.33	…
579	31~~,~~.65	…
580	32~~,~~.02	…
581	32~~,~~.39	…
582	32~~,~~.68	…
583	32~~,~~.84	…
584	32~~,~~.93	…
585	33~~,~~.22	…
586	33~~,~~.89	…
587	34~~,~~.96	…
588	36~~,~~.28	…
589	37~~,~~.58	…
590	38~~,~~.58	…
591	39~~,~~.1	…
592	39~~,~~.22	…
593	39~~,~~.11	…
594	38~~,~~.8	…
595	38~~,~~.31	…
596	37~~,~~.73	…
597	37~~,~~.24	…
598	37~~,~~.06	…
599	37~~,~~.1	…
600	37~~,~~.42	…
601	38~~,~~.17	…
602	39~~,~~.19	…
603	40~~,~~.31	…
604	41~~,~~.46	…
605	42~~,~~.44	…
606	42~~,~~.95	…
607	42~~,~~.9	…
608	42~~,~~.43	…
609	41~~,~~.74	…
610	41~~,~~.04	…
611	40~~,~~.49	…
612	40~~,~~.8	…
613	41~~,~~.66	…
614	42~~,~~.48	…
615	42~~,~~.78	+1~~,~~.21E-07*~~p~~P^2 -4~~,~~.06E-04*~~p~~P +0~~,~~.33
616	42~~,~~.39	-4~~,~~.66E-06*~~p~~P^2 +4~~,~~.79E-03*~~p~~P -0~~,~~.81
617	40~~,~~.78	-9~~,~~.44E-06*~~p~~P^2 +9~~,~~.98E-03*~~p~~P -1~~,~~.95
618	37~~,~~.72	…
619	33~~,~~.29	…
620	27~~,~~.66	…
621	21~~,~~.43	…
622	15~~,~~.62	…
623	11~~,~~.51	…
624	9~~,~~.69	-4~~,~~.66E-06*~~p~~P^2 +4~~,~~.79E-03*~~p~~P -0~~,~~.81
625	9~~,~~.46	+1~~,~~.21E-07*~~p~~P^2 -4~~,~~.06E-04*~~p~~P +0~~,~~.33
626	10~~,~~.21	+4~~,~~.90E-06*~~p~~P^2 -5~~,~~.60E-03*~~p~~P +1~~,~~.47
627	11~~,~~.78	…
628	13~~,~~.6	…
629	15~~,~~.33	…
630	17~~,~~.12	…
631	18~~,~~.98	…
632	20~~,~~.73	…
633	22~~,~~.17	…
634	23~~,~~.29	…
635	24~~,~~.19	…
636	24~~,~~.97	…
637	25~~,~~.6	…
638	25~~,~~.96	…
639	25~~,~~.86	+1~~,~~.21E-07*~~p~~P^2 -4~~,~~.06E-04*~~p~~P +0~~,~~.33
640	24~~,~~.69	-4~~,~~.66E-06*~~p~~P^2 +4~~,~~.79E-03*~~p~~P -0~~,~~.81
641	21~~,~~.85	-9~~,~~.44E-06*~~p~~P^2 +9~~,~~.98E-03*~~p~~P -1~~,~~.95
642	17~~,~~.45	…
643	12~~,~~.34	…
644	7~~,~~.59	…
645	4	…
646	1~~,~~.76	…
647	0	…
648	0	…
649	0	…
650	0	…
651	0	…
652	0	-3~~,~~.90E-06*~~p~~P^2 +4~~,~~.11E-03*~~p~~P -1~~,~~.07
653	0	+1~~,~~.64E-06*~~p~~P^2 -1~~,~~.77E-03*~~p~~P -0~~,~~.19

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*	*Time* *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
654	0	+7~~,~~.18E-06*~~p~~P^2 -7~~,~~.64E-03*~~p~~P +0~~,~~.70	701	30~~,~~.65	…
655	0	…	702	26~~,~~.46	…
656	0	…	703	22~~,~~.32	…
657	0	…	704	18~~,~~.15	…
658	2~~,~~.96	…	705	13~~,~~.79	…
659	7~~,~~.9	…	706	9~~,~~.29	…
660	13~~,~~.49	…	707	4~~,~~.98	…
661	18~~,~~.36	…	708	1~~,~~.71	…
662	22~~,~~.59	…	709	0	…
663	26~~,~~.26	…	710	0	…
664	29~~,~~.4	…	711	0	…
665	32~~,~~.23	…	712	0	…
666	34~~,~~.91	…	713	0	…
667	37~~,~~.39	…	714	0	…
668	39~~,~~.61	…	715	0	…
669	41~~,~~.61	…	716	0	…
670	43~~,~~.51	…	717	0	…
671	45~~,~~.36	…	718	0	…
672	47~~,~~.17	…	719	0	…
673	48~~,~~.95	…	720	0	…
674	50~~,~~.73	…	721	0	…
675	52~~,~~.36	…	722	0	…
676	53~~,~~.74	…	723	0	…
677	55~~,~~.02	…	724	0	…
678	56~~,~~.24	…	725	0	…
679	57~~,~~.29	…	726	0	…
680	58~~,~~.18	…	727	0	…
681	58~~,~~.95	…	728	0	…
682	59~~,~~.49	…	729	0	…
683	59~~,~~.86	…	730	0	…
684	60~~,~~.3	…	731	0	…
685	61~~,~~.01	…	732	0	…
686	61~~,~~.96	…	733	0	…
687	63~~,~~.05	…	734	0	…
688	64~~,~~.16	…	735	0	…
689	65~~,~~.14	…	736	0	…
690	65~~,~~.85	…	737	0	…
691	66~~,~~.22	…	738	0	…
692	66~~,~~.12	+2~~,~~.39E-06*~~p~~P^2 -2~~,~~.55E-03*~~p~~P +0~~,~~.23	739	0	-2~~,~~.53E-06*~~p~~P^2 +2~~,~~.43E-03*~~p~~P +0~~,~~.05
693	65~~,~~.01	-2~~,~~.39E-06*~~p~~P^2 +2~~,~~.55E-03*~~p~~P -0~~,~~.23	740	0	+2~~,~~.12E-06*~~p~~P^2 -2~~,~~.78E-03*~~p~~P +0~~,~~.81
694	62~~,~~.22	-7~~,~~.18E-06*~~p~~P^2 +7~~,~~.64E-03*~~p~~P -0~~,~~.70	741	0	+6~~,~~.77E-06*~~p~~P^2 -7~~,~~.99E-03*~~p~~P +1~~,~~.56
695	57~~,~~.44	…	742	0	…
696	51~~,~~.47	…	743	0	…
697	45~~,~~.98	…	744	0	…
698	41~~,~~.72	…	745	0	…
699	38~~,~~.22	…	746	0	…
700	34~~,~~.65	…	747	0	…

Time s	*Vehicle speed km/h*	*Road gradient per cent*
748	0	…
749	0	…
750	0	…
751	0	…
752	0	…
753	0	…
754	0	…
755	0	…
756	0	…
757	0	…
758	0	…
759	0	…
760	0	…
761	0	…
762	0	…
763	0	…
764	0	…
765	0	…
766	0	…
767	0	…
768	0	…
769	0	…
770	0	…
771	0	…
772	1~~,~~.6	…
773	5~~,~~.03	…
774	9~~,~~.49	…
775	13	…
776	14~~,~~.65	…
777	15~~,~~.15	…
778	15~~,~~.67	…
779	16~~,~~.76	…
780	17~~,~~.88	…
781	18~~,~~.33	…
782	18~~,~~.31	+2~~,~~.26E-06*~~p~~P^2 -2~~,~~.66E-03*~~p~~P +0~~,~~.52
783	18~~,~~.05	-2~~,~~.26E-06*~~p~~P^2 +2~~,~~.66E-03*~~p~~P -0~~,~~.52
784	17~~,~~.39	-6~~,~~.77E-06*~~p~~P^2 +7~~,~~.99E-03*~~p~~P -1~~,~~.56
785	16~~,~~.35	…
786	14~~,~~.71	…
787	11~~,~~.71	…
788	7~~,~~.81	…
789	5~~,~~.25	-2~~,~~.26E-06*~~p~~P^2 +2~~,~~.66E-03*~~p~~P -0~~,~~.52
790	4~~,~~.62	+2~~,~~.26E-06*~~p~~P^2 -2~~,~~.66E-03*~~p~~P +0~~,~~.52
791	5~~,~~.62	+6~~,~~.77E-06*~~p~~P^2 -7~~,~~.99E-03*~~p~~P +1~~,~~.56
792	8~~,~~.24	…
793	10~~,~~.98	…
794	13~~,~~.15	…
795	15~~,~~.47	…
796	18~~,~~.19	…
797	20~~,~~.79	…
798	22~~,~~.5	…
799	23~~,~~.19	…
800	23~~,~~.54	…
801	24~~,~~.2	…
802	25~~,~~.17	…
803	26~~,~~.28	…
804	27~~,~~.69	…
805	29~~,~~.72	…
806	32~~,~~.17	…
807	34~~,~~.22	…
808	35~~,~~.31	…
809	35~~,~~.74	…
810	36~~,~~.23	…
811	37~~,~~.34	…
812	39~~,~~.05	…
813	40~~,~~.76	…
814	41~~,~~.82	…
815	42~~,~~.12	…
816	42~~,~~.08	…
817	42~~,~~.27	…
818	43~~,~~.03	…
819	44~~,~~.14	…
820	45~~,~~.13	…
821	45~~,~~.84	…
822	46~~,~~.4	…
823	46~~,~~.89	…
824	47~~,~~.34	…
825	47~~,~~.66	…
826	47~~,~~.77	…
827	47~~,~~.78	…
828	47~~,~~.64	+2~~,~~.26E-06*~~p~~P^2 -2~~,~~.66E-03*~~p~~P +0~~,~~.52
829	47~~,~~.23	-2~~,~~.26E-06*~~p~~P^2 +2~~,~~.66E-03*~~p~~P -0~~,~~.52
830	46~~,~~.66	-6~~,~~.77E-06*~~p~~P^2 +7~~,~~.99E-03*~~p~~P -1~~,~~.56
831	46~~,~~.08	…
832	45~~,~~.45	…
833	44~~,~~.69	…
834	43~~,~~.73	…
835	42~~,~~.55	…
836	41~~,~~.14	…
837	39~~,~~.56	…
838	37~~,~~.93	…
839	36~~,~~.69	…
840	36~~,~~.27	…
841	36~~,~~.42	…
842	37~~,~~.14	…
843	38~~,~~.13	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
844	38~~,~~.55	…
845	38~~,~~.42	…
846	37~~,~~.89	…
847	36~~,~~.89	…
848	35~~,~~.53	…
849	34~~,~~.01	…
850	32~~,~~.88	-2~~,~~.26E-06*~~p~~P^2 +2~~,~~.66E-03*~~p~~P -0~~,~~.52
851	32~~,~~.52	+2~~,~~.26E-06*~~p~~P^2 -2~~,~~.66E-03*~~p~~P +0~~,~~.52
852	32~~,~~.7	+6~~,~~.77E-06*~~p~~P^2 -7~~,~~.99E-03*~~p~~P +1~~,~~.56
853	33~~,~~.48	…
854	34~~,~~.97	…
855	36~~,~~.78	…
856	38~~,~~.64	…
857	40~~,~~.48	…
858	42~~,~~.34	…
859	44~~,~~.16	…
860	45~~,~~.9	…
861	47~~,~~.55	…
862	49~~,~~.09	…
863	50~~,~~.42	…
864	51~~,~~.49	…
865	52~~,~~.23	…
866	52~~,~~.58	…
867	52~~,~~.63	…
868	52~~,~~.49	+2~~,~~.26E-06*~~p~~P^2 -2~~,~~.66E-03*~~p~~P +0~~,~~.52
869	52~~,~~.19	-2~~,~~.26E-06*~~p~~P^2 +2~~,~~.66E-03*~~p~~P -0~~,~~.52
870	51~~,~~.82	-6~~,~~.77E-06*~~p~~P^2 +7~~,~~.99E-03*~~p~~P -1~~,~~.56
871	51~~,~~.43	…
872	51~~,~~.02	…
873	50~~,~~.61	…
874	50~~,~~.26	…
875	50~~,~~.06	…
876	49~~,~~.97	…
877	49~~,~~.67	…
878	48~~,~~.86	…
879	47~~,~~.53	…
880	45~~,~~.82	…
881	43~~,~~.66	…
882	40~~,~~.91	…
883	37~~,~~.78	…
884	34~~,~~.89	…
885	32~~,~~.69	…
886	30~~,~~.99	…
887	29~~,~~.31	…
888	27~~,~~.29	…
889	24~~,~~.79	…
890	21~~,~~.78	…
891	18~~,~~.51	…
892	15~~,~~.1	…
893	11~~,~~.06	…
894	6~~,~~.28	…
895	2~~,~~.24	…
896	0	…
897	0	…
898	0	…
899	0	-3~~,~~.61E-06*~~p~~P^2 +4~~,~~.12E-03*~~p~~P -0~~,~~.93
900	0	-4~~,~~.47E-07*~~p~~P^2 +2~~,~~.44E-04*~~p~~P -0~~,~~.31
901	0	+2~~,~~.71E-06*~~p~~P^2 -3~~,~~.63E-03*~~p~~P +0~~,~~.32
902	2~~,~~.56	…
903	4~~,~~.81	…
904	6~~,~~.38	…
905	8~~,~~.62	…
906	10~~,~~.37	…
907	11~~,~~.17	…
908	13~~,~~.32	…
909	15~~,~~.94	…
910	16~~,~~.89	…
911	17~~,~~.13	…
912	18~~,~~.04	…
913	19~~,~~.96	…
914	22~~,~~.05	…
915	23~~,~~.65	…
916	25~~,~~.72	…
917	28~~,~~.62	…
918	31~~,~~.99	…
919	35~~,~~.07	…
920	37~~,~~.42	…
921	39~~,~~.65	…
922	41~~,~~.78	…
923	43~~,~~.04	…
924	43~~,~~.55	…
925	42~~,~~.97	…
926	41~~,~~.08	…
927	40~~,~~.38	…
928	40~~,~~.43	…
929	40~~,~~.4	…
930	40~~,~~.25	…
931	40~~,~~.32	…
932	40~~,~~.8	…
933	41~~,~~.71	…
934	43~~,~~.16	…
935	44~~,~~.84	…
936	46~~,~~.42	…
937	47~~,~~.91	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
938	49~~,~~.08	…
939	49~~,~~.66	…
940	50~~,~~.15	…
941	50~~,~~.94	…
942	51~~,~~.69	…
943	53~~,~~.5	…
944	55~~,~~.9	…
945	57~~,~~.11	…
946	57~~,~~.88	…
947	58~~,~~.63	…
948	58~~,~~.75	…
949	58~~,~~.26	…
950	58~~,~~.03	…
951	58~~,~~.28	…
952	58~~,~~.67	…
953	58~~,~~.76	…
954	58~~,~~.82	…
955	59~~,~~.09	…
956	59~~,~~.38	…
957	59~~,~~.72	…
958	60~~,~~.04	…
959	60~~,~~.13	+2~~,~~.08E-06*~~p~~P^2 -2~~,~~.00E-03*~~p~~P +0~~,~~.46
960	59~~,~~.33	+1~~,~~.44E-06*~~p~~P^2 -3~~,~~.72E-04*~~p~~P +0~~,~~.61
961	58~~,~~.52	+8~~,~~.03E-07*~~p~~P^2 +1~~,~~.26E-03*~~p~~P +0~~,~~.75
962	57~~,~~.82	…
963	56~~,~~.68	…
964	55~~,~~.36	…
965	54~~,~~.63	…
966	54~~,~~.04	…
967	53~~,~~.15	…
968	52~~,~~.02	+1~~,~~.44E-06*~~p~~P^2 -3~~,~~.72E-04*~~p~~P +0~~,~~.61
969	51~~,~~.37	+2~~,~~.08E-06*~~p~~P^2 -2~~,~~.00E-03*~~p~~P +0~~,~~.46
970	51~~,~~.41	+2~~,~~.71E-06*~~p~~P^2 -3~~,~~.63E-03*~~p~~P +0~~,~~.32
971	52~~,~~.2	…
972	53~~,~~.52	…
973	54~~,~~.34	…
974	54~~,~~.59	…
975	54~~,~~.92	…
976	55~~,~~.69	…
977	56~~,~~.51	…
978	56~~,~~.73	+2~~,~~.08E-06*~~p~~P^2 -2~~,~~.00E-03*~~p~~P +0~~,~~.46
979	56~~,~~.33	+1~~,~~.44E-06*~~p~~P^2 -3~~,~~.72E-04*~~p~~P +0~~,~~.61
980	55~~,~~.38	+8~~,~~.03E-07*~~p~~P^2 +1~~,~~.26E-03*~~p~~P +0~~,~~.75
981	54~~,~~.99	…
982	54~~,~~.75	…
983	54~~,~~.11	…
984	53~~,~~.32	…
985	52~~,~~.41	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
986	51~~,~~.45	…
987	50~~,~~.86	…
988	50~~,~~.48	…
989	49~~,~~.6	…
990	48~~,~~.55	…
991	47~~,~~.87	…
992	47~~,~~.42	…
993	46~~,~~.86	…
994	46~~,~~.08	…
995	45~~,~~.07	…
996	43~~,~~.58	…
997	41~~,~~.04	…
998	38~~,~~.39	…
999	35~~,~~.69	…
1000	32~~,~~.68	…
1001	29~~,~~.82	…
1002	26~~,~~.97	…
1003	24~~,~~.03	…
1004	21~~,~~.67	…
1005	20~~,~~.34	…
1006	18~~,~~.9	…
1007	16~~,~~.21	…
1008	13~~,~~.84	…
1009	12~~,~~.25	…
1010	10~~,~~.4	…
1011	7~~,~~.94	…
1012	6~~,~~.05	+1~~,~~.48E-07*~~p~~P^2 +2~~,~~.76E-04*~~p~~P +0~~,~~.25
1013	5~~,~~.67	-5~~,~~.06E-07*~~p~~P^2 -7~~,~~.04E-04*~~p~~P -0~~,~~.26
1014	6~~,~~.03	-1~~,~~.16E-06*~~p~~P^2 -1~~,~~.68E-03*~~p~~P -0~~,~~.77
1015	7~~,~~.68	…
1016	10~~,~~.97	…
1017	14~~,~~.72	…
1018	17~~,~~.32	…
1019	18~~,~~.59	…
1020	19~~,~~.35	…
1021	20~~,~~.54	…
1022	21~~,~~.33	…
1023	22~~,~~.06	…
1024	23~~,~~.39	…
1025	25~~,~~.52	…
1026	28~~,~~.28	…
1027	30~~,~~.38	…
1028	31~~,~~.22	…
1029	32~~,~~.22	…
1030	33~~,~~.78	…
1031	35~~,~~.08	…
1032	35~~,~~.91	…
1033	36~~,~~.06	…

Time *s*	*Vehicle speed km/h*	*Road gradient per cent*
1034	35~~,~~.5	…
1035	34~~,~~.76	…
1036	34~~,~~.7	…
1037	35~~,~~.41	…
1038	36~~,~~.65	…
1039	37~~,~~.57	…
1040	38~~,~~.51	…
1041	39~~,~~.88	…
1042	41~~,~~.25	…
1043	42~~,~~.07	…
1044	43~~,~~.03	…
1045	44~~,~~.4	…
1046	45~~,~~.14	…
1047	45~~,~~.44	…
1048	46~~,~~.13	…
1049	46~~,~~.79	…
1050	47~~,~~.45	…
1051	48~~,~~.68	…
1052	50~~,~~.13	…
1053	51~~,~~.16	…
1054	51~~,~~.37	…
1055	51~~,~~.3	…
1056	51~~,~~.15	…
1057	50~~,~~.88	…
1058	50~~,~~.63	…
1059	50~~,~~.2	…
1060	49~~,~~.12	…
1061	48~~,~~.02	…
1062	47~~,~~.7	…
1063	47~~,~~.93	…
1064	48~~,~~.57	…
1065	48~~,~~.88	…
1066	49~~,~~.03	…
1067	48~~,~~.94	…
1068	48~~,~~.32	…
1069	47~~,~~.97	…
1070	47~~,~~.92	-1~~,~~.80E-06*~~p~~P^2 -5~~,~~.59E-05*~~p~~P -0~~,~~.62
1071	47~~,~~.54	-2~~,~~.43E-06*~~p~~P^2 +1~~,~~.57E-03*~~p~~P -0~~,~~.48
1072	46~~,~~.79	-3~~,~~.07E-06*~~p~~P^2 +3~~,~~.20E-03*~~p~~P -0~~,~~.34
1073	46~~,~~.13	…
1074	45~~,~~.73	…
1075	45~~,~~.17	…
1076	44~~,~~.43	…
1077	43~~,~~.59	…
1078	42~~,~~.68	…
1079	41~~,~~.89	…
1080	41~~,~~.09	…
1081	40~~,~~.38	…
1082	39~~,~~.99	…
1083	39~~,~~.84	…
1084	39~~,~~.46	…
1085	39~~,~~.15	…
1086	38~~,~~.9	…
1087	38~~,~~.67	…
1088	39~~,~~.03	…
1089	40~~,~~.37	…
1090	41~~,~~.03	…
1091	40~~,~~.76	…
1092	40~~,~~.02	…
1093	39~~,~~.6	…
1094	39~~,~~.37	…
1095	38~~,~~.84	…
1096	37~~,~~.93	…
1097	37~~,~~.19	…
1098	36~~,~~.21	-2~~,~~.43E-06*~~p~~P^2 +1~~,~~.57E-03*~~p~~P -0~~,~~.48
1099	35~~,~~.32	-1~~,~~.80E-06*~~p~~P^2 -5~~,~~.59E-05*~~p~~P -0~~,~~.62
1100	35~~,~~.56	-1~~,~~.16E-06*~~p~~P^2 -1~~,~~.68E-03*~~p~~P -0~~,~~.77
1101	36~~,~~.96	…
1102	38~~,~~.12	…
1103	38~~,~~.71	…
1104	39~~,~~.26	…
1105	40~~,~~.64	…
1106	43~~,~~.09	…
1107	44~~,~~.83	…
1108	45~~,~~.33	…
1109	45~~,~~.24	…
1110	45~~,~~.14	…
1111	45~~,~~.06	…
1112	44~~,~~.82	…
1113	44~~,~~.53	…
1114	44~~,~~.77	…
1115	45~~,~~.6	…
1116	46~~,~~.28	…
1117	47~~,~~.18	…
1118	48~~,~~.49	…
1119	49~~,~~.42	…
1120	49~~,~~.56	…
1121	49~~,~~.47	…
1122	49~~,~~.28	…
1123	48~~,~~.58	…
1124	48~~,~~.03	…
1125	48~~,~~.2	…
1126	48~~,~~.72	…
1127	48~~,~~.91	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
1128	48~~,~~.93	…
1129	49~~,~~.05	…
1130	49~~,~~.23	…
1131	49~~,~~.28	-1~~,~~.80E-06*~~p~~P^2 -5~~,~~.59E-05*~~p~~P -0~~,~~.62
1132	48~~,~~.84	-2~~,~~.43E-06*~~p~~P^2 +1~~,~~.57E-03*~~p~~P -0~~,~~.48
1133	48~~,~~.12	-3~~,~~.07E-06*~~p~~P^2 +3~~,~~.20E-03*~~p~~P -0~~,~~.34
1134	47~~,~~.8	…
1135	47~~,~~.42	…
1136	45~~,~~.98	…
1137	42~~,~~.96	…
1138	39~~,~~.38	…
1139	35~~,~~.82	…
1140	31~~,~~.85	…
1141	26~~,~~.87	…
1142	21~~,~~.41	…
1143	16~~,~~.41	…
1144	12~~,~~.56	…
1145	10~~,~~.41	…
1146	9~~,~~.07	…
1147	7~~,~~.69	…
1148	6~~,~~.28	…
1149	5~~,~~.08	…
1150	4~~,~~.32	…
1151	3~~,~~.32	…
1152	1~~,~~.92	…
1153	1~~,~~.07	…
1154	0~~,~~.66	…
1155	0	…
1156	0	…
1157	0	…
1158	0	…
1159	0	…
1160	0	…
1161	0	…
1162	0	…
1163	0	…
1164	0	…
1165	0	…
1166	0	…
1167	0	…
1168	0	…
1169	0	…
1170	0	…
1171	0	…
1172	0	…
1173	0	…
1174	0	…
1175	0	-7~~,~~.73E-07*~~p~~P^2 +5~~,~~.68E-04*~~p~~P +0~~,~~.07
1176	0	+1~~,~~.53E-06*~~p~~P^2 -2~~,~~.06E-03*~~p~~P +0~~,~~.47
1177	0	+3~~,~~.82E-06*~~p~~P^2 -4~~,~~.70E-03*~~p~~P +0~~,~~.87
1178	0	…
1179	0	…
1180	0	…
1181	0	…
1182	0	…
1183	0	…
1184	0	…
1185	0	…
1186	0	…
1187	0	…
1188	0	…
1189	0	…
1190	0	…
1191	0	…
1192	0	…
1193	0	…
1194	0	…
1195	0	…
1196	1~~,~~.54	…
1197	4~~,~~.85	…
1198	9~~,~~.06	…
1199	11~~,~~.8	…
1200	12~~,~~.42	…
1201	12~~,~~.07	…
1202	11~~,~~.64	…
1203	11~~,~~.69	…
1204	12~~,~~.91	…
1205	15~~,~~.58	…
1206	18~~,~~.69	…
1207	21~~,~~.04	…
1208	22~~,~~.62	…
1209	24~~,~~.34	…
1210	26~~,~~.74	…
1211	29~~,~~.62	…
1212	32~~,~~.65	…
1213	35~~,~~.57	…
1214	38~~,~~.07	…
1215	39~~,~~.71	…
1216	40~~,~~.36	…
1217	40~~,~~.6	…
1218	41~~,~~.15	…
1219	42~~,~~.23	…
1220	43~~,~~.61	…
1221	45~~,~~.08	…
1222	46~~,~~.58	…
1223	48~~,~~.13	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
1224	49~~,~~.7	…
1225	51~~,~~.27	…
1226	52~~,~~.8	…
1227	54~~,~~.3	…
1228	55~~,~~.8	…
1229	57~~,~~.29	…
1230	58~~,~~.73	…
1231	60~~,~~.12	…
1232	61~~,~~.5	…
1233	62~~,~~.94	…
1234	64~~,~~.39	…
1235	65~~,~~.52	…
1236	66~~,~~.07	…
1237	66~~,~~.19	…
1238	66~~,~~.19	…
1239	66~~,~~.43	…
1240	67~~,~~.07	…
1241	68~~,~~.04	…
1242	69~~,~~.12	…
1243	70~~,~~.08	…
1244	70~~,~~.91	…
1245	71~~,~~.73	…
1246	72~~,~~.66	…
1247	73~~,~~.67	…
1248	74~~,~~.55	…
1249	75~~,~~.18	…
1250	75~~,~~.59	…
1251	75~~,~~.82	…
1252	75~~,~~.9	…
1253	75~~,~~.92	…
1254	75~~,~~.87	…
1255	75~~,~~.68	…
1256	75~~,~~.37	…
1257	75~~,~~.01	+7~~,~~.07E-06*~~p~~P^2 -7~~,~~.30E-03*~~p~~P +1~~,~~.19
1258	74~~,~~.55	+1~~,~~.03E-05*~~p~~P^2 -9~~,~~.91E-03*~~p~~P +1~~,~~.51
1259	73~~,~~.8	+1~~,~~.36E-05*~~p~~P^2 -1~~,~~.25E-02*~~p~~P +1~~,~~.83
1260	72~~,~~.71	…
1261	71~~,~~.39	…
1262	70~~,~~.02	…
1263	68~~,~~.71	…
1264	67~~,~~.52	…
1265	66~~,~~.44	…
1266	65~~,~~.45	…
1267	64~~,~~.49	…
1268	63~~,~~.54	…
1269	62~~,~~.6	…
1270	61~~,~~.67	…
1271	60~~,~~.69	…
1272	59~~,~~.64	…
1273	58~~,~~.6	…
1274	57~~,~~.64	…
1275	56~~,~~.79	…
1276	55~~,~~.95	…
1277	55~~,~~.09	…
1278	54~~,~~.2	…
1279	53~~,~~.33	…
1280	52~~,~~.52	…
1281	51~~,~~.75	…
1282	50~~,~~.92	…
1283	49~~,~~.9	…
1284	48~~,~~.68	…
1285	47~~,~~.41	…
1286	46~~,~~.5	~~+9,40E-06*p^2 -8,92E-03*p +1,50~~+1.06E-05*P^2 -1.01E-02*P +1.57
1287	46~~,~~.22	+~~5,22E~~7.62E-06*~~p^2 -5,32E~~P^2 -7.70E-03*~~p~~P +1~~,16~~.30
1288	46~~,~~.44	+~~1,04E~~4.65E-06*~~p^2 -1,72E~~P^2 -5.29E-03*~~p +0,82~~P +1.03
1289	47~~,~~.35	…
1290	49~~,~~.01	…
1291	50~~,~~.93	…
1292	52~~,~~.79	…
1293	54~~,~~.66	…
1294	56~~,~~.6	…
1295	58~~,~~.55	…
1296	60~~,~~.47	…
1297	62~~,~~.28	…
1298	63~~,~~.9	…
1299	65~~,~~.2	…
1300	66~~,~~.02	…
1301	66~~,~~.39	…
1302	66~~,~~.74	…
1303	67~~,~~.43	…
1304	68~~,~~.44	…
1305	69~~,~~.52	…
1306	70~~,~~.53	…
1307	71~~,~~.47	…
1308	72~~,~~.32	…
1309	72~~,~~.89	…
1310	73~~,~~.07	…
1311	73~~,~~.03	~~…~~+2.39E-06*P^2 -3.13E-03*P +0.89
1312	72~~,~~.94	~~…~~+1.26E-07*P^2 -9.74E-04*P +0.74
1313	73~~,~~.01	~~…~~-2.14E-06*P^2 +1.18E-03*P +0.60
1314	73~~,~~.44	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
1315	74~~,~~.19	…
1316	74~~,~~.81	…
1317	75~~,~~.01	…
1318	74~~,~~.99	…
1319	74~~,~~.79	…
1320	74~~,~~.41	…
1321	74~~,~~.07	…
1322	73~~,~~.77	…
1323	73~~,~~.38	…
1324	72~~,~~.79	…
1325	71~~,~~.95	…
1326	71~~,~~.06	…
1327	70~~,~~.45	…
1328	70~~,~~.23	…
1329	70~~,~~.24	…
1330	70~~,~~.32	…
1331	70~~,~~.3	…
1332	70~~,~~.05	…
1333	69~~,~~.66	…
1334	69~~,~~.26	+~~4,29E~~1.12E-06*~~p² -4,33E~~P² -1.42E-03*~~p +1,14~~P +0.92
1335	68~~,~~.73	+~~7,54E~~4.37E-06*~~p² -6,94E~~P² -4.03E-03*~~p~~P +1~~,46~~.24
1336	67~~,~~.88	~~+1,08E-05*p² -9,54E~~+7.62E-06*P² -6.64E-03*~~p~~P +1~~,78~~.56
1337	66~~,~~.68	…
1338	65~~,~~.29	…
1339	63~~,~~.95	…
1340	62~~,~~.84	+~~7,54E~~4.37E-06*~~p² -6,94E~~P² -4.03E-03*~~p~~P +1~~,46~~.24
1341	62~~,~~.21	+~~4,29E~~1.12E-06*~~p² -4,33E~~P² -1.42E-03*~~p +1,14~~P +0.92
1342	62~~,~~.04	~~+1,04E~~-2.14E-06*~~p² -~~P² +1~~,72E~~.18E-03*~~p~~P +0~~,82~~.60
1343	62~~,~~.26	…
1344	62~~,~~.87	…
1345	63~~,~~.55	…
1346	64~~,~~.12	…
1347	64~~,~~.73	…
1348	65~~,~~.45	…
1349	66~~,~~.18	…
1350	66~~,~~.97	…
1351	67~~,~~.85	…
1352	68~~,~~.74	…
1353	69~~,~~.45	…
1354	69~~,~~.92	…
1355	70~~,~~.24	…
1356	70~~,~~.49	…
1357	70~~,~~.63	…
1358	70~~,~~.68	…
1359	70~~,~~.65	…
1360	70~~,~~.49	+~~4,29E~~1.12E-06*~~p² -4,33E~~P² -1.42E-03*~~p +1,14~~P +0.92
1361	70~~,~~.09	+~~7,54E~~4.37E-06*~~p² -6,94E~~P² -4.03E-03*~~p~~P +1~~,46~~.24
1362	69~~,~~.35	~~+1,08E-05*p² -9,54E~~+7.62E-06*P² -6.64E-03*~~p~~P +1~~,78~~.56
1363	68~~,~~.27	…
1364	67~~,~~.09	…
1365	65~~,~~.96	…
1366	64~~,~~.87	…
1367	63~~,~~.79	…
1368	62~~,~~.82	+~~7,54E~~4.37E-06*~~p² -6,94E~~P² -4.03E-03*~~p~~P +1~~,46~~.24
1369	63~~,~~.03	+~~4,29E~~1.12E-06*~~p² -4,33E~~P² -1.42E-03*~~p +1,14~~P +0.92
1370	63~~,~~.62	~~+1,04E~~-2.14E-06*~~p² -~~P² +1~~,72E~~.18E-03*~~p~~P +0~~,82~~.60
1371	64~~,~~.8	…
1372	65~~,~~.5	…
1373	65~~,~~.33	+~~4,29E~~1.12E-06*~~p² -4,33E~~P² -1.42E-03*~~p +1,14~~P +0.92
1374	63~~,~~.83	+~~7,54E~~4.37E-06*~~p² -6,94E~~P² -4.03E-03*~~p~~P +1~~,46~~.24
1375	62~~,~~.44	~~+1,08E-05*p² -9,54E~~+7.62E-06*P² -6.64E-03*~~p~~P +1~~,78~~.56
1376	61~~,~~.2	…
1377	59~~,~~.58	…
1378	57~~,~~.68	…
1379	56~~,~~.4	…
1380	54~~,~~.82	…
1381	52~~,~~.77	+~~8,89E~~6.78E-06*~~p² -8,29E~~P² -6.35E-03*~~p~~P +2~~,21~~.06
1382	52~~,~~.22	+~~6,99E~~5.95E-06*~~p² -7,03E~~P² -6.07E-03*~~p~~P +2~~,63~~.56
1383	52~~,~~.48	+5~~,09E~~.11E-06*~~p~~P² -5~~,77E~~.78E-03*~~p~~P +3~~,~~.06
1384	52~~,~~.74	…
1385	53~~,~~.14	…
1386	53~~,~~.03	…
1387	52~~,~~.55	…
1388	52~~,~~.19	…
1389	51~~,~~.09	…
1390	49~~,~~.88	…
1391	49~~,~~.37	…
1392	49~~,~~.26	…
1393	49~~,~~.37	…
1394	49~~,~~.88	…
1395	50~~,~~.25	…
1396	50~~,~~.17	…
1397	50~~,~~.5	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
1398	50~~,~~.83	…
1399	51~~,~~.23	…
1400	51~~,~~.67	…
1401	51~~,~~.53	…
1402	50~~,~~.17	…
1403	49~~,~~.99	…
1404	50~~,~~.32	…
1405	51~~,~~.05	…
1406	51~~,~~.45	…
1407	52	…
1408	52~~,~~.3	…
1409	52~~,~~.22	…
1410	52~~,~~.66	…
1411	53~~,~~.18	…
1412	53~~,~~.8	…
1413	54~~,~~.53	…
1414	55~~,~~.37	…
1415	56~~,~~.29	…
1416	57~~,~~.31	…
1417	57~~,~~.94	…
1418	57~~,~~.86	…
1419	57~~,~~.75	…
1420	58~~,~~.67	…
1421	59~~,~~.4	…
1422	59~~,~~.69	…
1423	60~~,~~.02	…
1424	60~~,~~.21	…
1425	60~~,~~.83	…
1426	61~~,~~.16	…
1427	61~~,~~.6	…
1428	62~~,~~.15	…
1429	62~~,~~.7	+2~~,29E~~.30E-06*~~p~~P^2 -3~~,17E~~.18E-03*~~p~~P +1~~,~~.81
1430	63~~,~~.65	-5~~,13E~~.04E-07*~~p~~P^2 -5~~,70E~~.74E-04*~~p~~P +0~~,~~.57
1431	64~~,~~.27	-3~~,~~.31E-06*~~p~~P^2 +2~~,~~.03E-03*~~p~~P -0~~,~~.68
1432	64~~,~~.31	…
1433	64~~,~~.13	…
1434	64~~,~~.27	…
1435	65~~,~~.22	…
1436	66~~,~~.25	…
1437	67~~,~~.09	…
1438	68~~,~~.37	…
1439	69~~,~~.36	…
1440	70~~,~~.57	…
1441	71~~,~~.89	…
1442	73~~,~~.35	…
1443	74~~,~~.64	…

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
1444	75~~,~~.81	…
1445	77~~,~~.24	…
1446	78~~,~~.63	…
1447	79~~,~~.32	…
1448	80~~,~~.2	…
1449	81~~,~~.67	…
1450	82~~,~~.11	…
1451	82~~,~~.91	…
1452	83~~,~~.43	…
1453	83~~,~~.79	…
1454	83~~,~~.5	…
1455	84~~,~~.01	…
1456	83~~,~~.43	…
1457	82~~,~~.99	…
1458	82~~,~~.77	…
1459	82~~,~~.33	…
1460	81~~,~~.78	…
1461	81~~,~~.81	…
1462	81~~,~~.05	…
1463	80~~,~~.72	-6~~,~~.93E-06*~~p~~P^2 +5~~,~~.24E-03*~~p~~P -1~~,~~.21
1464	80~~,~~.61	-1~~,~~.05E-05*~~p~~P^2 +8~~,~~.45E-03*~~p~~P -1~~,~~.74
1465	80~~,~~.46	-1~~,~~.42E-05*~~p~~P^2 +1~~,~~.17E-02*~~p~~P -2~~,~~.27
1466	80~~,~~.42	…
1467	80~~,~~.42	…
1468	80~~,~~.24	…
1469	80~~,~~.13	…
1470	80~~,~~.39	…
1471	80~~,~~.72	…
1472	81~~,~~.01	…
1473	81~~,~~.52	…
1474	82~~,~~.4	…
1475	83~~,~~.21	…
1476	84~~,~~.05	…
1477	84~~,~~.85	…
1478	85~~,~~.42	…
1479	86~~,~~.18	…
1480	86~~,~~.45	…
1481	86~~,~~.64	…
1482	86~~,~~.57	…
1483	86~~,~~.43	…
1484	86~~,~~.58	…
1485	86~~,~~.8	…
1486	86~~,~~.65	…
1487	86~~,~~.14	…
1488	86~~,~~.36	…
1489	86~~,~~.32	…
1490	86~~,~~.25	…

Time s	*Vehicle speed km/h*	*Road gradient per cent*	*Time s*	*Vehicle speed km/h*	*Road gradient per cent*
1491	85~~,~~.92	…	1539	87~~,~~.25	…
1492	86~~,~~.14	…	1540	87~~,~~.04	…
1493	86~~,~~.36	…	1541	86~~,~~.98	…
1494	86~~,~~.25	…	1542	87~~,~~.05	…
1495	86~~,~~.5	…	1543	87~~,~~.1	…
1496	86~~,~~.14	…	1544	87~~,~~.25	…
1497	86~~,~~.29	…	1545	87~~,~~.25	…
1498	86~~,~~.4	…	1546	87~~,~~.07	…
1499	86~~,~~.36	…	1547	87~~,~~.29	…
1500	85~~,~~.63	…	1548	87~~,~~.14	…
1501	86~~,~~.03	…	1549	87~~,~~.03	…
1502	85~~,~~.92	…	1550	87~~,~~.25	…
1503	86~~,~~.14	…	1551	87~~,~~.03	…
1504	86~~,~~.32	…	1552	87~~,~~.03	…
1505	85~~,~~.92	…	1553	87~~,~~.07	…
1506	86~~,~~.11	…	1554	86~~,~~.81	…
1507	85~~,~~.91	…	1555	86~~,~~.92	…
1508	85~~,~~.83	…	1556	86~~,~~.66	…
1509	85~~,~~.86	-1~~,~~.09E-05*~~p~~P^2 +9~~,~~.06E-03*~~p~~P -1~~,~~.95	1557	86~~,~~.92	…
1510	85~~,~~.5	-7~~,~~.66E-06*~~p~~P^2 +6~~,~~.45E-03*~~p~~P -1~~,~~.63	1558	86~~,~~.59	…
1511	84~~,~~.97	-4~~,~~.41E-06*~~p~~P^2 +3~~,~~.84E-03*~~p~~P -1~~,~~.31	1559	86~~,~~.92	…
1512	84~~,~~.8	…	1560	86~~,~~.59	…
1513	84~~,~~.2	…	1561	86~~,~~.88	…
1514	83~~,~~.26	…	1562	86~~,~~.7	…
1515	82~~,~~.77	…	1563	86~~,~~.81	…
1516	81~~,~~.78	…	1564	86~~,~~.81	…
1517	81~~,~~.16	…	1565	86~~,~~.81	…
1518	80~~,~~.42	…	1566	86~~,~~.81	…
1519	79~~,~~.21	…	1567	86~~,~~.99	…
1520	78~~,~~.83	…	1568	87~~,~~.03	…
1521	78~~,~~.52	-5~~,~~.24E-06*~~p~~P^2 +4~~,~~.57E-03*~~p~~P -1~~,~~.18	1569	86~~,~~.92	…
1522	78~~,~~.52	-6~~,~~.08E-06*~~p~~P^2 +5~~,~~.30E-03*~~p~~P -1~~,~~.06	1570	87~~,~~.1	…
1523	78~~,~~.81	-6~~,~~.91E-06*~~p~~P^2 +6~~,~~.04E-03*~~p~~P -0~~,~~.93	1571	86~~,~~.85	…
1524	79~~,~~.26	…	1572	87~~,~~.14	…
1525	79~~,~~.61	…	1573	86~~,~~.96	…
1526	80~~,~~.15	…	1574	86~~,~~.85	…
1527	80~~,~~.39	…	1575	86~~,~~.77	…
1528	80~~,~~.72	…	1576	86~~,~~.81	…
1529	81~~,~~.01	…	1577	86~~,~~.85	…
1530	81~~,~~.52	…	1578	86~~,~~.74	…
1531	82~~,~~.4	…	1579	86~~,~~.81	…
1532	83~~,~~.21	…	1580	86~~,~~.7	…
1533	84~~,~~.05	…	1581	86~~,~~.52	…
1534	85~~,~~.15	…	1582	86~~,~~.7	…
1535	85~~,~~.92	…	1583	86~~,~~.74	…
1536	86~~,~~.98	…	1584	86~~,~~.81	…
1537	87~~,~~.45	…	1585	86~~,~~.85	…
1538	87~~,~~.54	…	1586	86~~,~~.92	…

Time s	Vehicle speed km/h	Road gradient per cent
1587	86~~,~~.88	…
1588	86~~,~~.85	…
1589	87~~,~~.1	…
1590	86~~,~~.81	…
1591	86~~,~~.99	…
1592	86~~,~~.81	…
1593	87~~,~~.14	…
1594	86~~,~~.81	…
1595	86~~,~~.85	…
1596	87~~,~~.03	…
1597	86~~,~~.92	…
1598	87~~,~~.14	…
1599	86~~,~~.92	…
1600	87~~,~~.03	…
1601	86~~,~~.99	…
1602	86~~,~~.96	…
1603	87~~,~~.03	…
1604	86~~,~~.85	…
1605	87~~,~~.1	…
1606	86~~,~~.81	…
1607	87~~,~~.03	…
1608	86~~,~~.77	…
1609	86~~,~~.99	…
1610	86~~,~~.96	…
1611	86~~,~~.96	…
1612	87~~,~~.07	…
1613	86~~,~~.96	…
1614	86~~,~~.92	…
1615	87~~,~~.07	…
1616	86~~,~~.92	…
1617	87~~,~~.14	…
1618	86~~,~~.96	…
1619	87~~,~~.03	…
1620	86~~,~~.85	…
1621	86~~,~~.77	…
1622	87~~,~~.1	…
1623	86~~,~~.92	…
1624	87~~,~~.07	…
1625	86~~,~~.85	…
1626	86~~,~~.81	…
1627	87~~,~~.14	…
1628	86~~,~~.77	…
1629	87~~,~~.03	…
1630	86~~,~~.96	…
1631	87~~,~~.1	…
1632	86~~,~~.99	…
1633	86~~,~~.92	…
1634	87~~,~~.1	…
1635	86~~,~~.85	…
1636	86~~,~~.92	…
1637	86~~,~~.77	…
1638	86~~,~~.88	…
1639	86~~,~~.63	…
1640	86~~,~~.85	…
1641	86~~,~~.63	…
1642	86~~,~~.77	-6~~,~~.00E-06*~~p~~P^2 +5~~,~~.11E-03*~~p~~P -0~~,~~.41
1643	86~~,~~.77	-5~~,~~.09E-06*~~p~~P^2 +4~~,~~.19E-03*~~p~~P +0~~,~~.10
1644	86~~,~~.55	-4~~,~~.18E-06*~~p~~P^2 +3~~,~~.26E-03*~~p~~P +0~~,~~.61
1645	86~~,~~.59	…
1646	86~~,~~.55	…
1647	86~~,~~.7	…
1648	86~~,~~.44	…
1649	86~~,~~.7	…
1650	86~~,~~.55	…
1651	86~~,~~.33	…
1652	86~~,~~.48	…
1653	86~~,~~.19	…
1654	86~~,~~.37	…
1655	86~~,~~.59	…
1656	86~~,~~.55	…
1657	86~~,~~.7	…
1658	86~~,~~.63	…
1659	86~~,~~.55	…
1660	86~~,~~.59	…
1661	86~~,~~.55	…
1662	86~~,~~.7	…
1663	86~~,~~.55	…
1664	86~~,~~.7	…
1665	86~~,~~.52	…
1666	86~~,~~.85	…
1667	86~~,~~.55	…
1668	86~~,~~.81	…
1669	86~~,~~.74	…
1670	86~~,~~.63	…
1671	86~~,~~.77	…
1672	87~~,~~.03	…
1673	87~~,~~.07	…
1674	86~~,~~.92	…
1675	87~~,~~.07	…
1676	87~~,~~.18	…
1677	87~~,~~.32	…
1678	87~~,~~.36	…
1679	87~~,~~.29	…
1680	87~~,~~.58	-6~~,~~.58E-06*~~p~~P^2 +5~~,~~.65E-03*~~p~~P -0~~,~~.51

Time *s*	*Vehicle speed* *km/h*	*Road gradient* *per cent*
1681	87~~,~~.61	-8~~,~~.97E-06*~~p~~P^2 +8~~,~~.04E-03*~~p~~P -1~~,~~.64
1682	87~~,~~.76	-1~~,~~.14E-05*~~p~~P^2 +1~~,~~.04E-02*~~p~~P -2~~,~~.77
1683	87~~,~~.65	…
1684	87~~,~~.61	…
1685	87~~,~~.65	…
1686	87~~,~~.65	…
1687	87~~,~~.76	…
1688	87~~,~~.76	…
1689	87~~,~~.8	…
1690	87~~,~~.72	…
1691	87~~,~~.69	…
1692	87~~,~~.54	…
1693	87~~,~~.76	…
1694	87~~,~~.5	…
1695	87~~,~~.43	…
1696	87~~,~~.47	…
1697	87~~,~~.5	…
1698	87~~,~~.5	…
1699	87~~,~~.18	…
1700	87~~,~~.36	…
1701	87~~,~~.29	…
1702	87~~,~~.18	…
1703	86~~,~~.92	…
1704	87~~,~~.36	…
1705	87~~,~~.03	…
1706	87~~,~~.07	…
1707	87~~,~~.29	…
1708	86~~,~~.99	…
1709	87~~,~~.25	…
1710	87~~,~~.14	…
1711	86~~,~~.96	…
1712	87~~,~~.14	…
1713	87~~,~~.07	…
1714	86~~,~~.92	…
1715	86~~,~~.88	…
1716	86~~,~~.85	…
1717	86~~,~~.92	…
1718	86~~,~~.81	…
1719	86~~,~~.88	…
1720	86~~,~~.66	…
1721	86~~,~~.92	…
1722	86~~,~~.48	…
1723	86~~,~~.66	…
1724	86~~,~~.74	-1~~,~~.01E-05*~~p~~P^2 +9~~,~~.14E-03*~~p~~P -2~~,~~.12
1725	86~~,~~.37	-8~~,~~.83E-06*~~p~~P^2 +7~~,~~.85E-03*~~p~~P -1~~,~~.47
1726	86~~,~~.48	-7~~,~~.56E-06*~~p~~P^2 +6~~,~~.56E-03*~~p~~P -0~~,~~.83
1727	86~~,~~.33	…
1728	86~~,~~.3	…
1729	86~~,~~.44	…
1730	86~~,~~.33	…
1731	86	…
1732	86~~,~~.33	…
1733	86~~,~~.22	…
1734	86~~,~~.08	…
1735	86~~,~~.22	…
1736	86~~,~~.33	…
1737	86~~,~~.33	…
1738	86~~,~~.26	…
1739	86~~,~~.48	…
1740	86~~,~~.48	…
1741	86~~,~~.55	…
1742	86~~,~~.66	…
1743	86~~,~~.66	…
1744	86~~,~~.59	…
1745	86~~,~~.55	…
1746	86~~,~~.74	-4~~,~~.31E-06*~~p~~P^2 +3~~,~~.96E-03*~~p~~P -0~~,~~.51
1747	86~~,~~.21	-1~~,~~.06E-06*~~p~~P^2 +1~~,~~.35E-03*~~p~~P -0~~,~~.19
1748	85~~,~~.96	+2~~,~~.19E-06*~~p~~P^2 -1~~,~~.26E-03*~~p~~P +0~~,~~.13
1749	85~~,~~.5	…
1750	84~~,~~.77	…
1751	84~~,~~.65	…
1752	84~~,~~.1	…
1753	83~~,~~.46	…
1754	82~~,~~.77	…
1755	81~~,~~.78	…
1756	81~~,~~.16	…
1757	80~~,~~.42	…
1758	79~~,~~.21	…
1759	78~~,~~.48	…
1760	77~~,~~.49	…
1761	76~~,~~.69	…
1762	75~~,~~.92	…
1763	75~~,~~.08	…
1764	73~~,~~.87	…
1765	72~~,~~.15	…
1766	69~~,~~.69	…
1767	67~~,~~.17	…
1768	64~~,~~.75	…
1769	62~~,~~.55	…
1770	60~~,~~.32	…
1771	58~~,~~.45	…
1772	56~~,~~.43	…
1773	54~~,~~.35	…
1774	52~~,~~.22	…
1775	50~~,~~.25	…

Time s	Vehicle speed km/h	Road gradient per cent
1776	48~~,~~.23	…
1777	46~~,~~.51	…
1778	44~~,~~.35	…
1779	41~~,~~.97	…
1780	39~~,~~.33	…
1781	36~~,~~.48	…
1782	33~~,~~.8	…
1783	31~~,~~.09	…
1784	28~~,~~.24	…
1785	26~~,~~.81	…
1786	23~~,~~.33	…
1787	19~~,~~.01	…
1788	15~~,~~.05	…
1789	12~~,~~.09	…
1790	9~~,~~.49	…
1791	6~~,~~.81	…
1792	4~~,~~.28	…
1793	2~~,~~.09	…
1794	0~~,~~.88	…
1795	0~~,~~.88	…
1796	0	…
1797	0	…
1798	0	…
1799	0	…
1800	0	…

Section A.6.2., amend to read

A.6.2. Basic data for stoichiometric calculations

Atomic mass of hydrogen	1.00794 g/~~atom~~mol
Atomic mass of carbon	12.011 g/~~atom~~mol
Atomic mass of sulphur	32.065 g/~~atom~~mol
Atomic mass of nitrogen	14.0067 g/~~atom~~mol
Atomic mass of oxygen	15.9994 g/~~atom~~mol
Atomic mass of argon	39.9 g/~~atom~~mol

…..

Annex 9., amend to read

Annex 9

Test procedure for engines installed in hybrid vehicles using the HILS method

A.9.1. This annex contains the requirements and general description for testing engines installed in hybrid vehicles using the HILS method.

A.9.2. Test procedure

A.9.2.1 HILS method

The HILS method shall follow the general guidelines for execution of the defined process steps as outlined below and shown in the flow chart of Figure 16. The details of each step are described in the relevant paragraphs. Deviations from the guidance are permitted where appropriate, but the specific requirements shall be mandatory.

For the HILS method, the procedure shall follow:

(a) Selection and confirmation of the HDH object for approval

(b) Build HILS system setup

(c) Check HILS system performance

(d) Build and verification of HV model

(e) Component test procedures

(f) Hybrid system rated power ~~mapping~~determination

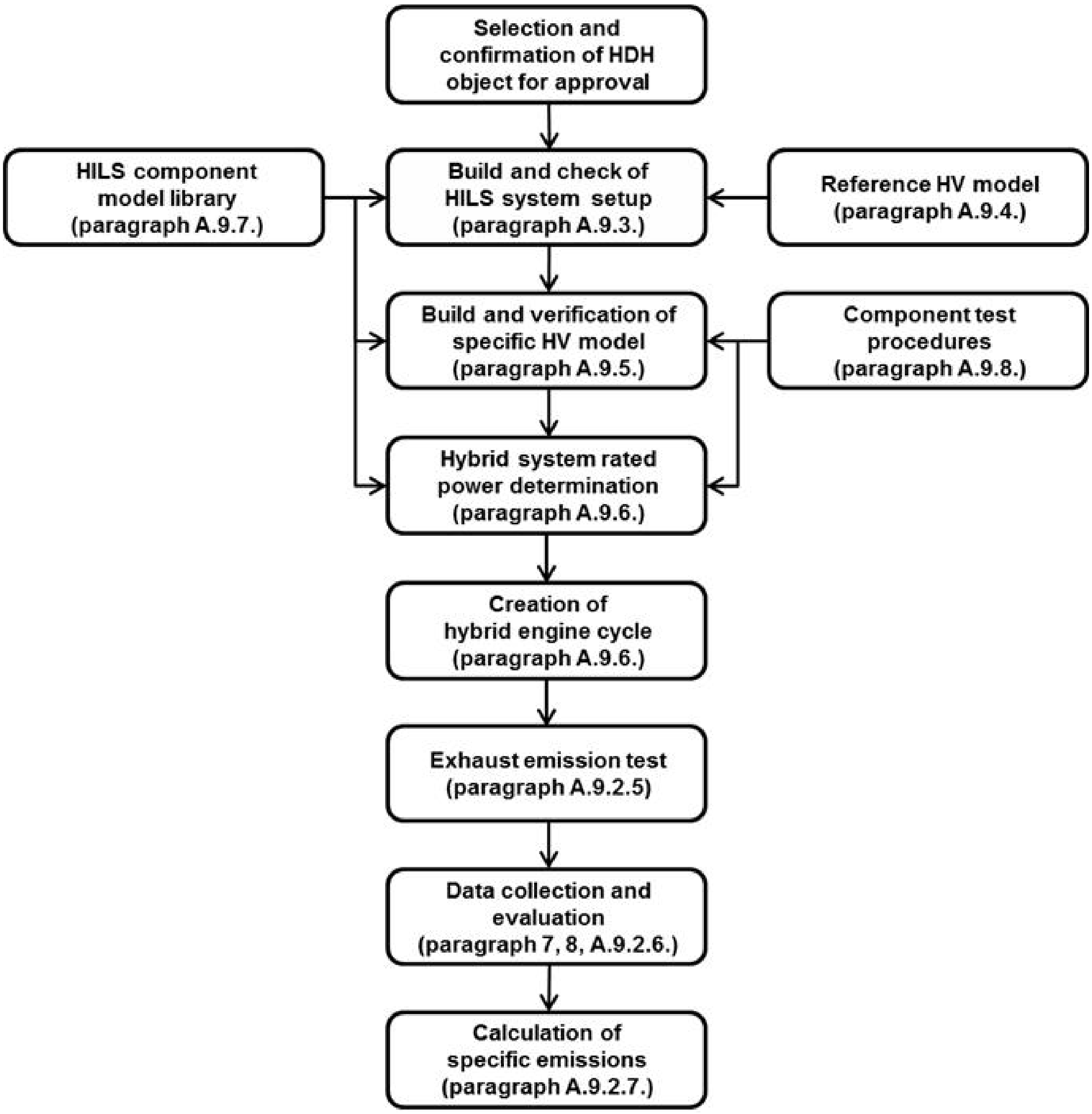
(g) Creation of the hybrid engine cycle

(h) Exhaust emission test

(i) Data collection and evaluation

(j) Calculation of specific emissions

Figure 16
HILS method flow chart



A.9.2.2. Build and verification of the HILS system setup

The HILS system setup shall be constructed and verified in accordance with the provisions of paragraph A.9.3.

A.9.2.3. Build and verification of HV model

The reference HV model shall be replaced by the specific HV model for approval representing the specified HD hybrid vehicle/powertrain and after enabling all other HILS system parts, the HILS system shall meet the provisions of paragraph A.9.5. to give the confirmed representative HD hybrid vehicle operation conditions.

A.9.2.4. Creation of the Hybrid Engine Cycle

As part of the procedure for creation of the hybrid engine test cycle, the hybrid system power shall be determined in accordance with the provisions of paragraph A.9.6.3. or A.10.4. to obtain the hybrid system rated power. The hybrid engine test cycle (HEC) shall be the result of the HILS simulated running procedure in accordance with the provisions of paragraph A.9.6.4.

A.9.2.5. Exhaust emission test

The exhaust emission test shall be conducted in accordance with paragraphs 6 and 7.

A.9.2.6. Data collection and evaluation

A.9.2.~~5~~6.1. Emission relevant data

All data relevant for the pollutant emissions shall be recorded in accordance with paragraphs 7.6.6. during the engine emission test run.

If the predicted temperature method in accordance with paragraph A.9.6.2.18. is used, the temperatures of the elements that influence the hybrid control shall be recorded.

A.9.2.6.2. Calculation of hybrid system work

The hybrid system work shall be determined over the test cycle by synchronously using the hybrid system rotational speed and torque values at the wheel hub (HILS chassis model output signals in accordance with paragraph A.9.7.3.) from the valid HILS simulated run of paragraph A.9.6.4. to calculate instantaneous values of hybrid system power. Instantaneous power values shall be integrated over the test cycle to calculate the hybrid system work from the HILS simulated running W_{sys_HILS} (kWh). Integration shall be carried out using a frequency of 5 Hz or higher (10 Hz recommended) and include ~~all~~only positive power values in accordance with paragraph A.9.7.3.

The hybrid system work W_{sys} shall be calculated as follows:

(a) Cases where $W_{act} < W_{eng\_HILS}$:

~~(Eq. 107)~~

$$W_{sys} = W_{sys\_HILS} \times W_{act} / W_{eng\_HILS} \times \left(\frac{1}{0.95}\right)^2 \qquad (107)$$

(b) Cases where $W_{act} \geq W_{eng\_HILS}$

~~(Eq. 108)~~

$$W_{sys} = W_{sys\_HILS} \times \left(\frac{1}{0.95}\right)^2 \qquad (108)$$

Where:

W_{sys} ~~:~~ ~~Hybrid~~is the hybrid system work~~(~~, kWh~~)~~

W_{sys_HILS} ~~:~~ ~~Hybrid~~is the hybrid system work from the final HILS simulated run~~(~~, kWh~~)~~

W_{act} ~~:~~ ~~Actual~~is the actual engine work in the HEC test~~(~~, kWh~~)~~

W_{eng_HILS} ~~:~~ ~~Engine~~is the engine work from the final HILS simulated run~~(~~, kWh~~)~~

All parameters shall be reported.

~~A.9.2.6~~

A.9.2.6.3. Validation of predicted temperature profile

In case the predicted temperature profile method in accordance with paragraph A.9.6.2.18. is used, it shall be proven, for each individual temperature of the elements that affect the hybrid control, that this temperature used in the HILS run is equivalent to the temperature of that element in the actual HEC test.

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

$$y = a_1 x + a_0 \qquad \text{(XX)}$$

Where:

y is the predicted value of element temperature, °C

a_1 is the slope of the regression line

x is the measured reference value of element temperature, °C

a_0 is the 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 the regression to be considered valid, the criteria of Table XXX shall be met.

Table XXX
Tolerances for temperature profiles

	Element temperature
Standard error of estimate (SEE) of y on x	maximum 5 per cent of maximum measured element temperature
Slope of the regression line, a_1	0.95 to 1.03
Coefficient of determination, r^2	minimum 0.970
y-intercept of the regression line, a_0	maximum 10 per cent of minimum measured element temperature

A.9.2.7. Calculation of specific emissions for hybrids

The specific emissions e_{gas} or e_{PM} (g/kWh) shall be calculated for each individual component as follows:

~~(Eq.~~

$$e = \frac{m}{W_{sys}} \qquad (109)$$

Where:

e is the specific emission~~ (~~, g/kWh~~)~~

m is the mass emission of the component~~ (~~, g/test~~)~~

W_{sys} is the cycle work as determined in accordance with paragraph A.9.2.~~5.1. (~~6.2., kWh~~)~~

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

~~(Eq. 110)~~

$$e = \frac{(0.14 \times m_{cold}) + (0.86 \times m_{hot})}{(0.14 \times W_{sys,cold}) + (0.86 \times W_{sys,hot})} \qquad (110)$$

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~~)~~
$W_{\text{sys,cold}}$	is the hybrid system cycle work on the cold start test~~(~~, kWh~~)~~
$W_{\text{sys,hot}}$	is the hybrid system cycle work on the hot start test~~(~~, kWh~~)~~

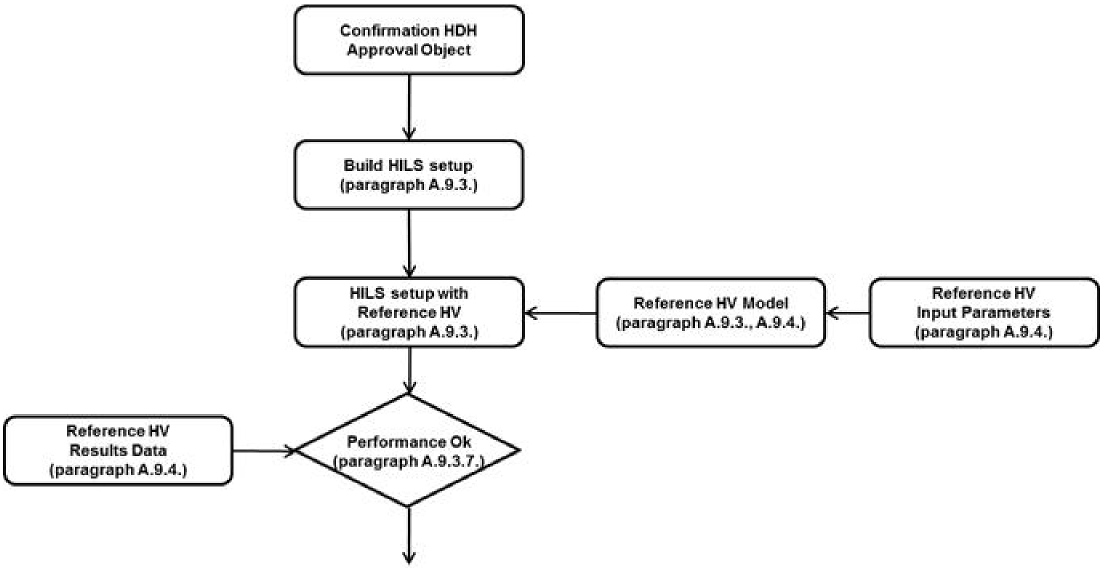
If periodic regeneration in accordance with paragraph 6.6.2. applies, the regeneration adjustment factors $k_{r,u}$ or $k_{r,d}$ shall be multiplied with or be added to, respectively, the specific emission result e as determined in equations 109 and 110.

A.9.3. Build and verification of ~~hils~~HILS system setup

A.9.3.1 General introduction

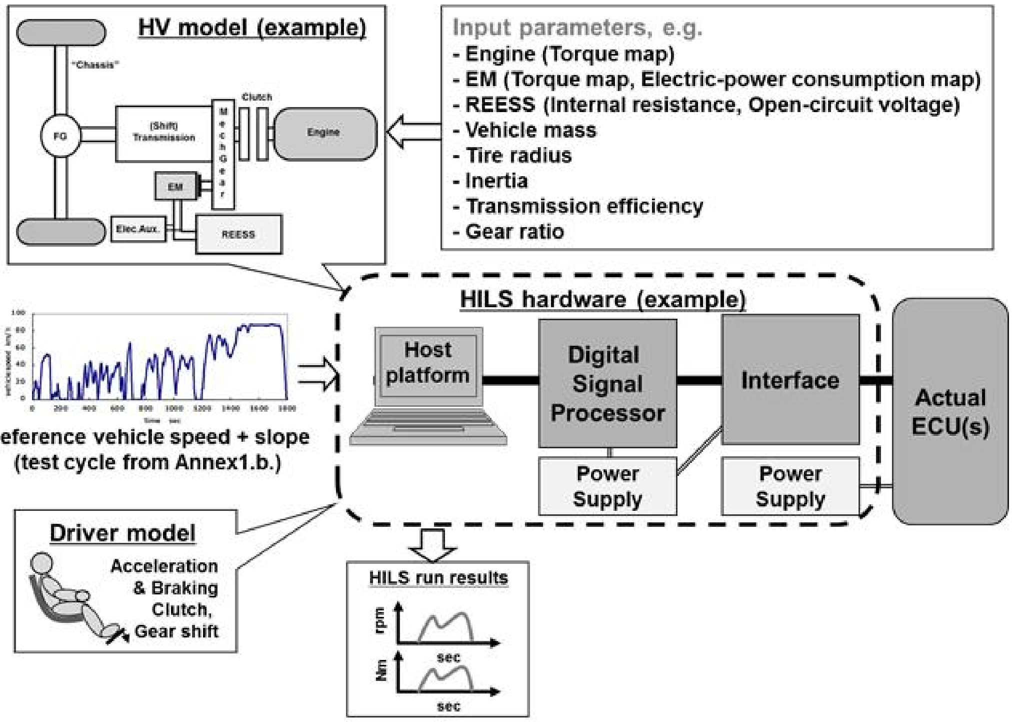
The build and verification of the HILS system setup procedure is outlined in Figure 17 below and provides guidelines on the various steps that shall be executed as part of the HILS procedure.

Figure 17
HILS system build and verification diagram



The HILS system shall consist of, as shown in Figure 18, all required HILS hardware, a HV model and its input parameters, a driver model and the test cycle as defined in Annex 1.b., as well as the hybrid ECU(s) of the test motor vehicle (hereinafter referred to as the "actual ECU") and its power supply and required interface(s). The HILS system setup shall be defined in accordance with paragraph A.9.3.2. through A.9.3.6. and considered valid when meeting the criteria of paragraph A.9.3.7. The reference HV model (paragraph A.9.4.) and HILS component library (paragraph A.9.7.) shall be applied in this process.

Figure 18:
Outline of HILS system setup



A.9.3.2. HILS hardware

The HILS hardware shall contain all physical systems to build up the HILS system, but excludes the actual ECU(s).

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 the procedures of paragraph A.9.3.7. and using the reference HV model of paragraph A.9.4.

A.9.3.3. HILS software interface

The HILS software interface shall be specified and set up in accordance with the requirements for the (hybrid) vehicle model as specified in paragraph A.9.3.5. and required for the operation of the HV model and actual ECU(s). It shall be the functional connection between the HV model and driver model to the HILS hardware. In addition, specific signals can be defined in the interface model to allow correct functional operation of the actual ECU(s), e.g. ABS signals.

The interface shall not contain key hybrid control functionalities as specified in paragraph A.9.3.4.1.

A.9.3.4. Actual ECU(s)

The hybrid system ECU(s) shall be used for the HILS system setup. 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 included in and executed by the hardware controller(s) as part of the HILS system setup.

A.9.3.4.1. Key hybrid functionalities

~~Reserved.~~

The key hybrid functionality shall contain at least the energy management and power distribution between the hybrid powertrain energy converters and the RESS.

A.9.3.5. Vehicle model

A vehicle model shall represent all relevant physical characteristics of the (heavy-duty) hybrid vehicle/powertrain to be used for the HILS system. The HV model shall be constructed by defining its components in accordance with paragraph A.9.7.

Two HV models are required for the HILS method and shall be constructed as follows:

(a) A reference HV model in accordance with its definition in paragraph A.9.4. shall be used for a SILS run using the HILS system to confirm the HILS system performance.

(b) A specific HV model defined in accordance with paragraph A.9.5. shall qualify as the valid representation of the specified heavy-duty hybrid powertrain. It shall be used for determination of the hybrid engine test cycle in accordance with paragraph A.9.6. as part of this HILS procedure.

A.9.3.6. Driver model

The driver model shall contain all required tasks to drive the HV model over the test cycle and typically includes e.g. accelerator and brake pedal signals as well as clutch and selected gear position in case of a manual shift transmission.

The driver model tasks may be implemented as a closed-loop controller or lookup tables as function of test time.

A.9.3.7. Operation check of HILS system setup

The operation check of the HILS system setup shall be verified through a SILS run using the reference HV model (paragraph A.9.4.) on the HILS systemA.9.

Linear regression of the calculated output values of the reference HV model SILS run on the provided reference values (paragraph A.9.4.4.) shall be performed. The method of least squares shall be used, with the best-fit equation having the form:

$$y = a_1 x + a_0 \qquad (111)$$

Where:

y ~~=~~is the actual HILS value of the signal

x ~~=~~is the measured reference value of the signal

~~a =~~

a_1 is the slope of the regression line

~~b~~ ~~=~~

a_0 is the y-intercept value of the regression line

For the HILS system setup to be considered valid, the criteria of Table 10 shall be met.

In case the programming language for the HV model is other than Matlab®/Simulink®, the confirmation of the calculation performance for the HILS system setup shall be proven using the specific HV model verification in accordance with paragraph A.9.5.

Table 10
Tolerances for HILS system setup operation check

Verification items	*Criteria*		
	slope, ~~a~~ a_1	*y-intercept,* ~~b~~ a_0	*coefficient of determination,* r^2
Vehicle speed	0.9995 ~~–~~to 1.0005	±0.05 % or less of the maximum value	minimum 0.995 ~~or higher~~
ICE speed			
ICE torque			
EM speed			
EM torque			
REESS voltage			
REESS current			
REESS SOC			

A.9.4. Reference hybrid vehicle model

A.9.4.1. General introduction

The purpose of the reference HV model shall be the use in confirmation of the calculation performance (e.g. accuracy, frequency) of the HILS system setup (paragraph A.9.3.) by using a predefined hybrid topology and control functionality for verifying the corresponding HILS calculated data against the expected reference values.

A.9.4.2 Reference HV model description

The reference HV model has a parallel hybrid powertrain topology consisting of following components, as shown in Figure 19, and includes its control strategy:

(a) Internal Combustion Engine

(b) Clutch

(c) Battery

(d) Electric Motor

(e) Mechanical gearing (for connection of EM between clutch and transmission)

(f) Shift transmission

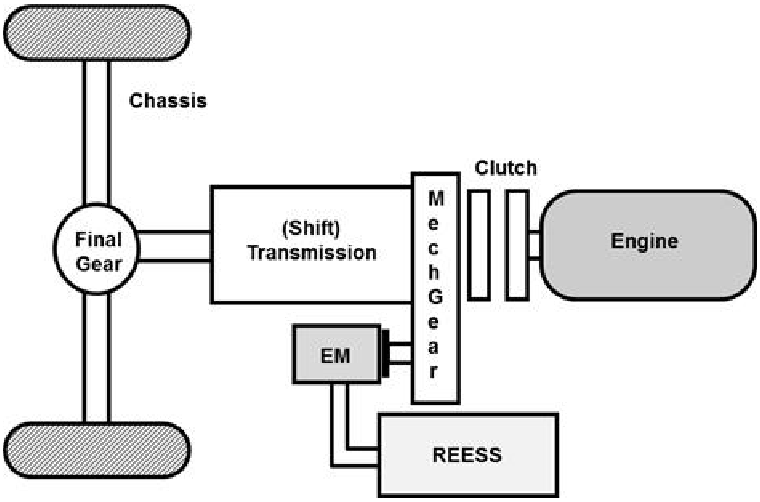
(g) Final gear

(h) Chassis, including wheels and body

The reference HV model is available as part of the HILS library available at http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob_registry.html~~.~~ at the GTR No.4 addendum.

The reference HV model is named "reference_hybrid_vehicle_model.mdl" and its parameter files as well as the SILS run output data are available at the following directory in the HILS library: "<root>\HILS_GTR\Vehicles\ReferenceHybridVehicleModel" (and all of its subdirectories).

Figure 19
Reference HV model powertrain topology



A.9.4.3. Reference HV model input parameters

All component input data for the reference HV model is predefined and located in the model directory:

"<root>\HILS_GTR\Vehicles\ReferenceHybridVehicleModel\ParameterData".

This directory contains files with the specific input data for:

(a)	The (internal combustion) engine model	: "para_engine_ref.m"
(b)	The clutch model	: "para_clutch_ref.m"
(c)	The battery model	: "para_battery_ref.m"
(d)	The electric machine model	: "para_elmachine_ref.m"
(e)	The mechanical gearing	: "para_mechgear_ref.m"
(f)	The (shift) transmission model	: "para_transmission_ref.m"
(g)	The final gear model	: "para_finalgear_ref.m"
(h)	The vehicle chassis model	: "para_chassis_ref.m"
(i)	The test cycle	: "para_drivecycle_ref.m"
(j)	The hybrid control strategy	: "ReferenceHVModel_Input.mat"

The hybrid control strategy is included in the reference HV model and its control parameters for the engine, electric machine, clutch and so on are defined in lookup tables and stored in the specified file.

A.9.4.4. Reference HV output parameters

A selected part of the test cycle as defined in Annex 1.b. covering the first 140 seconds is used to perform the SILS run with the reference HV model. The calculated data for the SILS run using the HILS system shall be recorded with at least 5 Hz and be compared to the reference output data stored in file "ReferenceHVModel_Output.mat" available in the HILS library directory:

"<root>\HILS_GTR\Vehicles\ReferenceHybridVehicleModel\SimResults".

The SILS run output data shall be rounded to the same number of significant digits as specified in the reference output data file and shall meet the criteria listed in Table 10.

A.9.5. Build and verification of the specific HV model

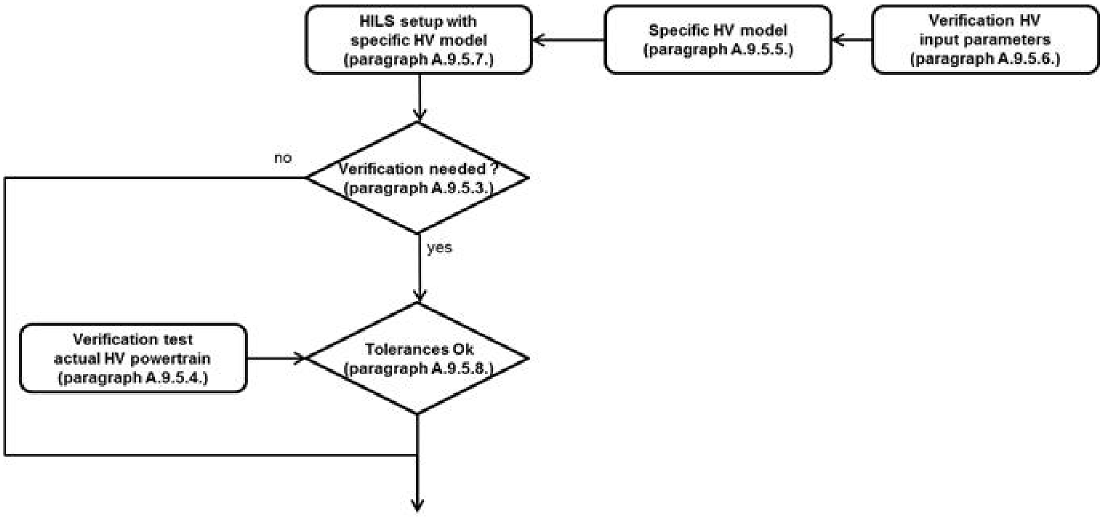
A.9.5.1. Introduction

This procedure shall apply as the build and verification procedure for the specific HV model as equivalent representation of the actual hybrid powertrain to be used with the HILS system setup in accordance with paragraph A.9.3.

A.9.5.2. General procedure

The diagram of Figure 20 provides an overview of the various steps towards the verified specific HV model.

Figure 20
Specific HV model build and verification flow diagram



A.9.5.3. Cases requiring verification of specific HV model and HILS system

The verification aims at checking the operation and the accuracy of the simulated running of the specific HV model. The verification shall be conducted when the equivalence of the HILS system setup or specific HV model to the test hybrid powertrain needs to be confirmed.

In case any of following conditions applies, the verification process in accordance with paragraph A.9.5.4. through A.9.5.8. shall be required:

(a) The HILS system including the actual ECU(s) is run for the first time~~, e.g. after changes to its hardware or actual ECU(s) calibration.~~.

(b) The HV system layout has changed.

(c) ~~Changes~~Structural 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) ~~Response delay times or time constants of (e.g. internal combustion engine or electric motor, gear shifting and so on) models are modified.~~

~~(f)~~ Changes are made to the interface model~~.~~ that have relevant impact on the hybrid functionality.

(~~g~~f) A manufacturer specific component model is used for the first time.

The type approval or certification authority may conclude that other cases exist and request verification.

The HILS system and specific HV model including the need for verification shall be subject to approval by the type approval or certification authority. All deviations that affect the above mentioned verification criteria shall be provided to the type approval or certification authority along with the rationale for justification and all appropriate technical information as proof therefore~~.~~, e.g. the deviation by changes to the HILS system hardware, modification of the response delay times or time constants of models. The technical information shall be based on calculations, simulations, estimations, description of the models, experimental results and so on.

A.9.5.4. Actual hybrid powertrain test

A.9.5.4.1 Specification and selection of the test hybrid powertrain

~~Reserved.~~

The test hybrid powertrain shall be the parent hybrid powertrain. If a new hybrid powertrain configuration is added to an existing family in accordance with paragraph 5.3.2., which becomes the new parent powertrain, HILS model validation is not required.

A.9.5.4.2. Test procedure

The verification test using the test hybrid powertrain (hereinafter referred to as the "actual powertrain test") which serves as the standard for the HILS system verification shall be conducted by either of the test methods described in paragraphs A.9.5.4.2.1. to A.9.5.4.2.2.

~~Provisions concerning~~

A.9.5.4.2.1. Powertrain dynamometer test

The test shall be carried out in accordance with the provisions of paragraphs A.10.3. and A.10.5. in order to determine the measurement ~~of~~items specified in paragraph A.9.5.4.4.

The measurement of the exhaust emissions may be omitted.

~~A.9.5.4.2.1. Powertrain dynamometer test~~

~~Reserved.~~

A.9.5.4.2.2. Chassis dynamometer test

~~Reserved.~~A.9.5.4.2.2.1. General introduction

The test shall be carried out on a chassis dynamometer with adequate characteristics to perform the test cycle specified in Annex 1.b.

The dynamometer shall be capable of performing an (automated) coastdown procedure to determine and set the correct road load values as follows:

(1) the dynamometer shall be able to accelerate the vehicle to a speed above the highest test cycle speed or the maximum vehicle speed, whichever is the lowest.

(2) run a coastdown

(3) calculate and subtract the $Dyno_{\mathrm{measured}}$ load coefficients from the $Dyno_{\mathrm{target}}$ coefficients

(4) adjust the $Dyno_{\mathrm{settings}}$

(5) run a verification coastdown

The dynamometer shall automatically adjust its $Dyno_{\mathrm{settings}}$ by repeating steps (1) through (5) above until the maximum deviation of the $Dyno_{\mathrm{measured}}$ load curve is less than 5 per cent of the $Dyno_{\mathrm{target}}$ load curve for all individual speeds within the test range.

The $Dyno_{\mathrm{target}}$ road load coefficients are defined as A, B and C and the corresponding road load is calculated as follows:

$$F_{roadload} = A + B \times v + C \times v^2 \qquad (112)$$

Where:

F_{roadload}	is the dynamometer road load, N
$Dyno_{\mathrm{measured}}$	are the A_{m}, B_{m} and C_{m} dynamometer coefficients calculated from the dynamometer coastdown run
$Dyno_{\mathrm{settings}}$	are the A_{set}, B_{set} and C_{set} coefficients which command the road load simulation done by the dynamometer
$Dyno_{\mathrm{target}}$	are the A_{target}, B_{target} and C_{target} dynamometer target coefficients in accordance with paragraphs A.9.5.4.2.2.2. through A.9.5.4.2.2.6.

Prior to execution of the dynamometer coastdown procedure, the dynamometer shall have been calibrated and verified in accordance with the dynamometer manufacturer specifications. The dynamometer and vehicle shall be preconditioned in accordance with good engineering judgement to stabilize the parasitic losses.

All measurement instruments shall meet the applicable linearity requirements of A.9.8.3.

All modifications or signals required to operate the hybrid vehicle on the chassis dynamometer shall be documented and reported to the type approval authorities or certification agency.

A.9.5.4.2.2.2. Vehicle test mass

The vehicle test mass m_{vehicle} shall be calculated using the hybrid system rated power P_{rated}, as specified by the manufacturer for the actual test hybrid powertrain, as follows:

$$m_{vehicle} = 15.1 \times P_{rated}^{1.31} \quad (113)$$

Where:

$m_{vehicle}$ is the vehicle test mass, kg

P_{rated} is the hybrid system rated power, kW

A.9.5.4.2.2.3. Air resistance coefficients

The vehicle frontal area A_{front} (m^2) shall be calculated as function of vehicle test mass in accordance with A.9.5.4.2.2.2. using following equations:

(a) for $m_{vehicle} \leq 18050$ kg :

$$A_{front} = -1.69 \times 10^{-8} \times m_{vehicle}^{2} + 6.33 \times 10^{-4} \times m_{vehicle} + 1.67 \quad (114)$$

or

(b) for $m_{vehicle} > 18050$ kg :

$$A_{front} = 7.59\ m^2 \quad (115)$$

The vehicle air drag resistance coefficient C_{drag} (-) shall be calculated as follows:

$$C_{drag} = \frac{3.6^2 \times (0.00299 \times A_{front} - 0.000832) \times g}{0.5 \times \rho_a \times A_{front}} \quad (116)$$

Where:

g is the gravitational acceleration with a fixed value of 9.80665 m/s^2

ρ_a is the air density with a fixed value of 1.17 kg/m^3

A.9.5.4.2.2.4. Rolling resistance coefficient

The rolling resistance coefficient (-) shall be calculated as follows:

$$f_{roll} = 0.00513 + \frac{17.6}{m_{vehicle}} \quad (118)$$

Where:

$m_{vehicle}$ is the test vehicle mass in accordance with paragraph A.9.5.4.2.2.2., kg

A.9.5.4.2.2.5. Rotating inertia

The inertia setting used by the dynamometer to simulate the vehicle inertia shall equal the vehicle test mass in accordance with paragraph A.9.5.4.2.2.2. No correction shall be carried out to account for axle inertias in the dynamometer load settings.

A.9.5.4.2.2.6. Dynamometer settings

The road load at a certain vehicle speed *v* shall be calculated using equation 112.

The *A*, *B* and *C* coefficients are as follows:

$$A = m_{vehicle} \times g \times f_{roll} \quad (X)$$

$$B = 0 \qquad \text{(X)}$$

$$C = \frac{1}{2} \times \rho_a \times C_{drag} \times A_{front} \qquad \text{(X)}$$

Where:

v	is the vehicle speed, m/s
m_{vehicle}	is the vehicle test mass in accordance with paragraph A.9.5.4.2.2.2., kg
f_{roll}	is the rolling resistance coefficient specified in accordance with paragraph A.9.5.4.2.2.4.
g	is the gravitational acceleration as specified in accordance with paragraph A.9.5.4.2.2.3., m/s^2
ρ_{a}	is the ambient air density as specified in accordance with paragraph A.9.5.4.2.2.3., kg/m^3
C_{drag}	is the vehicle air drag coefficient as specified in accordance with paragraph A.9.5.4.2.2.3.
A_{front}	is the vehicle frontal area as specified in accordance with paragraph A.9.5.4.2.2.3., m^2

A.9.5.4.2.2.7. Dynamometer road load simulation mode

The dynamometer shall be operated in a mode that it simulates the vehicle inertia and the road load curve defined by the Dyno$_{\mathrm{setting}}$ coefficients.

The dynamometer shall be capable of correctly implementing road gradients as defined in accordance with the test cycle in Annex 1.b. so that A effectively satisfies:

$$A = m_{vehicle} \times g \times f_{roll} \times \cos(\alpha_{road}) + m_{vehicle} \times g \times \sin(\alpha_{road}) \qquad \text{(X)}$$

$$\alpha_{road} = \operatorname{atan}(\alpha_{road}/100) \qquad \text{(X)}$$

Where:

α_{road}	is the road gradient, rad
$\alpha_{\mathrm{road\_pct}}$	is the road gradient as specified in Annex 1.b., per cent

A.9.5.4.3. Test conditions

A.9.5.4.3.1. Test cycle run

The test shall be conducted as a time-based test by running the full test cycle as defined in Annex 1.b. using the hybrid system rated power in accordance with the manufacturer specification.

A.9.5.4.3.2. Various system settings

The following conditions shall be met, if applicable:

(1) The road gradient shall not be fed into the ECU (level ground position) or inclination sensor should be disabled

(2) The ambient test conditions shall be between 20°C and 30°C

(3) Ventilation systems with adequate performance shall be used to condition the ambient temperature and air flow condition to represent on-road driving conditions.

(4) Continuous brake systems shall not be used or shall be switched off if possible

(5) All auxiliary or PTO systems shall be turned off or their power consumption measured. If measurement is not possible, the power consumption shall be based on calculations, simulations, estimations, experimental results and so on. Alternatively, an external power supply for 12/24V systems may be used.

(6) Prior to test start, the test powertrain may be key-on, but not enabling a driving mode, so that data communication for recording may be possible. At test start, the test powertrain shall be fully enabled to the driving mode.

(7) The chassis dynamometer roller(s) shall be clean and dry. The driven axle load shall be sufficient to prevent tire slip on the chassis dynamometer roller(s). Supplementary ballast or lashing systems to secure sufficient axle load may be applied.

(8) If the desired deceleration of the test cycle cannot be achieved by braking within the allowable errors in accordance with paragraph A.9.5.4.3.3., e.g. a heavy vehicle with one axle on the chassis dynamometer roller(s), the chassis dynamometer may assist decelerating the vehicle. This may result in a modification of the applied road gradient as specified in accordance with Annex 1.b. during these decelerations.

(9) Preconditioning of test systems:

For cold start cycles, the systems shall be soaked so that the system temperatures are between 20°C and 30°.

A warm start cycle shall be preconditioned by running of the complete test cycle in accordance with Annex 1.b. followed by a 10 minute (hot) soak.

A.9.5.4.3.3. Validation of vehicle speed

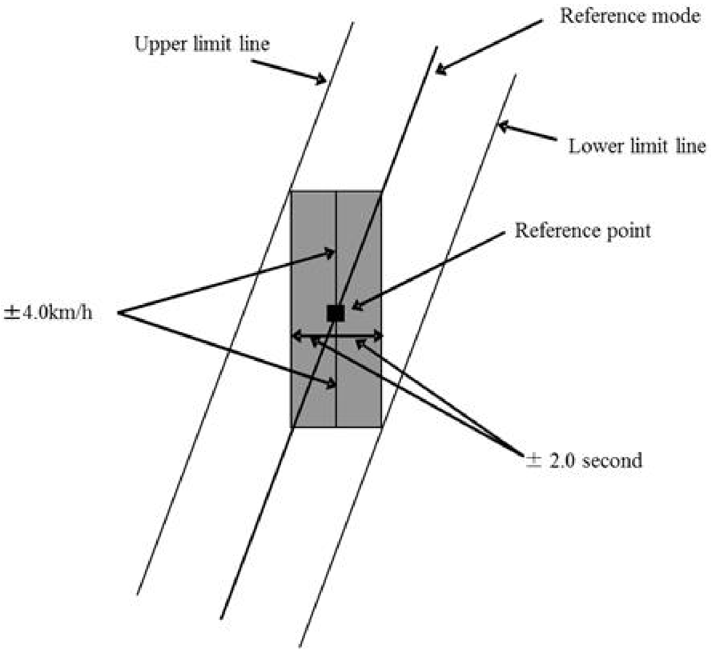
The allowable errors in speed and time during the actual powertrain test shall be, at any point during each running mode, within ±4.0 km/h in speed and ±2.0 second in time as shown with the coloured section in Figure 21. Moreover, if deviations are within the tolerance corresponding to the setting items posted in the left column of Table 11, they shall be deemed to be within the allowable errors. The duration of deviations at gear change operation as specified in accordance with paragraph A.9.5.8.1. shall not be included in the total cumulative time. In addition, this provision on error duration shall not apply in case the demanded accelerations and speeds are not obtained during periods where the accelerator pedal is fully depressed (maximum performance shall be requested from hybrid powertrain).

Table 11
Tolerances for vehicle speed deviations in chassis dynamometer test

Setting item	*Tolerance*
1. Tolerable time range for one deviation	< ±2.0 second
2. Tolerable time range for the total cumulative value of (absolute) deviations	< 2.0 seconds
3. Tolerable speed range for one deviation	< ±4.0 km/h

Figure 21

Tolerances for speed deviation and duration during chassis dynamometer test



A.9.5.4.3.4. Test data analysis

The testing shall allow for analysing the measured data in accordance with the following two conditions:

(a) Selected part of test cycle, defined as the period covering the first 140 seconds;

(b) The full test cycle.

A.9.5.4.4. Measurement items

For all applicable components, at least the following items shall be recorded using dedicated equipment and measurement devices (preferred) or ECU data (e.g. ~~using CAN signals). The accuracy of measuring devices shall be in accordance with the provisions of paragraphs 9.2. and A.8.8.3. The sampling frequency shall be 5 Hz 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"):~~using CAN signals) in order to enable the verification:

(a) ~~Hybrid system speed (min-1), hybrid system torque (Nm), hybrid system power (kW);~~

~~(b)~~ ~~Setpoint~~Target and actual vehicle speed (km/h);

(~~c~~b) Quantity of driver manipulation of the vehicle (typically accelerator, brake, clutch and shift operation signals, and alike) or quantity of manipulation on the engine dynamometer (throttle valve opening angle). All signals shall be in units as applicable to the system and suitable for conversion towards use in conversion and interpolation routines;

(~~d~~c) Engine speed (min^{-1}~~),~~) and engine command values (-, ~~%,~~per cent, Nm, units as applicable~~);~~

) or, alternatively, fuel injection value (e.g. mg/str);

(d) Electric motor speed (min^{-1}), torque command value (-, ~~%,~~per cent, Nm as applicable) (or their respective physically equivalent signals for non-electric energy converters);

(~~f~~e) (Rechargeable) energy storage system power (kW), voltage (V) and current (A) (or their respective physically equivalent signals for non-electric RESS).

The accuracy of measuring devices shall be in accordance with the provisions of paragraphs 9.2. and A.9.8.3.

The sampling frequency for all signals shall be 5 Hz or higher.

The recorded CAN signals in (d) and (e) shall be used for post processing using actual speed and the CAN (command) value (e.g. fuel injection amount) and the specific characteristic component map as obtained in accordance with paragraph A.9.8. to obtain the value for verification by means of the Hermite interpolation procedure (in accordance with appendix 1 to Annex 9).

All recorded and post process data so obtained shall become the actually-measured data for the HILS system verification (hereinafter referred to as the "actually-measured verification values").

A.9.5.5. Specific HV model

The specific HV model for approval shall be defined in accordance with A.9.3.5.(b) and its input parameters defined in accordance with A.9.5.6.

A.9.5.6. Specific HV model verification input parameters

A.9.5.6.1. General introduction

Input parameters for the applicable specific HV model components shall be defined as outlined in paragraphs A.9.5.6.2. to A.9.5.6.16.

A.9.5.6.2. Engine characteristics

The parameters for the engine torque characteristics shall be the table data obtained in accordance with paragraph A.9.8.3. However, values equivalent to or lower than the minimum engine revolution speed may be added.

A.9.5.6.3. Electric machine characteristics

The parameters for the electric machine torque and electric power consumption characteristics shall be the table data obtained in accordance with paragraph A.9.8.4. However, characteristic values at a revolution speed of 0 rpm may be added.

A.9.5.6.4. Battery characteristics

~~A.9.5.6.4.1. Resistor based model~~

The parameters for the ~~internal resistance and open-circuit voltage of the~~ battery model shall be the input data obtained in accordance with paragraph A.9.8.5.~~1.~~

~~A.9.5.6.4.2. RC-circuit based model~~

~~The parameters for the RC-circuit battery model shall be the input data obtained in accordance with paragraph A.9.8.5.2.~~

A.9.5.6.5. Capacitor characteristics

The parameters for the capacitor model shall be the data obtained in accordance with paragraph A.9.8.~~5.3~~6.

A.9.5.6.6. Vehicle test mass ~~and curb mass~~

The vehicle test mass ~~$m_{vehicle}$~~ shall be ~~calculated using the hybrid system rated power P_{rated},~~defined as ~~specified by the manufacturer~~ for the actual hybrid powertrain test ~~hybrid powertrain, as follows:~~in accordance with paragraph A.9.5.4.2.2.2.

~~(Eq. 114)~~

A.9.5.6.7. Air resistance coefficients

The ~~vehicle frontal area A_{front}~~air resistance coefficients shall be ~~calculated~~defined as ~~function of vehicle~~for the actual hybrid powertrain test ~~mass~~ in accordance with paragraph A.9.5. ~~(Eq. 117)~~

~~Where:~~

~~g : gravitational acceleration with a fixed value of 9.80665 (m/s^2)~~

~~ρ_a : air density w~~

A.9.5.6.8. Rolling resistance coefficient

The rolling resistance ~~coefficient~~coefficients shall be ~~calculated~~defined as ~~(Eq. 118)~~

~~Where:~~

~~$m_{vehicle}$~~ :for the

A.9.5.6.9. Wheel radius

The wheel radius shall be the manufacturer specified value as used in the actual test hybrid powertrain.

A.9.5.6.10. Final gear ratio

The final gear ratio shall be the manufacturer specified ratio representative for the actual test hybrid powertrain.

A.9.5.6.11. Transmission efficiency

The transmission efficiency shall be the manufacturer specified value for the transmission of the actual test hybrid powertrain.

A.9.5.6.12. Clutch maximum transmitted torque

For the maximum transmitted torque of the clutch and the synchronizer, the design value specified by the manufacturer shall be used.

A.9.5.6.13. Gear change period

The gear-change periods for a manual transmission shall be the actual test values.

A.9.5.6.14. Gear change method

Gear positions at the start, acceleration and deceleration during the verification test shall be the respective gear positions in accordance with the specified methods for the types of transmission listed below:

(a) For manual shift transmission: gear positions are defined by actual test values.

(b) For automated shift transmission (AMT) or automatic gear box (AT): gear positions are generated by the shift strategy of the actual transmission ECU during the HILS simulation run and shall not be the recorded values from the actual test.

A.9.5.6.15. Inertia moment of rotating sections

The inertia for all rotating sections shall be the manufacturer specified values representative for the actual test hybrid powertrain.

A.9.5.6.16. Other input parameters

All other input parameters shall have the manufacturer specified value representative for the actual test hybrid powertrain.

A.9.5.7. Specific HV model HILS run for verification

A.9.5.7.1. Method for HILS running

Use the HILS system pursuant to the provisions of paragraph A.9.3. and include the specific HV model for approval with its verification parameters (paragraph A.9.5.6.) to perform a simulated running pursuant to paragraph A.9.5.7.2. and record the calculated HILS data related to paragraph A.9.5.4.4. The data so obtained is the HILS simulated running data for HILS system verification (hereinafter referred to as the "HILS simulated running values").

Auxiliary loads measured in the actual test hybrid powertrain may be used as input to the auxiliary load models (either mechanical or electrical).

A.9.5.7.2. Running conditions

The HILS running test shall be conducted as one or two runs allowing for both of the following two conditions to be analysed (see Figure 21):

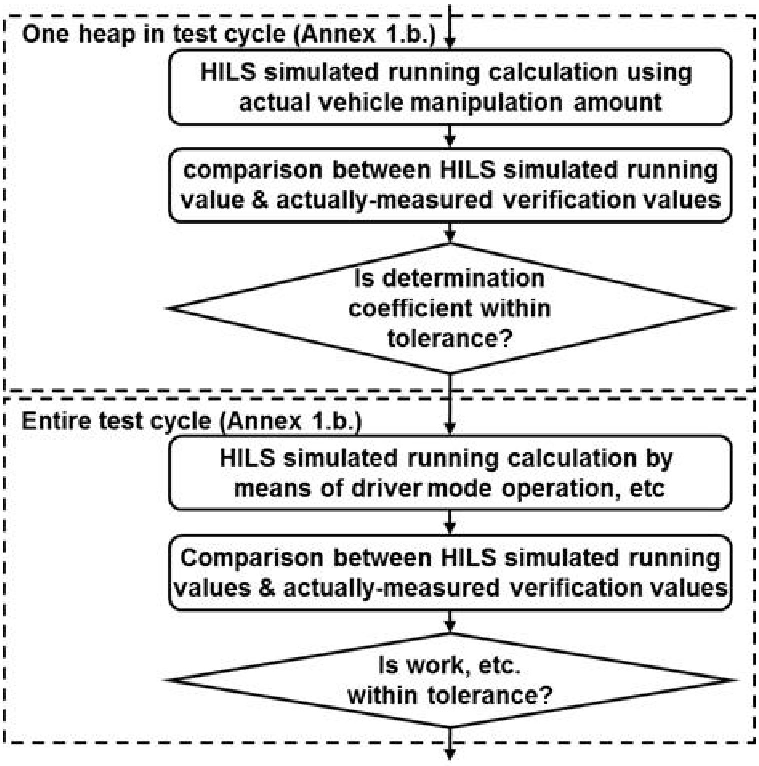
(a) Selected part of test cycle shall cover the first 140 seconds of the test cycle as defined in Annex 1.b. for which the road gradient are calculated using the manufacturer specified hybrid system rated power also applied for the actual powertrain test. The driver model shall output the recorded values as obtained in the actual hybrid powertrain test (paragraph A.9.5.4.) to actuate the specific HV model.

(b) The full test cycle as defined in Annex 1.b. for which the road gradients are calculated using the manufacturer specified hybrid system rated power also applied for the actual hybrid powertrain test. The driver model shall output all relevant signals to actuate the specific HV model based on either the reference test cycle speed or the actual vehicle speed as recorded in accordance with paragraph A.9.5.4.

~~If~~If the manufacturer declares that the resulting HEC engine operating conditions for cold and hot start cycles are different~~, both the~~ (e.g. due to the application of a specific cold ~~and hot~~ start ~~cycles~~strategy), a verification shall be ~~verified.~~carried out by use of the predicted temperature method in accordance with paragraphs A.9.6.2.18. and A.9.2.6.3.~~.~~ It shall then be proven that the predicted temperature profile of the elements affecting the hybrid control operation is equivalent to the temperatures of those elements measured during the HEC exhaust emission test run.

In order to reflect the actual hybrid powertrain test conditions (e.g. temperatures, RESS available energy content), the initial conditions shall be the same as those in the actual test and applied to component parameters, interface parameters and so on as needed for the specific HV model.

Figure 21
Flow diagram for verification test HILS system running with specific HV model



A.9.5.8. Validation statistics for verification of specific HV model for approval

A.9.5.8.1. Confirmation of correlation on the selected part of the test cycle

Correlation between the actually-measured verification values (as reference values) and the HILS simulated running values shall be verified for the selected test cycle part in accordance with paragraph A.9.5.7.2.(a). Table 11 shows the requirements for the tolerance criteria between those values. ~~Here, the data during gear change periods may be omitted for this regression analysis, but no more than a period of 2.0 seconds per gear change.~~

The following points may be omitted from the regression analysis:

(a) the gear change period

(b) 1.0 second before and after the gear change period

A gear change period is defined from the actually-measured values as:

(1) for gear change systems that require the disengagement and engagement of a clutch system, the period from the disengagement of the clutch to the engagement of the clutch,

or

(2) for gear change systems that do not require the disengagement or engagement of a clutch system, the period from the moment a gear is disengaged to the moment another gear is engaged.

The omission of test points shall not apply for the calculation of the engine work.

Table 11
Tolerances (for the selected part of the test cycle) for actually measured and HILS simulated running values for specific HV model verification

	Vehicle and/or engine	***Engine***		***Electric Motor (or equivalent)***		***Electric Storage Device (or equivalent)***
	Speed	***Torque***	***Power***	***Torque***	***Power***	***Power***
Coefficient of determination, r^2	**>0.97**	**>0.88**	**>0.88**	**>0.88**	**>0.88**	**0.88**

A.9.5.8.2. Overall verification for complete test cycle

A.9.5.8.2.1. 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 (in accordance with paragraph A.9.5.7.2.(b).). ~~Here, the data during gear change periods may be omitted for this regression analysis, but no more than a period of 2.0 seconds per gear change.~~

The following points may be omitted from the regression analysis:

(a) the gear change period

(b) 1.0 second before and after the gear change period

A gear change period is defined from the actually-measured values as:

(1) for gear change systems that require the disengagement and engagement of a clutch system, the period from the disengagement of the clutch to the engagement of the clutch,

or

(2) for gear change systems that do not require the disengagement or engagement of a clutch system, the period from the moment a gear is disengaged to the moment another gear is engaged.

The omission of test points shall not apply for the calculation of the engine work.

For the specific HV model to be considered valid, the criteria of Table 12 and those of paragraph A.9.5.8.1. shall be met.

Table 12

Tolerances (for full test cycle) for actually measured verification values and HILS simulated running values

	Vehicle speed	*Engine*	*Positive engine work*
		Torque	$\frac{W_{eng\_HILS}}{W_{eng\_test}}$
Coefficient of determination, r^2	**> 0.97**	**> 0.88**	
Conversion ratio			**0.97** < **…** < **Y**

Where:

W_{eng_HILS} ~~: Engine~~is the engine work in the HILS simulated running~~ (,~~ kWh~~)~~

W_{eng_test} ~~: Engine~~is the engine work in the actual powertrain test~~ (,~~ kWh~~)~~

~~Wsys_HILS : Hybrid system work in HILS simulated running (kWh)~~

~~Wsys_test : Hybrid system work in actual powertrain test (kWh)~~

A.9.5.8.2.2. Calculation method for verification items

The engine torque, power and the positive work shall be acquired by the following methods, respectively, in accordance with the test data enumerated below:

(a) Actually-measured verification values in accordance with paragraph A.9.5.4.:

Methods that are technically valid, such as a method where the value is calculated from the operating conditions of the hybrid system (revolution speed, shaft torque) obtained by the actual hybrid powertrain test, using the input/output voltage and current to/from the electric machine (high power) electronic controller, or a method where the value is calculated by using the data such acquired pursuant the component test procedures in paragraph A.9.8.

(b) HILS simulated running values in accordance with paragraph A.9.5.7:

A method where the value is calculated from the engine operating conditions (speed, torque) obtained by the HILS simulated running.

A.9.5.8.2.3. Tolerance of net energy change for RESS

The net energy changes in the actual hybrid powertrain test and that during the HILS simulated running shall satisfy the following equation:

$$|\Delta E_{HILS} - \Delta E_{test}|/W_{eng\_HILS} < 0.01 \qquad (119)$$

Where:

ΔE_{HILS} ~~: Net~~ is the net energy change of RESS during the HILS simulated running~~ (,~~ kWh~~)~~

ΔE_{test} ~~: Net~~ is the net energy change of RESS during the actual powertrain test~~ (,~~ kWh~~)~~

W_{eng_HILS} ~~: Positive~~is the positive engine work from the HILS simulated run~~ (,~~ kWh~~)~~

And where the net energy change of the RESS shall be calculated as follows in case of:

(a) Battery

~~(Eq.~~ $\Delta E = \Delta Ah \times V_{nominal}$ (120)

Where:

ΔAh ~~:~~ ~~Electricity~~is the electricity balance obtained by integration of the battery current~~(~~, Ah ~~)~~

V_{nominal} ~~:~~ ~~Rated~~ is the rated nominal voltage~~(~~, V~~)~~

(b) Capacitor

$$\Delta E = 0.5 \times C_{cap} \times \left(U_{final}^2 - U_{init}^2\right) \qquad (121)$$

Where:

C_{cap} ~~: Rated~~is the rated capacitance of the capacitor~~(~~, F~~)~~

U_{init} ~~: Initial~~is the initial voltage at start of test~~(~~, V~~)~~

U_{final} ~~: Final~~is the final voltage at end of test~~(~~, V~~)~~

(c) Flywheel:

$$\Delta E = 0.5 \times J_{flywheel} \times \left(\frac{\pi}{30}\right)^2 \times \left(n_{final}^2 - n_{init}^2\right) \qquad (122)$$

Where:

J_{flywheel} ~~: Flywheel~~is the flywheel inertia~~(~~, kgm^2~~)~~

n_{init} ~~: Initial~~is the initial speed at start of test~~(~~, min^{-1}~~)~~

n_{final} ~~: Final~~is the final speed at end of test~~(~~, min^{-1}~~)~~

(d) Other RESS:

The net change of energy shall be calculated using physically equivalent signal(s) as for cases (a) through (c) in this paragraph. This method shall be reported to the Type Approval Authorities or Certification Agency.

A.9.5.8.2.4. Additional provision on tolerances in case of fixed point engine operation

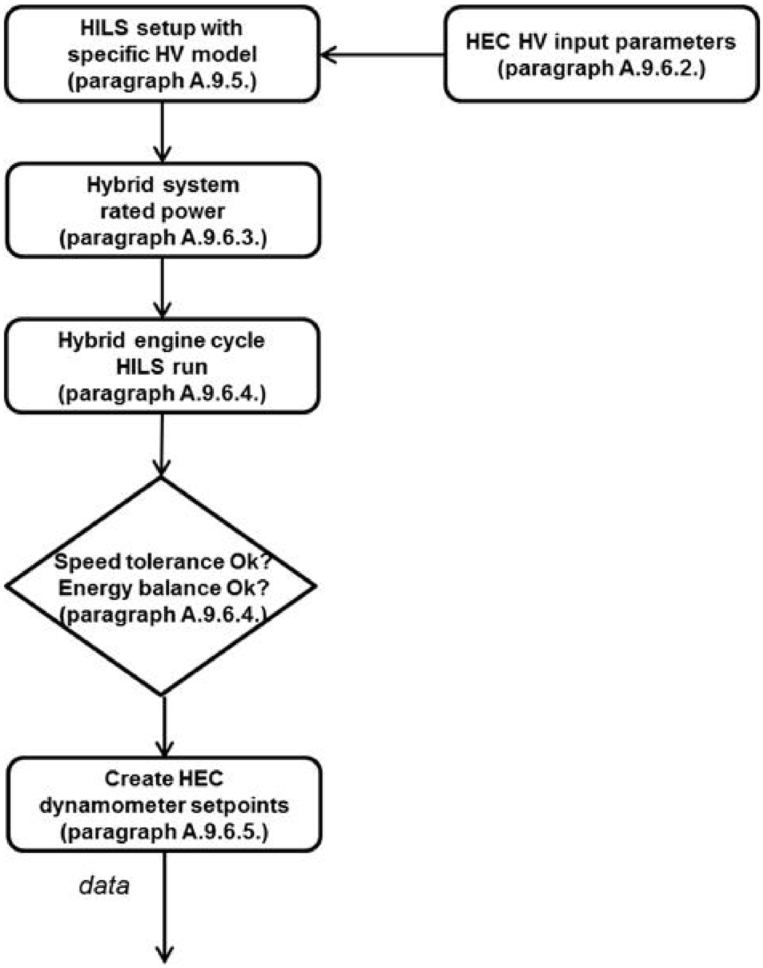
In case of fixed point engine operating conditions (both speed and torque), the verification shall be valid when the criteria for vehicle speed, positive engine work and engine running duration (same criteria as positive engine work) are met.

A.9.6. Creation of the hybrid engine cycle

A.9.6.1. General introduction

Using the verified HILS system setup with the specific HV model for approval, the creation of the hybrid engine cycle shall be carried out in accordance with the provisions of paragraphs A.9.6.2 to A.9.6.5. Figure 22 provides a flow diagram of required steps for guidance in this process.

Figure 22
Flow diagram for Creation of the Hybrid Engine Cycle



A.9.6.2. HEC run input parameters for specific HV model

A.9.6.2.1 General introduction

The input parameters for the specific HV model shall be specified as outlined in paragraphs A.9.6.2.2. to A.9.6.2.16. such as to represent a generic heavy-duty vehicle with the specific hybrid powertrain, which is subject to approval. All input parameter values shall be rounded to 4 significant digits (e.g. x.xxxEyy in scientific representation).

A.9.6.2.2. Engine characteristics

The parameters for the engine torque characteristics shall be the table data obtained in accordance with paragraph A.9.8.3. 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.~~

A.9.6.2.3. Electric machine characteristics

The parameters for the electric machine torque and electric power consumption characteristics shall be the table data obtained in accordance with paragraph A.9.8.4. However, characteristic values at a revolution speed of 0 rpm may be added.

A.9.6.2.4. Battery characteristics

~~A.9.6.2.4.1. Resistor based battery model~~

The ~~input~~ parameters for the ~~internal resistance and open-circuit voltage of the resistor based~~ battery model shall be the ~~table~~ data obtained in accordance with paragraph A.9.8.5.~~1.~~

~~A.9.6.2.4.2. RC-circuit based battery model~~

~~The parameters for the RC-circuit battery model shall be the data obtained in accordance with paragraph A.9.8.5.2.~~

A.9.6.2.5. Capacitor characteristics

The parameters for the capacitor model shall be the data obtained in accordance with paragraph A.9.8.6.

A.9.6.2.6. Vehicle test mass ~~and curb mass~~

The vehicle test mass shall be calculated as function of the system rated power (~~A.10.~~as declared by the manufacturer) in accordance with equation 112.

~~The vehicle curb mass shall be calculated using equations 113 and 114.~~

A.9.6.2.7. Vehicle frontal area and air drag coefficient

The vehicle frontal area shall be calculated using equation 115 and 116 using the test vehicle mass in accordance with paragraph A.9.6.2.6.

The vehicle air drag resistance coefficient shall be calculated using equation 117 and the test vehicle mass in accordance with paragraph A.9.6.2.6.

A.9.6.2.8. Rolling resistance coefficient

The rolling resistance coefficient shall be calculated by equation 118 using the test vehicle mass in accordance with paragraph A.9.6.2.6.

A.9.6.2.9. Wheel radius

The wheel radius shall be defined as 0.40 m or a manufacturer specified value~~, whichever~~. In case a manufacturer specified value is used, the wheel radius that represents the worst case with regard to ~~the~~ exhaust emissions shall be applied.

A.9.6.2.10. Final gear ratio and efficiency

The efficiency shall be set to 0.95.

The final gear 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 final gear ratio shall be calculated as follows:

$$r_{fg} = \frac{60 \times 2 \times \pi \times r_{wheel}}{1000 \times v_{max}} \times \frac{0.566 \times (0.45 \times n_{lo} + 0.45 \times n_{pref} + 0.1 \times n_{hi} - n_{idle}) \times 2.0327 + n_{idle}}{r_{gear\_high}} \quad (123)$$

Where:

r_{gear_high} ~~:~~ is the ratio of highest gear number for powertrain transmission ~~(-)~~

r_{wheel} ~~:~~ is the dynamic tire radius ~~(m)~~ in accordance with paragraph A.9.6.2.9~~.~~., m

v_{max} ~~:~~ is the maximum vehicle speed with a fixed value of 87 km/h

n_{lo}, n_{hi}, n_{idle}, n_{pref} ~~:~~ are the reference engine speeds in accordance with paragraph 7.4.6.

(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.

A.9.6.2.11. Transmission efficiency

In case of a parallel HV, the ~~following shall be used:~~

~~(a) The~~ efficiency of ~~the transmission shall be 0.98 for a direct transmission, and 0.95 for all others.~~

~~(b) The efficiency of the final reduction~~each gear shall be set to 0.95.

or:

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 the test hybrid powertrain 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.

A.9.6.2.12. Transmission gear ratio

The gear ratios of the (shift) transmission shall have the manufacturer specified values for the test hybrid powertrain.

A.9.6.2.13. Transmission gear inertia

The inertia of each gear of the (shift) transmission shall have the manufacturer specified value for the test hybrid powertrain.

A.9.6.2.14. Clutch maximum transmitted torque

For the maximum transmitted torque of the clutch and the synchronizer, the design value specified by the manufacturer for the test hybrid powertrain shall be used.

A.9.6.2.~~13~~15. Gear change period

The gear-change period for a manual transmission shall be set to one (1.0) second.

A.9.6.2.~~14~~16. 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:

(a) Parallel HV fitted with a manual shift transmission: gear positions are defined by the shift strategy in accordance with paragraph A.9.7.4.3. and shall be part of the driver model.

(b) Parallel HV fitted with automated shift transmission (AMT) or automatic shift transmission (AT): gear positions are generated by the shift strategy of the actual transmission ECU during the HILS simulation.

(c) Series HV: in case of a shift transmission being applied, the gear positions as defined by the shift strategy of the actual transmission ECU control shall be used.

A.9.6.2.~~15~~17. Inertia ~~moment~~ of rotating sections

Different inertia ~~moment~~ (J in kgm^2) of the rotating sections shall be used for the respective conditions as specified below:

In case of a parallel HV:

(a) The inertia ~~moment~~ of the section ~~from the gear on the driven side of~~between the (shift) transmission output shaft up to and including the ~~tyres~~wheels shall be calculated ~~that it matches 7 per cent of~~using the vehicle curb mass $m_{vehicle,0}$ ~~(paragraph A.9.6.2.6.) multiplied by the squared~~ and wheel radius r_{wheel} (in accordance with paragraph A.9.6.2.9~~.6.2.9~~.) as follows:

$$J_{drivetrain} = 0.07 \times m_{vehicle,0} \times r_{wheel}^2 \qquad (124)$$

The vehicle curb mass $m_{vehicle,0}$ shall be calculated as function of the vehicle test mass in accordance with following equations:

(1) for $m_{vehicle} \le 35240$ kg :

$$m_{vehicle,0} = -7.38 \times 10^{-6} \times m_{vehicle}^2 + 0.604 \times m_{vehicle} \qquad (113)$$

or

(2) for $m_{vehicle} > 35240$ kg :

$$m_{vehicle,0} = 12120\ kg \qquad (114)$$

The wheel inertia parameter shall be used for the total drivetrain inertia. All inertias parameters from the transmission output shaft up to, and excluding, the wheel shall be set to zero.

(b) The inertia ~~moment~~ of the section from the engine to the ~~gear on the driving side~~output of the (shift) transmission shall be the manufacturer specified value(s~~).~~) for the test hybrid powertrain.

In case of a 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 for the test hybrid powertrain.

A.9.6.2.~~16~~18. Predicted input temperature data

In case the predicted temperature method is used, the predicted temperature profile of the elements affecting the hybrid control shall be defined through input parameters in the software interface system.

A.9.6.2.19. Other input parameters

All other input parameters shall have the manufacturer specified value ~~representative~~ for the ~~worst case exhaust emissions.~~test hybrid powertrain.

A.9.6.3. Hybrid ~~Power Mapping~~system rated power determination

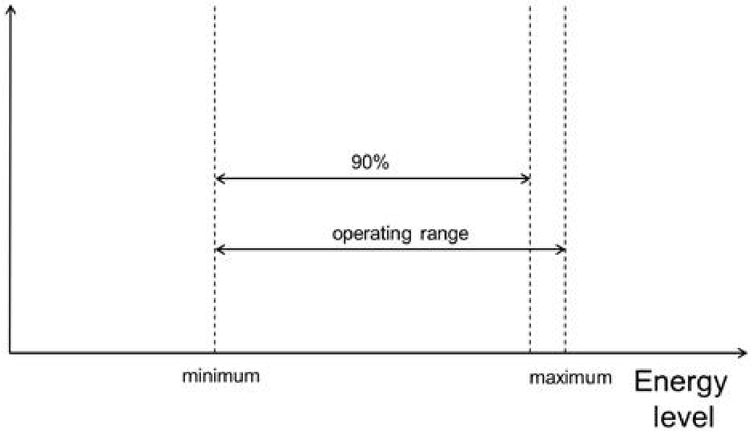
~~Reserved.~~

The rated power of the hybrid system shall be determined as follows:

(a) The initial energy level of the RESS at start of the test shall be equal or higher than 90 per cent of the operating range between the minimum and maximum RESS energy levels that occur in the in-vehicle usage of the storage as specified by the manufacturer. In case of a battery this energy level is commonly referred to as SOC.

Prior to each test , it shall be ensured that the conditions of all hybrid system components shall be within their normal operating range as declared by the manufacturer and restrictions (e.g. power limiting, thermal limits, etc.) shall not be active.

Figure 23
Initial energy level at start of test



(b) Set maximum driver demand for a full load acceleration starting from the initial speed condition and applying the respective constant road gradient as specified in table XXX. The test run shall be stopped 30 seconds after the vehicle speed is no longer increasing to values above the already observed maximum during the test.

(c) Record hybrid system speed and torque values at the wheel hub (HILS chassis model output signals in accordance with paragraph A.9.7.3.) with 100Hz to calculate P_{sys_HILS}.

(d) Repeat (a), (b), (c) for all test runs specified in table XXX. All deviations from Table XXX conditions shall be reported to the type approval and certification authority along with all appropriate information for justification therefore.

All provisions defined in (a) shall be met at the start of the full load acceleration test run.

Table XXX
Hybrid system rated power conditions

Road gradient (per cent)	*Initial vehicle speed (km/h)*		
	0	30	60
0	test #1	test #4	test #7
2	test #2	test #5	test #8
6	test #3	test #6	test #9

(e) Calculate the hybrid system power for each test run from the recorded signals as follows:

$$P_{sys} = P_{sys\_HILS} \times \left(\frac{1}{0.95}\right)^2 \qquad (X)$$

Where:

P_{sys} is the hybrid system power, kW

P_{sys_HILS} is the calculated hybrid system power in accordance with paragraph A.9.6.3.(c), kW

(f) The hybrid system rated power shall be the highest determined power where the coefficient of variation *COV* is below 2 per cent:

$$P_{rated} = max(P_{sys}(COV < 0.02)) \qquad (X)$$

For the results of each test run, the power vector $P_{\mu}(t)$ shall be calculated as the moving averageing of 20 consecutive samples of P_{sys} in the 100 Hz signal so that $P_{\mu}(t)$ effectively shall be a 5 Hz signal.

The standard deviation $\sigma(t)$ is calculated using the 100 Hz and 5 Hz signals:

$$\sigma(t) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - P_{\mu}(t))^2} \qquad (X)$$

Where:

x_i are the N=20 samples in the 100 Hz signal previously used to calculate the respective $P_{\mu}(t)$ values at the time step t, kW

The resulting power and covariance signals shall now be effectively 5 Hz traces covering the test time and these shall be used to determine hybrid system rated power.

The covariance *COV*(t) shall be calculated as the ratio of the standard deviation $\sigma(t)$ to the mean value of power $P_{\mu}(t)$ for each time step t.

$$COV(t) = \sigma(t)/P_{\mu}(t) \qquad (X)$$

If the determined hybrid system rated power is outside ± 3 per cent of the hybrid system rated power as declared by the manufacturer, the HILS verification in accordance with paragraph A.9.5. shall be repeated using the HILS determined hybrid system rated power instead of the manufacturer declared value.

If the determined hybrid system rated power is inside ± 3 per cent of the hybrid system rated power as declared by the manufacturer, the declared hybrid system rated power shall be used.

A.9.6.4. Hybrid Engine Cycle HILS run

A.9.6.4.1. General introduction

The HILS system shall be run in accordance with paragraphs A.9.6.4.2. through A.9.6.4.5. for the creation of the hybrid engine cycle using the full test cycle as defined in Annex 1.b.

A.9.6.4.2. HILS run data to be recorded

At least following input and calculated signals from the HILS system shall be recorded at a frequency of 5 Hz or higher (10 Hz recommended):

(a) ~~Setpoint~~Target and actual vehicle speed (km/h)

(b) (Rechargeable) energy storage system power (kW), voltage (V) and current (A) (or their respective physically equivalent signals in case of another ~~rechargeable energy storage system~~type of RESS)

(c) Hybrid system speed (min^{-1}), hybrid system torque (Nm), hybrid system power (kW) at the wheel hub (in accordance with paragraph A.9.2.6.2.)

(d) Engine speed (min^{-1}), engine torque (Nm) and engine power (kW)

(e) Electric machine speed(s) (min^{-1}), electric machine torque(s) (Nm) and electric machine mechanical power(s) (kW) as well as the electric machine(s) (high power) controller current (A), voltage and electric power (kW) (or their physically equivalent signals in case of a non-electrical HV powertrain)

(d) Quantity of driver manipulation of the vehicle (typically accelerator, brake, clutch and shift operation signals and so on).

A.9.6.4.3. HILS run adjustments

In order to satisfy the tolerances defined in paragraphs A.9.6.4.4. and A.9.6.4.5., following adjustments in interface and driver may be carried out for the HILS run:

(a) Quantity of driver manipulation of the vehicle (typically accelerator, brake, clutch and manual gear shift operation signals)

(b) Initial value for available energy content of Rechargeable Energy Storage System

In order to reflect cold or hot start cycle conditions, following initial temperature conditions shall be applied to component, interface parameters, and so on:

(1) 25 °C for a cold start cycle

(2) The specific warmed-up state operating condition for a hot start cycle, either following from a cold start and soak period by HILS run of the

model or in accordance with the manufacturer specified running conditions for the warmed up operating conditions.

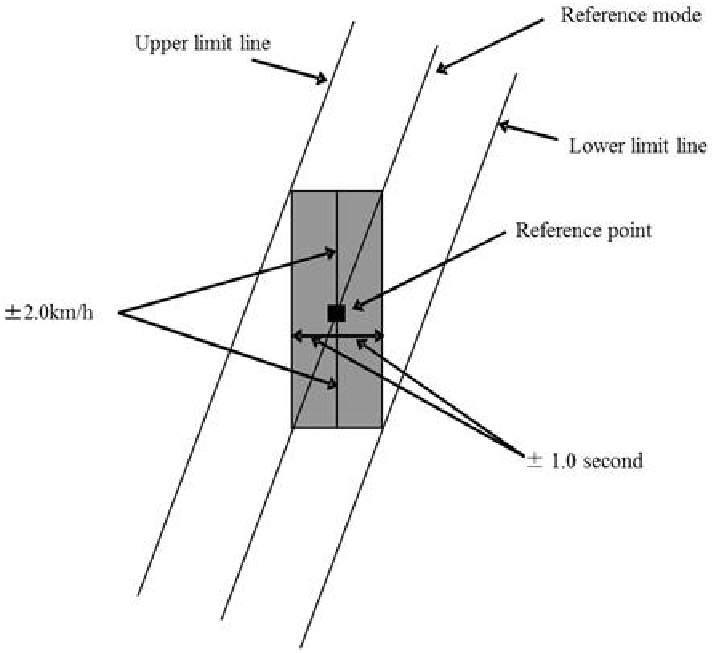
A.9.6.4.4. Validation of vehicle speed

The 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 ±1.0 second in time as shown with the coloured section in Figure 23. Moreover, if deviations are within the tolerance corresponding to the setting items posted in the left column of Table 13, they shall be deemed to be within the allowable errors. Time deviations at the times of test start and gear change operation, however, shall not be included in the total cumulative time. In addition, this provision shall not apply in case demanded accelerations and speeds are not obtained during periods where the accelerator pedal is fully depressed (maximum performance shall be requested from hybrid powertrain).

Table 13
Tolerances for vehicle speed deviations

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	< ±2.0 km/h

Figure ~~23~~24
Tolerances for speed deviation and duration during HILS simulated running



A.9.6.4.5. Validation of RESS net energy change

The initial available energy content of the RESS shall be set so that the ratio of the RESS net energy change to the (positive) engine work shall satisfy the following equation:

~~(Eq.~~ $|\Delta E / W_{eng\_HILS}| < 0.03$ (125)

Where:

ΔE ~~:~~ ~~Net~~ is the net energy change of the RESS in accordance with paragraph A.9.5.8.2.3.(a)-(d~~) (~~), kWh~~)~~

$W_{\text{eng\_}}$~~ref~~ ~~:~~ ~~Integrated positive~~$_{\text{HILS}}$ is the engine ~~shaft power~~work in the HILS simulated run~~ (~~, kWh~~)~~

A.9.6.5. Hybrid Engine Cycle dynamometer setpoints

A.9.6.5.1. From the HILS system generated data in accordance with paragraph A.9.6.4., select and define the engine speed and torque values at a frequency of at least 5 Hz (10 Hz recommended) as the command setpoints for the engine exhaust emission test on the engine dynamometer.

If the engine is not capable of following the cycle, smoothing of the 5 Hz or higher frequency signals to 1 Hz is permitted with the prior approval of the type approval or certification authority. In such case, the manufacturer shall demonstrate to the type approval or certification authority, why the engine cannot satisfactorily be run with a 5 Hz or higher frequency, and provide the technical details of the smoothing procedure and justification as to its use will not have an adverse effect on emissions.

A.9.6.5.2. Replacement of test torque value at time of motoring

When the test torque command setpoint obtained in paragraph A.9.6.5.1. is negative, this negative torque value shall be replaced by a motoring request on the engine dynamometer.

A.9.7. ~~Hils~~HILS component models

A.9.7.1. General introduction

Component models in accordance with paragraphs A.9.7.2. to A.9.7.9. shall be used for constructing both the reference HV model and the specific HV model. A Matlab®/Simulink® library environment that contains implementation of the component models in accordance with these specifications is available at:

http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/~~wp29glob_registry~~wp29globregistry.html.

Parameters for the component models are defined in three (3) categories, regulated parameters, manufacturer specified parameters and tuneable parameters. Regulated parameters are parameters which shall be determined in accordance with paragraphs A.8.6.2 and A.9.8. The manufacturer specified parameters are model parameters that are vehicle specific and that do not require a specific test procedure in order to be determined. The tuneable parameters are parameters that can be used to tune the performance of the component model when it is working in a complete vehicle system simulation.

A.9.7.2. Auxiliary system model

A.9.7.2.1. Electric Auxiliary model

The electrical auxiliary system~~ (likely required~~, valid for both high and low voltage ~~loads only)~~auxiliary application, shall be modelled as a ~~constant~~ ~~(~~controllable~~ desired)~~ electrical power loss, $P_{el,aux}$. The current that is discharging the electrical energy storage, i_{aux}, is determined as:

~~(Eq.~~ $$i_{el,aux} = P_{el,aux}/u \quad (126)$$

Where:

$P_{el,aux}$ ~~:~~is the electric auxiliary power demand~~ (~~, W~~)~~

~~x : on/off/duty-cycle control signal to control auxiliary load level (-)~~

u ~~:~~is the electrical DC-bus voltage~~ (~~, V~~)~~

$i_{el,aux}$ ~~:~~is the auxiliary current~~ (~~, A~~)~~

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 14.

Table 14
Electrical ~~Auxiliary~~auxiliary model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
~~Parameter~~	~~$P_{el,aux}$~~	~~W~~	~~Auxiliary system load~~	~~dat.auxiliaryload.value~~
Command Signal	~~x~~$P_{el,aux}$	~~0-1~~W	Control signal for auxiliary system power ~~level~~demand	Aux_~~flgOnOff_B~~pwrElecReq_W
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

A.9.7.2.2. Mechanical Auxiliary model

The mechanical auxiliary system shall be modelled using a controllable power loss, $P_{mech,aux}$. The power loss shall be implemented as a torque loss acting on the representative shaft.

$$M_{mech,aux} = P_{mech,aux}/\omega \quad (127)$$

Where:

$P_{mech,aux}$ ~~:~~is the mechanical auxiliary power demand~~ (~~, W~~)~~

~~x : on/off/duty-cycle signal to control auxiliary load level (-)~~

ω ~~:~~is the shaft rotational speed~~ (~~, min^{-1}~~)~~

$M_{mech,aux}$ ~~:~~is the auxiliary torque~~ (~~, Nm~~)~~

An auxiliary inertia load J_{aux} shall be part of the model and affect the powertrain inertia.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 15.

Table 15
Mechanical ~~Auxiliary~~auxiliary model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*

~~Parameter~~	~~$P_{mech,aux}$~~	~~W~~	~~Auxiliary system load~~	~~dat.auxiliaryload.value~~
Parameter	J_{aux}	kgm^2	Inertia	Dat.inertia.value
Command signal	~~x~~$P_{mech,aux}$	~~0-1~~W	Control signal for auxiliary system power demand	Aux_~~flgOnOff_B~~pwrMechReq_W
Sensor signal	~~M_{out}~~M_{aux}	Nm	Auxiliary system torque output	Aux_tqAct_A
Mech ~~in~~out [Nm]	~~M_{out}~~M_{aux}	Nm	Torque	phys_torque_Nm
	~~J_{out}~~J_{aux}	kgm^2	Inertia	phys_inertia_kgm2
Mech fb ~~out~~in [rad/s]	ω	rad/s	~~speed~~Speed	phys_speed_radps

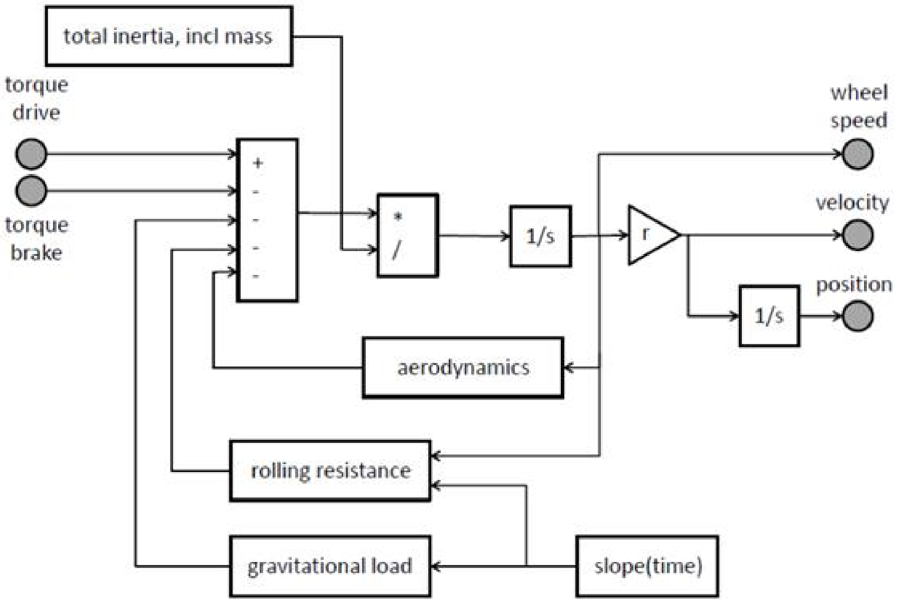
Table XXX
Mechanical auxiliary model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_{aux}	Manufacturer specified	-

A.9.7.3. 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 include rolling and aerodynamic drag resistances and take into account the road slope resistance. A schematic diagram is shown in Figure 24.

Figure ~~24~~25
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}.~~

The drive torque M_{drive} shall be counteracted by the friction brake torque ~~M_{brake}. The resulting~~M_{fric_brake}. The brake torque actuator shall be modelled as a first order system as follows:

$$\dot{M}_{fric\_brake} = -\frac{1}{\tau_1}\left(M_{fric\_brake} - M_{fric\_brake,des}\right) \qquad \text{(XXX)}$$

Where:

$M_{\text{fric\_brake}}$ is the friction brake torque~~ shall be converted to~~, Nm

$M_{\text{fric\_brake,des}}$ is the ~~drive force using~~desired friction brake torque, Nm

τ_1 is the ~~wheel radius r_{wheel} in accordance with equation 129 and acts on the road to drive the vehicle:~~ friction brake actuator time response constant

~~(Eq. 129)~~

The ~~force F_{drive}~~total drive torque shall balance with ~~forces~~torques for aerodynamic drag ~~F_{aero}~~M_{aero}, rolling resistance ~~F_{roll}~~M_{roll} and gravitation ~~F_{grav}~~M_{grav} to find resulting acceleration ~~force according~~ torque in accordance with differential equation 130:

$$J_{tot}\dot{\omega}_{wheel} = M_{drive} - M_{fric\_brake} - M_{aero} - M_{roll} - M_{grav} \qquad (130)$$

Where:

~~m_{tot}~~ : J_{tot} is the total ~~mass~~inertia of the vehicle ~~(kg)~~, kgm^2

$\dot{\omega}_{wheel}$ is the wheel rotational acceleration ~~(m~~, rad/s~~)~~

The total ~~mass~~inertia of the vehicle ~~m_{tot}~~J_{tot} shall be calculated using the vehicle mass $m_{vehicle}$ and the inertia load from the powertrain components:

$$J_{tot} = m_{vehicle} \times r_{fg}^2 + J_{powertrain} + J_{wheel} \qquad (131)$$

Where:

m_{vehicle} ~~: Mass~~is the mass of the vehicle ~~(~~, kg~~)~~

~~J_{fg} : Inertia of the final gear (kgm^2)~~

$J_{\text{powertrain}}$ ~~: Sum~~is the sum of all powertrain inertias ~~(~~, kgm^2~~)~~

J_{wheel} ~~: Inertia~~is the inertia of the wheels ~~(~~, kg/m^2~~)~~

The ~~wheel~~vehicle speed v_{vehicle} shall be determined from the ~~vehicle~~wheel speed ω_{wheel} and wheel radius r_{wheel} as:

$$v_{vehicle} = \omega_{wheel} \times r_{wheel} \qquad (132)$$

The aerodynamic ~~drag force~~torque shall be calculated as:

$$M_{aero} = 0.5 \times \rho_a \times C_{drag} \times A_{front} \times v_{vehicle}^2 \times r_{wheel} \qquad (133)$$

Where:

~~P_{air}~~ ~~:~~ρ_{a} is the air density ~~(~~, kg/m^3~~)~~

C_{drag} ~~:~~is the air drag coefficient ~~(-)~~

A_{front} ~~:~~is the total vehicle frontal area ~~(~~, m^2~~)~~

v_{vehicle} ~~:~~ is the vehicle speed~~(,~~ m/s~~)~~

The rolling resistance and gravitational torque shall be calculated ~~using~~as follows:

~~(Eq. 134)~~

$$M_{roll} = f_{roll} \times m_{vehicle} \times g \times \cos(\alpha_{road}) \times r_{wheel} \qquad (134)$$

$$M_{grav} = m_{vehicle} \times g \times \sin(\alpha_{road}) \times r_{wheel} \qquad (XXX)$$

Where:

f_{roll} ~~:~~is the friction factor for wheel-road contact ~~(-)~~

g ~~:~~is the standard earth gravitation~~(,~~ m/s^2~~)~~

~~α~~ ~~:~~ α_{road} is the road slope~~(,~~ rad

The positive hybrid system work shall be determined in the chassis model as:

$$W_{sys} = \int_0^T max(0, M_{drive}) \times \omega_{wheel}\, dt \qquad (134)$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 16.

Table 16
Chassis model parameters and interface

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~~C_{drag}	-	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~~f_{roll}	-	Rolling resistance coefficient	dat.wheel.rollingres.value
	τ_1		Brake actuator time constant	dat.brakeactuator.timeconstant.value
Command signal	M_{brake}	Nm	Requested brake torque	~~Chassis~~chassis_tqBrakeReq_Nm
Sensor signal	v_{vehicle}	m/s	Actual vehicle speed	~~Chassis~~chassis_vVehAct_mps
	ω_{wheel}	rad/s	Actual wheel speed	~~Chassis~~chassis_nWheelAct_radps

	m_{tot}	kg	Vehicle mass	~~Chassis~~chassis_massVehAct_kg
	M_{drive}	Nm	Actual wheel hub torque	chassis_tqSysAct_Nm
	~~α~~α_{road}	rad	Road slope	~~Chassis~~chassis_slopRoad_rad
Mech in [Nm]	M_{drive}	Nm	~~torque~~Torque	phys_torque_Nm
	$J_{powertrain}$	kgm^2	~~inertia~~Inertia	phys_inertia_kgm2
Mech fb out [rad/s]	ω_{wheel}	rad/s	Rotational speed	phys_speed_radps

Table XXX
Chassis model parameters

Parameter	*Parameter type*	*Reference paragraph*
$m_{vehicle}$	Regulated	A.9.5.6.X., A.9.6.2.X., A.10.X.X.
A_{front}	Regulated	A.9.5.6.X., A.9.6.2.X., A.10.X.X.
C_{drag}	Regulated	A.9.5.6.X., A.9.6.2.X., A.10.X.X.
r_{wheel}	Regulated	A.9.5.6.X., A.9.6.2.X., A.10.X.X.
J_{wheel}	Regulated	A.9.5.6.X., A.9.6.2.X., A.10.X.X.
f_{roll}	Regulated	A.9.5.6.X., A.9.6.2.X., A.10.X.X.
τ_1	Tuneable	default: 0.1 second

A.9.7.4. Driver ~~model~~models

The driver model shall actuate the 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. Three different models are available in the standardized HILS library.

~~Figure 25~~

A.9.7.4.1 Driver output of recorded data

Recorded driver output data from actual powertrain tests may be used to run the vehicle model ~~diagram~~ –in open loop mode. The ~~driver model was prepared by following a modular approach~~ data for the accelerator pedal, the brake pedal and ~~therefore contains different sub-modules. The model shown in Figure 25 is capable of running a vehicle equipped~~ , in case a vehicle with ~~either~~ a manual ~~gearbox with accelerator, brake and clutch pedal signals or a vehicle equipped with an automated gearbox where only accelerator and brake pedal are used. For the manual~~ shift transmission ~~vehicle the decisions for gear shift manoeuvres are taken by the gear selector submodule. For automated gearboxes this is bypassed but can be enabled also if needed.~~

~~The presented 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~~is represented, the clutch pedal~~;~~

~~(d) Sub-module switching signals when either a manual or an automated gearbox is used.~~

~~For specific demands, the individual sub-modules (as listed above) can~~ and gear position shall therefore be ~~easily removed or be copied to manufacturer specific driver models.~~

~~Details for the submodules (a) through (d) are given below:~~

~~(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 to 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~~provided in a dataset as a 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 26 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 for the transmission;~~
- ~~Status of the drivetrain (next gear engaged and all clutches closed and synchronized again).~~

~~Figure 26:~~
~~Gear shift model using polygons~~

~~Internally, also the test cycle and the~~ time ~~of clutch actuation during a shift manoeuvre are loaded in order to detect vehicle starts form 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 ~~17~~X.

Table ~~17~~ X
Driver model parameters and interface

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.clutchthershold.value~~
		~~-~~	~~Driver PID controller~~	~~dat.controller~~
Command signal	$pedal_{brake}$	0-1	~~Accelerator~~Requested brake pedal position	Drv_~~AccPedl_rat~~BrkPedl_Rt
	$pedal_{accelerator}$	0-1	~~Brake~~Requested accelerator pedal position	Drv_~~BrkPedl_rat~~AccPedl_Rt
	$pedal_{clutch}$	0-1	~~Clutch~~Requested clutch pedal position	Drv_CluPedl_~~rat~~Rt

	-	-	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~~

A.9.7.4.2 Driver model for vehicles without a shift transmission or equipped with automatic or automated manual transmissions

The driver model is represented by a commonly known PID-controller. The model output is depending on the difference between the reference target speed from the test cycle and the actual vehicle speed feedback. For vehicle speeds below the desired speed the accelerator pedal is actuated to reduce the deviation, for vehicle speeds greater than the desired speed the brake pedal is actuated. An anti-windup function is included for vehicles not capable of running the desired speed (e.g. their design speed is lower than the demanded speed) to prevent the integrator windup. When the reference speed is zero the model always applies the brake pedal to prevent moving of the vehicle due to gravitational loads. For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Table X
Driver model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	K_P K_I K_D	- - -	PID controller parameters	dat.controller.p.value dat.controller.i.value dat.controller.d.value
	K_K	-	Anti-windup term	dat.controller.k.value
Command signal	$pedal_{brake}$	0-1	Requested brake pedal position	Drv_BrkPedl_Rt
	$pedal_{accelerator}$	0-1	Requested accelerator pedal position	Drv_AccPedl_Rt
	-	m/s	Reference target speed	Drivecycle_RefSpeed_mps
Sensor signal	$v_{vehicle}$	m/s	Actual vehicle speed	Chassis_vVehAct_mps

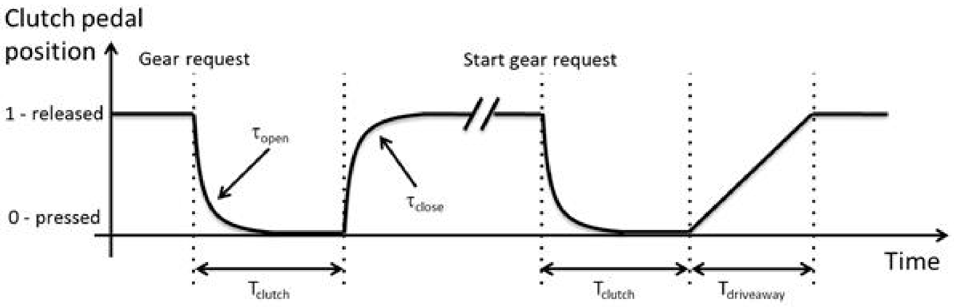
Table XXX
Driver model parameters

Parameter	*Parameter type*	*Reference paragraph*
K_P, K_I, K_D	Tuneable	-
K_K	Tuneable	-

A.9.7.4.3 Driver model for vehicles equipped with manual transmission

The driver model consist of a PID-controller as described in A.9.7.4.2, a clutch actuation module and a gearshift logic as described in A.9.7.4.3.1. The gear shift logics module requests a gear change depending on the actual vehicle running condition. This induces a release of the accelerator pedal and simultaneously actuates the clutch pedal. The accelerator pedal is fully released until the drivetrain is synchronized in the next gear, but at least for the specified clutch time. Clutch pedal actuation of the driver (opening and closing) is modelled using a first order transfer function. For starting from standstill, a linear clutch behaviour is realized and can be parameterized separately (see Figure X).

Figure 26
Clutch pedal operation (example)



For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X.

Table X
Driver model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	K_P K_I K_D	- - -	PID controller parameters	dat.controller.p.value dat.controller.i.value dat.controller.d.value
	K_K	-	Anti-windup term	dat.controller.k.value

	T_{clutch}	s	Specified clutch time	dat.clutchtime.value
	τ_{open}	s	Opening time constant	dat.clutchtime.open.value
	τ_{close}	s	Closing time constant	dat.clutchtime.close.value
	$T_{\mathrm{driveaway}}$	s	Closing time at drive away	dat.clutchtime.driveaway.value
Command signal	$pedal_{\mathrm{brake}}$	0-1	Requested brake pedal position	Drv_BrkPedl_Rt
	$pedal_{\mathrm{accelerator}}$	0-1	Requested accelerator pedal position	Drv_AccPedl_Rt
	-	m/s	Reference target speed	Drivecycle_RefSpeed_mps
	-	-	Gear request	Drv_nrGearReq
	$pedal_{\mathrm{clutch}}$	0-1	Requested clutch pedal position	Drv_CluPedl_Rt
Sensor signal	v_{vehicle}	m/s	Actual vehicle speed	Chassis_vVehAct_mps
	ω_{in}	rad/s	Transmission input speed	Transm_nInAct_radps
	-	-	Actual gear engaged	Transm_nrGearAct
	-	Boolean	Clutch disengaged or not	Clu_flgConnected_B

Table XXX
Driver model parameters

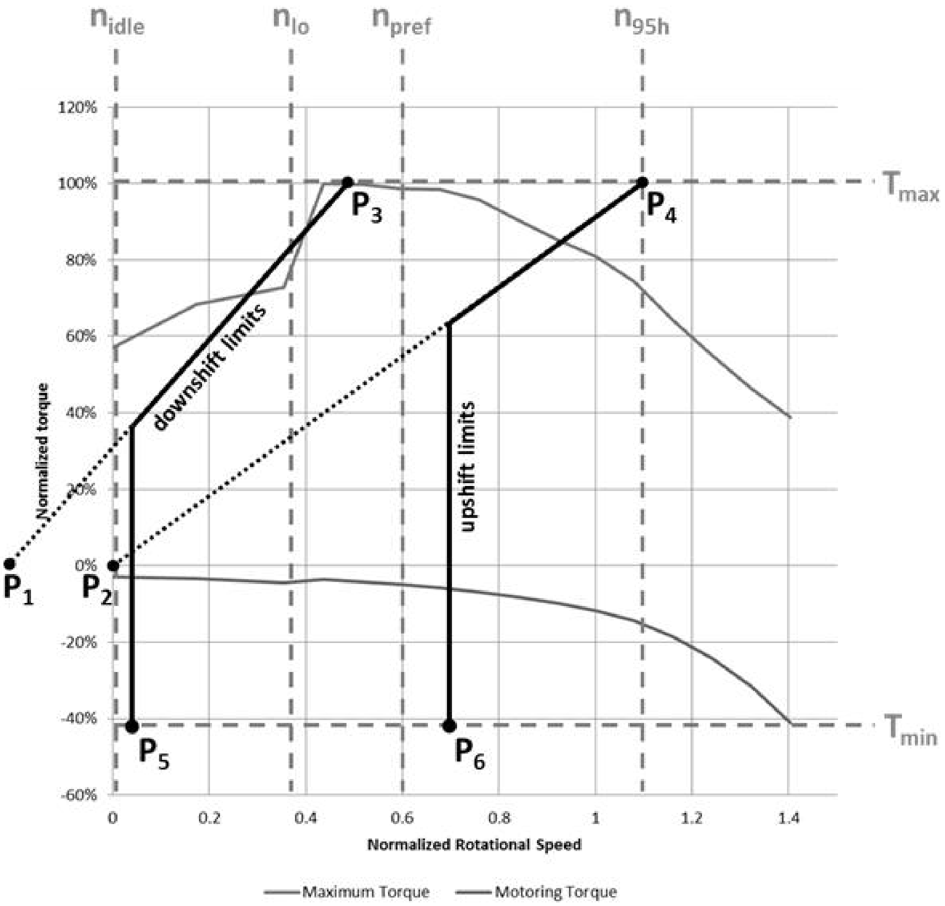
Parameter	*Parameter type*	*Reference paragraph*
$K_{\mathrm{P}}, K_{\mathrm{I}}, K_{\mathrm{D}}$	Tuneable	-
K_{K}	Tuneable	-
T_{clutch}	Regulated	A.9.6.2.15.
τ_{open}	Tuneable	Default: 0.01
τ_{close}	Tuneable	Default: 0.02
$T_{\mathrm{driveaway}}$	Tuneable	Default: 2

A.9.7.4.3.1 Gear shift strategy for manual transmissions

The gear shift strategy for a (manual) shift transmission is available as a separate component module and therefore can be integrated in other driver models different from the one as described in paragraph A.9.7.4.3. Besides the specified parameters below, the gear shift strategy also depends on vehicle and driver parameters which have to be set in the parameter file according to the respective component data as specified in Table X.

The implemented gearshift strategy is based on the definition of shifting thresholds as function of engine speed and torque for up- and down shift manoeuvres. Together with a full load torque curve and a friction torque curve, they describe the permitted operating range of the system. Crossing the upper shifting limit forces selection of a higher gear, crossing the lower one will request the selection of a lower gear (see Figure 27 below).

Figure 27
Gear shift logic (example)



The values for the shifting thresholds specified in Table X shall be calculated based on the data of the internal combustion engine full load torque curve and friction torque curve (as obtained in accordance with paragraph A.9.8.3.) as follows:

(a) The characteristic points P_1 to P_6 in Figure X are defined by the coordinate pairs listed in Table X.

(b) The slope k_1 of the line between P_1 and P_3 as well as the slope k_2 of the line between P_2 and P_4 are calculated as follows:

$$k_1 = \frac{y_3 - y_1}{x_3 - x_1} \quad \text{(XXX)}$$

$$k_2 = \frac{y_4 - y_2}{x_4 - x_2} \quad \text{(XXX)}$$

(c) The downshift limits speed vector shall consist of the three values: $[x_5, \; x_5, \; x_3]$

(d) The downshift limits torque vector shall consist of the three values:

$$[y_5, \; k_1 \times (x_5 - \frac{n_{idle}}{2}), \; y_3]$$

(e) The upshift limits speed vector shall consist of the three values:

$$[x_6, \; x_6, \; x_4]$$

(f) The upshift limits torque vector shall consist of the three values:

$$[y_6, \; k_2 \times (x_6 - n_{idle}), \; y_4].$$

Table XXX

Shift logic coordinate pairs

Point	*x-coordinate (engine speed, min^{-1})*	*y-coordinate (engine torque, Nm)*
P_1	$x_1 = \frac{n_{idle}}{2}$	$y_1 = 0$
P_2	$x_2 = n_{idle}$	$y_2 = 0$
P_3	$x_3 = \frac{n_{lo} + n_{pref}}{2}$	$y_3 = T_{max}$
P_4	$x_4 = n_{95h}$	$y_4 = T_{max}$
P_5	$x_5 = 0.85 \times n_{idle} + 0.15 \times n_{lo}$	$y_5 = T_{min}$
P_6	$x_6 = 0.80 \times n_{pref} + 0.20 \times n_{95h}$	$y_6 = T_{min}$

Where in the above:

T_{max} is the overall maximum positive engine torque, Nm

T_{min} is the overall minimum negative engine torque, Nm

n_{idle}, n_{lo}, n_{pref}, n_{95h} are the reference speeds as defined in accordance with paragraph 7.4.6., min^{-1}

Also the driving cycle and the time of clutch actuation during a shift manoeuvre (T_{clutch}) are loaded in order to detect vehicle starts from standstill and engage the start gear in time ($T_{startgear}$) before the reference driving cycle speed changes from zero speed to a value above 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 is at stand still is the neutral gear.

After a gear change is requested, a subsequent gear change request is suppressed for a period of 3 seconds and as long as the drivetrain is not connected to all propulsion machines and not fully synchronized again ($Dt_{syncindi}$). These limiting conditions are rejected and a next gear change is forced when certain defined limits for the gearbox input speed (lower than ICE idle speed or higher than ICE normalized speed of 1.2 (i.e. 1.2 x (rated speed – idle speed) + idle speed)) are exceeded.

After a gear change is finished, the friction clutch actuated by the driver has to be fully connected again. This is particularly important during decelerations of the vehicle. If a deceleration occurs from a certain speed down to standstill, the friction clutch actuated by the driver has to be connected again after each downshift. Otherwise, the gear shift algorithm will not work properly and the simulation will result in an internal error. If shifting down one gear after the other (until the neutral gear is selected) during braking with very high decelerations shall be avoided, the friction clutch actuated by the driver has to be fully disconnected during the entire deceleration until the vehicle is standing still. Once the vehicle speed is zero the neutral gear will be selected and the friction clutch actuated by the driver can be connected again allowing the vehicle to start from standstill as soon as the driving cycle demands so.

If the accelerator pedal is fully pressed, the upper shifting limit is not in force. In this case, the upshift is triggered when the gearbox input speed gets higher than the ICE rated speed (i.e. when the point of maximum power is exceeded).

A skip gear function for upshifting can be enabled (SG_{flg}) for transmissions with a high number of gears to avoid unrealistic, too frequent shift behaviour. In this case, the highest gear for which the gearbox input speed is located above the downshift limit and below the upshift limit for the actual operation point is selected.

Automatic start gear detection is also available (ASG_{flg}) for transmissions with a high number of gears to avoid unrealistic, too frequent shift behaviour. If activated, the highest gear for which the gearbox input speed is above ICE idle speed when the vehicle is driving at 2 m/s and for which a vehicle acceleration of 1.6 m/s² can be achieved is selected for starting from standstill. If deactivated, starting from standstill is performed in the first (1^{st}) gear.

The flag signal $Dt_{syncindi}$ is used as an indicator for a fully synchronized and connected drivetrain. It is involved in triggering upcoming gear shift events. It has to be ensured that this signal becomes active only if the entire drivetrain runs on fully synchronized speeds. Otherwise the gear shift algorithm will not work properly and the simulation will result in an internal error.

For a correct engagement of the starting gear, the actual vehicle speed has to be zero (no rolling of the vehicle, application of brake necessary). Otherwise a time delay can occur until the starting gear is engaged.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table X, where “satp” is used for “set according to respective parameter file and provisions of”. Additional explanations are listed below the table for all descriptions marked with an asterisk (*).

Table X
Gear shift strategy parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	T_{clutch}	s	satp driver	dat.vecto.clutchtime.value
	-	kg	satp chassis	dat.vecto.vehicle.mass.value
	-	m	satp chassis	dat.vecto.wheel.radius.value
	-	kgm^2	satp chassis	dat.vecto.wheel.inertia.value
	-	-	satp chassis	dat.vecto.wheel.rollingres.value
	-	m^2	satp chassis	dat.vecto.aero.af.value
	-	-	satp chassis	dat.vecto.aero.cd.value
	-	-	satp final gear	dat.vecto.fg.ratio.value
	-	-	satp transmission	dat.vecto.gear.number.vec
	-	-	satp transmission	dat.vecto.gear.ratio.vec
	-	-	satp transmission $*^1$	dat.vecto.gear.efficiency.vec
	-	rad/s	satp engine $*^2$	dat.vecto.ICE.maxtorque_speed.vec
	-	Nm	satp engine	dat.vecto.ICE.maxtorque_torque.vec
	-	Nm	satp engine $*^3$	dat.vecto.ICE.maxtorque_friction.vec
	-	rad/s	satp engine $*^4$	dat.vecto.ICE.ratedspeed.value
	-	rad/s	downshift limits speed vector	dat.vecto.downshift_speed.vec
	-	Nm	downshift limits torque vector	dat.vecto.downshift_torque.vec
	-	rad/s	upshift limits speed vector	dat.vecto.upshift_speed.vec
	-	Nm	upshift limits torque vector	dat.vecto.upshift_torque.vec
	SG_{flg}	Boolean	skip gears when upshifting active or	dat.vecto.skipgears.value

			not Default: 0	
	$T_{startgear}$	s	engage startgear prior driveaway	dat.vecto.startgearengaged.value
	ASG_{flg}	Boolean	automatic start gear detection active or not Default: 0	dat.vecto.startgearactive.value
Command signal	-	-	Requested gear	nrGearReq
Sensor signal	$v_{vehicle}$	m/s	Actual vehicle speed	Chassis_vVehAct_mps
	ω_{in}	rad/s	Transmission input speed	Transm_nInAct_radps
	-	-	Actual gear engaged	Transm_nrGearAct
	$Dt_{syncindi}$	Boolean	Clutch disengaged or not and drivetrain synchronized or not	Clu_flgConnected_B
		-	Actual position of accelerator pedal	Drv_AccPedl_rat

*[1] The efficiencies of each gear of the transmission do not require a map, but only a single value for each gear since constant efficiencies are defined for the creation of the HEC cycle (in accordance with paragraph A.9.6.2.11.). The gear shift logics for manual transmissions must not be used for model verification (in accordance with paragraph A.9.5.6.14.). and thus do not require an efficiency map for each gear since in this case the gear shifting behaviour from the actual powertrain test is fed into the model.

*[2] The vector of engine speed setpoints defining the full load and friction torque curve has to start with engine idle speed. Otherwise the gear shift algorithm will not work properly.

*[3] The vector defining the engine friction torque curve has to consist of values of negative torque (in accordance with paragraph A.9.7.3.).

*[4] The engine rated speed value used for parameterizing the gear shift logics for manual transmissions shall be the highest engine speed where maximum power is available. Otherwise the gear shift algorithm will not work properly.

A.9.7.5. Electrical component models

A.9.7.5.1. DCDC converter model

The DC/DC converter is a device that changes the voltage level to the 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:

~~(Eq.~~ $$u_{out} = x_{DCDC} \times u_{in} \qquad (135)$$

Where:

u_{in} ~~:~~is the input voltage level~~ (~~, V~~)~~

u_{out} ~~:~~is the output voltage level~~ (~~, V~~)~~

x_{DCDC} ~~:~~is the conversion ratio, i.e. control signal ~~(–)~~

The conversion ratio x_{DCDC} shall be determined by an open-loop controller to the desired voltage u_{req} as:

~~(Eq.~~ $$x_{DCDC} = u_{req}/u_{in} \qquad (136)$$

The DC/DC converter losses shall be defined as current loss using ~~a constant DC/DC converter~~an efficiency ~~as follows~~map in accordance with:

~~(Eq. 137)~~

$$i_{in} = x_{DCDC} \times i_{out} \times \eta_{DCDC}(u_{in}, i_{in}) \qquad (137)$$

Where:

η_{DCDC} ~~:~~is the DC/DC converter efficiency ~~(–)~~

i_{in} ~~:~~is the input current to the DC/DC converter~~ (~~, A~~)~~

~~$i_{DCDCloss}$:~~ i_{out} is the output current from the 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 18.

Table 18
DC/DC converter model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	η_{DCDC}	-	~~efficiency~~Efficiency	dat.elecefficiency.efficiency.~~value~~map
Command signal	u_{req}	V	Requested output voltage	dcdc_uReq_V
Sensor signal	u_{out}	V	Actual output voltage	dcdc_uAct_V
Elec in [V]	u_{in}	V	~~voltage~~Voltage	phys_voltage_V
Elec out [V]	u_{out}	V	~~voltage~~Voltage	phys_voltage_V
Elec fb in [A]	i_{out}	A	~~current~~Current	phys_current_A
Elec fb out [A]	i_{in}	A	~~current~~Current	phys_current_A

Table XXX
DC/DC converter model parameters

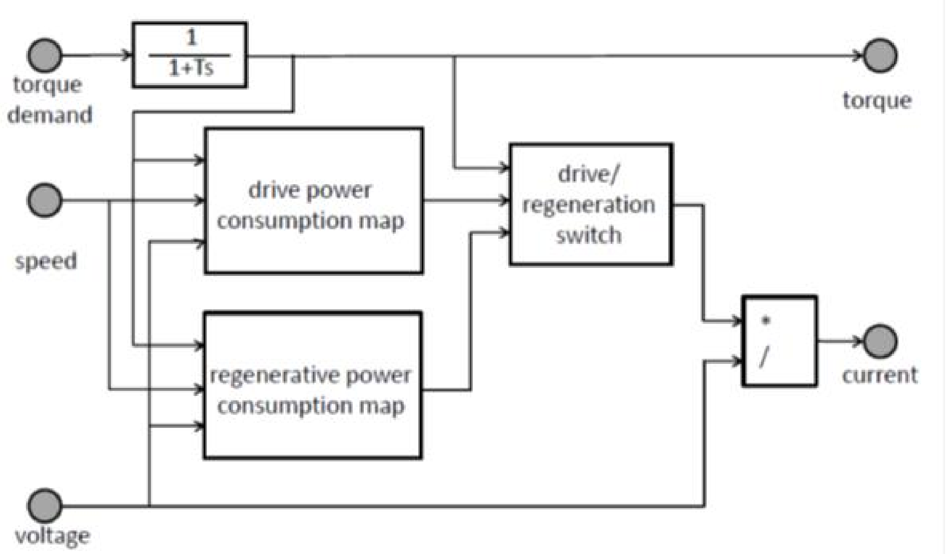
Parameter	*Parameter type*	*Reference paragraph*
η_{DCDC}	Manufacturer specified	-

A.9.7.6. Energy converter models

A.9.7.6.1. Electric machine system model

An electric machine can generally be divided into three parts, the stator, rotor and the ~~(high~~ power~~) electronic controller~~ electronics. The rotor is the rotating part of the machine. The electric machine shall be modelled using maps to represent the relation between its mechanical and electrical (DC) power, see Figure ~~27~~28.

Figure ~~27~~28:
Electric machine model diagram



The electric machine dynamics shall be modelled as a first order system

$$\dot{M}_{em} = -\frac{1}{\tau_1} \times \left(M_{em} - M_{em,des}\right) \quad (138)$$

Where:

M_{em} ~~: Electric~~is the electric machine torque~~ (~~, Nm~~)~~

$M_{em,des}$ ~~: Desired~~is the desired electric machine torque~~ (~~, Nm~~)~~

τ_1 ~~: Electric~~is the 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~~, its torque M_{em}~~.~~ and DC-bus voltage level u. Two separate maps shall be defined for the positive and negative ~~torques~~torque ranges, respectively.

~~(Eq.~~ $P_{el,em} = f(M_{em}, \omega_{em}, u)$(139)

The efficiency of the electric machine system shall be calculated as:

$$\eta_{em} = \frac{M_{em} \times \omega_{em}}{P_{el,em}} \quad (140)$$

The electric machine system current i_{em} shall be calculated as:

$$i_{em} = \frac{P_{el,em}}{u} \quad (141)$$

~~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~~provides a simple thermodynamics model that may be used to derive its temperature T_{em} as follows:

~~(Eq. 143)~~

$$P_{loss,em} = P_{el,em} - M_{em} \times \omega_{em} \quad (142)$$

$$\dot{T}_{em} = \frac{1}{\tau_{em,heat}} \times \left(P_{loss,em} - \left(T_{em} - T_{em,cool}\right)/R_{em,th}\right) \quad (143)$$

Where:

T_{em} ~~: Electric~~is the electric machine system temperature~~(~~, K~~)~~

$\tau_{em,heat}$ ~~: Time constant~~is the thermal capacity for electric machine thermal mass ~~()~~, J/K

$T_{em,cool}$ ~~: Electric~~is the electric machine system cooling medium temperature~~(~~, K~~)~~

$R_{em,th}$ ~~: Electric machine system~~is the thermal resistance ~~()~~between electric machine and cooling fluid, K/W

The electric machine system shall be torque or speed controlled using, respectively, an open-loop (feed-forward) ~~control~~controller or PI-controller~~.~~ as follows:

$$M_{em,des} = K_P \times \left(\omega_{ref} - \omega_{em}\right) + K_I \times \int\left(\omega_{ref} - \omega_{em}\right)dt \quad (XXX)$$

Where:

K_P is the proportional gain of speed controller

K_I is the integral gain of speed controller

The electric machine torque shall be limited as follows:

$$M_{min}(\omega_{em}) \leq M_{em,des} \leq M_{max}(\omega_{em}) \quad (XXX)$$

Where:

M_{min}, M_{max} are the minimum and maximum torque maps as function of the rotational speed.

The electric machine model shall also include an inertia load J_{em} that shall be 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 19.

Table 19:
Electric machine model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	J_{em}	kgm^2	Inertia	dat.inertia.value

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
	τ_1	-	Time constant	dat.timeconstant.value
	M_{max}	Nm	Maximum torque =f(speed)	dat.maxtorque.torque.vec
	M_{min}	Nm	Minimum torque =f(speed)	dat.mintorque.torque.vec
	K_P K_I	- -	Speed controller (PI)	dat.~~ctrl~~controller.p.value dat.controller.p.value
	$P_{el,em}$	W	Power map =f(speed,torque,voltage)	dat.elecpowmap.motor.elecpowmap dat.elecpowmap.genertor.elecpowmap
		~~kg/s~~	~~mass flow cooling fluid~~	~~dat.mflFluid~~
Optional parameters	$\tau_{em,heat}$	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	ω_{ref}	rad/s	Requested speed	ElecMac_nReq_radps
	-	boolean	Switch speed/torque control	ElecMac_flgReqSwitch_B
	$M_{em,des}$	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

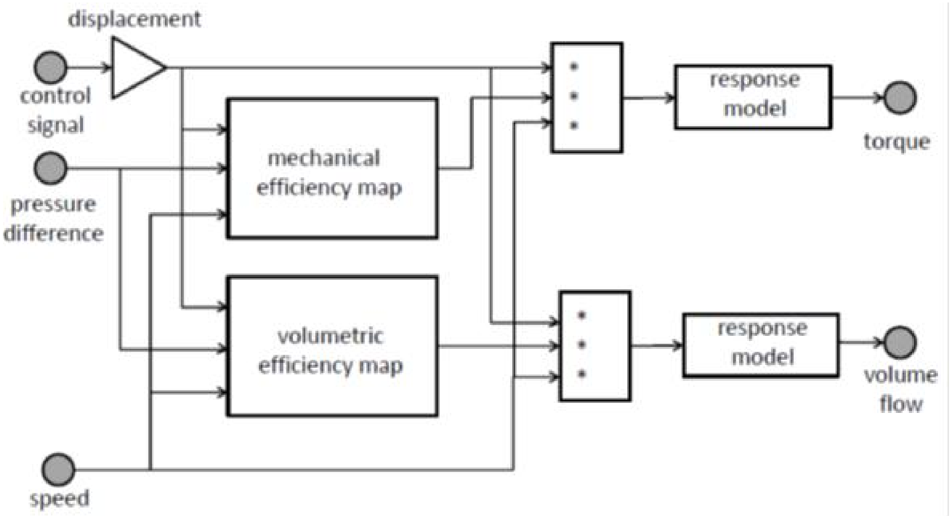
Table XXX
Electric machine model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_{em}	Manufacturer specified	-
τ_1	Tunable	-
M_{max}	Regulated	A.9.8.4.
M_{min}	Regulated	A.9.8.4.
K_P, K_I	Tunable	
$P_{el,em}$	Regulated	A.9.8.4.

A.9.7.6.2. Hydraulic pump/motor model

A hydraulic pump/motor generally converts energy stored in a hydraulic accumulator to mechanical energy as schematically shown in Figure 29.

Figure 29:
Hydraulic pump/motor model diagram



The pump/motor torque shall be modelled as:

$$M_{pm} = x \times D_{pm} \times (p_{acc} - p_{res}) \times \eta_{pm} \quad (144)$$

Where:

M_{pm}	~~:~~is the pump/motor torque~~(~~, Nm~~)~~
x	~~:~~is the pump/motor control command signal between 0 and 1 ~~(–)~~
~~D~~	:D_{pm} is the pump/motor displacement~~(~~, m^3~~)~~
p_{acc}	~~:~~is the pressure in high pressure accumulator~~(~~, Pa~~)~~
p_{res}	~~:~~is the pressure in low pressure sump/reservoir~~(~~, Pa~~)~~
η_{pm}	~~:~~is the mechanical pump/motor efficiency ~~(–)~~

The mechanical efficiency ~~η_{pm}~~ shall be determined ~~using:~~

~~(Eq. 145)~~

~~And be calculated~~from measurements and mapped as function of ~~friction losses, hydrodynamic losses and viscous losses~~the control command signal x, the pressure difference over the pump/motor and its speed as follows:

~~(Eq. 146)~~

$$\eta_{pm} = f(x, p_{acc}, p_{res}, \omega_{pm}) \qquad (145)$$

Where:

ω_{pm} ~~:~~is the 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:

~~(Eq. 148)~~

$$Q_{pm} = x \times D_{pm} \times \omega_{pm} \times \eta_{vpm} \qquad (147)$$

The volumetric efficiency ~~may~~shall be determined from measurements and mapped as function of the control command signal x, the pressure difference ~~of~~over the pump/motor and its speed as follows:

~~(Eq. 149)~~

$$\eta_{vpm} = f(x, p_{acc}, p_{res}, \omega_{pm}) \qquad (149)$$

The hydraulic pump/motor dynamics shall be modelled as a first order system in accordance with:

$$\dot{x}_{pm} = -\frac{1}{\tau_1} \times (x_{pm} - u_{pm,des}) \qquad (138)$$

Where:

x_{pm} is the output pump/motor torque or volume flow, Nm or m^3/s

$u_{pm,des}$ is the input pump/motor torque or volume flow, Nm or m^3/s

τ_1 is the pump/motor time response constant

The pump/motor system shall be torque or speed controlled using, respectively, an open-loop (feed-forward) control or PI-controller~~.~~ as follows:

$$M_{pm,des} = K_P \times (\omega_{ref} - \omega_{pm}) + K_I \times \int(\omega_{ref} - \omega_{pm})dt \qquad (XXX)$$

Where:

K_P is the proportional gain of speed controller

K_I is the integral gain of speed controller

The hydraulic pump/motor torque shall be limited as follows:

$$M_{pm,des} \leq M_{max}(\omega_{pm}) \qquad (XXX)$$

Where:

M_{max} is the and maximum torque map as function of the rotational speed.

The hydraulic pump/motor model shall also include an inertia load J_{pm} that shall be 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 20.

Table 20
Hydraulic Pump/Motor model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	J_{pm}	kgm^2	Inertia	dat.inertia.value
	τ_1	-	Time constant	dat.timeconstant.value
	M_{max}	Nm	Maximum torque =f(speed)	dat.maxtorque
	D	m^3	Displacement volume	dat.displacement.value
	η_v	-	Volumetric efficiency	dat.volefficiency.efficiency.map
	η_m	-	Mechanical efficiency	dat.mechefficiency.efficiency.map
	K_P K_I	- -	PI controller	dat.~~ctrl~~controller.p.value dat.controller.i.value
Command signal	ω_{ref}	rad/s	Requested speed	Hpm_nReq_radps
	-	boolean	Switch speed/torque control	Hpm_flgReqSwitch_B
	$M_{pm,des}$	Nm	Requested torque	Hpm_tqReq_Nm
Sensor signal	~~M_{em}~~M_{pm}	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

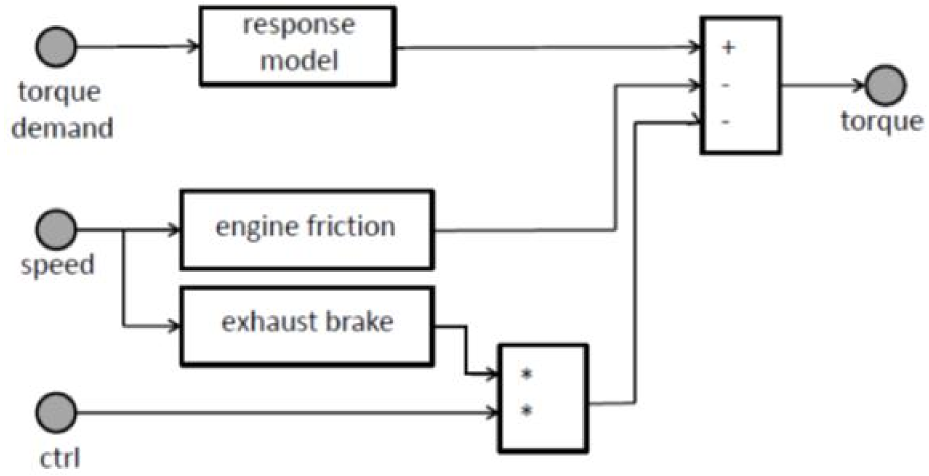
Table XXX
Hydraulic pump/motor model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_{pm}	Manufacturer specified	-
τ_1	Manufacturer specified	-
M_{max}	Manufacturer specified	-
D	Manufacturer specified	-
η_v	Manufacturer specified	-
η_m	Manufacturer specified	-
K_P, K_I	Tuneable	-

A.9.7.6.3. 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~~.~~ for torque build up. The internal combustion engine model diagram is shown in Figure ~~28~~29.

Figure ~~28~~29
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~~.~~ or continuous signal between 0 and 1. The model shall also include a starter motor, modelled using a constant torque M_{start}. The internal combustion engine shall be started and stopped by a control signal.

The torque build-up response model shall ~~use either of the following methods:~~

~~(a) Using a~~be modelled using two first ~~-~~order ~~model with fixed time constant (version 1)~~models. The first shall account for almost direct torque build-up representing the fast dynamics as follows:

~~(Eq. 150)~~

$$\dot{M}_{ice,1} = -\frac{1}{\tau_{ice,1}} \times \left(M_{ice,1} - M_{ice,des1}(\omega_{ice})\right) \qquad (150)$$

Where:

M_{ice} ~~: ICE~~ $_{,1}$ is the fast dynamic engine torque ~~(~~, Nm~~)~~

$M_{\mathrm{ice,}}$~~des~~ ~~: ICE~~ $_{\mathrm{des1}}$ is the fast dynamic engine torque demand ~~torque (~~, Nm ~~)~~

~~T_{ice}~~ ~~:~~ $\tau_{\mathrm{ice,1}}$ is the time constant for ~~ICE~~fast engine torque response ~~model (s)~~

~~(b) Using a~~ ω_{ice} is the engine speed, rad/s

The second first-order ~~model with~~system shall account for the slower dynamics corresponding to turbo charger effects and boost pressure build-up as follows:

$$\dot{M}_{ice,2} = -\frac{1}{\tau_{ice,2}(\omega_{ice})} \times \left(M_{ice,2} - M_{ice,des2}(\omega_{ice})\right) \qquad (151)$$

Where:

$M_{\mathrm{ice,2}}$ is the slow dynamic engine torque, Nm

$M_{\mathrm{ice,des2}}$ is the slow dynamic engine torque demand, Nm

$\tau_{\mathrm{ice,2}}$ is the speed dependent time constant ~~(version 2) as follows:~~

~~(Eq. 152)~~

~~Where:~~

~~M_{ice} : ICE torque (Nm)~~

~~M_{ice1} : dynamic ICE torque (Nm)~~

~~$M_{\mathrm{ice,des1}}$: dynamic ICE demand torque (Nm)~~

~~$M_{\mathrm{ice,des2}}$: direct ICE demand torque (Nm)~~

~~τ_{ice} : speed dependent time constant for ICE~~for slow engine 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 total engine torque M_{ice} shall be calculated as:

$$M_{ice} = M_{ice,1} + M_{ice,2} \qquad (152)$$

The internal combustion engine model ~~shall have~~provides a thermodynamics model that may be used to represent the engine heat-up from cold start to its normal stabilized operating temperatures in accordance with:

$$T_{ice,oil} = max\left(T_{ice,oil,heatup} = f\left(P_{ice,loss}\right), T_{ice,oil,hot}\right) \qquad (153)$$

Where:

$T_{\mathrm{ice,oil}}$ ~~:~~ is the ICE oil temperature ~~(~~, K~~)~~

$P_{\mathrm{ice,loss}}$ ~~:~~ are the ICE power losses ~~(~~, W~~)~~

~~η : fraction of power loss that goes to heating (-)~~

~~$\theta_{ice,oil,cold}$:~~ Since no fuel consumption and efficiency map is available in the model $P_{ice,loss} = (\omega_{ice} \times M_{ice})$ is used as a simplified approach. Adaption of the warm-up behaviour can be made via the function $T_{ice,oil,heatup} = f(P_{ice,loss})$.

$T_{ice,oil,heatup}$ is the ICE oil temperature at (cold) start~~(~~, K~~)~~

~~θ_{ice}~~$T_{ice,oil,hot}$ ~~:~~ is the ICE oil temperature at normal warm-up ~~operating~~operation condition~~(~~, K~~)~~

The internal combustion engine shall be torque or speed controlled using, respectively, an open-loop (feed-forward) control or PI-controller. For both controllers the desired engine torque can be either the desired indicated torque or the desired crankshaft torque. This shall be selected by the parameter $M_{des,type}$. The PI controller shall be in accordance with:

$$M_{ice,des} = K_P \times (\omega_{ref} - \omega_{ice}) + K_I \times \int(\omega_{ref} - \omega_{ice})dt \qquad \text{(XXX)}$$

Where:

K_P is the proportional gain of speed controller

K_I is the integral gain of speed controller

The internal combustion engine torque shall be limited as follows:

$$M_{ice,des} \leq M_{max}(\omega_{ice}) \qquad \text{(XXX)}$$

Where:

M_{max} is the and maximum torque map as function of the rotational speed.

The internal combustion engine model shall also include an inertia load J_{ice} that shall be 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 21.

Table 21
Internal Combustion Engine model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	J_{ice}	kgm^2	Inertia	dat.inertia.value
	$\tau_{ice,1}$	-	Time constant	dat.boost.insttorque.timeconstant.T1.value
	$\tau_{ice,2}$	-	Time constant = f(speed)	dat.boost.timeconstant.T2.value
	M_{fric}	Nm	Engine friction torque	dat.friction.friction.vec
	M_{exh}	Nm	Exhaust brake torque	dat.exhaustbrake.brake.vec
	M_{max}	Nm	Maximum torque =f(speed)	dat.maxtorque.torque.vec

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
	K_P K_I	- -	PI controller	dat.~~ctrl~~controller.p.value dat.controller.i.value
		~~kg/s~~	~~Fuel flow~~	~~dat.fuelmap~~
	M_{start}	~~kJ/kg~~Nm	~~Net calorific value of fuel~~Starter motor torque	dat.~~nev~~startertorque.value
	$M_{des,type}$	~~kg/m^3~~-	~~Fuel density~~Desired torque type selector: (0) indicated (1) crankshaft	dat.~~rho~~torquereqtype.value
		~~-~~	~~Power loss to cooling and oil~~	~~dat.eta.value~~
Optional parameters		-	Properties of oil	dat.oil
		-	Properties of coolant	dat.cf
Command signal	ω_{ref}	rad/s	Requested speed	Eng_nReq_radps
	-	boolean	Switch speed/torque control	Eng_flgReqSwitch_B
	$M_{ice,des}$	Nm	Requested torque	Eng_tqReq_Nm
		boolean	Exhaust brake on/off, continuous between 0-1	Eng_flgExhaustBrake_B
		boolean	Engine on or off	Eng_flgOnOff_B
		boolean	Starter motor on or off	Eng_flgStrtReq_B
		boolean	Fuel cut off	Eng_flgFuelCut_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 temperature	Eng_tOilAct_K

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
~~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_kgm 2
Mech fb in [rad/s]	ω_{ice}	rad/s	rotational speed	phys_speed_radps

Table XXX
Internal combustion engine model parameters

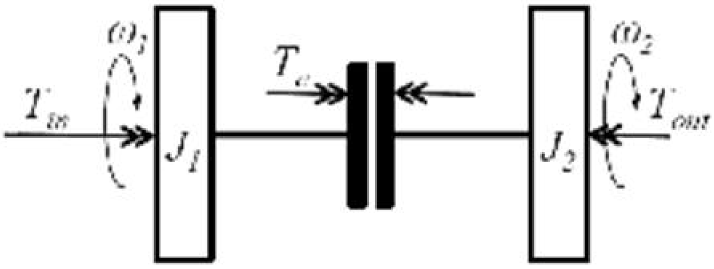
Parameter	*Parameter type*	*Reference paragraph*
J_{ice}	Manufacturer specified	-
$\tau_{ice,1}$	Regulated	A.9.8.3.
$\tau_{ice,2}$	Regulated	A.9.8.3.
M_{fric}	Regulated	A.9.8.3.
M_{exh}	Regulated	A.9.8.3.
M_{max}	Regulated	A.9.8.3.
K_P, K_I	Tunable	-
M_{start}	Manufacturer specified	-
$M_{des,type}$	Manufacturer specified	-

A.9.7.7. Mechanical component models

A.9.7.7.1. Clutch model

The clutch model shall transfer the input torque on the primary clutch plate to the secondary clutch plate ~~applying~~moving through three operating phases, i.e. 1) opened, 2) slipping and 3) closed. Figure ~~29~~ 30 shows the clutch model diagram.

Figure ~~29~~30
Clutch model diagram



The clutch model shall be defined in accordance with following (differential) equations of motion:

$$J_{cl,1} \times \dot{\omega}_{cl,1} = M_{cl1,in} - M_{cl} \qquad (154)$$

$$J_{cl,2} \times \dot{\omega}_{cl,2} = M_{cl} - M_{cl2,out} \qquad (155)$$

During clutch slip operation following relation is defined:

$$M_{cl} = u_{cl} \times M_{cl,maxtorque} \times \tanh(c \times (\omega_1 - \omega_2)) \qquad (156)$$

$$\omega_1 = \omega_2|_{t=0} + \int_0^t \left(M_{cl1,in}(t) - M_{cl}(t)\right) dt \qquad (157)$$

Where:

$M_{\mathrm{cl,maxtorque}}$ ~~:~~is the maximum ~~transferrable~~ torque transfer through the clutch~~ (~~, Nm~~)~~

u_{cl} ~~:~~is the clutch actuation control signal between 0 and 1 ~~(-)~~

c is a tuning constant for the hyperbolic function *tanh*().

When the speed difference between $\omega_1 - \omega_2$ is below the threshold limit $slip_{\mathrm{limit}}$ and the clutch pedal position is above the threshold limit $pedal_{\mathrm{limit}}$, the clutch shall no longer be slipping and considered to be in closed locked mode.

During clutch open and closed operation, the following relations shall apply:

1) for clutch open~~ (Eq. ~~:

$$M_{cl} = 0 \qquad (158)$$

2) for clutch closed~~ (Eq. ~~:

$$M_{cl2,out} = M_{cl1,in} \qquad (159)$$

The clutch pedal actuator shall be represented as a first order system:

$$\dot{u}_{cl} = -\frac{1}{\tau_1} \times \left(u_{cl} - u_{pedal}\right) \qquad (XXX)$$

Where:

u_{cl} is the clutch actuator position between 0 and 1

u is the clutch pedal position between 0 and 1

τ_1 is the clutch time constant

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 22.

Table 22
Clutch model parameters and interface

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
	~~$M_{maxtorque}$~~$M_{cl,maxtorque}$	Nm	Maximum clutch torque	dat.maxtorque.value
	c	-	Tuning constant	dat.tanh.value
	$slip_{limit}$	rad/s	Slipping clutch, relative speed limit	dat.speedtolerance.value
	$pedal_{limit}$	-	Slipping clutch, pedal limit	dat.clutchthreshold.value
	τ_1	-	Time constant clutch actuator	dat.actuator.timeconstant.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 XXX
Clutch model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_1	Manufacturer specified	A.9.5.6.X.
J_2	Manufacturer specified	A.9.5.6.X.
$M_{cl,maxtorque}$	Manufacturer specified	A.9.5.6.X.

c	Tuneable	default: 0.2
$slip_{\text{limit}}$	Tuneable	default: 1
$pedal_{\text{limit}}$	Tuneable	default: 0.8
τ_1	Manufacturer specified	-

A.9.7.7.2. 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:

~~(Eq. 160)~~

$$M_{CVT,out} = r_{CVT} M_{CVT,in} \eta_{CVT} \quad (160)$$

Where:

$M_{\text{CVT,in}}$ ~~:~~is the CVT input torque~~(~~, Nm~~)~~

$M_{\text{CVT,out}}$ ~~:~~is the CVT output torque~~(~~, Nm~~)~~

r_{CVT} ~~:~~is the CVT ratio ~~(-)~~

η_{CVT} ~~:~~is the CVT efficiency ~~(-)~~

The CVT efficiency shall be defined as function of input torque, output speed and gear ratio:

~~(Eq.~~

$$\eta_{CVT} = f\left(r_{CVT}, M_{CVT,in}, \omega_{CVT,out}\right) \quad (161)$$

The CVT model shall assume zero speed slip, so that following relation for speeds can be used:

~~(Eq. 162)~~

$$\omega_{CVT,in} = r_{CVT} \omega_{CVT,out} \quad (162)$$

The gear ratio of the CVT shall be controlled by a command setpoint and using a first-order representation for the CVT ratio change actuation in accordance with:

~~(Eq. 163)~~

$$\frac{d}{dt} r_{CVT} = \frac{1}{\tau_{CVT}} \left(-r_{CVT} + r_{CVT,des}\right) \quad (163)$$

Where:

τ_{CVT} ~~:~~is the CVT time constant~~(~~, s~~)~~

$r_{\text{CVT,des}}$ ~~:~~is the CVT commanded gear ratio~~(-)~~

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 23.

Table 23
CVT model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	τ_{CVT}	-	Time constant	dat.timeconstant.value
	η_{CVT}	-	Efficiency	dat.mechefficiency.efficiency.map
	~~$M_{maxtorque}$~~	~~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~~Torque	phys_torque_Nm
	J_{in}	kgm^2	~~inertia~~Inertia	phys_inertia_kgm2
Mech out [Nm]	M_{out}	Nm	~~torque~~Torque	phys_torque_Nm
	J_{out}	kgm^2	~~inertia~~Inertia	phys_inertia_kgm2
Mech fb in [rad/s]	ω_{out}	rad/s	~~rotational~~Rotational speed	phys_speed_radps
Mech fb out [rad/s]	ω_{in}	rad/s	~~rotational~~Rotational speed	phys_speed_radps

~~A.9.7.7.3. 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:~~

~~(Eq. 165)~~

~~Where:~~

~~$M_{flywheel,in}$: input torque to flywheel (Nm)~~

~~$M_{flywheel,loss}$: (speed dependent) flywheel losses (Nm)~~

~~The losses may be determined from measurements and modelled using maps.~~

~~For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 24.~~

~~Table 24~~

~~Flywheel~~

Table XXX

CVT model parameters ~~and interface~~

Parameter	*Parameter type*	*Reference paragraph*		
τ_{CVT}	Manufacturer specified	-		
η_{CVT}	Manufacturer specified	-		

A.9.7.7.3. Final gear model

A final gear transmission with a set of cog wheels and fixed ratio shall be represented in accordance with following equation:

$$\omega_{fg,out} = \omega_{fg,in}/r_{fg} \qquad (X)$$

The gear losses shall be considered as torque losses and implemented through an efficiency as:

$$M_{out} = M_{in}\eta_{fg}(\omega_{fg,in}, M_{in}) \qquad (X)$$

where the efficiency can be a function of speed and torque, represented in a map.

The final gear inertia shall be included as:

$$J_{out} = J_{in}r_{fg}^2 + J_{fg} \qquad (X)$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in table X.

Table 23

Final gear model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	J_{fg}	kgm^2	Inertia	dat.inertia.value
	r_{fg}	-	Gear ratio	dat.ratio.value
	η_{fg}	-	Efficiency	dat.mechefficiency.efficiency.map
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]	$\omega_{fg,out}$	rad/s	rotational speed	phys_speed_radps
Mech fb out [rad/s]	$\omega_{fg,in}$	rad/s	rotational speed	phys_speed_radps

Table XXX
Final gear model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_{fg}	Manufacturer specified	-
r_{fg}	Regulated	A.9.5.6.X., A.9.6.2.14.
η_{fg}	Manufacturer specified	-

A.9.7.7.4. Mechanical summation gear 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 in accordance with:

$$M_{out} = \eta_{out} r_{out} \left(\eta_{in,1} r_{in,1} M_{in,1} + \eta_{in,2} r_{in,2} M_{in,2} \right) \qquad (166)$$

Where:

$M_{in,1}$ ~~: Input~~is the input torque on shaft 1~~(~~, Nm~~)~~

$M_{in,2}$ ~~: Input~~is the input torque on shaft 2~~(~~, Nm~~)~~

M_{out} ~~: Output~~ is the output torque on shaft~~(~~, Nm~~)~~

$r_{in,1}$ ~~: Ratio~~is the ratio of gear of shaft 1 ~~(-)~~

$r_{in,2}$ ~~: Ratio~~is the ratio of gear of shaft 2 ~~(-)~~

$\eta_{in,1}$ ~~: Efficiency~~is the efficiency on gear of shaft 1 ~~(-)~~

$\eta_{in,2}$ ~~: Efficiency~~is the efficiency on gear of shaft 2 ~~(-)~~

r_{out} ~~: Ratio~~is the ratio of gear on output shaft ~~(-)~~

η_{out} ~~: Efficiency~~is the efficiency of gear on output shaft ~~(-)~~

The efficiencies shall be defined using speed and torque dependent look-up tables.

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 25.

Table 25
Mechanical ~~Connection~~connection model parameters and interface

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.mechefficiency.efficiency.~~value~~map
	J_2	kgm^2	Inertia	dat.in2.inertia.value
	$r_{in,2}$	-	Gear ratio	dat.in2.ratio.value
	$\eta_{in,2}$	-	Efficiency	dat.in2. mechefficiency.efficiency.~~value~~map
	J_{out}	kgm^2	Inertia	dat.out.inertia.value
	r_{out}	-	Gear ratio	dat.out.ratio.value
	η_{out}	-	Efficiency	dat.out. mechefficiency.efficiency.~~value~~map
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 XXX
Mechanical connection model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_1	Manufacturer specified	-
$r_{in,1}$	Manufacturer specified	-
$\eta_{in,1}$	Manufacturer specified	-
J_2	Manufacturer specified	-
$r_{in,2}$	Manufacturer specified	-
$\eta_{in,2}$	Manufacturer specified	-
J_{out}	Manufacturer specified	-
r_{out}	Manufacturer specified	-
η_{out}	Manufacturer specified	-

A.9.7.7.5. Retarder model

A retarder model shall be represented by a simple torque reduction as follows:

$$M_{retarder,out} = M_{retarder,in} - uM_{retarder,max}(\omega_{retarder}) \quad (167)$$

Where:

u ~~: Retarder~~ is the retarder command signal between 0 and 1 ~~(-)~~

$M_{retarder,max}$ ~~:~~is the (speed dependent) maximum retarder brake torque (Nm)

$\omega_{retarder}$ ~~: Retarder~~is the retarder speed (rad/s)

$M_{retarder,in}$ ~~: Retarder~~is the retarder input torque (Nm)

$M_{retarder,out}$ ~~: Retarder~~is the retarder output torque (Nm)

The model shall also implement an inertial load $J_{retarder}$ to be 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 26.

Table 26
Retarder model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	~~T_{loss}~~$M_{retarder,max}$	Nm	Retarder brake torque map	dat.braketorque.torque.vec
	$J_{retarder}$	kgm^2	Inertia	dat.inertia.value
Command signal	u	-	Retarder ~~on/off~~control signal between 0-1	Ret_flgOnOff~~_B~~
Sensor signal	~~T_{loss}~~M_{loss}	Nm	Retarder brake	Ret_tqBrkAct_Nm

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
			torque	
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

~~A.9.7.7.6. Fixed~~

Table XXX
Retarder model parameters

Parameter	*Parameter type*	*Reference paragraph*
$M_{\text{retarder,max}}$	Manufacturer specified	-
J_{retarder}	Manufacturer specified	-

A.9.7.7.6. Spur gear model

~~A~~ A spur gear transmission or fixed gear transmission with a set of cog wheels and fixed gear ratio shall be represented in accordance with following equation:

$$\omega_{spur,out} = \omega_{spur,in}/r_{spur} \qquad (168)$$

The gear losses shall be considered as torque losses and implemented through an efficiency ~~as~~implemented as function of speed and torque:

$$M_{out} = M_{in}\eta_{spur}(\omega_{spur,in},$$

The gear inertias shall be included as:

~~(Eq. 170)~~

$$J_{spur,out} = J_{spur,in}r_{spur}^2 + J_{spur} \qquad (170)$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 27.

Table 28
Fixed gear model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	~~J_{gear}~~J_{spur}	kgm^2	Inertia	dat.in.inertia.value
	~~r_{gear}~~r_{spur}	-	Gear ratio	dat.in.ratio.value
	~~η_{gear}~~η_{spur}	-	Efficiency	dat.in.mechefficiency.efficiency.~~value~~map
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}~~$\omega_{\text{spur,out}}$	rad/s	rotational speed	phys_speed_radps
Mech fb out [rad/s]	~~ω_{in}~~$\omega_{\text{spur,in}}$	rad/s	rotational speed	phys_speed_radps

Table XXX
Spur gear model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_{spur}	Manufacturer specified	-
r_{spur}	Manufacturer specified	-
η_{spur}	Manufacturer specified	-

A.9.7.7.7. Torque converter model

A 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. A torque converter equipped with a stator will create torque multiplication in slipping mode. ~~A torque converter is often applied as the coupling device in an automatic (shift) transmission.~~

The torque converter shall transfer the input torque to the output torque according to two operating phases: slipping and closed.

The torque converter model shall be defined in accordance with following (differential) equations of motion:

~~(Eq.~~ $$J_p \dot{\omega}_p = M_{in} - M_p \quad (171)$$

~~The representation of~~ $$J_t \dot{\omega}_t = M_t - M_{out} \quad (171)$$

Where:

J_p is the pump inertia, kgm^2

J_t is the turbine inertia, kgm^2

ω_p is the pump rotational speed, rad/s

ω_t is the turbine rotational speed, rad/s

M_{in} is the input torque ~~converter model is shown in Figure 31.~~, Nm

~~Figure 31~~
~~Torque converter model diagram~~

M_{out} is the output torque, Nm

M_p is the pump torque, Nm

M_t is the turbine torque, Nm

The pump torque ~~converter model characteristics~~ shall be ~~defined~~mapped as function of ~~(rotational) speeds using typical parameters like torque (multiplication)~~the speed ratio ~~and efficiency.~~as:

$$M_p = f_{pump}(\omega_t/\omega_p)(\omega_p/\omega_{ref})^2 \quad (172a)$$

Where:

ω_{ref} is the reference mapping speed, rad/s

$f_{pump}(\omega_t/\omega_p)$ is the mapped pump torque as function of the speed ratio at the constant mapping speed ω_{ref}, Nm

The ~~speed~~turbine torque shall be determined as an amplification of the pump torque as:

$$M_t = f_{amp}(\omega_t/\omega_p) M_p \quad (X)$$

where:

$f_{amp}(\omega_t/\omega_p)$ is the mapped torque amplification as function of the speed ratio

During closed operation, the following relations shall apply:

$$M_{out} = M_{in} - M_{tc,loss}(\omega_p) \quad (X)$$

$$\omega_t = \omega_p \qquad \text{(X)}$$

where:

$M_{tc,loss}$ is the torque loss at locked lock-up, Nm

A clutch shall be used to switch between the slipping phase and ~~torque ratios~~the closed phase. The clutch shall be modelled in the same way as the clutch device in A.9.7.7.1. During the transition from slipping to closed operation, equtiion 172a shall be modified as:

$$M_p = f_{pump}(\omega_t/\omega_p)(\omega_p/\omega_{ref})^2 + u_{lu} M_{lu,maxtorque} \tanh(c(\omega_p - \omega_t)) \qquad \text{(X)}$$

Where:

$M_{lu,maxtorque}$ is the maximum torque transfer through the clutch, Nm

u_{lu} is the clutch actuation control signal between 0 and 1

c is a tuning constant for the ~~torque converter model shall be in accordance with:~~hyperbolic function *tanh.*

When the speed difference ω_p - ω_t is below the threshold limit $slip_{limit}$ and the clutch actuator is above the threshold position u_{limit}, the clutch is considered not to be slipping and shall be considered as locked closed.

The lock-up device actuator shall be represented as a first order system:

$$\dot{u}_{lu} = -\frac{1}{\tau_1} \times (u_{lu} - u) \qquad \text{(X)}$$

Where:

u_{lu} is the lock-up actuator position between 0 and 1

u is the desired lock-up actuator position between 0 and 1

τ_1 is the time constant

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 29.

Table 29
Torque Converter model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	~~$J_{impeller}$~~J_p	kgm^2	Inertia	dat.inertia.in.value
	J_t	kgm^2	Inertia	dat.inertia.out.value
	$M_{lu,maxtorque}$	Nm	Maximum clutch torque	dat.clutch.maxtorque.value
	c	-	Tuning constant	dat.clutch.tanh.value

	$slip_{limit}$	rad/s	Slipping clutch, relative speed limit	dat.clutch.speedtolerance.value
	u_{limit}	-	Slipping clutch, pedal limit	dat.clutch.threshold.value
	τ_1	-	Time constant actuator	dat.clutch.actuator.timeconstant.value
	ω_{ref}	rad/s	Reference speed	dat.characteristics.refspeed.value
	ω_t/ω_p	-	~~Torque~~Speed ratio~~ map~~	~~dat.torqueratiomap~~dat.characteristics.speedratio.vec
	f_{pump}	Nm		dat.characteristics.inputtorque.vec
	f_{amp}	-		dat.characteristics.torqueratio.vec
	-	rad/s	Speed vector for torque loss	dat.characteristics.loss.torque.vec
Command signal	u	boolean	Torque converter lockup signal	TC_flgLockUp_B
Sensor signal	ω_p	rad/s	Pump speed	TC_nPumpAct_radps
	M_p	Nm	Pump torque	TC_tqPumpAct_Nm
~~Sensor signal~~	~~ω_{out}~~ω_t	rad/s	Turbine speed	TC_nTurbineAct_radps
	M_t	Nm	Turbine torque	TC_tqTurbineAct_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_{out}~~ω_t	rad/s	rotational speed	phys_speed_radps

Mech fb out [rad/s]	~~ω_{in}~~ω_p	rad/s	rotational speed	phys_speed_radps

Table XXX
Torque converter model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_1	Manufacturer specified	-
J_2	Manufacturer specified	-
$M_{lu,maxtorque}$	Manufacturer specified	-
c	Tuneable	default: 0.2
$slip_{limit}$	Tuneable	default: 3
u_{limit}	Tuneable	default: 0.8
f_{pump}	Manufacturer specified	-
f_{amp}	Manufacturer specified	-
M_{loss}	Manufacturer specified	-

A.9.7.7.8. Shift transmission model

The shift transmission model shall be implemented as gears in contact, with a specific gear ratio r_{gear} in accordance with:

$$\omega_{tr,in} = \omega_{tr,out} r_{gear} \tag{174}$$

All losses in the transmission model shall be defined as torque losses and implemented through a fixed transmission efficiency for each individual gear. The transmission model shall than be in accordance with:

~~(Eq.~~

$$M_{out} = \begin{cases} M_{in} r_{gear} \eta_{gear}, & for\ M_{in} \leq 0 \\ M_{in} r_{gear} / \eta_{gear}, & for\ M_{in} > 0 \end{cases} \tag{175}$$

The total gearbox inertia shall depend on the active gear selection and is defined with following equation:

~~(Eq. 176)~~

$$J_{gear,out} = J_{gear,in} r_{gear}^2 + J_{gear,out} \tag{176}$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table ~~30.~~26.

The model in the standardized HILS library includes a clutch model. This is used to enable a zero torque transfer during gearshifts. Other solutions are possible. The time duration where the transmission is not transferring torque is defined as the torque interrupt time $t_{interrupt}$. This implementation directly links some of the parameters listed in table X to the clutch model as described in paragraph A.9.8.7.1.

Table 26
Shift transmission model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
~~Parameter~~		~~s~~	~~Shift time~~	~~dat.shifttime.value~~
		~~Nm~~	~~Maximum torque~~	~~dat.maxtorque.value~~
Parameter	nr_{gears}	-	Number of gears	dat.nofgear.value
	$gear_{num}$	-	Gear numbers (vector)	dat.gear.number.~~value~~vec
	$J_{gearbox}$	kgm^2	Inertia (vector)	dat.gear.inertia.~~value~~vec
	r_{gear}	-	Gear ratio (vector)	dat.gear.ratio.~~value~~vec
	η_{gear}	-	Gear efficiency (~~vector~~map)	dat.gear.mechefficiency.efficiency.~~value~~map
Clutch related parameters	$t_{interrupt}$	s	Shift time	dat.torqueinterrupt.value
	-	Nm	Maximum torque	dat.maxtorque.value
	c	-	Tuning constant	dat.tanh.value
	-	rad/s	Slipping clutch, relative speed limit	dat.speedtolerance.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

Table XXX
Shift transmission model parameters

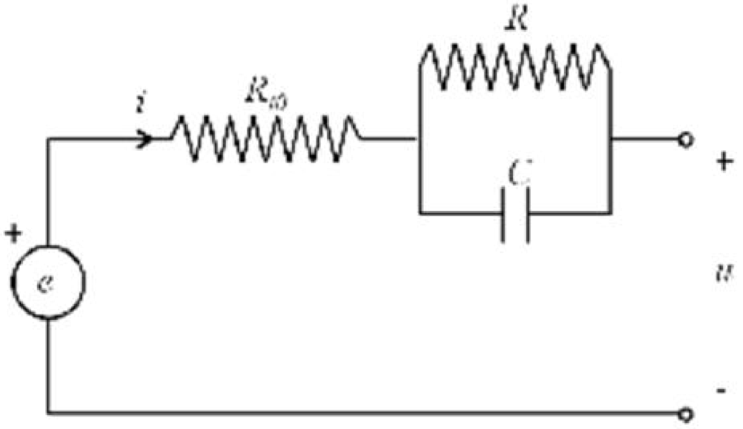
Parameter	*Parameter type*	*Reference paragraph*
$t_{interrupt}$	Manufacturer specified	A.9.6.2.X.
$gear_{num}$	Manufacturer specified	Example: 0, 1, 2, 3, 4, 5, 6
nr_{gear}	Manufacturer specified	-
$J_{gearbox}$	Manufacturer specified	-
r_{gear}	Manufacturer specified	-
η_{gear}	Regulated	A.9.6.2.X.
dat.maxtorque.value	Tuneable	-
dat.tanh.value	Tuneable	-
dat.speedtolerance.value	Tuneable	-

A.9.7.8. Rechargeable Energy Storage Systems

A.9.7.8.1. Battery ~~(resistor)~~ model

~~A resistor based~~The battery model ~~(Figure 32) can be used and~~be based on the representation using resistor and capacitor circuits as shown in Figure 34.

Figure 34
Representation diagram for RC-circuit battery model



The battery voltage shall satisfy:

~~(Eq.~~ $u = e - R_{i0}i - u_{RC}$(181)

With:

~~(Eq. 182)~~

$$\frac{d}{dt} u_{RC} = -\frac{1}{RC} u_{RC} + \frac{1}{C} i \qquad (182)$$

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 resistances R_{i0} and R and the capacitance C shall have current directional dependency included.

The battery state-of-charge SOC shall be defined as:

$$SOC = SOC(0) - \int_0^t \frac{i}{3600CAP} dt \qquad (X)$$

Where:

$SOC(0)$ is the initial state of charge at test start

CAP is the battery capacity, Ah

The battery can be scalable using a number of cells.

The battery model ~~can include~~provides a thermodynamics model that may be used and applies similar modelling as for the electric machine system ~~and calculation its losses as follows~~in accordance with:

~~(Eq. 183)~~

$$P_{loss,bat} = R_{i0} i^2 + R\, i_R^2 = R_{i0} i^2 + \frac{u_{RC}^2}{R} \qquad (183)$$

The power losses ~~shall be~~are converted to heat energy affecting the battery temperature that will be in accordance with:

$$\dot{T}_{bat} = \frac{1}{\tau_{bat,heat}} \left(P_{loss,bat} - \left(T_{bat} - T_{bat,cool}\right)/R_{bat,th}\right) \qquad (184)$$

Where:

T_{bat} ~~: Battery~~ is the battery temperature~~ (~~, K~~)~~

~~T_{bat}~~$T_{\text{bat,heat}}$ ~~: Time constant~~is the thermal capacity for battery thermal mass ~~()~~, J/K

$T_{\text{bat,cool}}$ ~~: Battery~~ is the battery cooling medium temperature~~ (~~, K~~)~~

$R_{\text{bat,th}}$ ~~: Battery~~is the thermal resistance ~~()~~between battery and cooling fluid, K/W

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 32.

Table 32

~~Standard RC-based battery~~Battery model parameters and interface

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	dat.np.value

			parallel	
	CAP	Ah	Cell capacity	dat.capacity.value
	$SOC(0)$	per cent	Initial state of charge	dat.initialSOC.value
	e	V	Open circuit voltage =f(SOC)	dat.ocv.ocv.vec
	R_{i0}	Ω	Cell resistance =f(SOC)	dat.resi.charge.R0.vec dat.resi.discharge.R0.vec
	R	Ω	Cell resistance =f(SOC)	dat.resi.charge.R.vec dat.resi.discharge.R.vec
	C	F	Cell resistance =f(SOC)	dat.resi.charge.C.vec dat.resi.discharge.C.vec
Optional parameters	$\tau_{bat,heat}$	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			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 XXX
Battery model parameters

Parameter	*Parameter type*	*Reference paragraph*
n_s	Manufacturer specified	-
n_p	Manufacturer specified	-
CAP	Regulated	A.9.8.8.5.
$SOC(0)$	Manufacturer specified	-

e	Regulated	A.9.8.8.5.
R_{i0}	Regulated	A.9.8.8.5.
R	Regulated	A.9.8.8.5.
C	Regulated	A.9.8.8.5.

A.9.7.8.2. Capacitor model

A capacitor model shall satisfy:

$$u = u_C - R_i i \qquad (X)$$

where u_C is the capacitor voltage and R_i is the internal resistance. The capacitor voltage shall be determined according to:

$$u_C = -\frac{1}{C}\int i dt \qquad (X)$$

where C is the capacitance.

For a capacitor system the state-of-charge is directly proportional to the capacitor voltage:

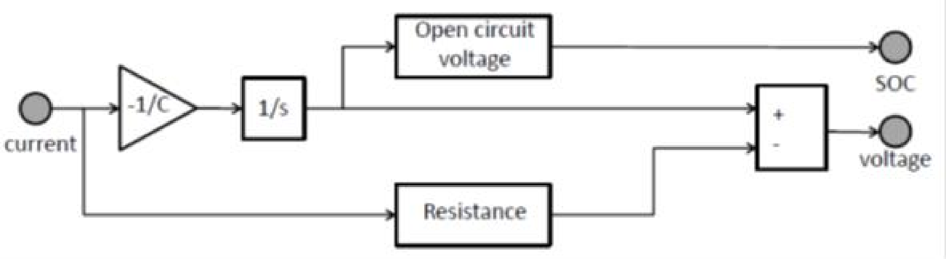
$$SOC_{cap} = \frac{u_C - V_{min}}{V_{C,max} - V_{C,min}} \qquad (X)$$

Where:

$V_{C,min}$ and $V_{C,max}$ are, respectively, the minimum and maximum capacitor voltage.

A diagram for the capacitor model is shown in figure X.

Figure X
Capacitor model diagram



The capacitor can be scalable using a number of capacitors connected in parallel and series.

The capacitor model provides a thermodynamics model similar to the battery model.

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in table X.

Table X
Capacitor model parameters and interface

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	F	Capacitance	dat.C.value
	~~C~~R_i	~~Ah~~Ω	Cell ~~capacity~~resistance	dat.~~capacity~~R.value
	~~SOC~~$u_C(0)$	~~%~~V	Initial ~~state of charge~~capacitor voltage	dat.~~initialSOC~~initialVoltage.value
	~~e~~$V_{C,min}$	V	~~Open circuit~~Minimum capacitor voltage ~~=f(SOC)~~	dat.~~ocv.ocv~~Vmin.value
	~~R_{i0}~~$V_{C,max}$	~~Ω~~V	~~Cell resistance~~Maximum capacitor voltage	dat.~~resistance.R0~~Vmax.value
	~~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}~~$T_{capacitor}$	K	~~Battery~~Capacitor temperature	REESS_tAct_K
Elec out [V]	u	V	Voltage	phys_voltage_V
Elec fb in [A]	i	A	Current	phys_current_A

~~A.9.7.8.3.~~

Table XXX
Capacitor model parameters

~~Reserved.~~

Parameter	*Parameter type*	*Reference paragraph*
n_s	Manufacturer specified	-
n_p	Manufacturer specified	-
V_{min}	Regulated	A.9.8.8.6.

V_{max}	Regulated	A.9.8.8.6.
$u_C(0)$	Manufacturer specified	-
R_i	Regulated	A.9.8.8.6.
C	Regulated	A.9.8.8.6.

A.9.7.8.3. 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:

$$E_{flywheel} = J_{flywheel}\omega_{flywheel}^{2} \quad (164)$$

Where:

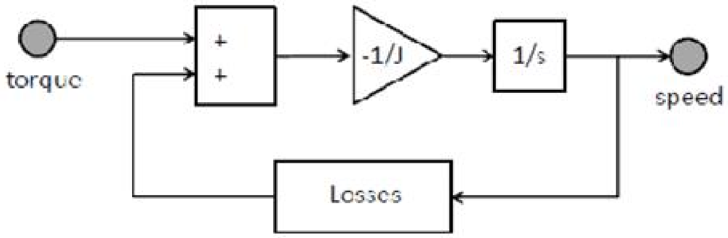
$E_{flywheel}$ is the kinetic energy of the flywheel, J

$J_{flywheel}$ is the inertia of the flywheel, kgm^2

$\omega_{flywheel}$ is the flywheel speed, rad/s

The basic flywheel model diagram is shown in Figure 30.

Figure 30
Flywheel model diagram



The flywheel model shall be defined in accordance with following differential equation:

$$J_{flywheel}\frac{d}{dt}\omega_{flywheel} = -M_{flywheel,in} - M_{flywheel,loss}(\omega_{flywheel}) \quad (165)$$

Where:

$M_{flywheel,in}$ is the input torque to flywheel, Nm

$M_{flywheel,loss}$ is the (speed dependent) flywheel loss, Nm

The losses may be determined from measurements and modelled using maps.

The flywheel speed shall be restricted by a lower and upper threshold value, respectively, $\omega_{flywheel\_low}$ and $\omega_{flywheel\_high}$:

$$\omega_{flywheel\_low} \leq \omega_{flywheel} \leq \omega_{flywheel\_high} \quad (X)$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 24.

Table 24
Flywheel model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	J_{fly}	kgm^2	Inertia	dat.inertia.value

	M_{loss}	Nm	Torque loss map	dat.loss.torqueloss.vec
	$\omega_{flywheel\_low}$	rad/s	Lower speed limit	dat.speedlimit.lower.value
	$\omega_{flywheel\_high}$	rad/s	Upper speed limit	dat.speedlimit.upper.value
Command signal			no 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

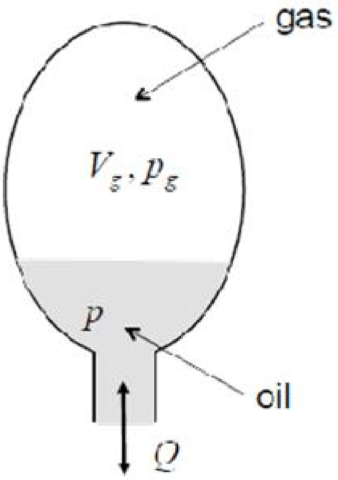
Table XXX
Flywheel model parameters

Parameter	*Parameter type*	*Reference paragraph*
J_{fly}	Manufacturer specified	-
M_{loss}	Manufacturer specified	-
$\omega_{flywheel\_low}$	Manufacturer specified	-
$\omega_{flywheel\_high}$	Manufacturer specified	-

A.9.7.8.4. 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 35.

Figure 35
Accumulator representation



The accumulator shall be represented in accordance with following equations, assuming ideal gas law, gas and fluid pressure to be equal and no losses in the accumulator:

~~(Eq.~~ $$\frac{d}{dt}V_{gas} = -Q \qquad (185)$$

~~(Eq. 186)~~

The process shall be assumed to be a reversible adiabatic process:

$$p_{gas}V_{gas}^{\gamma} = constant \qquad (186)$$

Where:

~~m_g : charge~~ p_{gas} is the gas ~~mass (kg)~~pressure, Pa

~~R :~~V_{gas} is the gas volume, m^3

γ is the adiabatic index

This assumption means that no energy is transferred between the gas and the surroundings.

The constant shall be determined from the precharging of the accumulator:

~~T_g : charge gas temperature (K)~~

~~The model can contain a heat transfer model using following relation:~~

$$p_{gas,pre}V_{gas,pre}^{\gamma} = constant \qquad (XXX)$$

Where:

~~c_v : Charge~~$p_{gas,pre}$ is the precharged gas ~~specific~~pressure, Pa

$V_{gas,pre}$ is the precharged gas volume ~~()~~, m^3

~~h : Accumulator heat transfer coefficient ()~~

~~A_w : Accumulator surface area (m^2)~~

~~T_w : Accumulator surface temperature (K)~~

γ is the adiabatic index

The work done by the pressure-volume changes as a result from this adiabatic process, is equal to:

$$W = \frac{-p_{gas,pre}V_{gas,pre}^{\gamma}\left(V_{gas}^{1-\gamma} - V_{gas,pre}^{1-\gamma}\right)}{(1-\gamma)3600000} \qquad (XXX)$$

and the corresponding state-of-charge shall be determined as:

$$SOC_{acc} = \frac{W}{c_{acc}} \qquad (XXX)$$

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 33.

Table 33
Accumulator model parameters and interface

Type / Bus	*Name*	*Unit*	*Description*	*Reference*
Parameter	~~T~~$p_{gas,pre}$	~~K~~Pa	~~Gas temperature~~Precharged gas pressure	dat.~~gas.temperature~~pressure.precharge.value
	~~m_g~~γ	~~kg~~-	~~Mass of gas~~Adiabatic index	dat.gas.~~mass~~adiabaticindex.value
	~~R~~	~~J/kg~~	~~Gas constant~~	~~dat.gas.constant.value~~
	~~V_g~~V_{gas}	m^3	~~Tank~~Precharged volume	dat.~~capacity.volume~~vol.pressure.value
	~~V_f~~C_{acc}	~~m^3~~kWh	~~Fluid volume~~Accumulator capacity	dat.capacity.~~fluid.~~value
	$V_{gas}(0)$	~~%~~m^3	Initial ~~fluid~~ volume	dat.~~capacity.fluid.init~~vol.initial.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 XXX
Accumulator model parameters

Parameter	*Parameter type*	*Reference paragraph*
$p_{gas,pre}$	Manufacturer specified	-
γ	Manufacturer specified	-
$V_{gas,pre}$	Manufacturer specified	-
$V_{gas}(0)$	Manufacturer specified	-
C_{acc}	Manufacturer specified	-

A.9.7.9. Provisions on OEM specific component models

The manufacturer may use alternative powertrain component models that are deemed to at least include equivalent representation, though with better matching performance, than the models listed in paragraphs A.9.7.2. to A.9.7.8. An alternative model shall satisfy the intent of the library model. Deviations from the powertrain component models specified in paragraph A.9.7. shall be reported and be subject to approval 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. This information shall be based on calculations, simulations, estimations, description of the models, experimental results and so on.

The chassis model shall be in accordance with paragraph A.9.7.3.

The reference HV model shall be set up in accordance with paragraphs A.9.7.2. to A.9.7.8.

A.9.8. Test procedures for energy converter(s) and storage device(s)

A.9.8.1. General introduction

The procedures described in paragraphs A.9.8.2. to A.9.8.5. 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.

A manufacturer specific component test procedure may be used in the following cases:

(a) Specific component test procedure not available in this gtr;

(b) Unsafe or unrepresentative for the specific component;

(c) Not appropriate for a manufacturer specific component model.

These manufacturer specific procedures shall be in accordance with the intent of specified component test procedures to determine representative data for use of the model in the HILS system. The technical details of these manufacturer component test procedures shall be reported to and subject to approval by the type approval or certification authority along with all appropriate information relating to and including the procedure along with the justification for its use. This information shall be based on calculations, simulations, estimations, description of the models, experimental results and so on.

A.9.8.~~3~~2. Equipment specification

Equipment with adequate characteristics shall be used to perform tests. Requirements are defined below and shall be in agreement with the linearity requirements and verification of paragraph 9.2.

The accuracy of the measuring equipment (serviced and calibrated according the handling procedures) shall be such that the linearity requirements, given in Table 34 and checked in accordance with paragraph 9.2, are not exceeded.

Table 34

Linearity requirements of instruments

Measurement system	$\lvert x_{min} \cdot (a_1 - 1) + a_o \rvert$ *(for maximum test value)*	*Slope,* a_1	*Standard error, SEE*	*Coefficient of determination,* r^2
Speed	≤ 0.05 % max	0.98 – 1.02	≤ 2 % max	≥ 0.990
Torque	≤ 1 % max	0.98 – 1.02	≤ 2 % max	≥ 0.990
Temperatures	≤ 1 % max	0.99 – 1.01	≤ 1 % max	≥ 0.998
Current	≤ 1 % max	0.98 – 1.02	≤ 1 % max	≥ 0.998
Voltage	≤ 1 % max	0.98 – 1.02	≤ 1 % max	≥ 0.998
Power	≤ 2 % max	0.98 – 1.02	≤ 2 % max	≥ 0.990

A.9.8.3. Internal Combustion Engine

The engine torque characteristics, the engine friction loss and auxiliary brake torque shall be determined and converted to table data as the input parameters for the HILS system engine model. The measurements and data conversion shall be carried out in accordance with paragraphs A.9.8.3.1. through A.9.8.3.7.

A.9.8.3.1~~.~~ ~~Test engine~~

~~The test engine shall be the engine of the parent hybrid powertrain in accordance with the provision of paragraph 5.3.4.~~

~~A.9.8.3.2~~. Test conditions and equipment

The test conditions and applied equipment shall be in accordance with the provisions of paragraphs 6 and 9, respectively.

A.9.8.3.~~3~~2. Engine warm-up

The engine shall be warmed up in accordance with paragraph 7.4.1.

A.9.8.3.~~4~~3. Determination of the mapping speed range

The ~~minimum and maximum mapping speeds are defined as follows:~~

~~(a) Minimum~~ mapping speed ~~= idle speed at the warmed-up condition~~

~~(b) Maximum mapping speed =~~ ~~n_{hi}~~ ~~x 1.02 or the speed where the full load torque drops off to zero, whichever is smaller~~range shall be in accordance with paragraph 7.4.2.

A.9.8.3.~~5~~4. Mapping of positive engine torque characteristics

When the engine is stabilized in accordance with paragraph A.9.8.3.~~3~~2., the engine torque mapping shall be performed in accordance with the following procedure.

(a) 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 at least 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. In such a case, a (shift) transmission with a known (pre-selected) fixed gear ratio and a known transmission efficiency shall be used and specified.

(b) 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.

(c) The engine torque as function of speed and command value shall be measured under at least 100 conditions in total, for the engine speed under at least 10 conditions within a range in accordance with paragraph A.9.8.3.~~4~~3, and for the engine command values under at least 10 conditions within a range from 100 per cent to 0 per cent operator command value. The ~~distribution~~measurement points may be equally distributed and shall be defined using good engineering judgement.

A.9.8.3.~~6~~5. Measurement of engine friction and auxiliary brake torque characteristics

After the engine is stabilized in accordance with paragraph A.9.8.3.2., the engine friction and auxiliary brake torque characteristics shall be measured as follows:

(a) The measurement of the friction torque of the engine shall be carried out by driving the test engine from the engine dynamometer at unloaded motoring condition (0 per cent operator command value and effectively realizing zero fuel injection) and performing the measurement under at least 10 conditions within a range from maximum to minimum mapping speed in accordance with paragraph A.9.8.3.3. ~~Additionally, the friction torque~~The measurement points may be equally distributed and shall be ~~measured with an enabled auxiliary brake system (such as an exhaust brake), if that brake is needed in the HILS system in addition to the engine brake~~defined using good engineering judgement.

(b) The engine friction torque including auxiliary braking torque shall be measured by repeating A.9.8.3.6.(a). with all auxiliary brake systems (such as an exhaust brake, jake brake and so on) fully enabled and operated at their maximum operator demand. This provision shall not apply if the auxiliary brake systems are not used during the actual powertrain test run for the HILS system verification in accordance with paragraph A.9.5.4.

A.9.8.3.6. Measurement of positive engine torque response

When the engine is stabilized in accordance with paragraph A.9.8.3.2., the engine torque response characteristics shall be measured as follows (and illustrated in Figure X).

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

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

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

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

(a) The engine shall be operated at engine speed A and an operator command value of 10 per cent for 20 ± 2 seconds. The specified speed shall be held to within ± 20 min^{-1} and the specified torque shall be held to within ± 2 per cent of the maximum torque at the test speed.

(b) The operator command value shall be moved rapidly to, and held at 100 per cent for 10 ± 1 seconds. The necessary dynamometer load shall be applied to keep the engine speed within ± 150 min^{-1} during the first 3 seconds, and within ± 20 min^{-1} during the rest of the segment.

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

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

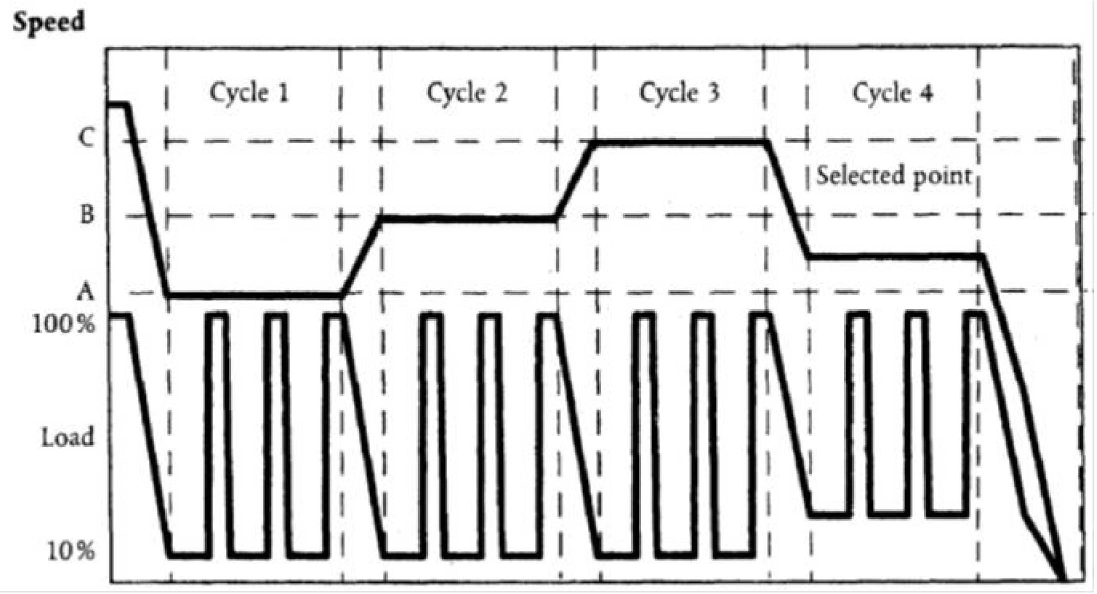
(e) The sequence (a) to (c) shall be run with the engine operating at engine speed B.

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

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

(h) Additional sequences (a) to (c) shall be run at selected speed points when selected by the manufacturer.

Figure X
Engine positive torque response test



A.9.8.3.7. Engine model torque input data

The tabulated input parameters for the engine model shall be obtained from the recorded data of speed, torque and operator command values as required to obtain valid and representative conditions during the HILS system running. Values equivalent to or lower than the minimum engine speed may be added according to good engineering judgement to prevent non-representative or instable model performance during the HILS system running.

At least ~~100~~10 points for torque shall be included in the engine maximum torque table with dependency of ~~at least 10 values for ~~engine speed and ~~at least 10 values for the operator~~a 100 per cent command value.~~ The distribution may be evenly spread and shall be defined using good engineering judgement. Cubic Hermite interpolation in accordance with Appendix 1 to this annex shall be used when interpolation is required. Values equivalent to or lower than the minimum engine speed may be added to prevent non-representative or instable model performance during the HILS system running according to good engineering judgement.~~

At least 10 points for torque shall be included in the engine friction torque table with dependency of engine speed and a 0 per cent command value.

At least 10 points for torque shall be included in the engine auxiliary brake torque table with dependency of engine speed and a 0 per cent ~~command value~~engine command value and a 100 per cent auxiliary brake system(s) command value. The input values shall be calculated by subtracting the values determined in A.9.8.3.6.(a) from the values determined in A.9.8.3.6.(b) for each set speed. In case the auxiliary brake system(s) are not used during the actual powertrain test run for a HILS system verification in accordance with paragraph A.9.5.4 all values shall be set to zero.

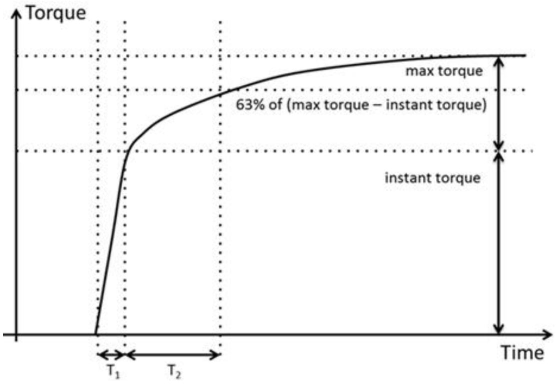
The engine torque response tables with dependency of engine speed shall be determined in accordance with paragraph A.9.8.3.7. and the following procedure for each speed set point (and illustrated in Figure X):

(a) T_1 shall be 0.1 seconds or a manufacturer specific value.

(b) The instant torque value shall be the average value of 3 load steps at T_1 for each set speed according to A.9.8.3.6.

(c) T_2 shall be the time it takes to reach 63% of the difference between the instant torque and the average maximum torque of 3 load steps for each set speed according to A.9.8.3.6.

Figure X
Engine torque response parameters



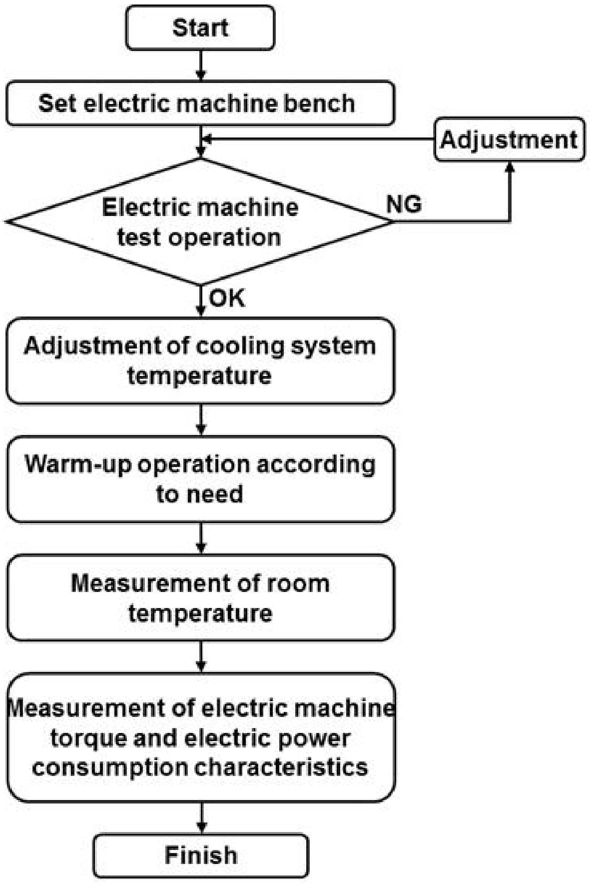
At least 100 points for torque shall be included in the engine torque table with dependency of at least 10 values for engine speed and at least 10 values for the operator command value. The table points may be evenly spread and shall be defined using good engineering judgement. Cubic Hermite interpolation in accordance with Appendix 1 to this annex shall be used when interpolation is required.

A.9.8.4. Electric Machine

A.9.8.4.1. General

The torque map and electric power consumption map of the electric machine shall be determined and converted to table data as the input parameters for the HILS system electric machine model. The test method shall be as prescribed and schematically shown in Figure 36.

Figure 36
Electric machine test procedure diagram



A.9.8.4.2. Test electric machine and its controller

The test electric machine including its controller (high power electronics and ECU) shall be in the condition described below:

(a) The test electric machine and controller shall be serviced in accordance with the inspection and maintenance procedures.

(b) The electric power supply shall be a direct-current constant-voltage power supply or (rechargeable) electric energy storage system, which is capable of supplying/absorbing adequate electric power to/from the power electronics at the maximum (mechanical) power of the electric machine for the duration of the test part.

(c) The voltage of the power supply and applied to the power electronics shall be within ± 5 per cent of the nominal voltage of the REESS in the HV powertrain according to the manufacturer specification.

(d) If performance 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 at least 3 conditions for the applied voltage: the maximum, minimum and nominal in its control or according to the manufacturer specification.

(e) The wiring between the electric ~~mchine~~machine and its power electronics shall be in accordance with its 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 machine performance. In addition, the wiring between the power electronics and the power supply need not be in accordance with its in-vehicle specifications.

(f) 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 though with sufficient capacity to maintain a normal safe operating temperature as prescribed by the manufacturer.

(g) No transmission shall be installed. However, in the case of an electric machine that cannot be operated if it is separated from the transmission due to the in-vehicle configuration, or an electric machine 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.

A.9.8.4.3. Test conditions

A.9.8.4.3.1. The electric machine and its entire equipment assembly must be conditioned at a temperature of 25 °C ± 5 °C.

A.9.8.4.3.2. The test cell temperature shall remain conditioned at 25 °C ± 5 °C during the test.

A.9.8.4.3.3. The cooling system for the test motor shall be in accordance with paragraph A.9.8.4.2.(f).

A.9.8.4.3.4. The test motor shall have been run-in according to the manufacturer’s recommendations.

A.9.8.4.4. Mapping of electric machine torque and power maps

A.9.8.4.4.1. General introduction

The test motor shall be driven in accordance with the method in paragraph A.9.8.4.4.2. and the measurement shall be carried out to obtain at least the measurement items in paragraph A.9.8.4.4.3.

A.9.8.4.4.2. 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.

(a) The torque output of the test motor shall be set under at least 6 conditions on the positive side (‘motor’ operation) as well as the negative side (‘generator’ operation) (if applicable), within a range of the electric machine torque command values between the ~~minimum~~ zero (0~~ per cent~~) to the maximum ~~(±100 per cent) or their equivalent~~ command values~~.~~ (positive and negative). The ~~distribution~~measurement points may be equally distributed and shall be defined using good engineering judgement.

(b) The test speed shall be set at least 6 conditions between the stopped state (0 ~~rpm~~min^{-1}) to the maximum design revolution speed as declared by the manufacturer. 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 ~~distribution~~measurement points may be equally distributed and shall be defined using good engineering judgement. In case negative speeds are also used on the in-vehicle installation, this procedure may be expanded to cover the required speed range.

(c) The minimum stabilized running for each command value shall be at least 3 seconds up to the rated power conditions.

(d) 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.

(e) The cooling system may be operated at its maximum cooling capacity.

A.9.8.4.4.3. Measurement items

The following items shall be simultaneously measured after confirmed stabilization of the shaft speed and torque values:

(a) The shaft torque setpoint and actual value. If the test electric machine and the dynamometer are connected via a transmission, the recorded value shall be divided by the known transmission efficiency and the known gear ratio of the transmission;

(b) The (electric machine) speed setpoint and actual values. If the test electric machine and the dynamometer are connected via a transmission, the electric machine speed may be calculated from the recorded speed of the dynamometer by multiplying the value by the known transmission gear ratio;

(c) The DC-power to/from the power electronics shall be recorded from measurement device(s) for the electric power, voltage and current. The input power may be calculated by multiplying the measured voltage by the measured current;

(d) In the operating condition prescribed in paragraph A.9.8.4.4.2., the electric machine internal temperature and temperature of its 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;

(e) The test cell temperature and coolant temperature (in the case of liquid-cooling) shall be measured and recorded during the test.

A.9.8.4.5. Calculation formulas

The shaft output of the electric machine shall be calculated as follows:

$$P_{em} = \frac{2\pi \times M_{em} \times n_{em}}{60 \times 1000} \qquad (188)$$

Where:

P_{em} ~~: Electric~~is the electric machine mechanical power~~ (~~, kW~~)~~

M_{em} ~~: Electric~~is the electric machine shaft torque~~ (~~, Nm~~)~~

~~N_{em} : Electric~~ n_{em} is the electric machine rotational speed~~ (~~, min^{-1}~~)~~

A.9.8.4.6. Electric machine tabulated input parameters

The tabulated input parameters for the electric machine model shall be obtained from the recorded data of speed, torque, (operator/torque) command values, current, voltage and electric power as required to obtain valid and representative conditions during the HILS system running. At least 36 points for the power maps shall be included in the table with dependency of at least 6 values for speed and at least 6 values for the command value. This shall be valid for both the motor and generator operation, if applicable. The ~~distribution~~table points may be equally distributed and shall be defined using good engineering judgement. Cubic Hermite interpolation in accordance with Appendix 1 to this annex shall be used when interpolation is required. Values equivalent to or lower than the minimum electric machine speed may be added to prevent non-representative or instable model performance during the HILS system running according to good engineering judgement.

A.9.8.5. Battery

A.9.8.5.1. ~~Resistor based battery model~~

~~A.9.8.5.1.1.~~ General

The ~~direct-current internal resistance and open-circuit voltage~~characteristics of the battery shall be determined ~~as~~and converted to the input parameters for the HILS system battery model ~~and obtained from~~in accordance with the ~~battery test. The test method shall be as prescribed and schematically shown below in Figure 37:~~

~~Figure 37~~
~~Battery test procedure diagram~~

measurements and data conversion of paragraphs A.9.8.5.2. through A.9.8.5.~~1~~5.

A.9.8.5.2. Test battery

The test battery shall be in the condition described below:

(a) 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 results can represent the performance of the complete battery under the same conditions;

(b) The test battery shall be one that has reached its rated capacity C after 5 or less repeated charging / discharging cycles with a current of C/n ~~C~~, where n is a value between 1 and 3 specified by the battery manufacturer.

A.9.8.5.~~1~~.3. Equipment specification

Measuring devices in accordance with paragraph A.9.8.2. shall be used. In addition, the measuring devices shall comply with following requirements:

~~A.9.8.5.1.4.~~(a) temperature accuracy: ≤ 1 °C

(b) voltage accuracy: ≤ 0.2 per cent of displayed reading

(c) the resolution of voltage measurement shall be sufficiently small to measure the change in voltage during the lowest applied currents in accordance with the procedures of paragraphs A.9.8.5.5.1., A.9.8.5.5.2. and A.9.8.6.5.

(d) current accuracy: ≤ 0.5 per cent of the displayed reading

A.9.8.5.4. Test conditions

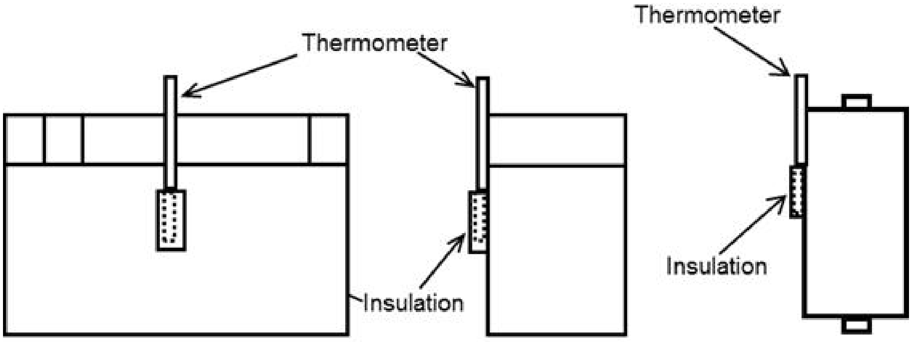
(a) The test battery shall be placed in a temperature controlled test cell. The room temperature shall be conditioned at 298 ± 2K (25 ± 2°C) or 318 ± 2K (45 ± 2°C), whatever is more appropriate according to the manufacturer;

(b) The voltage shall be measured at the terminals of the test battery.

~~(c) The~~ (c) The battery temperature shall be measured continuously during the test and the temperature measurement shall follow the method specified by the manufacturer or it shall be performed, as shown in Figure 38 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;

(d) The battery cooling system may be either activated or deactivated during the test.

Figure 38
Battery temperature measurement locations
(left: rectangular battery; right: cylindrical battery)



A.9.8.5.~~1.~~5. ~~Current and~~ Battery characteristics test

A.9.8.5.5.1. Open circuit voltage ~~characteristic test~~

~~During this test,~~ If the measurement is performed with a representative subsystem the final result is obtained by averaging at least three individual measurements of different subsystems.

(a) After fully charging the test battery in accordance with the charging method specified by the manufacturer, it shall be soaked for at least 12 hours.

(b) The battery temperature at the start of each SOC discharge level shall be 298 ± 2 K (25 °C ± 2 °C). However, 318 ± 2 K (45 °C ± 2 °C) may be selected by reporting to the type approval or certification authority that this temperature level is more representative for the conditions of the in-vehicle application in the test cycle as specified in Annex 1.b.

(c) The test battery shall be discharged with a current of 0.1C in 5 per cent SOC steps calculated based on the rated capacity specified by the battery manufacturer.

(d) Each time a required 5 per cent SOC discharge level is reached the discharge current is disabled and the test battery is soaked for at least 1 hour, but no more than 4 hours (e.g. by disconnecting the cell). The open circuit voltage (OCV) for this SOC level is measured at the ~~10th second~~end of the soak time.

(e) When the voltage drops below the minimum allowed limit the discharge current is prematurely interrupted and the last soak period starts. The last OCV value corresponds to the empty battery condition. With this definition of the empty battery the actual measured rated capacity of the test battery can be calculated by integrating the recorded discharging ~~and charging with a constant~~ current ~~shall be~~over time.

(f) Each measured ~~in accordance~~OCV value is now assigned to a corresponding SOC value based on the actual measured rated capacity of the test battery.

If the measurement is performed with a representative subsystem, data obtained through spline interpolation is used for averaging the individual measurements.

Figure XXX exemplarily shows a typical voltage progress during a complete measurement cycle for a single cell.

Figure XXX
Example of typical cell voltage level during the open circuit voltage measurement

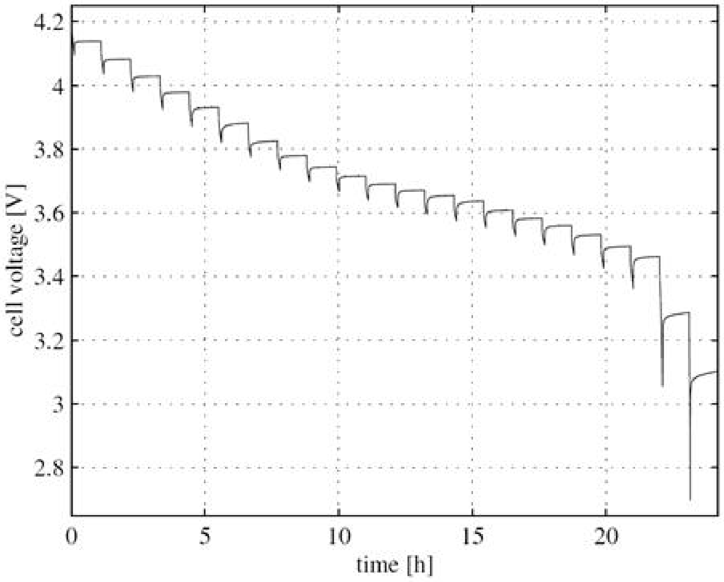
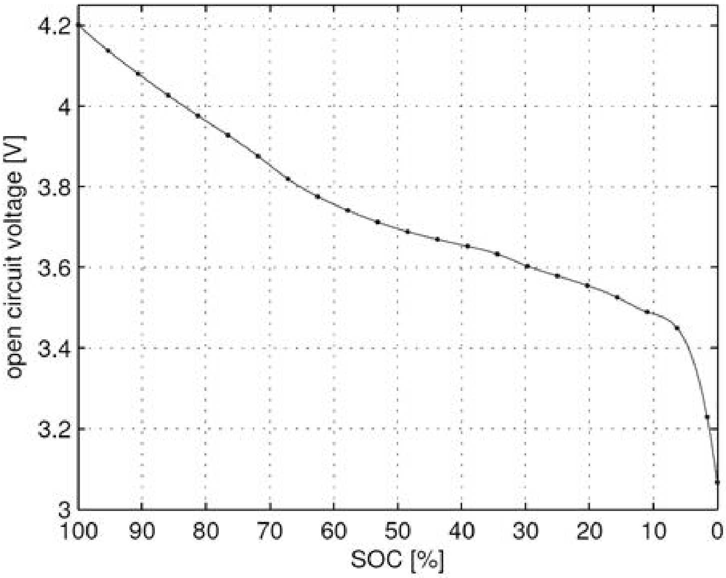


Figure XXX
Example of resulting open circuit voltage as a function of SOC
(measured points are marked with ~~the~~ a dot, spline interpolation is used for data in between measured values)



A.9.8.5.5.2. Test procedure ~~given below:~~ for R_0, R and C characteristics

In case the measurement is performed with a representative subsystem, the final results for R_0, R and C shall be obtained by averaging at least five individual measurements of different subsystems.

All SOC values used shall be calculated based on the actual measured rated capacity of the test battery determined in accordance with paragraph A.9.8.5.5.1.

The current and voltage over time shall be recorded at a sampling rate of at least 10 Hz.

(a) The test shall be conducted ~~by changing the depth of discharge (100 per cent – SOC) within~~for at least 5 different levels of SOC which shall be set in such a way as to allow for accurate interpolation. The selected levels of SOC shall at least cover 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.~~

(b) ~~As for the depth of discharge, after~~ After fully charging the ~~battery at an ambient temperature of 298 ± 2 K (25 °C ± 2 °C)~~test battery in accordance with the charging method specified by the manufacturer, it shall be soaked ~~under the same condition~~ for at least 1 hour, but ~~less~~no more than 4 hours.

(c) The adjustment of the desired SOC before starting the test sequence shall be performed by ~~changing~~discharging or charging the ~~discharge time~~test battery with a constant current ~~I_n (~~*C/n* according to paragraph A~~). The depth of discharge (a per cent) is~~.9.8.5.2.

(d) After the ~~state after discharging~~ adjustment of the desired SOC, the test battery ~~at I_n (A)~~shall be soaked for ~~(0.01 × a × n)~~at least 1 hour, but no more than 4 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 and 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.~~

~~(c~~(e) The battery temperature at the start of ~~the~~each test sequence shall be 298 ± 2 K (25 ºC ± 2 ºC). However, 318 ± 2 K (45 ºC ± 2 ºC) may be selected by reporting ~~in the~~ to the type approval or certification authority that this temperature level is more representative for the conditions of the in-vehicle application ~~the actually measured battery temperature at the time of~~in the test cycle as specified in Annex 1.b. ~~running equivalent to the in-vehicle condition.~~

~~(d) 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 45ºC.~~

~~(e) The test~~(f) The test sequence at each SOC level shall be conducted in accordance with the sequence listed in Table XXX and shown in Figure ~~39:~~XXX.

~~Figure 39~~
~~Test sequence of current-voltage characteristic test~~
~~(Example: when for rated capacity below 20Ah)~~

~~(f)~~ The ~~battery voltage at~~ highest value of the ~~10th second shall be measured by~~charging and discharging ~~and charging at each current specified for each category of the rated capacity posted in Table 35 below. The upper limit of the charging or discharging current shall be 200 (A) but at least higher than~~current I_{max} for the test battery shall be the maximum value used in the ~~HV~~in-vehicle application of the hybrid powertrain under test as defined by the manufacturer. ~~However, if the battery voltage at the 10th second exceeds the lower limit of~~ The lower step values of the charging and discharging current shall be calculated from this maximum value by successively dividing it by a factor of three for three times (e.g. I_{max} = 27A gives a sequence for the charging and discharging ~~voltage or the upper limit of charging voltage, that measurement data shall be discarded.~~ current pulses of 1, 3, 9 and 27A).

~~Table 35~~
~~Charge/Discharge current values for test~~

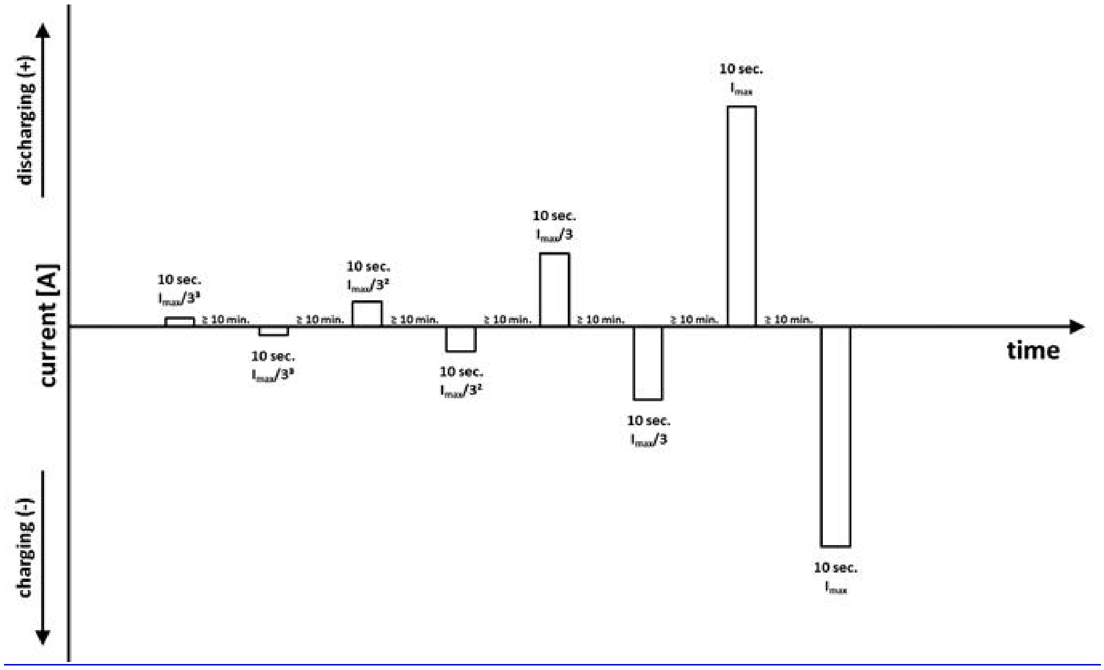
~~*Category of rated capacity*~~	~~*Charge / Discharge current*~~				
~~Less than 20Ah~~	~~$\frac{1}{3}\cdot n\cdot I_n$~~	~~$n\cdot I_n$~~	~~$5\cdot n\cdot I_n$~~	~~$10\cdot n\cdot I_n$~~	~~I_{max}~~
~~20Ah or more~~	~~$\frac{1}{3}\cdot n\cdot I_n$~~	~~$n\cdot I_n$~~	~~$2\cdot n\cdot I_n$~~	~~$5\cdot n\cdot I_n$~~	~~I_{max}~~

~~(g)~~ 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 ~~ºC~~K before continuing with the next discharging or charging ~~level.~~ current step.

Table XXX
Test sequence at each SOC level

Step	*Action*
1	Discharge for 10 seconds with $I_{max}/3^3$
2	No-load period for at least 10 minutes
3	Charge for 10 seconds with $I_{max}/3^3$
4	No-load period for at least 10 minutes
5	Discharge for 10 seconds with $I_{max}/3^2$
6	No-load period for at least 10 minutes
7	Charge for 10 seconds with $I_{max}/3^2$
8	No-load period for at least 10 minutes
9	Discharge for 10 seconds with $I_{max}/3$
10	No-load period for at least 10 minutes
11	Charge for 10 seconds with $I_{max}/3$
12	No-load period for at least 10 minutes
13	Discharge for 10 seconds with I_{max}
14	No-load period for at least 10 minutes
15	Charge for 10 seconds with I_{max}

Figure XXX
Test sequence at each SOC level

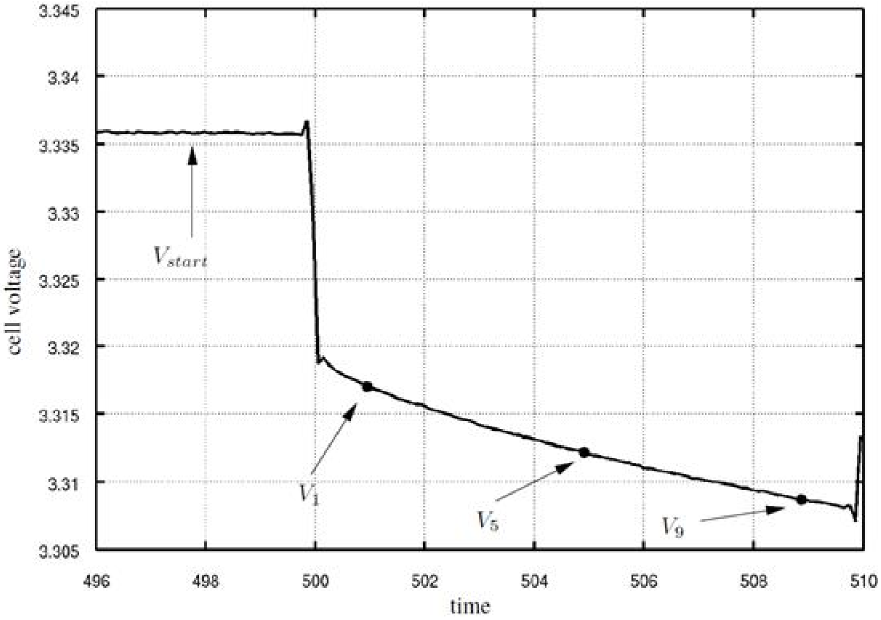


(g) For each discharging and charging current level specified in Table XXX, the no-load voltage before the start of the current pulse V_{start}, and the voltages at 1, 5 and 9 seconds after the pulse has started (V_1, V_5 and V_9) shall be measured (shown in Figure XXX).

If the voltage signal contains signal noise, low-pass filtering of the signal or averaging of the values over a short time frame of ± 0.05 - 0.1 seconds from the respective voltage value may be used.

If a voltage value exceeds the lower limit of discharging voltage or the upper limit of charging voltage, that measurement data shall be discarded.

Figure XXX
Example of single voltage pulse during a discharge pulse



A.9.8.5.~~1.6~~5.3. Calculation of ~~direct-current internal resistance and open-circuit voltage~~ R_0, R and C

The measurement data obtained in accordance with paragraph A.9.8.5.~~4.1.~~5.2. shall be used to calculate the ~~current~~R_0, R and ~~voltage characteristics from~~C values for each charging and discharging current level at each SOC level by using the following equations:

$$V_\infty = \frac{V_1 \times V_9 - V_5^2}{V_1 - 2 \times V_5 + V_9} \qquad \text{(XXX)}$$

$$\tau = \frac{-4}{\ln\left(1 - (V_9 - V_5)/(V_\infty - V_5)\right)} \qquad \text{(XXX)}$$

For a charge pulse:

$$K = -\tau \times \ln(1 - V_1/V_\infty) \qquad \text{(XXX)}$$

$$V_0 = V_\infty \times \left(1 - e^{(1-K)/\tau}\right) \qquad \text{(XXX)}$$

For a discharge pulse:

$$V_0 = \frac{V_1 - V_\infty}{e^{-1/\tau}} + V_\infty \qquad \text{(XXX)}$$

The values for $R_{0,\text{pulse}}$, R_{pulse} and C_{pulse} for a specific current level I_{pulse} shall be calculated as:

$$R_{0,pulse} = \frac{V_0 - V_{start}}{I_{pulse}} \quad \text{(XXX)}$$

$$R_{pulse} = \frac{V_\infty - V_0}{I_{pulse}} \quad \text{(XXX)}$$

$$C_{pulse} = \frac{\tau}{R_{pulse}} \quad \text{(XXX)}$$

The required values for R_0, R and C for, respectively, ~~discharging currents and their corresponding voltages.~~ charging or discharging at one specific SOC level shall be calculated as the mean values of the all the corresponding charging or discharging current levels. The same calculations shall be performed for all selected levels of SOC in order to get the specific values for R_0, R and C not only depending on charging or discharging, but also on the SOC.

~~The method~~ A.9.8.5.5.4. Correction of R_0 for battery subsystems

In case the ~~least-squares shall be used to determine~~measurement is performed with a representative subsystem the ~~best-fit equation having~~final results for all R_0 values may be corrected if the ~~form:~~ internal connections between the subsystems have a significant influence on the R_0 values.

~~$\boldsymbol{y = a \times x + b}$ (Eq. 189)~~

~~Where:~~

~~y = actual value of voltage (V)~~

~~x = actual value of current (A)~~

~~a = slope of the regression line~~

~~b = y~~ The validity of the values used for correction of the original R_0 values shall be demonstrated to the type approval or certification authority by calculations, simulations, estimations, experimental results and so on.

A.9.8.6. Capacitor

A.9.8.6.1. General

The characteristics of the (super)capacitor shall be determined and converted to the input parameters for the HILS system supercapacitor model in accordance with the measurements and data conversion of paragraphs A.9.8.6.2. through A.9.8.6.7.

The characteristics for a capacitor are hardly dependent of its state of charge or current, respectively. Therefore only a single measurement is prescribed for the calculation of the model input parameters.

A.9.8.6.2. Test supercapacitor

The test supercapacitor shall be either the complete supercapacitor system or a representative subsystem. If the manufacturer chooses to test with a representative subsystem, the manufacturer shall demonstrate that the test results can represent the performance of the complete supercapacitor under the same conditions;

A.9.8.6.3. Equipment specification

Measuring devices that meet the requirements in accordance with paragraph A.9.8.5.3. shall be used.

A.9.8.6.4. Test conditions

(a) The test supercapacitor shall be placed in a temperature controlled test cell. The room temperature shall be conditioned at 298 ± 2 K (25 ± 2 °C) or 318 ± 2 K (45 ± 2 °C), whatever is more appropriate according to the manufacturer;

(b) The voltage shall be measured at the terminals of the test supercapacitor.

(c) The supercapacitor cooling system may be either activated or deactivated during the test.

A.9.8.6.5. Supercapacitor characteristics test

In case the measurement is performed with a representative subsystem, the final result is obtained by averaging at least three individual measurements of different subsystems.

(a) After fully charging and then fully discharging the test supercapacitor to its lowest operating voltage in accordance with the charging method specified by the manufacturer, it shall be soaked for at least 2 hours, but no more than 6 hours.

(b) The supercapacitor temperature at the start of the test shall be 298 ± 2 K (25 ± 2 ºC). However, 318 ± 2 K (45 ± 2 ºC) may be selected by reporting to the type approval or certification authority that this temperature level is more representative for the conditions of the in-vehicle application in the test cycle as specified in Annex 1.b.

(c) After the soak time, a complete charge and discharge cycle according to Figure XXX with a constant current I_{test} shall be performed. I_{test} shall be the maximum allowed continuous current for the test supercapacitor as specified by the manufacturer or the maximum continuous current occurring in the in-vehicle application.

(d) After a waiting period of at least 30 seconds (t_0 to t_1), the supercapacitor shall be charged with a constant current I_{test} until the maximum operating voltage V_{max} is reached. Then the charging shall be stopped and the supercapacitor shall be soaked for 30 seconds (t_2 to t_3) so that the voltage can settle to its final value V_b before the discharging is started. After that the supercapacitor shall be discharged with a constant current I_{test} until the lowest operating voltage V_{min} is reached. Afterwards (from t_4 onwards) there shall be another waiting period of 30 seconds until the voltage will settle to its final value V_c.

(e) The current and voltage over time, respectively I_{meas} and V_{meas}, shall be recorded at a sampling rate of at least 10 Hz.

(f) The following characteristic values shall be determined from the measurement (illustrated in Figure XXX):

V_a is the no-load voltage right before start of the charge pulse

V_b is the no-load voltage right before start of the discharge pulse

V_c is the no-load voltage recorded 30 seconds after the end of the discharge pulse

$\Delta V(t_1)$, $\Delta V(t_3)$ are the voltage changes directly after applying the constant charging or discharging current I_{test} at the time of t_1 and t_3, respectively. These voltage changes shall be determined by applying a linear approximation to the voltage characteristics as defined in detail A of Figure XXX by usage of the least squares method.

$\Delta V(t_1)$ is the absolute difference of voltages between V_a and the intercept value of the ~~regression line~~straight-line approximation at the time of t_1.

~~(a) For~~$\Delta V(t_3)$ is the ~~discharge pulses, calculate the direct-current internal resistance~~ ~~R_d~~ ~~(i.e.~~ absolute ~~value~~difference of ~~the slope)~~voltages between V_b and the ~~open-circuit voltage~~ ~~V_{d0}~~ ~~(i.e. the y-~~intercept ~~) from the data (displayed in Figure 40).~~

~~(b) 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 41).~~

~~(c) The open-circuit voltage~~ ~~V_0~~ ~~as input parameter for the model shall be the calculated average~~straight-line approximation at the time of ~~V_{d0}~~ ~~and~~ ~~V_{c0}~~~~.~~ t_3.

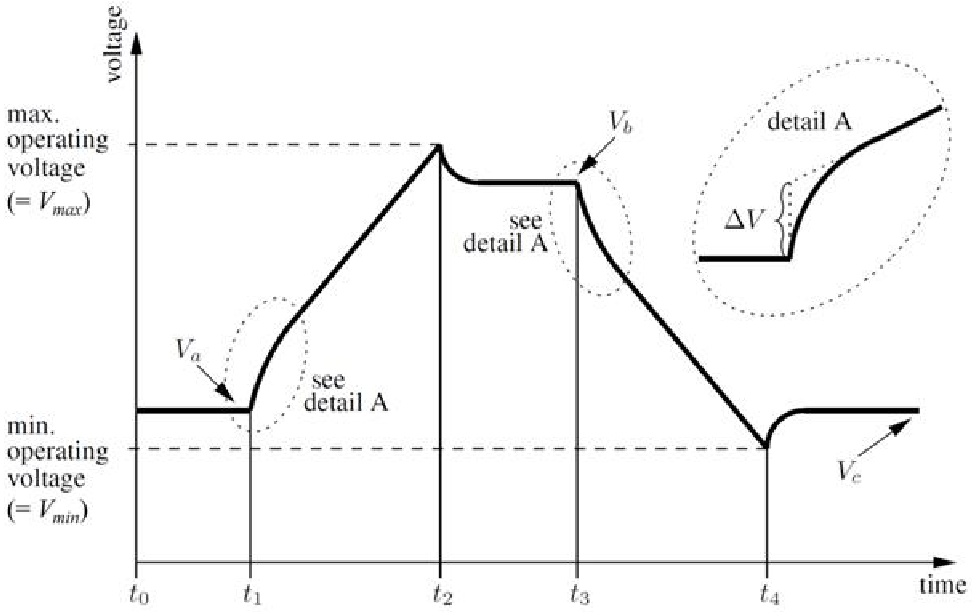
~~(d) When a single internal resistance parameter is used as input parameter for the model, the direct-current internal resistance~~ ~~R_0~~ ~~shall be the calculated average of~~ ~~R_d~~ ~~and~~ ~~R_c~~~~. Separate charge and discharge internal resistances may be used.~~

~~(e) In case a REESS subsystem is used for the test, the representative system values~~ $\Delta V(t_2)$ is the absolute difference of voltages between V_{max} and V_b.

$\Delta V(t_4)$ is the absolute difference of voltages between V_{min} and V_c.

Figure XXX

Example of voltage curve for the supercapacitor measurement



A.9.8.6.6. Calculation of R and C

The measurement data obtained in accordance with paragraph A.9.8.6.5. shall be used to calculate the *R* and *C* values according as follows.

(a) The capacitance for charging and discharging shall be calculated as follows:

For charging:

$$C_{charge} = \frac{\Sigma_{t_1}^{t_2} I_{meas}\Delta t}{V_b - V_a} \qquad \text{(XXX)}$$

For discharging:

$$C_{discharge} = \frac{\Sigma_{t_3}^{t_4} I_{meas}\Delta t}{V_c - V_b} \qquad \text{(XXX)}$$

(b) The internal resistance for charging and discharging shall be calculated~~.~~ as follows:

~~Figure 40~~
~~Determination of the Internal Resistance and Open-Circuit Voltage during Discharging~~

~~Figure 41~~
~~Determination of the Internal Resistance and Open-Circuit Voltage during Charging~~

~~A.9.8.5.2. RC-based battery model~~

~~Reserved.~~

~~A.9.8.6. Capacitor~~

~~Reserved.~~

For charging:

$$R_{charge} = \frac{\Delta V(t_1) + \Delta V(t_2)}{2\, I_{test}} \qquad \text{(XXX)}$$

For discharging:

$$R_{discharge} = \frac{\Delta V(t_3) + \Delta V(t_4)}{2\, I_{test}} \qquad \text{(XXX)}$$

(c) For the model, only a single capacitance and resistance are needed and these shall be calculated as follows:

Capacitance C:

$$C = \frac{C_{charge} + C_{discharge}}{2} \qquad \text{(XXX)}$$

Resistance R:

$$R = \frac{R_{charge} + R_{discharge}}{2} \qquad \text{(XXX)}$$

A.9.8.6.7. Correction of resistance of supercapacitor subsystems

In case the measurement is performed with a representative subsystem the final results for the system resistance value may be corrected if the internal connections between the subsystems have a significant influence on the resistance value.

The validity of the values used for correction of the original resistance values shall be demonstrated to the type approval or certification authority by calculations, simulations, estimations, experimental results and so on.

Appendix 1 ~~Cubic~~ Hermite interpolation procedure

~~Reserved.~~ The Hermite interpolation method approximates each of the intervals with a third order polynomial expression similar to spline interpolation. Hermite interpolation however creates continuous derivatives at connecting points through first derivatives.

The Hermite interpolation polynomial coincides with the given function value and the derivative of the point.

The interpolation polynomial between the interval of [(x_i, y_i), (x_{i+1}, y_{i+1})] is defined in equation (X1), where the equation is cubic polynomial based on the point of (x_i, y_i).

$$f(x) = a \times (x - x_i)^3 + b \times (x - x_i)^2 + c \times (x - x_i) + d \qquad \text{(X1)}$$

Since the Hermite interpolation polynomial coincides with the given function value and the derivative of the point, following conditions result:

$$f(x_i) = y_i = d \qquad \text{(X2)}$$

$$f'(x_i) = y_i{}' = c \qquad \text{(X3)}$$

If $\Delta x = x_{i+1} - x_i$, then:

$$f(x_{i+1}) = y_{i+1} = a \times \Delta x^3 + b \times \Delta x^2 + y_i{}' \times \Delta x + y_i \qquad \text{(X4)}$$

$$f'(x_{i+1}) = y_{i+1}{}' = 3 \times a \times \Delta x^2 + 2 \times b \times \Delta x + y_i{}' \qquad \text{(X5)}$$

Combining equation X4 and X5 yields:

$$a = \frac{y'_{i+1} + y'_i}{\Delta x^2} - 2 \times \frac{y_{i+1} - y_i}{\Delta x^3} \qquad \text{(X6)}$$

$$b = -\frac{y'_{i+1} + 2 \times y'_i}{\Delta \mathrm{x}} + 3 \times \frac{y_{i+1} - y_i}{\Delta x^2} \qquad \text{(X7)}$$

The derivatives used in equations X3, X6, and X7 can be calculated as follows:

$$y' = \frac{\left|\frac{y_{i+1} - y_i}{x_{i+1} - x_i}\right| \times \left|\frac{y_i - y_{i-1}}{x_i - x_{i-1}}\right|}{\left(\frac{2 \times x_{i+1} - x_i - x_{i-1}}{3 \times (x_{i+1} - x_{i-1})}\right) \times \left(\frac{y_{i+1} - y_i}{x_{i+1} - x_i}\right) + \left(\frac{x_{i+1} + x_i - 2 \times x_{i-1}}{3 \times (x_{i+1} - x_{i-1})}\right) \times \left(\frac{y_i - y_{i-1}}{x_i - x_{i-1}}\right)} \qquad \text{(X8)}$$

Annex 10., amend to read

Annex 10

Test procedure for engines installed in hybrid vehicles using the powertrain method

A.10.1. This annex contains the requirements and general description for testing engines installed in hybrid vehicles using the Powertrain method.

A.10.2. 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:

A.10.2.1 Powertrain method

The Powertrain method shall follow the general guidelines for execution of the defined process steps as outlined below and shown in the flow chart of Figure 42. The details of each step are described in the relevant paragraphs. Deviations from the guidance are permitted where appropriate, but the specific requirements shall be mandatory.

For the Powertrains method, the procedure shall follow:

(a) Selection and confirmation of the HDH object for approval~~;~~

(b) Set up of Powertrain system~~;~~

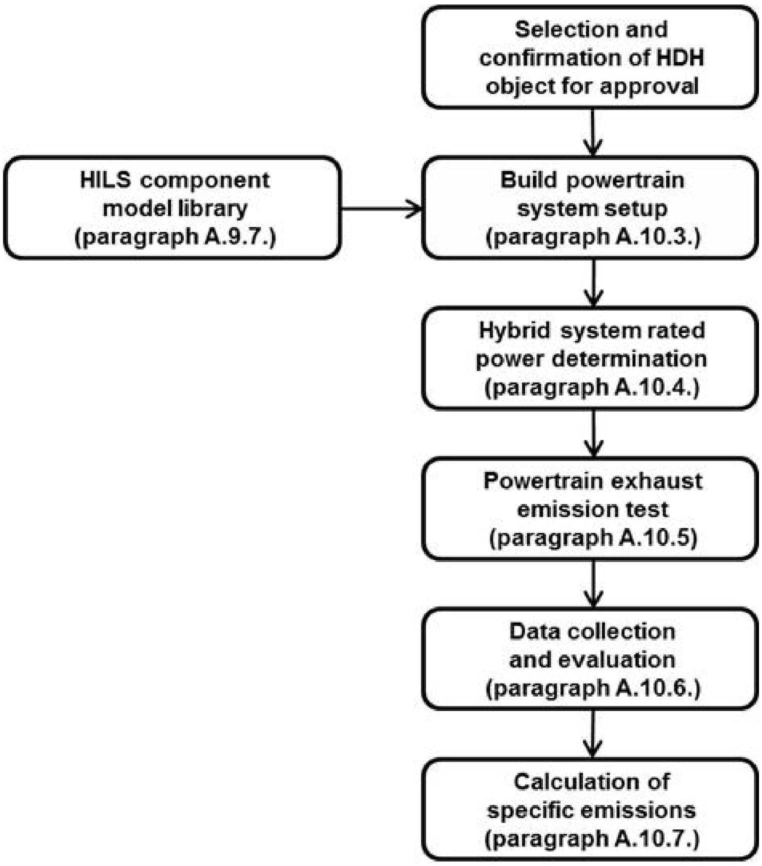
(c) Hybrid system rated power ~~mapping;~~determination

(d) Exhaust emission test~~;~~

(e) Data collection and evaluation~~;~~

(f) Calculation of specific emissions~~.~~

Figure 42
Powertrain method flow chart



A.10.2.2. Build of the Powertrain system setup

The Powertrain system setup shall be constructed in accordance with the provisions of paragraph A.10.3. and A.9.7. of the HILS method.

A.10.2.3. ~~System Power Mapping~~ Hybrid system rated power determination

The hybrid system rated power shall be determined in accordance with paragraph A.10.4.

A.10.2.4. Powertrain ~~Exhaust Emission Test~~exhaust emission test

The ~~Powertrain Exhaust Emission Test~~powertrain exhaust emission test shall be carried out in accordance with all provisions of paragraph A.10.5.

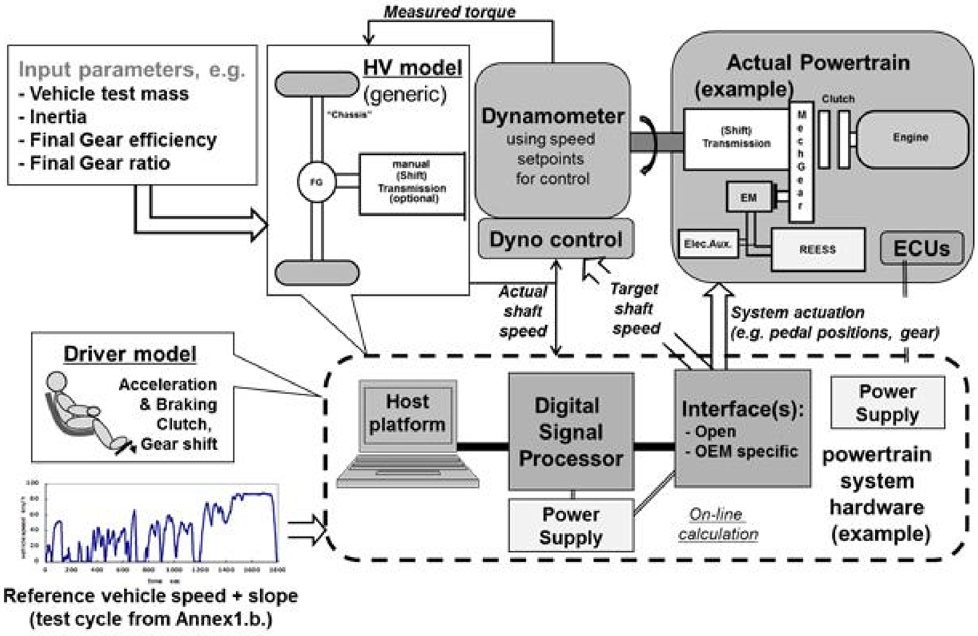
A.10.3. Set up of powertrain system

A.10.3.1 General introduction

The powertrain system shall consist of, as shown in Figure 43, a HV model and its input parameters, the test cycle as defined in Annex 1.b., as well as the complete physical hybrid powertrain and its ECU(s) (hereinafter referred to as the "actual powertrain") and a power supply and required interface(s). The powertrain system setup shall be defined in accordance with paragraph A.10.3.2. through A.10.3.5. The HILS component library (paragraph A.9.7.)

shall be applied in this process. The system update frequency shall be at least 100 Hz to accurately control the dynamometer.

Figure 43:
Outline of powertrain system setup



A.10.3.2. Powertrain system hardware

The powertrain system hardware shall have the signal types and number of channels that are required for constructing the interface between all hardware required for the functionality of and to connect the dynamometer and the actual powertrain.

A.10.3.3. Powertrain system interface

The powertrain system interface shall be specified and set up in accordance with the requirements for the (hybrid) vehicle model (paragraph A.10.3.5.) and required for the operation of the dynamometer and actual powertrain. In addition, specific signals can be defined in the interface model to allow proper operation of the actual ECU(s), e.g. ABS signals. All modifications or signals shall be documented and reported to the type approval authorities or certification agency.

The interface shall not contain key hybrid control functionalities as specified in paragraph A.9.3.4.1. of the HILS method.

The actual dynamometer torque shall be used as input to the HV model.

The calculated rotational input speed of the HV model (e.g. transmission or final gear input shaft) shall be used as setpoint for the dynamometer speed.

A.10.3.4. Actual powertrain

The powertrain including all of its ECU(s) in accordance with the in-vehicle installation shall be used for the powertrain system setup. The provisions for setup shall follow paragraph 6.~~3.~~ of this gtr.

The torque measuring device shall be rigidly mounted closely to the hybrid system output shaft. For example, if a damper is needed it should be mounted on the dynamometer and its damping characteristic should not affect the torque reading.

A.10.3.5. Vehicle model

A vehicle model shall represent all relevant characteristics of the ~~applicable hybrid vehicle for the~~ drivetrain and chassis and contain those components not present in the actual powertrain ~~system.~~(paragraph A.10.3.4.). The HV model shall be constructed by defining its components in accordance with paragraph A.9.7. of the HILS method. The relevant characteristics are defined as:

(a) Chassis (paragraph A.9.7.3.) to determine actual vehicle speed as function of powertrain torque and brake torque, ~~tyre~~tire rolling resistance, air drag resistance and road gradients. ~~The~~For validation purpose, the actual vehicle speed shall be compared with the desired vehicle speed defined in the test cycle of Annex 1.b.

(b) Final gear (paragraph A.9.7.7.6.) to represent the differential gear functionality, unless it is already included in the actual powertrain.

(c) In case of a manual transmission, the transmission (A.9.7.7.8.) and clutch model (A.9.7.7.1.) may be included as part of the HV model.

The input parameters for the HV model shall be defined in accordance with paragraph A.10.5.2.

A.10.3.6. Driver model

The driver model shall contain all required tasks to drive the HV model over the test cycle and typically includes e.g. accelerator and brake pedal signals as well as clutch and selected gear position in case of a manual shift transmission. The driver model shall use actual vehicle speed for comparison with the desired vehicle speed defined in accordance with the test cycle of Annex 1.b.

The driver model tasks shall be implemented as a closed-loop control~~.~~ and shall be in accordance with paragraph A.9.7.4.

The shift algorithm for the manual transmission shall be in accordance with paragraph A.9.7.4~~.(b).~~.3.

A.10.4. ~~System~~ Hybrid system rated power ~~mapping procedure~~determination

~~A.10.4.1. General~~

The ~~purpose of the mapping procedure in this paragraph is to determine the maximum~~ hybrid system ~~torque and~~rated power ~~available at each speed with a fully/sufficiently charged Rechargeable Energy Storage System. One of the following methods shall be used to generate a hybrid-active map.~~

~~A.10.4.2 Mapping conditions~~

~~Internal Combustion Engines as part of a hybrid system~~ shall be ~~mapped as described~~determined in ~~this~~ accordance with paragraph ~~when either the HILS method (annex 8. to this gtr) or the Powertrain method (annex 9. to this gtr) are used to determine their exhaust gas pollutant emissions. 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 activated as described in paragraphs A.10.4.3. or A.10.4.4. of this section~~A.9.6.3.

~~The operator command and speed setpoints may be defined as in standard engine testing.~~

~~A.10.4.3. 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 RESS 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 RESS when the power measured from the RESS drops below the expected maximum power from the RESS by more than 2 per cent of total declared system power (including engine and RESS power).~~

~~Unless good engineering judgment indicates otherwise, it may be assumed that the expected maximum power from the RESS is equal to the measured RESS power at the start of the sweep segment. For example, if the 3-second rolling average of total engine-RESS power is 200 kW and the power from the RESS at the beginning of the sweep segment is 50 kW, once the power from the RESS reaches 46 kW, the sweep shall be stopped to charge the RESS. 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 RESS 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.~~

~~A.10.4.4. Discrete speed mapping~~

~~A powertrain map shall be performed by using discrete speeds along its full load curve from minimum to maximum mapping speed with increments no greater than 100 min^{-1}. Speed set points shall be selected at at least 13 equally spaced powertrain speeds. Mapping may be stopped at the highest speed above maximum power at which 50 per cent of maximum power occurs. Powertrain speed shall be stabilized at each setpoint, targeting a torque value at 70per cent of peak torque at that speed without hybrid-assist. The engine shall be fully warmed up and the RESS 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. Paragraph 7.4.2. to this gtr shall be followed to calculate the maximum test speed. The measured maximum test speed shall fall in the range from 92 to 108per cent 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.~~In addition following conditions shall be respected:

(a) The hybrid powertrain shall be warmed up to its normal operating condition as specified by the manufacturer

(b) Prior to starting the test, the system temperatures shall be within their normal operating conditions as specified by the manufacturer

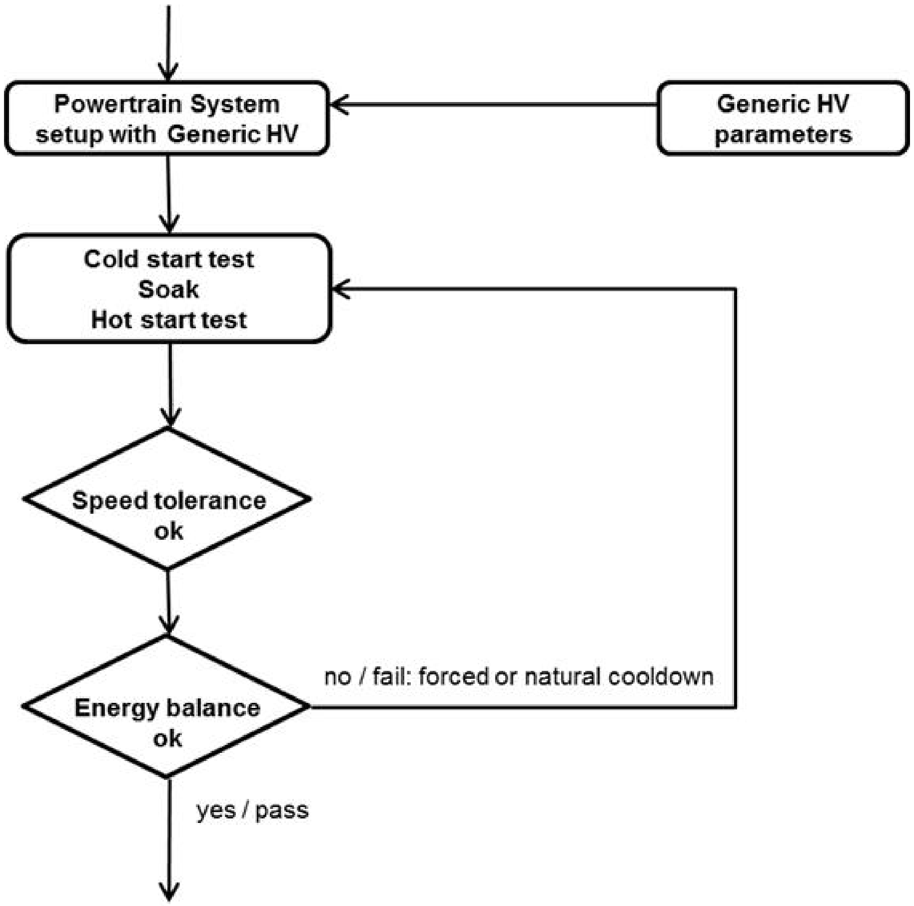
(c) The test cell shall be conditioned between 20 °C and 30 °C

A.10.5. Powertrain exhaust emission test

A.10.5.1. General introduction

Using the powertrain system setup and all required HV model and interface systems enabled, exhaust emission testing shall be conducted in accordance with the provisions of paragraphs A.10.5.2. to A.10.5.6. Guidance on test sequence is provided in the flow diagram of Figure 44.

Figure 44
Powertrain exhaust emission test sequence



A.10.5.2. Generic vehicle

Generic vehicle parameters shall be used in the HV model and defined in accordance with paragraphs A.10.5.2.1. to A.10.5.2.6. in case the respective components are not present in hardware during the powertrain test.

A.10.5.2.1. Test vehicle mass ~~and curb mass~~

~~Test~~The test vehicle mass m_{vehicle} ~~and curb mass $m_{\mathrm{vehicle,0}}$ are~~shall be defined with equation 112 using the hybrid system rated power in accordance with ~~equations 112 and 113 or 114, respectively.~~paragraph A.10.4.

A.10.5.2.2. Air drag coefficients

The generic vehicle air drag coefficients A_{front} and C_{drag} are calculated in accordance with equations 115 and 116 or 117, respectively.

A.10.5.2.3. ~~Tyre~~Tire rolling resistance coefficient

The ~~tyre~~tire rolling resistance coefficient f_{roll} is calculated in accordance with equation 118.

A.10.5.2.4. Wheel radius

The wheel radius shall be defined in accordance with paragraph A.9.5.6.9.

A.10.5.2.5. Final gear ratio and efficiency

The final gear ratio and efficiency shall be defined in accordance with paragraph A.9.6.2.10.

A.10.5.2.6. Transmission efficiency

The efficiency of each gear shall be set to 0.95.

A.10.5.2.7. Transmission gear ratio

The gear ratios of the (shift) transmission shall have the manufacturer specified values for the test hybrid powertrain.

A.10.5.2.8. Transmission gear inertia

The inertia of each gear of the (shift) transmission shall have the manufacturer specified value for the test hybrid powertrain.

A.10.5.2.9. Clutch maximum transmitted torque

For the maximum transmitted torque of the clutch and the synchronizer, the design value specified by the manufacturer shall be used.

A.10.5.2.10. Gear change period

The gear-change period for a manual transmission shall be set to one (1.0) second.

A.10.5.2.11. Gear change method

Gear positions at the start, acceleration and deceleration during the approval test shall be the respective gear positions defined by the shift strategy in accordance with paragraph A.9.7.4. and shall be part of the driver model.

A.10.5.2.12. Inertia of rotating sections

The inertia for the post transmission parts shall be defined in accordance with paragraph A.9.6.2.15.

In case a post transmission component is included in the actual hardware (e.g. final gear), this specific component inertia as specified by the manufacturer shall be used to correct the inertia as specified in accordance with paragraph

A.9.6.2.15. taking into account the gear ratios between this component and the wheels. The resulting post transmission inertia shall have a minimum value of 0 kgm^2.

A.10.5.2.13. Other input parameters

All other input parameters shall have the manufacturer specified value for the actual test hybrid powertrain.

A.10.5.3. Data to be recorded

All data required to allow for the checks of speed, net energy balance and determination of emissions shall be recorded at 5 Hz or higher (10 Hz recommended).

A.10.5.4. Emission test sequence

The test sequence shall be in accordance with paragraph 7.6.

A.10.5.5. Validation statistics

For each test, either cold or hot started, it shall be valid if the test conditions of paragraph A.10.5.5.1. and A.10.5.5.2. are met.

A.10.5.5.1. Validation of vehicle speed

The criteria for vehicle speed ~~and net energy change of the RESS~~ shall be in accordance with paragraph A.9.6.4.4.

A.10.5.5.2. Validation of RESS net energy change

The ratio of RESS net energy change to the cumulative fuel energy value shall satisfy the following equation:

~~(Eq.~~ $|\Delta E / C_{test}| < 0.01$ ((190)

Where:

ΔE ~~: Net~~ is the net energy change of the RESS in accordance with paragraph A.9.5.8.2.3.(a)-(d), kWh

C_{test} ~~: Energy~~ is the energy value for the cumulative amount of fuel mass flow during test, kWh

~~A.10.A.9.~~ In case the net energy change criterion is not met, the powertrain system shall be readied for another test run.

A.10.5.~~6.2~~5.3. Validation of dynamometer speed

Linear regression of the actual values for the dynamometer speed on the reference values shall be performed for each individual test cycle. The method of least squares shall be used, with the best-fit equation having the form:

~~(Eq.~~ $y = a_1 x + a_0$ ((191)

Where:

y ~~:~~is the actual value of speed~~(~~, min^{-1}~~)~~

x ~~:~~is the reference value of speed~~(~~, min^{-1}~~)~~

a_1 ~~:~~is the slope of the regression line

a_0 ~~:~~is the y-intercept value 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.

For a test to be considered valid, the criteria of Table 36 shall be met.

Table 36
Statistical criteria for speed validation

Parameter	*Speed control*
Slope, a_1	$0.950 \leq a_1 \leq 1.030$
Absolute value of intercept, $\lvert a_0 \rvert$	≤ 2.0 % of maximum test speed
Standard error of estimate, *SEE*	≤ 5.0 % of maximum test speed
Coefficient of determination, r^2	≥ 0.970

A.10.6. Data collection and evaluation

~~Reserved.~~

In addition to the data collection of gtr4 (in accordance with paragraph 7.6.6), the hybrid system work shall be determined over the test cycle by synchronously using the hybrid system rotational speed and torque values at the wheel hub (HV chassis model output signals in accordance with paragraph A.9.7.3.) recorded during the test in accordance with paragraph A.10.5. to calculate instantaneous values of hybrid system power. Instantaneous power values shall be integrated over the test cycle to calculate the hybrid system work W_{sys_test} (kWh). Integration shall be carried out using a frequency of 5 Hz or higher (10 Hz recommended) and include only positive power values.

The hybrid system work W_{sys} shall be calculated as follows:

$$W_{sys} = W_{sys\_test} \times \left(\frac{1}{0.95}\right)^2 \qquad (X)$$

Where:

W_{sys} is the hybrid system work, kWh

W_{sys_test} is the hybrid system work from the test run, kWh

All parameters shall be reported.

A.10.7. Calculation of the specific emissions

~~Reserved.~~

The specific emissions e_{gas} or e_{PM} (g/kWh) shall be calculated for each individual component as follows:

$$e = \frac{m}{W_{sys}} \qquad (109)$$

Where:

e is the specific emission, g/kWh

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

W_{sys} is the cycle work as determined in accordance with paragraph A.10.6., kWh

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

$$e = \frac{(0.14 \times m_{cold}) + (0.86 \times m_{hot})}{(0.14 \times W_{sys,cold}) + (0.86 \times W_{sys,hot})} \qquad (110)$$

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

$W_{\text{sys,cold}}$ is the hybrid system cycle work on the cold start test, kWh

$W_{\text{sys,hot}}$ is the hybrid system cycle work on the hot start test, kWh

If periodic regeneration in accordance with paragraph 6.6.2. applies, the regeneration adjustment factors $k_{\text{r,u}}$ or $k_{\text{r,d}}$ shall be multiplied with or be added to, respectively, the specific emission result e as determined in equations 109 and 110.