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.

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 vehiclesof 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 | m2 | 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 | m3 | 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* | m/s2 | gravitational coefficient |
| *i*aux | A | electric auxiliary current |
| *i*em | A | electric machine current |
| *J* | kgm2 | rotating inertia |
| *J*aux | kgm2 | mechanical auxiliary load inertia |
| *J*cl,1 / *J*cl,2 | kgm2 | clutch rotational inertias |
| *J*em | kgm2 | electric machine rotational inertia |
| *J*fg | kgm2 | final gear rotational inertia |
| *J*flywheel | kgm2 | flywheel inertia |
| *J*gear | kgm2 | transmission gear rotational inertia |
| *J*p / *J*t | kgm2 | torque converter pump / turbine rotational inertia |
| *J*pm | kgm2 | hydraulic pump/motor rotational inertia |
| *J*powertrain | kgm2 | total powertrain rotational inertia |
| *J*retarder | kgm2 | retarder rotational inertia |
| *Jspur* | kgm2 | spur gear rotational inertia |
| *J*tot | kgm2 | total vehicle powertrain inertia |
| *J*wheel | kgm2 | 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 |
| *Mcl,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 |
| *Mice* | 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 |
| *pedal*brake | - | brake pedal position |
| *pedal*clutch | - | clutch pedal position |
| *pedallimit* | - | clutch pedal threshold |
| *P*el,aux | kW | electric auxiliary power |
| *P*el,em | kW | electric machine electrical power |
| *P*em | kW | electric machine mechanical power |
| *p*gas | Pa | accumulator gas pressure |
| *P*ice,loss | W | ICE power loss |
| *P*loss,bat | W | battery power loss |
| *P*loss,em | kW | electric machine power loss |
| *P*mech,aux | kW | mechanical auxiliary load power |
| *P*rated | kW | (hybrid system) rated power |
| *p*res | Pa | hydraulic accumulator sump pressure |
| *Q*pm | m3/s | hydraulic pump/motor volumetric flow |
| *R*bat,th | K/W | battery thermal resistance |
| *r*CVT | - | CVT ratio |
| *R*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*limit | rad/s | clutch speed threshold |
| *SOC* | - | state-of-charge |
| *T*act*(n*act*)* | Nm | actual engine torque at actual engine speed |
| *T*bat | K | battery temperature |
| *T*bat,cool | K | battery coolant temperature |
| *T*capacitor | K | capacitor temperature |
| *T*clutch | s | clutch time |
| *T*em | K | electric machine temperature |
| *T*em,cool | K | electric machine coolant temperature |
| *T*ice,oil | K | ICE oil temperature |
| *T*max*(n*act*)* | Nm | maximum engine torque at actual engine speed |
| *T*norm | - | normalized duty cycle torque value |
| *T*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 |
| *u*in / *u*out | V | input / output voltage |
| *U*init | V | initial voltage at start of test |
| *u*req | V | requested voltage |
| *V*C,min/max | V | capacitor minimum / maximum voltage |
| *V*gas | m3 | 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*eng\_HILS | kWh | engine work in the HILS simulated run |
| *W*eng\_test | kWh | engine work in chassis dynamometer test |
| *W*sys | kWh | hybrid system work |
| *W*sys\_HILS | kWh | hybrid system work in the HILS simulated run |
| *W*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 | kg/m3 | air density |
| *τ*1 | - | first order time response constant |
| *τ*bat,heat | J/K | battery thermal capacity |
| *τ*close | s | clutch closing time constant |
| *τ*driveaway | s | clutch closing time constant for driveaway |
| *τ*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 |
|  | rad/s2 | 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.

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 5.1.4

5.1.4. 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.

The duty cycle torque values shall be normalized as follows:

(1)

Where:

*T*norm are the normalized duty cycle torque values

*n*act is the actual engine speed, min-1

*T*act*(n*act*)* is the actual engine torque at actual engine speed, Nm

*T*max*(n*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. 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

5.3.3.2. Internal combustion engine

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

*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.

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 |

a)Accuracy and repeatabilit

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.: NOx converter efficiency | Upon initial installation, within 35 days before testing, and after major maintenance. |
| (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.

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 9. The linearity verification according to paragraph 9.2.1. shall be performed for the gas analyzers within 35 days before testing 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.

*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

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.

9.3.1.3. Rise time

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

9.3.1.4. 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 NO2 loss-performance check specified in paragraph 9.3.9.4.

Chemical dryers are not 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 N2 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 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.

*Section 9.3.4., amend to read*

9.3.4. Vacuum-side 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. .

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

The system 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:

*Δp* = *p* / *V*s x 0.005 x *qv*s (74)

Where:

*V*s is the system volume, l

*qv*s 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. .

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 CO2 and water quench shall not exceed 2 per cent.

*Section 9.3.9.4.2., amend to read*

9.3.9.4.2. Sample dryer NO2 penetration

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

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

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

NO2 calibration gas that has an NO2 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 NOx data shall be calculated and this value recorded as *x*NOxref and the NO2 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 NO2 calibration gas used to establish *x*NOxref. It 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 NOx 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 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 9. This implies a precision of at least 0.5 µg and a resolution of at least 1 µg (1 digit = 1 µg).

In order to ensure accurate filter weighing, 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* |
| --- | --- | --- |
|
| 1 | 0 | +5.02E-06\*P² -6.80E-03\*P +0.77 |
| 2 | 0 | … |
| 3 | 0 | … |
| 4 | 0 | … |
| 5 | 0 | … |
| 6 | 0 | … |
| 7 | 2.35 | … |
| 8 | 5.57 | … |
| 9 | 8.18 | … |
| 10 | 9.37 | … |
| 11 | 9.86 | … |
| 12 | 10.18 | … |
| 13 | 10.38 | … |
| 14 | 10.57 | … |
| 15 | 10.95 | … |
| 16 | 11.56 | … |
| 17 | 12.22 | … |
| 18 | 12.97 | … |
| 19 | 14.33 | … |
| 20 | 16.38 | … |
| 21 | 18.4 | … |
| 22 | 19.86 | … |
| 23 | 20.85 | … |
| 24 | 21.52 | … |
| 25 | 21.89 | … |
| 26 | 21.98 | … |
| 27 | 21.91 | +1.67E-06\*P² -2.27E-03\*P +0.26 |
| 28 | 21.68 | -1.67E-06\*P² +2.27E-03\*P -0.26 |
| 29 | 21.21 | -5.02E-06\*P² +6.80E-03\*P -0.77 |
| 30 | 20.44 | … |
| 31 | 19.24 | … |
| 32 | 17.57 | … |
| 33 | 15.53 | … |
| 34 | 13.77 | … |
| 35 | 12.95 | … |
| 36 | 12.95 | … |
| 37 | 13.35 | … |
| 38 | 13.75 | … |
| 39 | 13.82 | … |
| 40 | 13.41 | … |
| 41 | 12.26 | … |
| 42 | 9.82 | … |
| 43 | 5.96 | … |
| 44 | 2.2 | … |
| 45 | 0 | … |
| 46 | 0 | … |
| 47 | 0 | -1.40E-06\*P² +2.31E-03\*P -0.81 |
| 48 | 0 | +2.22E-06\*P² -2.19E-03\*P -0.86 |
| 49 | 0 | +5.84E-06\*P² -6.68E-03\*P -0.91 |
| 50 | 1.87 | … |
| 51 | 4.97 | … |
| 52 | 8.4 | … |
| 53 | 9.9 | … |
| 54 | 11.42 | … |
| 55 | 15.11 | … |
| 56 | 18.46 | … |
| 57 | 20.21 | … |
| 58 | 22.13 | … |
| 59 | 24.17 | … |
| 60 | 25.56 | … |
| 61 | 26.97 | … |
| 62 | 28.83 | … |
| 63 | 31.05 | … |
| 64 | 33.72 | … |
| 65 | 36 | … |
| 66 | 37.91 | … |
| 67 | 39.65 | … |
| 68 | 41.23 | … |
| 69 | 42.85 | … |
| 70 | 44.1 | … |
| 71 | 44.37 | … |
| 72 | 44.3 | … |
| 73 | 44.17 | … |
| 74 | 44.13 | … |
| 75 | 44.17 | … |
| 76 | 44.51 | +3.10E-06\*P² -3.89E-03\*P -0.76 |
| 77 | 45.16 | +3.54E-07\*P² -1.10E-03\*P -0.61 |
| 78 | 45.64 | -2.39E-06\*P² +1.69E-03\*P -0.47 |
| 79 | 46.16 | … |
| 80 | 46.99 | … |
| 81 | 48.19 | … |
| 82 | 49.32 | … |
| 83 | 49.7 | … |
| 84 | 49.5 | … |
| 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\*P² +1.91E-03\*P -0.06 |
| 123 | 48.63 | -1.43E-06\*P² +2.13E-03\*P +0.34 |
| 124 | 44.83 | -9.50E-07\*P² +2.35E-03\*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\*P² -1.58E-03\*P +1.27 |
| 139 | 0 | +5.31E-06\*P² -5.52E-03\*P +1.80 |
| 140 | 0 | +8.44E-06\*P² -9.46E-03\*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 | … |
| 179 | 17.56 | … |
| 180 | 18.38 | +2.81E-06\*P² -3.15E-03\*P +0.78 |
| 181 | 17.49 | -2.81E-06\*P² +3.15E-03\*P -0.78 |
| 182 | 15.18 | -8.44E-06\*P² +9.46E-03\*P -2.33 |
| 183 | 13.08 | … |
| 184 | 12.23 | … |
| 185 | 12.03 | … |
| 186 | 11.72 | … |
| 187 | 10.69 | … |
| 188 | 8.68 | … |
| 189 | 6.2 | … |
| 190 | 4.07 | … |
| 191 | 2.65 | … |
| 192 | 1.92 | … |
| 193 | 1.69 | … |
| 194 | 1.68 | … |
| 195 | 1.66 | … |
| 196 | 1.53 | … |
| 197 | 1.3 | … |
| 198 | 1 | … |
| 199 | 0.77 | … |
| 200 | 0.63 | … |
| 201 | 0.59 | … |
| 202 | 0.59 | … |
| 203 | 0.57 | … |
| 204 | 0.53 | … |
| 205 | 0.5 | … |
| 206 | 0 | … |
| 207 | 0 | … |
| 208 | 0 | … |
| 209 | 0 | … |
| 210 | 0 | … |
| 211 | 0 | … |
| 212 | 0 | … |
| 213 | 0 | … |
| 214 | 0 | … |
| 215 | 0 | … |
| 216 | 0 | … |
| 217 | 0 | -5.63E-06\*P² +6.31E-03\*P -1.56 |
| 218 | 0 | -2.81E-06\*P² +3.15E-03\*P -0.78 |
| 219 | 0 | +0.00E+00\*P² +0.00E+00\*P +0.00 |
| 220 | 0 | … |
| 221 | 0 | … |
| 222 | 0 | … |
| 223 | 0 | … |
| 224 | 0 | … |
| 225 | 0 | … |
| 226 | 0.73 | … |
| 227 | 0.73 | … |
| 228 | 0 | … |
| 229 | 0 | … |
| 230 | 0 | … |
| 231 | 0 | … |
| 232 | 0 | … |
| 233 | 0 | … |
| 234 | 0 | … |
| 235 | 0 | … |
| 236 | 0 | … |
| 237 | 0 | … |
| 238 | 0 | … |
| 239 | 0 | … |
| 240 | 0 | … |
| 241 | 0 | … |
| 242 | 0 | +6.51E-06\*P² -6.76E-03\*P +1.50 |
| 243 | 0 | +1.30E-05\*P² -1.35E-02\*P +3.00 |
| 244 | 0 | +1.95E-05\*P² -2.03E-02\*P +4.49 |
| 245 | 0 | … |
| 246 | 0 | … |
| 247 | 0 | … |
| 248 | 0 | … |
| 249 | 0 | … |
| 250 | 0 | … |
| 251 | 0 | … |
| 252 | 0 | … |
| 253 | 1.51 | … |
| 254 | 4.12 | … |
| 255 | 7.02 | … |
| 256 | 9.45 | … |
| 257 | 11.86 | … |
| 258 | 14.52 | … |
| 259 | 17.01 | … |
| 260 | 19.48 | … |
| 261 | 22.38 | … |
| 262 | 24.75 | … |
| 263 | 25.55 | +6.51E-06\*P² -6.76E-03\*P +1.50 |
| 264 | 25.18 | -6.51E-06\*P² +6.76E-03\*P -1.50 |
| 265 | 23.94 | -1.95E-05\*P² +2.03E-02\*P -4.49 |
| 266 | 22.35 | … |
| 267 | 21.28 | … |
| 268 | 20.86 | … |
| 269 | 20.65 | … |
| 270 | 20.18 | … |
| 271 | 19.33 | … |
| 272 | 18.23 | … |
| 273 | 16.99 | … |
| 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\*P² +1.35E-02\*P -3.00 |
| 282 | 0 | -6.51E-06\*P² +6.76E-03\*P -1.50 |
| 283 | 0.5 | +0.00E+00\*P² +0.00E+00\*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\*P² -5.86E-03\*P -0.21 |
| 306 | 0 | +1.04E-05\*P² -1.17E-02\*P -0.42 |
| 307 | 0 | +1.56E-05\*P² -1.76E-02\*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 | … |
| 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\*P² -5.86E-03\*P -0.21 |
| 330 | 19.53 | -5.21E-06\*P² +5.86E-03\*P +0.21 |
| 331 | 17.92 | -1.56E-05\*P² +1.76E-02\*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\*P² +7.62E-03\*P +1.11 |
| 347 | 0 | +2.58E-06\*P² -2.34E-03\*P +1.60 |
| 348 | 0 | +1.17E-05\*P² -1.23E-02\*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 | … |
| 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\*P² -7.10E-03\*P +0.94 |
| 378 | 39.29 | +2.13E-06\*P² -1.91E-03\*P -0.20 |
| 379 | 37.23 | -2.65E-06\*P² +3.28E-03\*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\*P² -2.25E-03\*P +0.26 |
| 388 | 14.58 | +7.75E-06\*P² -7.79E-03\*P +1.86 |
| 389 | 14.72 | +1.30E-05\*P² -1.33E-02\*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\*P² -8.13E-03\*P +2.32 |
| 412 | 43.96 | +3.39E-06\*P² -2.94E-03\*P +1.18 |
| 413 | 43.41 | -1.39E-06\*P² +2.25E-03\*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\*P² -6.08E-04\*P +0.36 |
| 430 | 19.36 | +3.09E-06\*P² -3.47E-03\*P +0.69 |
| 431 | 19.79 | +5.33E-06\*P² -6.33E-03\*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\*P² -1.13E-03\*P -0.13 |
| 448 | 32.66 | -4.23E-06\*P² +4.06E-03\*P -1.26 |
| 449 | 31.73 | -9.01E-06\*P² +9.25E-03\*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\*P² +1.67E-03\*P -0.86 |
| 464 | 1.13 | +5.69E-06\*P² -5.91E-03\*P +0.68 |
| 465 | 2.2 | +1.30E-05\*P² -1.35E-02\*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\*P² -8.29E-03\*P +1.09 |
| 488 | 41.43 | +3.47E-06\*P² -3.10E-03\*P -0.05 |
| 489 | 39.99 | -1.31E-06\*P² +2.09E-03\*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\*P² -2.47E-04\*P -0.38 |
| 497 | 22.53 | +2.55E-06\*P² -2.58E-03\*P +0.43 |
| 498 | 22.62 | +4.48E-06\*P² -4.92E-03\*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\*P² +2.73E-04\*P +0.09 |
| 529 | 39.29 | -5.09E-06\*P² +5.46E-03\*P -1.04 |
| 530 | 38.59 | -9.87E-06\*P² +1.07E-02\*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\*P² +5.46E-03\*P -1.04 |
| 543 | 8.16 | -1.63E-07\*P² +4.68E-05\*P +0.17 |
| 544 | 8.95 | +4.76E-06\*P² -5.37E-03\*P +1.39 |
| 545 | 11.3 | +4.90E-06\*P² -5.60E-03\*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 | … |
| 558 | 25.72 | … |
| 559 | 26.77 | … |
| 560 | 28.01 | … |
| 561 | 29.23 | … |
| 562 | 30.06 | … |
| 563 | 30.31 | … |
| 564 | 30.29 | +1.21E-07\*P² -4.06E-04\*P +0.33 |
| 565 | 30.05 | -4.66E-06\*P² +4.79E-03\*P -0.81 |
| 566 | 29.44 | -9.44E-06\*P² +9.98E-03\*P -1.95 |
| 567 | 28.6 | … |
| 568 | 27.63 | … |
| 569 | 26.66 | … |
| 570 | 26.03 | -4.66E-06\*P² +4.79E-03\*P -0.81 |
| 571 | 25.85 | +1.21E-07\*P² -4.06E-04\*P +0.33 |
| 572 | 26.14 | +4.90E-06\*P² -5.60E-03\*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\*P² -4.06E-04\*P +0.33 |
| 616 | 42.39 | -4.66E-06\*P² +4.79E-03\*P -0.81 |
| 617 | 40.78 | -9.44E-06\*P² +9.98E-03\*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\*P² +4.79E-03\*P -0.81 |
| 625 | 9.46 | +1.21E-07\*P² -4.06E-04\*P +0.33 |
| 626 | 10.21 | +4.90E-06\*P² -5.60E-03\*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\*P² -4.06E-04\*P +0.33 |
| 640 | 24.69 | -4.66E-06\*P² +4.79E-03\*P -0.81 |
| 641 | 21.85 | -9.44E-06\*P² +9.98E-03\*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\*P² +4.11E-03\*P -1.07 |
| 653 | 0 | +1.64E-06\*P² -1.77E-03\*P -0.19 |
| 654 | 0 | +7.18E-06\*P² -7.64E-03\*P +0.70 |
| 655 | 0 | … |
| 656 | 0 | … |
| 657 | 0 | … |
| 658 | 2.96 | … |
| 659 | 7.9 | … |
| 660 | 13.49 | … |
| 661 | 18.36 | … |
| 662 | 22.59 | … |
| 663 | 26.26 | … |
| 664 | 29.4 | … |
| 665 | 32.23 | … |
| 666 | 34.91 | … |
| 667 | 37.39 | … |
| 668 | 39.61 | … |
| 669 | 41.61 | … |
| 670 | 43.51 | … |
| 671 | 45.36 | … |
| 672 | 47.17 | … |
| 673 | 48.95 | … |
| 674 | 50.73 | … |
| 675 | 52.36 | … |
| 676 | 53.74 | … |
| 677 | 55.02 | … |
| 678 | 56.24 | … |
| 679 | 57.29 | … |
| 680 | 58.18 | … |
| 681 | 58.95 | … |
| 682 | 59.49 | … |
| 683 | 59.86 | … |
| 684 | 60.3 | … |
| 685 | 61.01 | … |
| 686 | 61.96 | … |
| 687 | 63.05 | … |
| 688 | 64.16 | … |
| 689 | 65.14 | … |
| 690 | 65.85 | … |
| 691 | 66.22 | … |
| 692 | 66.12 | +2.39E-06\*P² -2.55E-03\*P +0.23 |
| 693 | 65.01 | -2.39E-06\*P² +2.55E-03\*P -0.23 |
| 694 | 62.22 | -7.18E-06\*P² +7.64E-03\*P -0.70 |
| 695 | 57.44 | … |
| 696 | 51.47 | … |
| 697 | 45.98 | … |
| 698 | 41.72 | … |
| 699 | 38.22 | … |
| 700 | 34.65 | … |
| 701 | 30.65 | … |
| 702 | 26.46 | … |
| 703 | 22.32 | … |
| 704 | 18.15 | … |
| 705 | 13.79 | … |
| 706 | 9.29 | … |
| 707 | 4.98 | … |
| 708 | 1.71 | … |
| 709 | 0 | … |
| 710 | 0 | … |
| 711 | 0 | … |
| 712 | 0 | … |
| 713 | 0 | … |
| 714 | 0 | … |
| 715 | 0 | … |
| 716 | 0 | … |
| 717 | 0 | … |
| 718 | 0 | … |
| 719 | 0 | … |
| 720 | 0 | … |
| 721 | 0 | … |
| 722 | 0 | … |
| 723 | 0 | … |
| 724 | 0 | … |
| 725 | 0 | … |
| 726 | 0 | … |
| 727 | 0 | … |
| 728 | 0 | … |
| 729 | 0 | … |
| 730 | 0 | … |
| 731 | 0 | … |
| 732 | 0 | … |
| 733 | 0 | … |
| 734 | 0 | … |
| 735 | 0 | … |
| 736 | 0 | … |
| 737 | 0 | … |
| 738 | 0 | … |
| 739 | 0 | -2.53E-06\*P² +2.43E-03\*P +0.05 |
| 740 | 0 | +2.12E-06\*P² -2.78E-03\*P +0.81 |
| 741 | 0 | +6.77E-06\*P² -7.99E-03\*P +1.56 |
| 742 | 0 | … |
| 743 | 0 | … |
| 744 | 0 | … |
| 745 | 0 | … |
| 746 | 0 | … |
| 747 | 0 | … |
| 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\*P² -2.66E-03\*P +0.52 |
| 783 | 18.05 | -2.26E-06\*P² +2.66E-03\*P -0.52 |
| 784 | 17.39 | -6.77E-06\*P² +7.99E-03\*P -1.56 |
| 785 | 16.35 | … |
| 786 | 14.71 | … |
| 787 | 11.71 | … |
| 788 | 7.81 | … |
| 789 | 5.25 | -2.26E-06\*P² +2.66E-03\*P -0.52 |
| 790 | 4.62 | +2.26E-06\*P² -2.66E-03\*P +0.52 |
| 791 | 5.62 | +6.77E-06\*P² -7.99E-03\*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\*P² -2.66E-03\*P +0.52 |
| 829 | 47.23 | -2.26E-06\*P² +2.66E-03\*P -0.52 |
| 830 | 46.66 | -6.77E-06\*P² +7.99E-03\*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 | … |
| 844 | 38.55 | … |
| 845 | 38.42 | … |
| 846 | 37.89 | … |
| 847 | 36.89 | … |
| 848 | 35.53 | … |
| 849 | 34.01 | … |
| 850 | 32.88 | -2.26E-06\*P² +2.66E-03\*P -0.52 |
| 851 | 32.52 | +2.26E-06\*P² -2.66E-03\*P +0.52 |
| 852 | 32.7 | +6.77E-06\*P² -7.99E-03\*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\*P² -2.66E-03\*P +0.52 |
| 869 | 52.19 | -2.26E-06\*P² +2.66E-03\*P -0.52 |
| 870 | 51.82 | -6.77E-06\*P² +7.99E-03\*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\*P² +4.12E-03\*P -0.93 |
| 900 | 0 | -4.47E-07\*P² +2.44E-04\*P -0.31 |
| 901 | 0 | +2.71E-06\*P² -3.63E-03\*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 | … |
| 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\*P² -2.00E-03\*P +0.46 |
| 960 | 59.33 | +1.44E-06\*P² -3.72E-04\*P +0.61 |
| 961 | 58.52 | +8.03E-07\*P² +1.26E-03\*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\*P² -3.72E-04\*P +0.61 |
| 969 | 51.37 | +2.08E-06\*P² -2.00E-03\*P +0.46 |
| 970 | 51.41 | +2.71E-06\*P² -3.63E-03\*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\*P² -2.00E-03\*P +0.46 |
| 979 | 56.33 | +1.44E-06\*P² -3.72E-04\*P +0.61 |
| 980 | 55.38 | +8.03E-07\*P² +1.26E-03\*P +0.75 |
| 981 | 54.99 | … |
| 982 | 54.75 | … |
| 983 | 54.11 | … |
| 984 | 53.32 | … |
| 985 | 52.41 | … |
| 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\*P² +2.76E-04\*P +0.25 |
| 1013 | 5.67 | -5.06E-07\*P² -7.04E-04\*P -0.26 |
| 1014 | 6.03 | -1.16E-06\*P² -1.68E-03\*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 | … |
| 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\*P² -5.59E-05\*P -0.62 |
| 1071 | 47.54 | -2.43E-06\*P² +1.57E-03\*P -0.48 |
| 1072 | 46.79 | -3.07E-06\*P² +3.20E-03\*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\*P² +1.57E-03\*P -0.48 |
| 1099 | 35.32 | -1.80E-06\*P² -5.59E-05\*P -0.62 |
| 1100 | 35.56 | -1.16E-06\*P² -1.68E-03\*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 | … |
| 1128 | 48.93 | … |
| 1129 | 49.05 | … |
| 1130 | 49.23 | … |
| 1131 | 49.28 | -1.80E-06\*P² -5.59E-05\*P -0.62 |
| 1132 | 48.84 | -2.43E-06\*P² +1.57E-03\*P -0.48 |
| 1133 | 48.12 | -3.07E-06\*P² +3.20E-03\*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\*P² +5.68E-04\*P +0.07 |
| 1176 | 0 | +1.53E-06\*P² -2.06E-03\*P +0.47 |
| 1177 | 0 | +3.82E-06\*P² -4.70E-03\*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 | … |
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| 1217 | 40.6 | … |
| 1218 | 41.15 | … |
| 1219 | 42.23 | … |
| 1220 | 43.61 | … |
| 1221 | 45.08 | … |
| 1222 | 46.58 | … |
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| 1224 | 49.7 | … |
| 1225 | 51.27 | … |
| 1226 | 52.8 | … |
| 1227 | 54.3 | … |
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| 1235 | 65.52 | … |
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| 1244 | 70.91 | … |
| 1245 | 71.73 | … |
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| 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 | … |
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| 1258 | 74.55 | +1.03E-05\*P² -9.91E-03\*P +1.51 |
| 1259 | 73.8 | +1.36E-05\*P² -1.25E-02\*P +1.83 |
| 1260 | 72.71 | … |
| 1261 | 71.39 | … |
| 1262 | 70.02 | … |
| 1263 | 68.71 | … |
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| 1265 | 66.44 | … |
| 1266 | 65.45 | … |
| 1267 | 64.49 | … |
| 1268 | 63.54 | … |
| 1269 | 62.6 | … |
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| 1272 | 59.64 | … |
| 1273 | 58.6 | … |
| 1274 | 57.64 | … |
| 1275 | 56.79 | … |
| 1276 | 55.95 | … |
| 1277 | 55.09 | … |
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| 1279 | 53.33 | … |
| 1280 | 52.52 | … |
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| 1282 | 50.92 | … |
| 1283 | 49.9 | … |
| 1284 | 48.68 | … |
| 1285 | 47.41 | … |
| 1286 | 46.5 | +1.06E-05\*P² -1.01E-02\*P +1.57 |
| 1287 | 46.22 | +7.62E-06\*P² -7.70E-03\*P +1.30 |
| 1288 | 46.44 | +4.65E-06\*P² -5.29E-03\*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 | … |
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| 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\*P² -3.13E-03\*P +0.89 |
| 1312 | 72.94 | +1.26E-07\*P² -9.74E-04\*P +0.74 |
| 1313 | 73.01 | -2.14E-06\*P² +1.18E-03\*P +0.60 |
| 1314 | 73.44 | … |
| 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 | +1.12E-06\*P² -1.42E-03\*P +0.92 |
| 1335 | 68.73 | +4.37E-06\*P² -4.03E-03\*P +1.24 |
| 1336 | 67.88 | +7.62E-06\*P² -6.64E-03\*P +1.56 |
| 1337 | 66.68 | … |
| 1338 | 65.29 | … |
| 1339 | 63.95 | … |
| 1340 | 62.84 | +4.37E-06\*P² -4.03E-03\*P +1.24 |
| 1341 | 62.21 | +1.12E-06\*P² -1.42E-03\*P +0.92 |
| 1342 | 62.04 | -2.14E-06\*P² +1.18E-03\*P +0.60 |
| 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 | +1.12E-06\*P² -1.42E-03\*P +0.92 |
| 1361 | 70.09 | +4.37E-06\*P² -4.03E-03\*P +1.24 |
| 1362 | 69.35 | +7.62E-06\*P² -6.64E-03\*P +1.56 |
| 1363 | 68.27 | … |
| 1364 | 67.09 | … |
| 1365 | 65.96 | … |
| 1366 | 64.87 | … |
| 1367 | 63.79 | … |
| 1368 | 62.82 | +4.37E-06\*P² -4.03E-03\*P +1.24 |
| 1369 | 63.03 | +1.12E-06\*P² -1.42E-03\*P +0.92 |
| 1370 | 63.62 | -2.14E-06\*P² +1.18E-03\*P +0.60 |
| 1371 | 64.8 | … |
| 1372 | 65.5 | … |
| 1373 | 65.33 | +1.12E-06\*P² -1.42E-03\*P +0.92 |
| 1374 | 63.83 | +4.37E-06\*P² -4.03E-03\*P +1.24 |
| 1375 | 62.44 | +7.62E-06\*P² -6.64E-03\*P +1.56 |
| 1376 | 61.2 | … |
| 1377 | 59.58 | … |
| 1378 | 57.68 | … |
| 1379 | 56.4 | … |
| 1380 | 54.82 | … |
| 1381 | 52.77 | +6.78E-06\*P² -6.35E-03\*P +2.06 |
| 1382 | 52.22 | +5.95E-06\*P² -6.07E-03\*P +2.56 |
| 1383 | 52.48 | +5.11E-06\*P² -5.78E-03\*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 | … |
| 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 | +2.30E-06\*P² -3.18E-03\*P +1.81 |
| 1430 | 63.65 | -5.04E-07\*P² -5.74E-04\*P +0.57 |
| 1431 | 64.27 | -3.31E-06\*P² +2.03E-03\*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 | … |
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| 1444 | 75.81 | … |
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| 1447 | 79.32 | … |
| 1448 | 80.2 | … |
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| 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\*P² +5.24E-03\*P -1.21 |
| 1464 | 80.61 | -1.05E-05\*P² +8.45E-03\*P -1.74 |
| 1465 | 80.46 | -1.42E-05\*P² +1.17E-02\*P -2.27 |
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| 1467 | 80.42 | … |
| 1468 | 80.24 | … |
| 1469 | 80.13 | … |
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| 1473 | 81.52 | … |
| 1474 | 82.4 | … |
| 1475 | 83.21 | … |
| 1476 | 84.05 | … |
| 1477 | 84.85 | … |
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| 1481 | 86.64 | … |
| 1482 | 86.57 | … |
| 1483 | 86.43 | … |
| 1484 | 86.58 | … |
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| 1487 | 86.14 | … |
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| 1492 | 86.14 | … |
| 1493 | 86.36 | … |
| 1494 | 86.25 | … |
| 1495 | 86.5 | … |
| 1496 | 86.14 | … |
| 1497 | 86.29 | … |
| 1498 | 86.4 | … |
| 1499 | 86.36 | … |
| 1500 | 85.63 | … |
| 1501 | 86.03 | … |
| 1502 | 85.92 | … |
| 1503 | 86.14 | … |
| 1504 | 86.32 | … |
| 1505 | 85.92 | … |
| 1506 | 86.11 | … |
| 1507 | 85.91 | … |
| 1508 | 85.83 | … |
| 1509 | 85.86 | -1.09E-05\*P² +9.06E-03\*P -1.95 |
| 1510 | 85.5 | -7.66E-06\*P² +6.45E-03\*P -1.63 |
| 1511 | 84.97 | -4.41E-06\*P² +3.84E-03\*P -1.31 |
| 1512 | 84.8 | … |
| 1513 | 84.2 | … |
| 1514 | 83.26 | … |
| 1515 | 82.77 | … |
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| 1517 | 81.16 | … |
| 1518 | 80.42 | … |
| 1519 | 79.21 | … |
| 1520 | 78.83 | … |
| 1521 | 78.52 | -5.24E-06\*P² +4.57E-03\*P -1.18 |
| 1522 | 78.52 | -6.08E-06\*P² +5.30E-03\*P -1.06 |
| 1523 | 78.81 | -6.91E-06\*P² +6.04E-03\*P -0.93 |
| 1524 | 79.26 | … |
| 1525 | 79.61 | … |
| 1526 | 80.15 | … |
| 1527 | 80.39 | … |
| 1528 | 80.72 | … |
| 1529 | 81.01 | … |
| 1530 | 81.52 | … |
| 1531 | 82.4 | … |
| 1532 | 83.21 | … |
| 1533 | 84.05 | … |
| 1534 | 85.15 | … |
| 1535 | 85.92 | … |
| 1536 | 86.98 | … |
| 1537 | 87.45 | … |
| 1538 | 87.54 | … |
| 1539 | 87.25 | … |
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| 1553 | 87.07 | … |
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| 1565 | 86.81 | … |
| 1566 | 86.81 | … |
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| 1569 | 86.92 | … |
| 1570 | 87.1 | … |
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| 1640 | 86.85 | … |
| 1641 | 86.63 | … |
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| 1644 | 86.55 | -4.18E-06\*P² +3.26E-03\*P +0.61 |
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| 1649 | 86.7 | … |
| 1650 | 86.55 | … |
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| 1674 | 86.92 | … |
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| 1678 | 87.36 | … |
| 1679 | 87.29 | … |
| 1680 | 87.58 | -6.58E-06\*P² +5.65E-03\*P -0.51 |
| 1681 | 87.61 | -8.97E-06\*P² +8.04E-03\*P -1.64 |
| 1682 | 87.76 | -1.14E-05\*P² +1.04E-02\*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 | … |
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| 1692 | 87.54 | … |
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| 1702 | 87.18 | … |
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| 1705 | 87.03 | … |
| 1706 | 87.07 | … |
| 1707 | 87.29 | … |
| 1708 | 86.99 | … |
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| 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\*P² +9.14E-03\*P -2.12 |
| 1725 | 86.37 | -8.83E-06\*P² +7.85E-03\*P -1.47 |
| 1726 | 86.48 | -7.56E-06\*P² +6.56E-03\*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\*P² +3.96E-03\*P -0.51 |
| 1747 | 86.21 | -1.06E-06\*P² +1.35E-03\*P -0.19 |
| 1748 | 85.96 | +2.19E-06\*P² -1.26E-03\*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 | … |
| 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/mol

Atomic mass of carbon 12.011 g/mol

Atomic mass of sulphur 32.065 g/mol

Atomic mass of nitrogen 14.0067 g/mol

Atomic mass of oxygen 15.9994 g/mol

Atomic mass of argon 39.9 g/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 determination

(g) Creation of the hybrid engine cycle

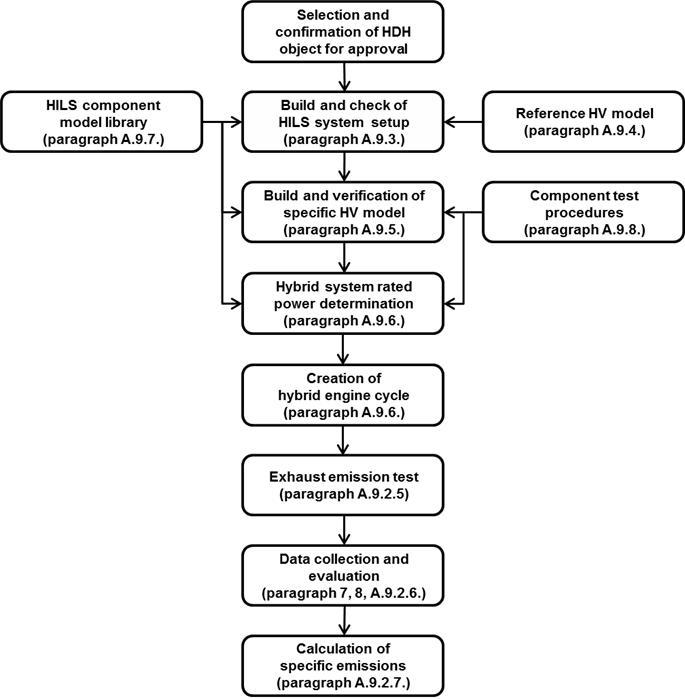
(h) Exhaust emission test

(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.9.2.6.1. 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 only positive power values in accordance with paragraph A.9.7.3.

The hybrid system work *W*sysshall be calculated as follows:

(a) Cases where *W*act < *W*eng\_HILS:

(107)

(b) Cases where *W*act ≥ *W*eng\_HILS

(108)

Where:

*W*sys is the hybrid system work, kWh

*W*sys\_HILS is the hybrid system work from the final HILS simulated run, kWh

*W*act is the actual engine work in the HEC test, kWh

*W*eng\_HILS is the engine work from the final HILS simulated run, kWh

All parameters shall be reported.

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 (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 (r²) 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:

(109)

Where:

*e*  is the specific emission, g/kWh

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

Wsys is the cycle work as determined in accordance with paragraph A.9.2.6.2., kWh

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

(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*sys,cold is the hybrid system cycle work on the cold start test, kWh

*W*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.

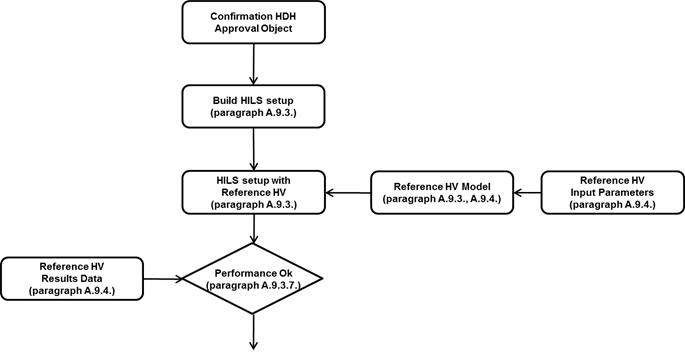
A.9.3. Build and verification of HILS system setup

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

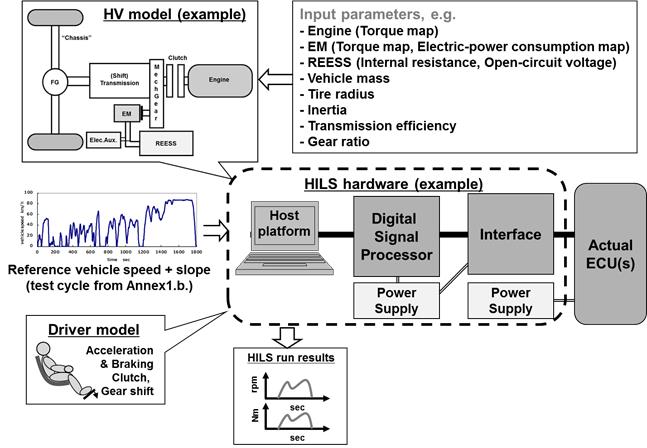
# HILS system build and verification diagram



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

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  (111)

Where:

*y* is the actual HILS value of the signal

*x* is the measured reference value of the signal

*a*1 is the slope of the regression line

*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*1 | *y-intercept,*  *a*0 | *coefficient of determination,*  *r2* |
| Vehicle speed | 0.9995 to 1.0005 | ±0.05 % or less of the maximum value | minimum 0.995 |
| 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

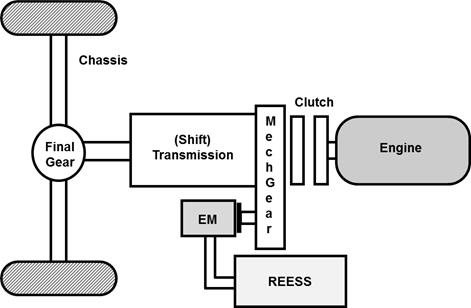
(h) Chassis, including wheels and body

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

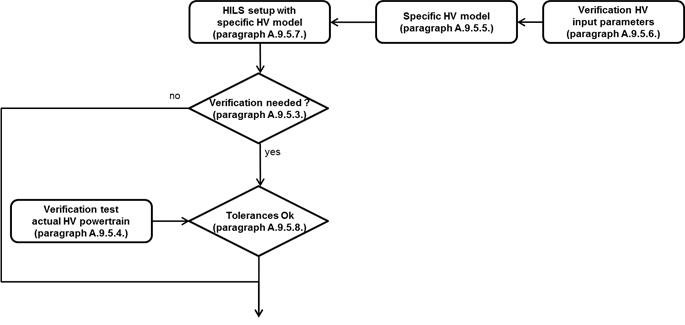
This procedure shall apply as the build and verification procedure for the specific HV model as equivalent representation of the actual hybrid powertrain to be used with the HILS system setup in accordance with paragraph A.9.3.

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.

(b) The HV system layout has changed.

(c) Structural changes are made to component models.

(d) Different use of model component (e.g. manual to automated transmission).

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

(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

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.

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 items specified in paragraph A.9.5.4.4.

The measurement of the exhaust emissions may be omitted.

A.9.5.4.2.2. Chassis dynamometer test

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*measured load coefficients from the *Dyno*target coefficients

(4) adjust the *Dyno*settings

(5) run a verification coastdown

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

The *Dyno*target road load coefficients are defined as A, B and C and the corresponding road load is calculated as follows:

(112)

Where:

*F*roadload is the dynamometer road load, N

*Dyno*measured are the *A*m, *B*m and *C*m dynamometer coefficients calculated from the dynamometer coastdown run

*Dyno*settings are the *A*set, *B*set and *C*set coefficients which command the road load simulation done by the dynamometer

*Dyno*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:

(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 (m2) 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 ≤ 18050 kg :

(114)

or

(b) for *m*vehicle > 18050 kg :

(115)

The vehicle air drag resistance coefficient *C*drag (-) shall be calculated as follows:

(116)

Where:

*g* is the gravitational acceleration with a fixed value of 9.80665 m/s2

*ρ*a is the air density with a fixed value of 1.17 kg/m3

A.9.5.4.2.2.4. Rolling resistance coefficient

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

(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:

(X)

B = 0 (X)

(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/s2

*ρ*a is the ambient air density as specified in accordance with paragraph A.9.5.4.2.2.3., kg/m3

*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., m2

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 Dynosetting 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:

(X)

(X)

Where:

*α*road is the road gradient, rad

*α*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).

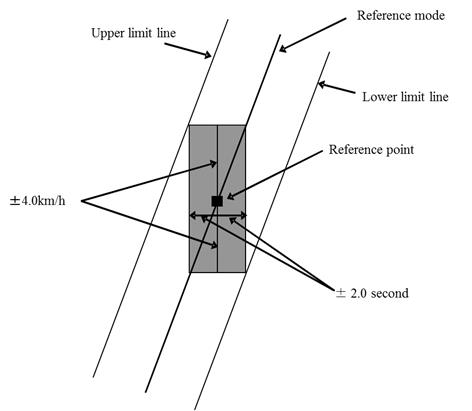
# Table 11

# 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) in order to enable the verification:

(a) Target and actual vehicle speed (km/h);

(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;

(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);

(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

The parameters for the battery model shall be the input data obtained in accordance with paragraph A.9.8.5.

A.9.5.6.5. Capacitor characteristics

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

A.9.5.6.6. Vehicle test mass

The vehicle test mass shall be defined as for the actual hybrid powertrain test in accordance with paragraph A.9.5.4.2.2.2.

A.9.5.6.7. Air resistance coefficients

The air resistance coefficients shall be defined as for the actual hybrid powertrain test in accordance with paragraph A.9.5.4.2.2.3.

A.9.5.6.8. Rolling resistance coefficient

The rolling resistance coefficients shall be defined as for the actual hybrid powertrain test in accordance with paragraph A.9.5.4.2.2.4.

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.

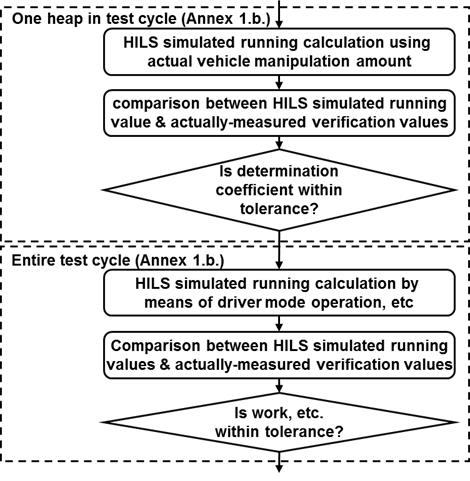
(b) The full test cycle as defined in Annex 1.b. for which the road gradients are calculated using the manufacturer specified hybrid system rated power also applied for the actual hybrid powertrain test. The driver model shall output all relevant signals to actuate the specific HV model based on either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

If the manufacturer declares that the resulting HEC engine operating conditions for cold and hot start cycles are different (e.g. due to the application of a specific cold start strategy), a verification shall be 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.

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



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).).

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



Where:

*W*eng\_HILS is the engine work in the HILS simulated running, kWh

*W*eng\_test is the engine work in the 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:

(119)

Where:

*ΔE*HILS is the net energy change of RESS during the HILS simulated running, kWh

*ΔE*test is the net energy change of RESS during the actual powertrain test, kWh

*W*eng\_HILS 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

(120)

Where:

*ΔAh* is the electricity balance obtained by integration of the battery current, Ah

*V*nominal is the rated nominal voltage, V

(b) Capacitor

(121)

Where:

*C*cap is the rated capacitance of the capacitor, F

*U*init is the initial voltage at start of test, V

*U*final is the final voltage at end of test, V

(c) Flywheel:

(122)

Where:

*J*flywheel is the flywheel inertia, kgm2

*n*init is the initial speed at start of test, min-1

*n*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.

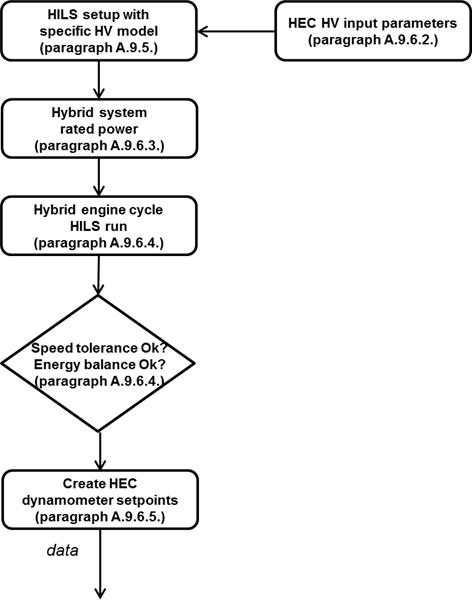
A.9.6. Creation of the hybrid engine cycle

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.

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

The parameters for the battery model shall be the data obtained in accordance with paragraph A.9.8.5.

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

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

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. In case a manufacturer specified value is used, the wheel radius that represents the worst case with regard to 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:

(123)

Where:

*r*gear\_high is the ratio of highest gear number for powertrain transmission

*r*wheel is the dynamic tire radius 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

nlo, nhi, nidle, npref 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 efficiency of each gear shall be set to 0.95.

or:

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

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.

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.9.6.2.15. Gear change period

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

A.9.6.2.16. 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.9.6.2.17. Inertia of rotating sections

Different inertia (*J* in kgm2) of the rotating sections shall be used for the respective conditions as specified below:

In case of a parallel HV:

(a) The inertia of the section between the (shift) transmission output shaft up to and including the wheels shall be calculated using the vehicle curb mass *m*vehicle,0 and wheel radius *r*wheel (in accordance with paragraph A.9.6.2.9.) as follows:

(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 ≤ 35240 kg :

(113)

or

(2) for *m*vehicle > 35240 kg :

(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 of the section from the engine to the 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 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.9.6.2.18. 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 for the test hybrid powertrain.

A.9.6.3. Hybrid system rated power determination

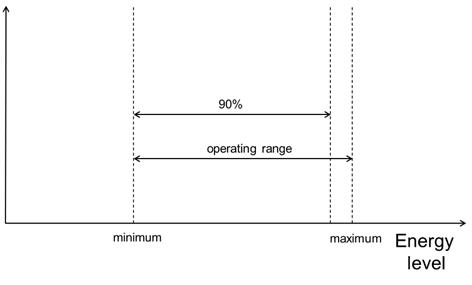
The rated power of the hybrid system shall be determined as follows:

(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:

(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:

(X)

For the results of each test run, the power vector *P*μ(t) shall be calculated as the moving averageing of 20 consecutive samples of *P*sys in the 100 Hz signal so that *P*μ(t) effectively shall be a 5 Hz signal.

The standard deviation *σ*(t) is calculated using the 100 Hz and 5 Hz signals:

(X)

Where:

*x*i are the N=20 samples in the 100 Hz signal previously used to calculate the respective *P*μ(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 *σ*(t) to the mean value of power *P*μ(t) for each time step t.

(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) 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 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).

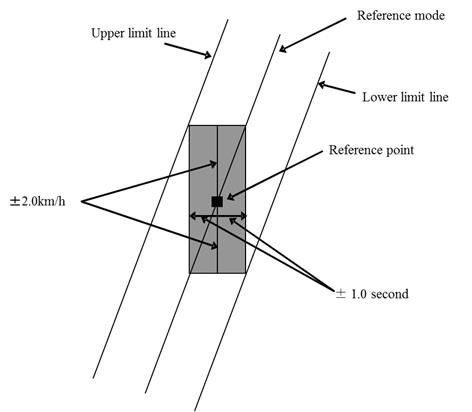
# Table 13

# 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 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:

(125)

Where:

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

*W*eng\_HILS is the engine 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 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/wp29globregistry.html](http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob_registry.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, valid for both high and low voltage auxiliary application, shall be modelled as a controllable electrical power loss, *P*el,aux. The current that is discharging the electrical energy storage, *i*aux, is determined as:

(126)

Where:

*P*el,aux is the electric auxiliary power demand, W

*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 model parameters and interface

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Type / Bus* | *Name* | *Unit* | *Description* | *Reference* |
| Command Signal | *P*el,aux | W | Control signal for auxiliary system power demand | Aux\_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, Pmech,aux. The power loss shall be implemented as a torque loss acting on the representative shaft.

(127)

Where:

*P*mech,aux is the mechanical auxiliary power demand, W

*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 model parameters and interface

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Type / Bus* | *Name* | *Unit* | *Description* | *Reference* |
| Parameter | *J*aux | kgm2 | Inertia | Dat.inertia.value |
| Command signal | *P*mech,aux | W | Control signal for auxiliary system power demand | Aux\_pwrMechReq\_W |
| Sensor signal | *M*aux | Nm | Auxiliary system torque output | Aux\_tqAct\_A |
| Mech out [Nm] | *M*aux | Nm | Torque | phys\_torque\_Nm |
|  | *J*aux | kgm2 | Inertia | phys\_inertia\_kgm2 |
| Mech fb in [rad/s] | *ω* | rad/s | Speed | phys\_speed\_radps |

# Table XXX

# Mechanical auxiliary model parameters

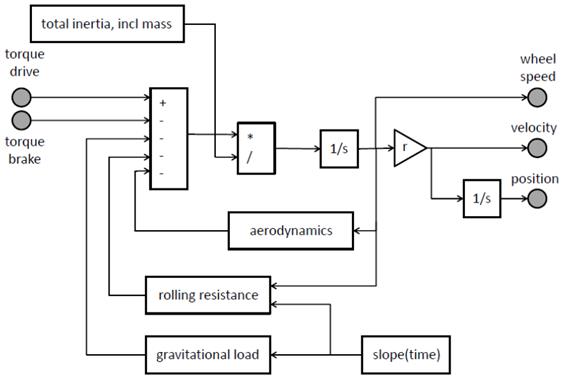
|  |  |  |
| --- | --- | --- |
| *Parameter* | *Parameter type* | *Reference paragraph* |
| *J*aux | Manufacturer specified | - |

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 25

# Chassis (vehicle) model diagram



The drive torque *Mdrive* shall be counteracted by the friction brake torque *Mfric\_brake*. The brake torque actuator shall be modelled as a first order system as follows:

(XXX)

Where:

*M*fric\_brake is the friction brake torque, Nm

*M*fric\_brake,des is the desired friction brake torque, Nm

*τ*1 is the friction brake actuator time response constant

The total drive torque shall balance with torques for aerodynamic drag *Maero*, rolling resistance *Mroll* and gravitation *Mgrav* to find resulting acceleration torque in accordance with differential equation 130:

(130)

Where:

*J*tot is the total inertia of the vehicle, kgm2

is the wheel rotational acceleration, rad/s

The total inertia of the vehicle *Jtot* shall be calculated using the vehicle mass *mvehicle* and the inertia load from the powertrain components:

(131)

Where:

*m*vehicle is the mass of the vehicle, kg

*J*powertrain is the sum of all powertrain inertias, kgm2

*J*wheel is the inertia of the wheels, kg/m2

The vehicle speed *v*vehicle shall be determined from the wheel speed *ω*wheel and wheel radius *r*wheel as:

(132)

The aerodynamic torque shall be calculated as:

(133)

Where:

*ρ*a is the air density, kg/m3

*C*drag is the air drag coefficient

*A*front is the total vehicle frontal area, m2

*v*vehicle is the vehicle speed, m/s

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

(134)

(XXX)

Where:

*f*roll is the friction factor for wheel-road contact

*g* is the standard earth gravitation, m/s2

*α*road is the road slope, rad

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

(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 | |
|  | *A*front | m2 | | Vehicle frontal area | | dat.aero.af.value | |
|  | *C*drag | - | | Air drag coefficient | | dat.aero.cd.value | |
|  | *r*wheel | m | | Wheel radius | | dat.wheel.radius.value | |
|  | *J*wheel | kgm2 | | Wheel inertia | | dat.wheel.inertia.value | |
|  | *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\_tqBrakeReq\_Nm | |
| Sensor signal | *v*vehicle | m/s | | Actual vehicle speed | | chassis\_vVehAct\_mps | |
|  | *ω*wheel | rad/s | | Actual wheel speed | | chassis\_nWheelAct\_radps | |
|  | *m*tot | kg | | Vehicle mass | | chassis\_massVehAct\_kg | |
|  | *M*drive | Nm | | Actual wheel hub torque | | chassis\_tqSysAct\_Nm | |
|  | *α*road | rad | | Road slope | | chassis\_slopRoad\_rad | |
| Mech in [Nm] | *M*drive | Nm | | Torque | | phys\_torque\_Nm | |
|  | *J*powertrain | kgm2 | | 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. |
| *τ1* | Tuneable | default: 0.1 second |

A.9.7.4. Driver models

The driver model shall actuate the accelerator and brake pedal 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.

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 in open loop mode. The data for the accelerator pedal, the brake pedal and, in case a vehicle with a manual shift transmission is represented, the clutch pedal and gear position shall therefore be provided in a dataset as a function of time. 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 |  |  |  |  |
| Command signal | *pedal*brake | 0-1 | Requested brake pedal position | Drv\_BrkPedl\_Rt |
|  | *pedal*accelerator | 0-1 | Requested accelerator pedal position | Drv\_AccPedl\_Rt |
|  | *pedal*clutch | 0-1 | Requested clutch pedal position | Drv\_CluPedl\_Rt |
|  | - | - | Gear request | Drv\_nrGearReq |
| Sensor signal | - | - | - | - |

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

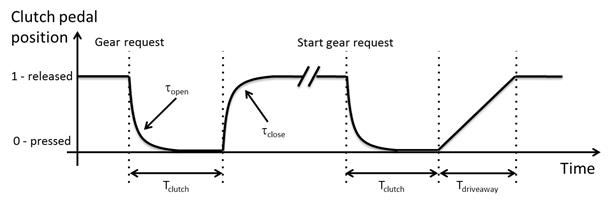
|  |  |  |
| --- | --- | --- |
| *Parameter* | *Parameter type* | *Reference paragraph* |
| *K*P, *K*I, *K*D | Tuneable | - |
| *K*K | Tuneable | - |

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*driveaway | s | Closing time at drive away | dat.clutchtime.driveaway.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 |
|  | *-* | - | Gear request | Drv\_nrGearReq |
|  | *pedal*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*P, *K*I, *K*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*driveaway | Tuneable | Default: 2 |

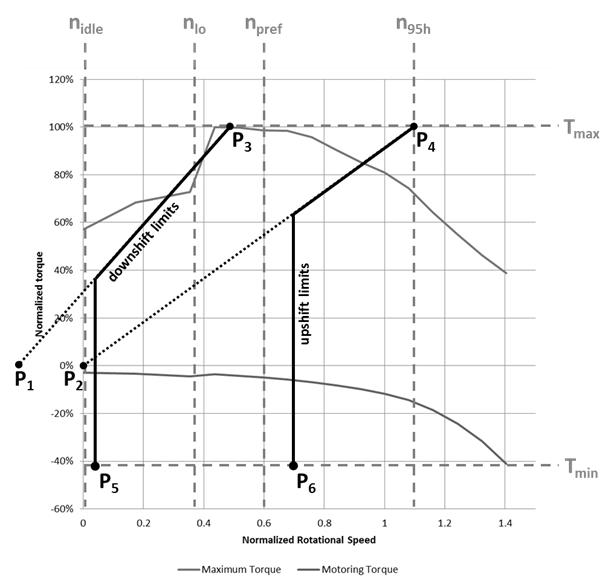
A.9.7.4.3.1 Gear shift strategy for manual transmissions

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 P1 to P6 in Figure X are defined by the coordinate pairs listed in Table X.

(b) The slope *k*1 of the line between P1 and P3 as well as the slope *k*2 of the line between P2 and P4 are calculated as follows:

(XXX)

(XXX)

(c) The downshift limits speed vector shall consist of the three values: [x5, x5, x3]

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

[y5, , y3]

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

[x6, x6, x4]

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

[y6, , y4].

# Table XXX

# Shift logic coordinate pairs

|  |  |  |
| --- | --- | --- |
| *Point* | *x-coordinate*  *(engine speed, min-1)* | *y-coordinate*  *(engine torque, Nm)* |
| P1 |  | y1 = 0 |
| P2 |  | y2 = 0 |
| P3 |  | y3 = *T*max |
| P4 |  | y4 = *T*max |
| P5 |  | y5 = *T*min |
| P6 |  | y6 = *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 (1st) 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 |
|  | *-* | kgm2 | satp chassis | dat.vecto.wheel.inertia.value |
|  | *-* | *-* | satp chassis | dat.vecto.wheel.rollingres.value |
|  | *-* | m2 | 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 not  Default: 0 | dat.vecto.skipgears.value |
|  | *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:

(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:

(136)

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

(137)

Where:

*η*DCDC is the DC/DC converter efficiency

*i*in is the input current to the DC/DC converter, A

*i*out is the output current from the DC/DC converter, 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 | dat.elecefficiency.efficiency.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 | phys\_voltage\_V |
| Elec out [V] | *u*out | V | Voltage | phys\_voltage\_V |
| Elec fb in [A] | *i*out | A | Current | phys\_current\_A |
| Elec fb out [A] | *i*in | A | Current | phys\_current\_A |

# Table XXX

# DC/DC converter model parameters

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Parameter type* | *Reference paragraph* |
| *η*DCDC | Manufacturer specified | - |

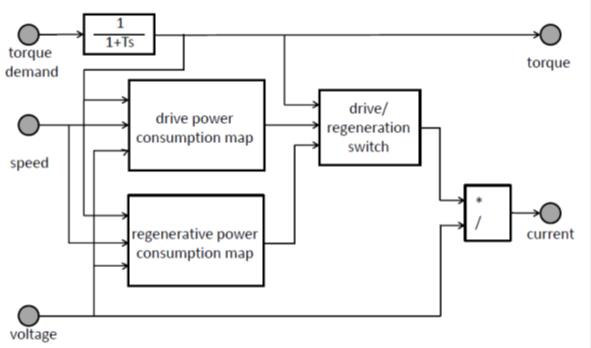
A.9.7.6. Energy converter models

A.9.7.6.1. Electric machine system model

An electric machine can generally be divided into three parts, the stator, rotor and the power 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 28.

# Figure 28:

# Electric machine model diagram



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

(138)

Where:

*M*em is the electric machine torque, Nm

*M*em,des is the desired electric machine torque, Nm

*τ*1 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 , its torque *M*em and DC-bus voltage level *u*. Two separate maps shall be defined for the positive and negative torque ranges, respectively.

(139)

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

(140)

The electric machine system current *i*em shall be calculated as:

(141)

Based on its power loss *P*loss,em, the electric machine model provides a simple thermodynamics model that may be used to derive its temperature *T*em as follows:

(142)

(143)

Where:

*T*em is the electric machine system temperature, K

*τ*em,heat is the thermal capacity for electric machine thermal mass, J/K

*T*em,cool is the electric machine system cooling medium temperature, K

*R*em,th 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) controller or PI-controller as follows:

(XXX)

Where:

KP is the proportional gain of speed controller

KI is the integral gain of speed controller

The electric machine torque shall be limited as follows:

(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 | kgm2 | Inertia | dat.inertia.value |
|  | *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.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 |
| Optional parameters | *τ*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 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech fb in [rad/s] | *ω*em | rad/s | rotational speed | phys\_speed\_radps |

# Table XXX

# Electric machine model parameters

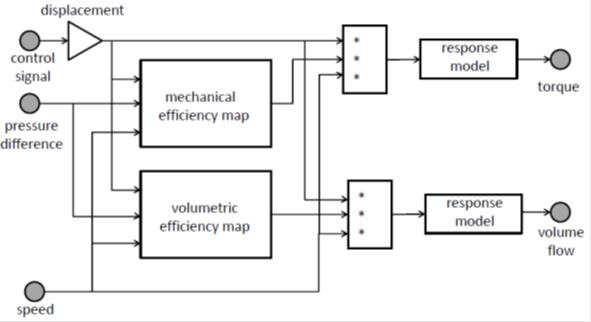
|  |  |  |
| --- | --- | --- |
| *Parameter* | *Parameter type* | *Reference paragraph* |
| *J*em | Manufacturer specified | - |
| *τ*1 | Tunable | - |
| *M*max | Regulated | A.9.8.4. |
| *M*min | Regulated | A.9.8.4. |
| *K*P, *K*I | Tunable |  |
| *P*el,em | Regulated | A.9.8.4. |

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:

(144)

Where:

*M*pm is the pump/motor torque, Nm

*x* is the pump/motor control command signal between 0 and 1

*D*pm is the pump/motor displacement, m3

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

(145)

Where:

*ω*pm is the pump/motor speed (rad/s)

The volumetric flow *Q*pm through the pump/motor shall be calculated as:

(147)

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

(149)

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

(138)

Where:

*x*pm is the output pump/motor torque or volume flow, Nm or m3/s

*u*pm,des is the input pump/motor torque or volume flow, Nm or m3/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:

(XXX)

Where:

KP is the proportional gain of speed controller

KI is the integral gain of speed controller

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

(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 | kgm2 | Inertia | dat.inertia.value |
|  | *τ*1 | - | Time constant | dat.timeconstant.value |
|  | *M*max | Nm | Maximum torque =f(speed) | dat.maxtorque |
|  | *D* | m3 | 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.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*pm | Nm | Actual machine torque | Hpm\_tqAct\_Nm |
|  | *ω*pm | rad/s | Actual machine speed | Hpm\_nAct\_radps |
|  | *Q*pm | m3/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 | m3/s | Volume flow | phys\_flow\_m3ps |
| Mech out [Nm] | *M*pm | Nm | torque | phys\_torque\_Nm |
|  | *J*pm | kgm2 | 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

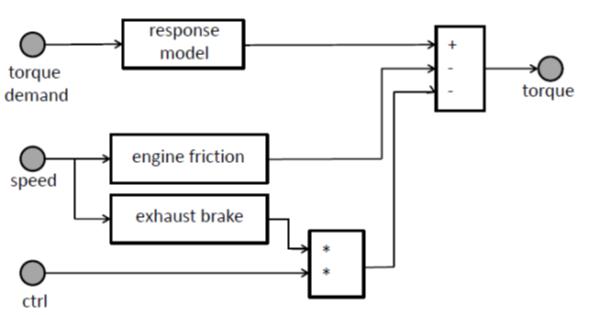
|  |  |  |
| --- | --- | --- |
| *Parameter* | *Parameter type* | *Reference paragraph* |
| *J*pm | Manufacturer specified | - |
| *τ*1 | Manufacturer specified | - |
| *M*max | Manufacturer specified | - |
| *D* | Manufacturer specified | - |
| *η*v | Manufacturer specified | - |
| *η*m | Manufacturer 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 29.

# Figure 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 be modelled using two first order models. The first shall account for almost direct torque build-up representing the fast dynamics as follows:

(150)

Where:

*M*ice,1 is the fast dynamic engine torque, Nm

*M*ice,des1 is the fast dynamic engine torque demand, Nm

*τ*ice,1 is the time constant for fast engine torque response

*ω*ice is the engine speed, rad/s

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

(151)

Where:

*M*ice,2 is the slow dynamic engine torque, Nm

*M*ice,des2 is the slow dynamic engine torque demand, Nm

*τ*ice,2 is the speed dependent time constant for slow engine torque response

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:

(152)

The internal combustion engine model 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:

(153)

Where:

*T*ice,oil is the ICE oil temperature, K

*P*ice,loss are the ICE power losses, W

Since no fuel consumption and efficiency map is available in the model *P*ice,loss = (ωice x Mice) 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

*T*ice,oil,hot is the ICE oil temperature at normal warm-up 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:

(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:

(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 | kgm2 | Inertia | dat.inertia.value |
|  | *τ*ice,1 | - | Time constant | dat.boost.insttorque.timeconstant.T1.value |
|  | *τ*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 |
|  | *K*P  *K*I | -  - | PI controller | dat.controller.p.value  dat.controller.i.value |
|  | *M*start | Nm | Starter motor torque | dat.startertorque.value |
|  | *M*des,type | - | Desired torque type selector:  (0) indicated  (1) crankshaft | dat.torquereqtype.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 |
| Mech out [Nm] | *M*ice | Nm | torque | phys\_torque\_Nm |
|  | *J*ice | kgm2 | inertia | phys\_inertia\_kgm2 |
| 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 | - |
| *τ*ice,1 | Regulated | A.9.8.3. |
| *τ*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 | - |

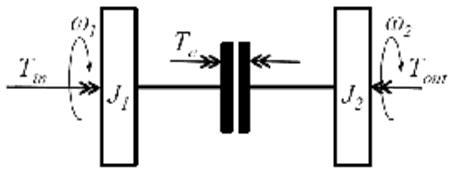
A.9.7.7. Mechanical component models

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 moving through three operating phases, i.e. 1) opened, 2) slipping and 3) closed. Figure 30 shows the clutch model diagram.

# Figure 30

# Clutch model diagram



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

(154)

(155)

During clutch slip operation following relation is defined:

(156)

(157)

Where:

*M*cl,maxtorque is the maximum 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 *ω*1 – *ω*2 is below the threshold limit *slip*limit and the clutch pedal position is above the threshold limit *pedal*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:

(158)

2) for clutch closed:

(159)

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

(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 | kgm2 | Inertia | dat.in.inertia.value |
|  | *J*2 | kgm2 | Inertia | dat.out.inertia.value |
|  | *M*cl,maxtorque | Nm | Maximum clutch torque | dat.maxtorque.value |
|  | *c* | - | Tuning constant | dat.tanh.value |
|  | *sliplimit* | rad/s | Slipping clutch, relative speed limit | dat.speedtolerance.value |
|  | *pedallimit* | - | 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 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | 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*limit | Tuneable | default: 1 |
| *pedal*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:

(160)

Where:

*M*CVT,in is the CVT input torque, Nm

*M*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:

(161)

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

(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:

(163)

Where:

*τ*CVT is the CVT time constant, s

*r*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 |
| Command signal | *r*des | - | Requested CVT gear ratio | CVT\_ratGearReq |
| Sensor signal | *r*CVT | - | Actual CVT gear ratio | CVT\_ratGearAct\_Rt |
|  | *ω*out | rad/s | Output speed | CVT\_nOutAct\_radps |
|  | *ω*in | rad/s | Input speed | CVT\_nInAct\_radps |
| Mech in [Nm] | *M*in | Nm | Torque | phys\_torque\_Nm |
|  | *J*in | kgm2 | Inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | Torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | 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

# CVT model parameters



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:

(X)

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

(X)

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

The final gear inertia shall be included as:

(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 | kgm2 | 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 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech fb in [rad/s] | *ω*fg,out | rad/s | rotational speed | phys\_speed\_radps |
| Mech fb out [rad/s] | *ω*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:

(166)

Where:

*M*in,1 is the input torque on shaft 1, Nm

*M*in,2 is the input torque on shaft 2, Nm

*M*out is the output torque on shaft, Nm

*r*in,1 is the ratio of gear of shaft 1

*r*in,2 is the ratio of gear of shaft 2

*η*in,1 is the efficiency on gear of shaft 1

*η*in,2 is the efficiency on gear of shaft 2

*r*out is the ratio of gear on output shaft

*η*out 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 model parameters and interface

| *Type / Bus* | *Name* | *Unit* | *Description* | *Reference* |
| --- | --- | --- | --- | --- |
| Parameter | *J*1 | kgm2 | Inertia | dat.in1.inertia.value |
|  | *r*in,1 | - | Gear ratio | dat.in1.ratio.value |
|  | *η*in,1 | - | Efficiency | dat.in1.mechefficiency.efficiency.map |
|  | *J*2 | kgm2 | Inertia | dat.in2.inertia.value |
|  | *r*in,2 | - | Gear ratio | dat.in2.ratio.value |
|  | *η*in,2 | - | Efficiency | dat.in2. mechefficiency.efficiency.map |
|  | *J*out | kgm2 | Inertia | dat.out.inertia.value |
|  | *r*out | - | Gear ratio | dat.out.ratio.value |
|  | *η*out | - | Efficiency | dat.out. mechefficiency.efficiency.map |
| Command signal |  |  | no signal |  |
| Sensor signal |  |  | no signal |  |
| Mech in 1 [Nm] | *M*in,1 | Nm | torque | phys\_torque\_Nm |
|  | *J*in,1 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech in 2 [Nm] | *M*in,2 | Nm | torque | phys\_torque\_Nm |
|  | *J*in,2 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech fb in [rad/s] | *ω*in | rad/s | rotational speed | phys\_speed\_radps |
| Mech fb out 1 [rad/s] | *ω*out,1 | rad/s | rotational speed | phys\_speed\_radps |
| Mech fb out 2 [rad/s] | *ω*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 | - |
| *η*in,1 | Manufacturer specified | - |
| *J*2 | Manufacturer specified | - |
| *r*in,2 | Manufacturer specified | - |
| *η*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:

(167)

Where:

*u* is the retarder command signal between 0 and 1

*M*retarder,max is the (speed dependent) maximum retarder brake torque (Nm)

*ω*retarder is the retarder speed (rad/s)

*M*retarder,in is the retarder input torque (Nm)

*M*retarder,out 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 | *M*retarder,max | Nm | Retarder brake torque map | dat.braketorque.torque.vec |
|  | *J*retarder | kgm2 | Inertia | dat.inertia.value |
| Command signal | *u* | - | Retarder control signal between 0-1 | Ret\_flgOnOff |
| Sensor signal | *M*loss | Nm | Retarder brake torque | Ret\_tqBrkAct\_Nm |
| Mech in [Nm] | *M*in | Nm | torque | phys\_torque\_Nm |
|  | *J*in | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech fb in [rad/s] | *ω*in | rad/s | rotational speed | phys\_speed\_radps |
| Mech fb out [rad/s] | *ω*out | rad/s | rotational speed | phys\_speed\_radps |

# Table XXX

# Retarder model parameters

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Parameter type* | *Reference paragraph* |
| *M*retarder,max | Manufacturer specified | - |
| *J*retarder | Manufacturer specified | - |

A.9.7.7.6. Spur gear model

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:

(168)

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

(169)

The gear inertias shall be included as:

(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*spur | kgm2 | Inertia | dat.in.inertia.value |
|  | *r*spur | - | Gear ratio | dat.in.ratio.value |
|  | *η*spur | - | Efficiency | dat.in.mechefficiency.efficiency.map |
| Command signal |  |  | no signal |  |
| Sensor signal |  |  | no signal |  |
| Mech in [Nm] | *M*in | Nm | torque | phys\_torque\_Nm |
|  | *J*in | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech fb in [rad/s] | *ω*spur,out | rad/s | rotational speed | phys\_speed\_radps |
| Mech fb out [rad/s] | *ω*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.

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:

(171)

(171)

Where:

*J*p is the pump inertia, kgm2

*J*t is the turbine inertia, kgm2

*ω*p is the pump rotational speed, rad/s

*ω*t is the turbine rotational speed, rad/s

*M*in is the input torque, Nm

*M*out is the output torque, Nm

*M*p is the pump torque, Nm

*M*t is the turbine torque, Nm

The pump torque shall be mapped as function of the speed ratio as:

(172a)

Where:

*ω*ref is the reference mapping speed, rad/s

*f*pump(ωt/ωp) is the mapped pump torque as function of the speed ratio at the constant mapping speed *ω*ref, Nm

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

(X)

where:

*f*amp(ωt/ωp) is the mapped torque amplification as function of the speed ratio

During closed operation, the following relations shall apply:

(X)

(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 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, eqution 172a shall be modified as:

(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 hyperbolic function *tanh*.

When the speed difference ωp - ωt 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:

(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*p | kgm2 | Inertia | dat.inertia.in.value |
|  | *J*t | kgm2 | 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 | - | Speed ratio | 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 |
|  | *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 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech fb in [rad/s] | *ω*t | rad/s | rotational speed | phys\_speed\_radps |
| Mech fb out [rad/s] | *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:

(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:

(175)

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

(176)

For the model as available in the standardized HILS library, the model parameter and interfacing definition is given in Table 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 | *nr*gears | - | Number of gears | dat.nofgear.value |
|  | *gear*num | - | Gear numbers (vector) | dat.gear.number.vec |
|  | *J*gearbox | kgm2 | Inertia (vector) | dat.gear.inertia.vec |
|  | *r*gear | - | Gear ratio (vector) | dat.gear.ratio.vec |
|  | *η*gear | - | Gear efficiency (map) | dat.gear.mechefficiency.efficiency.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 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech out [Nm] | *M*out | Nm | torque | phys\_torque\_Nm |
|  | *J*out | kgm2 | 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 | - |

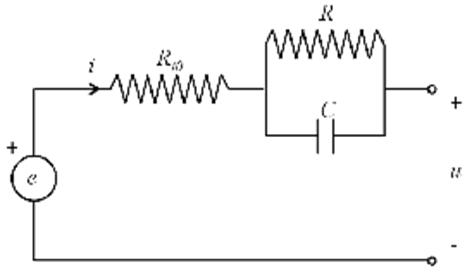
A.9.7.8. Rechargeable Energy Storage Systems

A.9.7.8.1. Battery model

The battery model 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:

(181)

With:

(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:

(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 provides a thermodynamics model that may be used and applies similar modelling as for the electric machine system in accordance with:

(183)

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

(184)

Where:

*T*bat is the battery temperature, K

*T*bat,heat is the thermal capacity for battery thermal mass, J/K

*T*bat,cool is the battery cooling medium temperature, K

*R*bat,th 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

# 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 parallel | dat.np.value |
|  | *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 |
|  | Ri0 | 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 | τbat,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 |
|  | Tbat | 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 (X)

where *u*C is the capacitor voltage and *R*i is the internal resistance. The capacitor voltage shall be determined according to:

(X)

where *C* is the capacitance.

For a capacitor system the state-of-charge is directly proportional to the capacitor voltage:

(X)

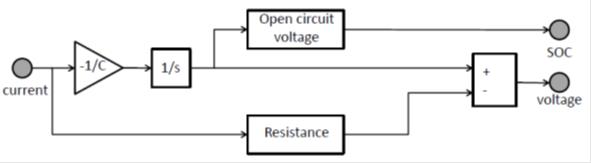
Where:

*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 |
|  | Ri | Ω | Cell resistance | dat.R.value |
|  | *uC(0)* | V | Initial capacitor voltage | dat.initialVoltage.value |
|  | *V*C,min | V | Minimum capacitor voltage | dat.Vmin.value |
|  | *V*C,max | V | Maximum capacitor voltage | dat.Vmax.value |
| 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 |
|  | Tcapacitor | K | Capacitor 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

# Capacitor model parameters

|  |  |  |
| --- | --- | --- |
| *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:

(164)

Where:

*E*flywheel is the kinetic energy of the flywheel, J

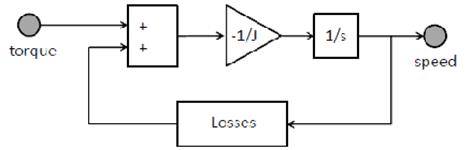
*J*flywheel is the inertia of the flywheel, kgm2

*ω*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:

(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, ωflywheel\_low  and ωflywheel\_high:

(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 | kgm2 | Inertia | dat.inertia.value |
|  | *M*loss | Nm | Torque loss map | dat.loss.torqueloss.vec |
|  | *ω*flywheel\_low | rad/s | Lower speed limit | dat.speedlimit.lower.value |
|  | *ω*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 | kgm2 | inertia | phys\_inertia\_kgm2 |
| Mech fb out [rad/s] | *ω*fly | rad/s | rotational speed | phys\_speed\_radps |

# Table XXX

# Flywheel model parameters

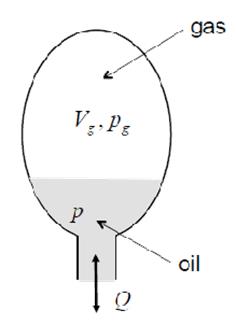
|  |  |  |
| --- | --- | --- |
| *Parameter* | *Parameter type* | *Reference paragraph* |
| *J*fly | Manufacturer specified | - |
| *M*loss | Manufacturer specified | - |
| *ω*flywheel\_low | Manufacturer specified | - |
| *ω*flywheel\_high | Manufacturer specified | - |

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:

(185)

The process shall be assumed to be a reversible adiabatic process:

(186)

Where:

*p*gas is the gas pressure, Pa

*V*gas is the gas volume, m3

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:

(XXX)

Where:

*p*gas,pre is the precharged gas pressure, Pa

*V*gas,pre is the precharged gas volume, m3

γ is the adiabatic index

The work done by the pressure-volume changes as a result from this adiabatic process, is equal to:

(XXX)

and the corresponding state-of-charge shall be determined as:

(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 | *p*gas,pre | Pa | Precharged gas pressure | dat.pressure.precharge.value |
|  | *γ* | - | Adiabatic index | dat.gas.adiabaticindex.value |
|  | *V*gas | m3 | Precharged volume | dat.vol.pressure.value |
|  | *C*acc | kWh | Accumulator capacity | dat.capacity.value |
|  | *V*gas(0) | m3 | Initial volume | dat.vol.initial.value |
| Command signal |  |  | no signal |  |
| Sensor signal | *p* | Pa | Pressure | Acc\_presAct\_Pa |
|  | *V*g | - | Gas volume | Acc\_volGas\_Rt |
| Fluid out [Pa] | *p* | Pa | Pressure | phys\_pressure\_Pa |
| Fluid fb in [m3/s] | *Q* | m3/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.9.8.2. 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* | *|xmin∙(a1-1)+ao|*  *(for maximum test value)* | *Slope,*  *a1* | *Standard error,*  *SEE* | *Coefficient of determination,*  *r2* |
| 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 conditions and equipment

The test conditions and applied equipment shall be in accordance with the provisions of paragraphs 6 and 9, respectively.

A.9.8.3.2. Engine warm-up

The engine shall be warmed up in accordance with paragraph 7.4.1.

A.9.8.3.3. Determination of the mapping speed range

The mapping speed range shall be in accordance with paragraph 7.4.2.

A.9.8.3.4. Mapping of positive engine torque characteristics

When the engine is stabilized in accordance with paragraph A.9.8.3.2., 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.9.8.3.3, 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 measurement points may be equally distributed and shall be defined using good engineering judgement.

A.9.8.3.5. 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. The measurement points may be equally distributed and shall be 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.

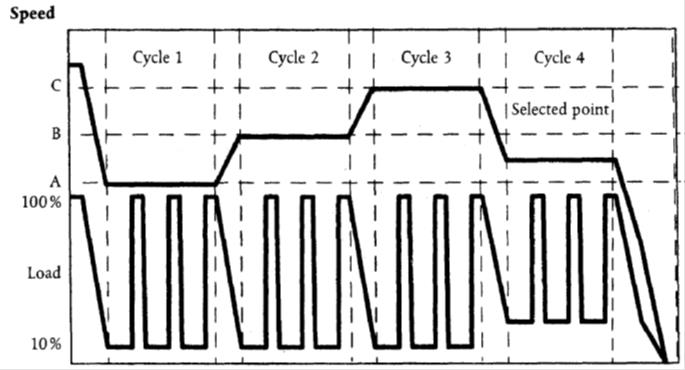
(f) Upon completion of the third load step, the engine shall be adjusted to engine speed C and 10 per cent load within 20 ± 2 seconds.

(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 10 points for torque shall be included in the engine maximum torque table with dependency of engine speed and a 100 per cent command value.

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 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):

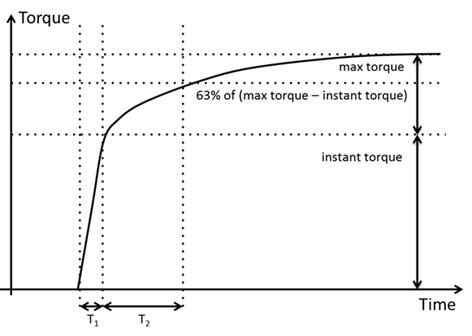
(a) T1 shall be 0.1 seconds or a manufacturer specific value.

(b) The instant torque value shall be the average value of 3 load steps at T1 for each set speed according to A.9.8.3.6.

(c) T2 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.

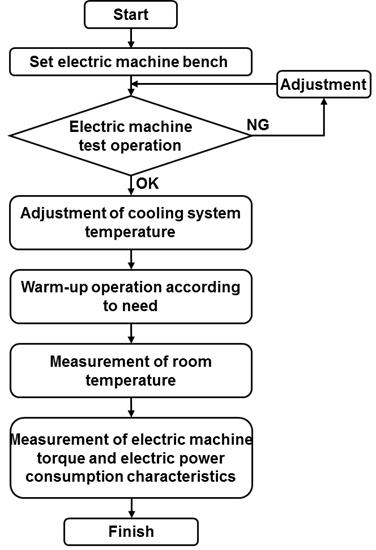
A.9.8.4. Electric Machine

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 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 zero (0) to the maximum command values (positive and negative). The 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 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 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:

(188)

Where:

*P*em is the electric machine mechanical power, kW

*M*em is the electric machine shaft torque, Nm

*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 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. General

The characteristics of the battery shall be determined and converted to the input parameters for the HILS system battery model in accordance with the measurements and data conversion of paragraphs A.9.8.5.2. through A.9.8.5.5.

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, where n is a value between 1 and 3 specified by the battery manufacturer.

A.9.8.5.3. 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) 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.

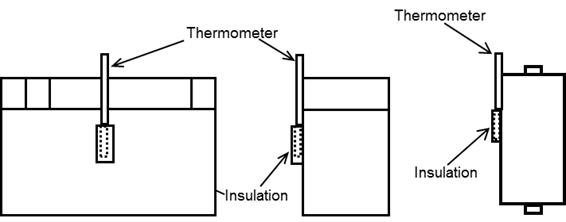
(c) The battery temperature shall be measured continuously during the test and the temperature measurement shall follow the method specified by the manufacturer or it shall be performed, as shown in Figure 38 below, in the condition not affected by the outside temperature, with the thermometer attached 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.9.8.5.5. Battery characteristics test

A.9.8.5.5.1. Open circuit voltage

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 ºC ± 2 ºC). However, 318 ± 2 K (45 ºC ± 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) 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 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 current over time.

(f) Each measured 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

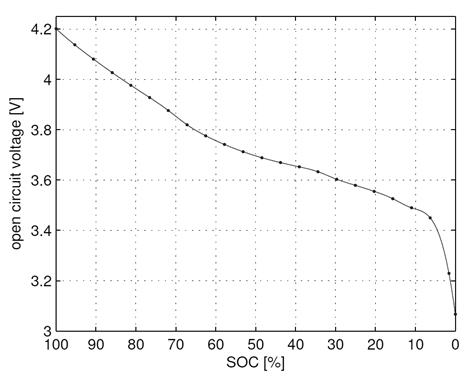
Example of typical cell voltage level during the open circuit voltage measurement



Figure XXX

Example of resulting open circuit voltage as a function of SOC

(measured points are marked with a dot, spline interpolation is used for data in between measured values)



A.9.8.5.5.2. Test procedure 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 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.

(b) After fully charging the test battery in accordance with the charging method specified by the manufacturer, it shall be soaked for at least 1 hour, but no more than 4 hours.

(c) The adjustment of the desired SOC before starting the test sequence shall be performed by discharging or charging the test battery with a constant current *C/n* according to paragraph A.9.8.5.2.

(d) After the adjustment of the desired SOC, the test battery shall be soaked for at least 1 hour, but no more than 4 hours.

(e) The battery temperature at the start of 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 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.

(f) The test sequence at each SOC level shall be conducted in accordance with the sequence listed in Table XXX and shown in Figure XXX.

The highest value of the charging and discharging current *I*max for the test battery shall be the maximum value used in the in-vehicle application of the hybrid powertrain under test as defined by the manufacturer. 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 current pulses of 1, 3, 9 and 27A).



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 K before continuing with the next discharging or charging current step.

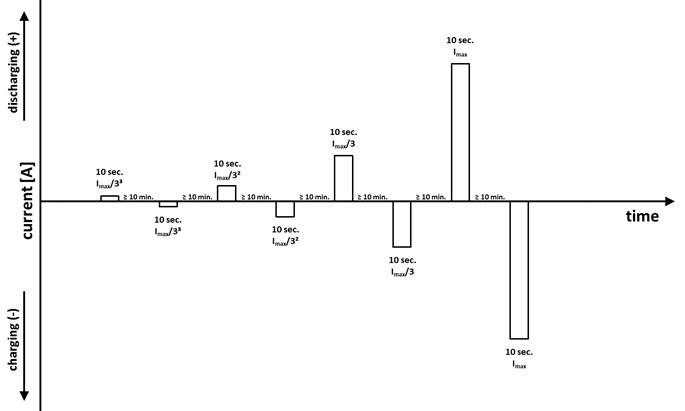
Table XXX

Test sequence at each SOC level

|  |  |
| --- | --- |
| *Step* | *Action* |
| 1 | Discharge for 10 seconds with Imax/33 |
| 2 | No-load period for at least 10 minutes |
| 3 | Charge for 10 seconds with Imax/33 |
| 4 | No-load period for at least 10 minutes |
| 5 | Discharge for 10 seconds with Imax/32 |
| 6 | No-load period for at least 10 minutes |
| 7 | Charge for 10 seconds with Imax/32 |
| 8 | No-load period for at least 10 minutes |
| 9 | Discharge for 10 seconds with Imax/3 |
| 10 | No-load period for at least 10 minutes |
| 11 | Charge for 10 seconds with Imax/3 |
| 12 | No-load period for at least 10 minutes |
| 13 | Discharge for 10 seconds with Imax |
| 14 | No-load period for at least 10 minutes |
| 15 | Charge for 10 seconds with Imax |

Figure XXX

Test sequence at each SOC level



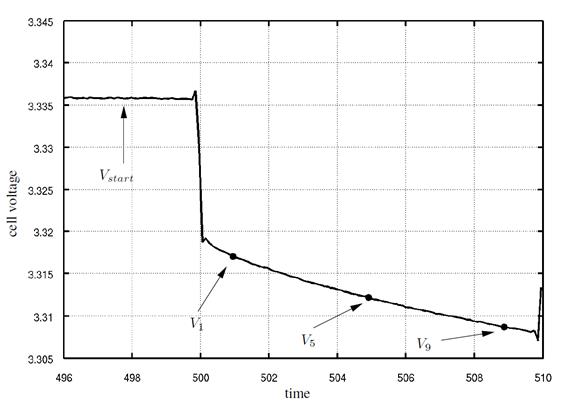
(g) For each discharging and charging current level specified in Table XXX, the no-load voltage before the start of the current pulse Vstart, and the voltages at 1, 5 and 9 seconds after the pulse has started (V1, V5 and V9) shall be measured (shown in Figure XXX).

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.9.8.5.5.3. Calculation of *R*0, *R* and *C*

The measurement data obtained in accordance with paragraph A.9.8.5.5.2. shall be used to calculate the *R*0, *R* and *C* values for each charging and discharging current level at each SOC level by using the following equations:

(XXX)

(XXX)

For a charge pulse:

(XXX)

(XXX)

For a discharge pulse:

(XXX)

The values for *R*0,pulse, *R*pulse and *C*pulse for a specific current level *I*pulse shall be calculated as:

(XXX)

(XXX)

(XXX)

The required values for *R*0, *R* and *C* for, respectively, 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.

A.9.8.5.5.4. Correction of *R*0 for battery subsystems

In case the measurement is performed with a representative subsystem the final results for all *R*0 values may be corrected if the internal connections between the subsystems have a significant influence on the *R*0 values.

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 (t0 to t1), the supercapacitor shall be charged with a constant current Itest 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 Itest 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

*∆V*(*t*1), *∆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.

*∆V*(*t*1) is the absolute difference of voltages between *V*a and the intercept value of the straight-line approximation at the time of *t*1.

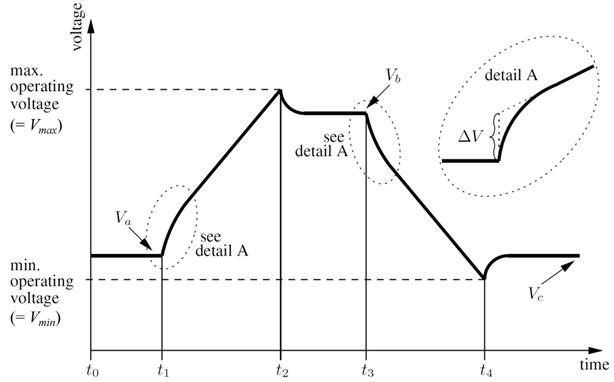
*∆V*(*t*3) is the absolute difference of voltages between *V*b and the intercept value of the straight-line approximation at the time of *t*3.

*∆V*(*t*2) is the absolute difference of voltages between *V*max and *V*b.

*∆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:

(XXX)

For discharging:

(XXX)

(b) The internal resistance for charging and discharging shall be calculated as follows:

For charging:

(XXX)

For discharging:

(XXX)

(c) For the model, only a single capacitance and resistance are needed and these shall be calculated as follows:

Capacitance C:

(XXX)

Resistance R:

(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 Hermite interpolation procedure

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 [(xi, yi), (xi+1, yi+1)] is defined in equation (X1), where the equation is cubic polynomial based on the point of (xi, yi).

(X1)

Since the Hermite interpolation polynomial coincides with the given function value and the derivative of the point, following conditions result:

(X2)

(X3)

If *Δx = xi+1 – xi*, then:

(X4)

(X5)

Combining equation X4 and X5 yields:

(X6)

(X7)

The derivatives used in equations X3, X6, and X7 can be calculated as follows:

(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 determination

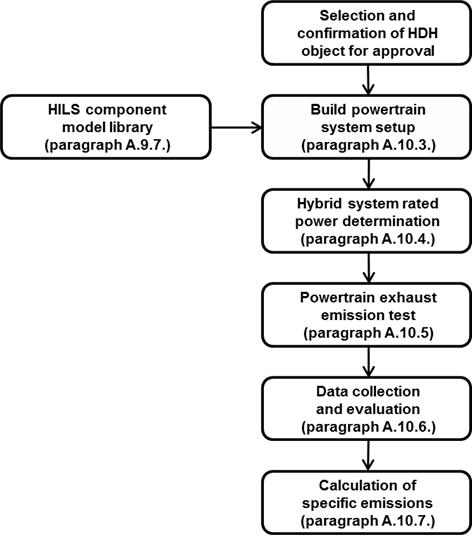
(d) Exhaust emission test

(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. 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

The powertrain exhaust emission test shall be carried out in accordance with all provisions of paragraph A.10.5.

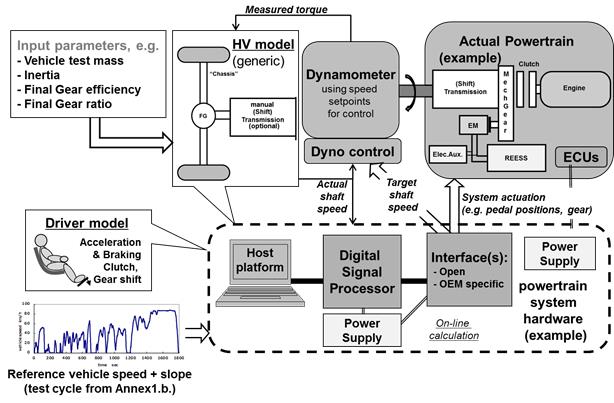
A.10.3. Set up of powertrain system

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. 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 drivetrain and chassis and contain those components not present in the actual powertrain (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, tire rolling resistance, air drag resistance and road gradients. 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.9.7.4.3.

A.10.4. Hybrid system rated power determination

The hybrid system rated power shall be determined in accordance with paragraph A.9.6.3.

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

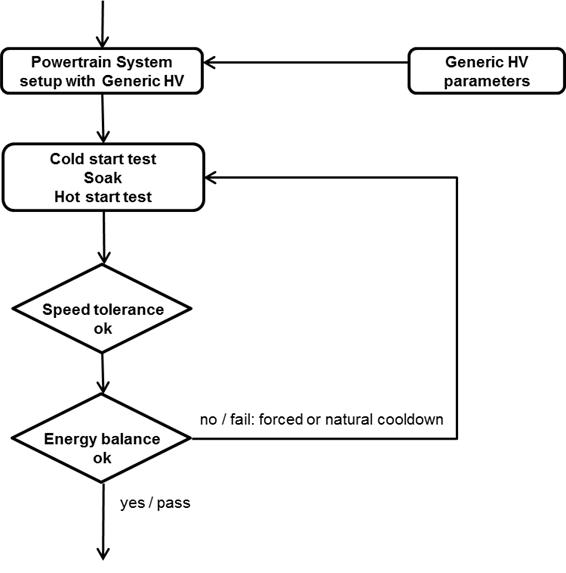
A.10.5. Powertrain exhaust emission test

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

The test vehicle mass *m*vehicle shall be defined with equation 112 using the hybrid system rated power in accordance with 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. Tire rolling resistance coefficient

The 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 kgm2.

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 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:

(190)

Where:

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

*C*test is the energy value for the cumulative amount of fuel mass flow during test, kWh

In case the net energy change criterion is not met, the powertrain system shall be readied for another test run.

A.10.5.5.3. 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:

(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 ≤ *a*1 ≤ 1.030 |
| Absolute value of intercept, |*a*0| | ≤ 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

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*sysshall be calculated as follows:

(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

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

(109)

Where:

*e*  is the specific emission, g/kWh

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

Wsys 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:

(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*sys,cold is the hybrid system cycle work on the cold start test, kWh

*W*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.