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AGREEMENT CONCERNING THE ESTABLISHING OF GLOBAL TECHNICAL
REGULATIONS FOR WHEELED VEHICLES, EQUIPMENT AND PARTS WHICH CAN BE
FITTED AND/OR BE USED ON WHEELED VEHICLES
(ECE/TRANS/132 and Corr.1)
Done at Geneva on 25 June 1998

Addendum

Global technical regulation 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

Amendment x

(Test procedure for heavy duty hybrid vehicles/engines)



UNITED NATIONS

REMARKS

Bold font: Necessary additions to gtr No. 4

Red font: Proposals by the HDH drafting group

Marked text: Items for further discussion

Structure of the draft:

- WHVC test cycle to be added to Annex 1
- New Annex 8 to cover hybrid related issues
- Annex 8, section 3 based on Kokujikan 281
- Annex 8, section 4 to be based on EPA powertrain test procedure
- Annex 8, section 4.1 based on EPA Part 1065 procedure

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I. STATEMENT OF TECHNICAL RATIONALE AND JUSTIFICATION

A. TECHNICAL AND ECONOMIC FEASIBILITY

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II. TEXT OF REGULATION

1. PURPOSE

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

2. SCOPE

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

3. DEFINITIONS, SYMBOLS AND ABBREVIATIONS

3.1. Definitions

For the purpose of this regulation:

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

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

“Rechargeable Energy Storage System (ReESS)” means a system storing energy carriers other than fuels.

“Electric ReESS” means an ReESS storing electrical energy.

“Mechanical ReESS” means an ReESS storing mechanical energy.

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

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

“Electric Motor (EM)” means an energy converter transferring electric energy into mechanical energy.

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

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

“Hybrid Vehicle (HV)” means a vehicle with a powertrain containing at least two different types of energy converters and two different types of energy storage systems.

“Hybrid Electric Vehicle (HEV)” means an HV with a powertrain containing electric machine(s) as energy converter(s).

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

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

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

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

4. GENERAL REQUIREMENTS

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

5. PERFORMANCE REQUIREMENTS

When implementing the test procedure contained in this gtr as part of their national legislation, Contracting Parties to the 1998 Agreement are encouraged to use limit values which represent at least the same level of severity as their existing regulations; pending the development of harmonized limit values, by the Executive Committee (AC.3) of the 1998 Agreement, for inclusion in the gtr at a later date.

5.1. Emission of gaseous and particulate pollutants

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

For hybrid vehicles, the development of the appropriate test cycles shall be determined in accordance with Annex 8.

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

5.1.1. Equivalency

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

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

5.2. Engine family

5.2.1. General

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

5.2.2. Special cases

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

In case of devices or features, which are not listed in paragraph 5.2.3. and which have a strong influence on the level of emissions, this equipment shall be identified by the manufacturer on the basis of good engineering practice, and shall be notified

to the type approval or certification authority. It shall then be taken into account as a criterion for creating a new engine family.

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

5.2.3. Parameters defining the engine family

5.2.3.1. Combustion cycle:

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

5.2.3.2. Configuration of the cylinders

5.2.3.2.1. Position of the cylinders in the block

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

5.2.3.2.2. Relative position of the cylinders

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

5.2.3.3. Main cooling medium

- (a) Air;
- (b) Water;
- (c) Oil.

5.2.3.4. Individual cylinder displacement

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

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

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

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

5.2.3.4.3. Engine with other unit cylinder displacement limits

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

5.2.3.5. Method of air aspiration

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

5.2.3.6. Fuel type

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

5.2.3.7. Combustion chamber type

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

5.2.3.8. Ignition Type

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

5.2.3.9. Valves and porting

- (a) Configuration;
- (b) Number of valves per cylinder.

5.2.3.10. Fuel supply type

- (a) Liquid fuel supply type;

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

5.2.3.11. Miscellaneous devices

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

5.2.3.12. Electronic control strategy

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

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

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

Examples of controlled features are:

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

5.2.3.13. Exhaust after-treatment systems

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

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

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

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

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

5.2.4. Choice of the parent engine

5.2.4.1. Compression ignition engines

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

5.2.4.2. Positive ignition engines

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

criterion, the parent engine shall be selected using the secondary criterion in the following order of priority:

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

5.2.4.3. Remarks on the choice of the parent engine

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

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

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

5.3 **Hybrid powertrain family**

6. TEST CONDITIONS

6.1. Laboratory test conditions

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

- (a) Compression-ignition engines:

Naturally aspirated and mechanically supercharged engines:

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

Turbocharged engines with or without cooling of the intake air:

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

(b) Positive ignition engines:

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

6.2. Engines with charge air-cooling

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

If a test laboratory system or external blower is used, the coolant flow rate shall be set to achieve a charge air temperature within ± 5 K of the maximum charge air temperature specified by the manufacturer at the rated speed and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall not be changed for the whole test cycle, unless this results in unrepresentative overcooling of the charge air. The charge air cooler volume shall be based upon good engineering practice and shall be representative of the production engine's in-use installation. The laboratory system shall be designed to minimize accumulation of condensate. Any accumulated condensate shall be drained and all drains shall be completely closed before emission testing.

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

6.3. Engine power

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

6.3.1. General engine installation

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

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

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

If it is inappropriate to install the auxiliaries/equipment required according to Annex 7 on the test bench, the power absorbed by them shall be determined and

subtracted from the measured engine power (reference and actual) over the whole engine speed range of the WHTC and over the test speeds of the WHSC.

6.3.3. Auxiliaries/equipment to be removed for the test

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

6.3.4. Determination of auxiliary power

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

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

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

6.3.5. Engine cycle work

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

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

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

where:

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

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

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

6.4. Engine air intake system

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

6.5. Engine exhaust system

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

7.4. Engine mapping and reference cycle

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

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

For the vehicle independent approach of HVs, the mapping procedure in paragraph 4.1 to Annex 8 shall be used.

Annex 1

a) WHTC ENGINE DYNAMOMETER SCHEDULE

b) WHVC VEHICLE SCHEDULE

Annex 7

INSTALLATION OF AUXILIARIES AND EQUIPMENT FOR EMISSIONS TEST

Number	Auxiliaries	Fitted for emission test
1	Inlet system Inlet manifold Crankcase emission control system Control devices for dual induction inlet manifold system Air flow meter Air inlet duct work Air filter Inlet silencer Speed-limiting device	Yes Yes Yes Yes Yes, or test cell equipment Yes, or test cell equipment Yes, or test cell equipment Yes
2	Induction-heating device of inlet manifold	Yes, if possible to be set in the most favourable condition
3	Exhaust system Exhaust manifold Connecting pipes Silencer Tail pipe Exhaust brake Pressure charging device	Yes Yes Yes Yes No, or fully open Yes
4	Fuel supply pump	Yes
5	Equipment for gas engines Electronic control system, air flow meter, etc. Pressure reducer Evaporator Mixer	Yes Yes Yes Yes
6	Fuel injection equipment Prefilter Filter Pump High-pressure pipe Injector Air inlet valve Electronic control system, sensors, etc. Governor/control system Automatic full-load stop for the control rack depending on atmospheric conditions	Yes Yes Yes Yes Yes Yes Yes Yes Yes
7	Liquid-cooling equipment Radiator Fan Fan cowl Water pump Thermostat	No No No Yes Yes, may be fixed fully open
8	Air cooling Cowl Fan or Blower Temperature-regulating device	No No No
9	Electrical equipment Generator	No

	Coil or coils	Yes
	Wiring	Yes
	Electronic control system	Yes
10	Intake air charging equipment	Yes
	Compressor driven either directly by the engine and/or by the exhaust gases	Yes
	Charge air cooler	Yes, or test cell system
	Coolant pump or fan (engine-driven)	No
	Coolant flow control device	Yes
11	Anti-pollution device (exhaust after-treatment system)	Yes
12	Starting equipment	Yes, or test cell system
13	Lubricating oil pump	Yes

Annex 8

REQUIREMENTS FOR ENGINES INSTALLED IN HYBRID VEHICLES

1. SCOPE

This annex shall apply to HVs, which are equipped with an internal combustion engine as one of their energy converters.

2. TEST PROCEDURE

2.1 HILS method

The HILS method consists of running the IC engine on the test bench. Construct the HILS system. Control the HEV model for approval referring to one of the components constituting the HILS system, which is a software model simulating the functions, mechanism, and other systems of the hybrid electric vehicle by inputting parameters obtained by component tests of engine torque characteristics, etc. of hybrid heavy-duty vehicles. Calculate the engine operating conditions by performing a simulated running (referring to the running with the HEV model for approval, etc. actuated on the HILS system according to the reference vehicle speed pattern, as laid down in Annex 1, section b.

2.2 Powertrain method

The powertrain method consists of running the complete hybrid powertrain on the test bench.

3. HILS METHOD

The HILS system consist of, as shown in Figure 1, the HILS hardware, the HV model for approval and its input parameters, the driver model and the reference vehicle speed pattern in Annex 1, section b, and the hybrid ECU of the test motor vehicle (hereinafter referred to as the “actual ECU”) and its power supply.

3.1. Models to be used

The models necessary for this test method are, in addition to an HV models for approval (including the reference ECU model for the Software-in-the-Loop Simulator (hereinafter referred to as the “SILS”) corresponding to parallel and series heavy-duty hybrid electric vehicles, that are obtained from the simulated running using the HILS system, as well as a **specific interpolation procedure (e.g. Hermite procedure)** to be used when creating table data of the input parameters, etc. The models to be used are listed below:

- Standard parallel HEV model
- Standard series HEV model

3.2. Hardware

The HILS hardware shall have the signal types (ADIO, PULSE, CAN) and number of channels that are sufficient for constructing the interface between the HILS hardware and the actual ECU, and shall be checked and calibrated.

3.3. Actual ECU

The hybrid system ECU of the test motor vehicle shall be used as the actual ECU. Furthermore, in the case of a motor vehicle equipped with a transmission ECU, this may be used as the hybrid ECU at the same time.

3.4. Driver model

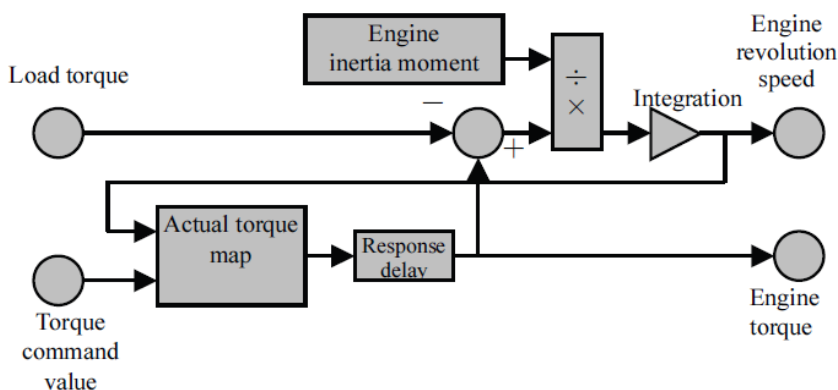
The driver model makes the standard HEV model to operate in such a way as to achieve the reference vehicle speed by generating accelerator, brake and shift signals, and is actuated by the PID control, etc. The driver model may be replaced by sequential data of accelerator, brake and shift signals.

3.5. HEV model

The HEV model shall be created based on the provisions in paragraphs 3.5.1. to 3.5.4.

3.5.1. Engine model

The engine model calculates the generated torque of the engine from the engine torque command value, throttle valve opening angle or injection amount command value and the torque map in relation to the revolution speed. The torque generated by the engine, the starter torque and the torque loaded on the engine from outside are combined. The revolution speed is determined from the combined torque and the inertia moment of the engine's rotating sections. If the actual ECU required revolution control or revolution limit, the PID control function inside the engine model controls the engine revolution speed. In addition, the idle revolution speed can be adjusted by the input for adjustment. It stops by the input of Ignition OFF or Fuel Cut ON signal (Fig. 2).



3.5.2. Electric motor model

The electric motor model has the voltage as its parameter. It has the torque map and the electric power consumption map in relation to the electric motor torque command value and the revolution speed. While driving or controlling the vehicle based on the electric motor command value inputted from the actual ECU, it calculates electric power consumption. The electric motor torque command value corresponds to the switching of power running / regeneration (Fig. 3).

3.5.3. Electric ReESS model

The charged / discharged power and the state of charge of the ReESS shall be calculated according to the provisions in paragraphs 3.5.3.1. to

TO BE CHECKED WITH SAE 1711

3.5.3.1. Battery

The state of charge shall be calculated by current integration assuming that the Coulomb efficiency is 100 %. Both the open voltage and internal resistance of the battery shall be calculated from the map in relation to the state of charge, since they change according to the state of charge (Fig. 4).

$$P = V_s I = (V_o - R_i I) I$$

$$SOC = SOC_{initial} - \int_0^t \frac{I}{C_{nominal} \times 3600} dt \times 100$$

where:

P	: Charged / discharged power	(W)
V _s	: Terminal voltage	(V)
I	: Electric current	(A)
V _o	: Open voltage	(V)
R _i	: Internal resistance	(Ω)
SOC	: State of charge	(%)
SOC _{initial}	: Initial state of charge	(%)
C _{nominal}	: Rated capacity	(Ah)
t	: Elapsed time	(s)

3.5.3.2. Capacitor

TO BE CHECKED WITH SAE 1711

3.5.3.3. Flywheel

TO BE CHECKED WITH SAE 1711

3.5.3.4. Hydraulic

3.5.4. Vehicle / powertrain system model

The vehicle / powertrain system model consist of the running resistance model, the transmission model and the clutch for electric motor model. This not only calculates the running resistance but also gives and receives the torque between the engine model and the electric motor model, generating the vehicle speed.

3.5.4.1. Running resistance model

This model calculates the running resistance from the vehicle speed, using the following formula:

Eq. to be added

3.5.4.2. Transmission model

This model calculates the torque transmitted to the vehicle from the engine torque, electric motor torque, reduction ratio at each speed, final reduction ratio, gear efficiency and inertia moment of each component. From this torque and the load torque consisting of the running resistance of the vehicle, vehicle mass, inertia moment of the tyres and axles, the acceleration of the vehicle shall be determined. The torque transmitted from the transmission input shaft to its output shaft is calculated from the clutch stroke and gear transmission efficiency, and inertia moment is set for each speed.

3.5.4.3. Clutch model

This model simulates the clutch operation between the engine and transmission, and calculates input shaft revolution speed of the transmission (including the electric motor), and the load torque to the engine. It adds the torque inputted from the electric motor and calculates the input shaft revolution speed from the inertia of the clutch section including the electric motor.

3.5.5. Reference ECU Model for SILS

The reference ECU model for SILS is used for the purpose of operation check of the HEV model for approval. The signals given from the reference ECU model for SILS to the HEV model for approval are command values of the torques of the engine and electric motor, of the gear change, clutch, lock up of hydraulic coupling, etc. Moreover, the reference ECU model for SILS shall be ancillary to the HEV model for approval, and shall be arranged in such a way that it can be used by switching from the actual ECU with a selector switch.

3.5.6. Operation check of standard HEV Model

The operation check of the HEV model for approval shall be performed by the following method:

Input the SILS reference parameters (attachment 1 to this Annex in the case of the parallel type, and attachment 2 to this Annex in the case of the series type) in the HEV model for approval, and control the HEV model for approval using the ancillary reference ECU model for SILS. Confirm that the calculation result of each parameter satisfies the criterion shown in Table x in relation to the SILS reference calculation result (attachment 3 to this Annex in the case of the parallel type, and attachment 4 to this Annex in the case of the series type). However, this provision shall not apply if changes have been made in the construction and constant of each component model of the HEV model for approval.

3.5.7. Construction of interface

In the HILS system, where the actual ECU, driver model and HEV model for approval are stored, connection is made by means of the interface shown in Table x and Table x for parallel and series heavy-duty hybrid electric vehicles, respectively. In addition, level tuning of the signal and the fail release correspondence, etc. can be handled by using a unique interface conversion model according to the system of the heavy-duty hybrid electric vehicle.

3.6. Test procedure for energy converter(s) and storage device(s)

3.6.1. Internal combustion engine

3.6.2. Electric motor

3.6.3.

3.6.4. Storage devices

3.6.4.1. Battery

3.7. Test procedure for exhaust emissions

3.8. Verification test procedure

4. POWERTRAIN METHOD

4.1 Powertrain mapping

Engines that include electric hybrid systems shall be mapped as described in this paragraph. These provisions may be applied to other types of hybrid engines, consistent with good engineering judgment. The mapping procedure as given in paragraph 7.4 of this gtr shall be used except as noted in this paragraph. The powertrain map shall be generated with the hybrid system active as described in paragraph 4.1.2 or 4.1.3 of this section.

4.1.1. General

The purpose of the mapping procedure in this paragraph is to determine the maximum torque available at each speed with a charged ReESS. One of the following methods shall be used to generate a hybrid-active map.

4.1.2. Continuous sweep mapping

A powertrain map shall be performed by using a series of continuous sweeps to cover the powertrain's full range of operating speeds. The powertrain shall be prepared for hybrid-active mapping by ensuring that the ReESS state of charge is representative of normal operation. The sweep shall be performed as specified in paragraph 7.4 of this gtr, but the sweep shall be stopped to charge the ReESS when the power measured from the ReESS drops below the expected maximum power from the RESS by more than 2% of total system power (including engine and ReESS power). Unless good engineering judgment indicates otherwise, it may be assumed that the expected maximum power from the ReESS is equal to the measured ReESS power at the start of the sweep segment. For example, if the 3-second rolling average of total engine-ReESS power is 200 kW and the power from the ReESS at the beginning of the sweep segment is 50 kW, once the power from the ReESS reaches 46 kW, the sweep shall be stopped to charge the ReESS. Note that this assumption is not valid where the hybrid motor is torque-limited. Total system power shall be calculated as a 3-second rolling average of instantaneous total system power. After each charging event, the engine shall be stabilized for 15 seconds at the speed at which the previous segment ended with operator demand set to maximum before continuing the sweep from that speed. The cycle of charging, mapping, and recharging shall be repeated until the engine map is completed. The system may be shut down or other operation may be included between segments to be consistent with the intent of this paragraph. For example, for systems in which continuous charging and discharging can overheat batteries to an extent that affects performance, the engine may be operated at zero power from the ReESS for enough time after the system is recharged to allow the batteries to cool. Good engineering judgment shall be used to smooth the torque curve to eliminate discontinuities between map intervals.

4.1.3. Discrete speed mapping

A powertrain map shall be performed by using discrete speeds. Map set points shall be selected at 13 equally spaced powertrain speeds. Mapping may be stopped at the highest speed above maximum power at which 50% of maximum power occurs. Powertrain speed shall be stabilized at each setpoint, targeting a torque value at 70% of peak torque at that speed without hybrid-assist. The engine shall be fully warmed up and the ReESS state of charge shall be within the normal operating range. The operator demand shall be moved to maximum, the powertrain shall

be operated there for at least 10 seconds, and the 3-second rolling average feedback speed and torque shall be recorded at 1 Hz or higher. The peak 3-second average torque and 3-second average speed shall be recorded at that point. Linear interpolation shall be used to determine intermediate speeds and torques. §7.4.x. shall be followed to calculate the maximum test speed. The measured maximum test speed shall fall in the range from 92 to 108% of the estimated maximum test speed. If the measured maximum test speed does not fall in this range, the map shall be rerun using the measured value of maximum test speed.