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(3rd HDH Drafting Group meeting, 22/23 October 2013)

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GLOBAL REGISTRY

Created on 18 November 2004, pursuant to Article 6 of the
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

GE.10-

REMARKS

Bold font: Necessary additions to gtr No. 4
Blue font: Technical Secretary suggestions/changes
Red font: Proposals by the HDH drafting group

Marked text: Items for further discussion (any colour)

Structure of the draft:

- -Annex 4 with modifications to adopt Hybrid Engines
- -
- -WHVC test cycle to be added to Annex 1

- -New Annex 8 to cover Hybrid HILS method
  - o Annex 8, section 3. based on Kokujikan No.281/Ch1
  - o Annex 8, section 4. is based on Kokujikan No.281/Ch2
  - o Annex 8, section 5. is based on Kokujikan No.281/Ch4
  - o Annex 8, section 6. is based on Kokujikan No.281/Ch5

- -New Annex 9 to cover Hybrid Powertrain method
  - o Annex 9, section 4 to be based on EPA powertrain test procedure
  - o Annex 9, 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

The objective of this proposal is to establish a harmonized global technical regulation (GTR) covering the type-approval for exhaust emissions from heavy-duty engines in hybrid vehicle applications. The basis will be the test procedure described in Kokujikan No.281 and further developed by the HDH informal working group of GRPE **(see the informal documents on "*reference to VTP1, VTP2 and so on*" as distributed during the XXth GRPE session)**

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

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

In parallel, … US/Japan and/or ISO developments … ???

It is recognised by the Contracting Parties to the 1998 Agreement that a long-term goal for road heavy-duty engine testing and non-road engine testing would be GTRs which are similar in structure and content with respect to measurement equipment, procedures and requirements. Therefore, the Contracting Parties recognize there will be a need in the future to amend this GTR in order to have as much commonality as is possible between the road heavy-duty (hybrid) engine GTR and the non-road (hybrid) engine GTR.

The HILS test procedure reflects engine operation in heavy-duty hybrid vehicle operation as closely as possible, and provides a marked improvement towards measuring the emission performance of hybrid engines. In summary, the HILS procedure was developed so that it would be:

(a) Representative of engine operation in a heavy-duty hybrid vehicle application

(b) Corresponding to state-of-the-art testing, sampling and measurement technology

(c) Applicable in practice to existing and foreseeable future hybrid technologies, and

(d) Capable of providing a reliable ranking of exhaust emission levels from different (hybrid) engine types.

At this stage, the GTR is being presented without limit values. In this way, the test procedure can be given a legal status, based on which the Contracting Parties are required to start the process of implementing it into their national law. The GTR contains several options, whose adoption is left to the discretion of the Contracting Parties.

Those options relate to …???

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

B. ANTICIPATED BENEFITS

Heavy (hybrid) commercial vehicles and their engines are increasingly produced for the global market. It is economically inefficient for manufacturers to have to prepare substantially different models in order to meet different emission regulations and methods of measuring emissions, which, in principle, aim at achieving the same objectives. To enable manufacturers to develop new models more effectively and within a shorter time, it is desirable that a GTR should be developed. These savings will accrue not only to the manufacturer, but more importantly, the consumer as well.

However, developing a test procedure just to address the economic question does not completely address the mandate given when work on this GTR was first started. The test procedure must also improve the state of testing heavy-duty hybrid engine systems and better reflect how these engines are used. Compared to the measurement methods defined in existing legislation of the Contracting Parties to the 1998 Agreement, the testing methods defined in this GTR are more representative of in-use engine operating behaviour of hybrid commercial vehicles. It should be noted that the requirements of this GTR should be complemented by the requirements relating to the control of the Off-Cycle Emissions (OCE) and OBD systems.

As a consequence, it can be expected that the application of this GTR for emission legislation within the Contracting Parties to the 1998 Agreement will result in a higher control of in-use emissions due to the improved correlation between the test method and the in-use operating behaviour.

C. POTENTIAL COST EFFECTIVENESS

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

II. TEXT OF REGULATION

Should all of the Annex 4 text be included in Annex 8 where is can be dedicated to HDH or is modification of GTR4 / Annex 4 possible as suggested below ?

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~~**fuel**.

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

"Generator (GE)" 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 **pollutants** by the engine shall be determined on the WHTC and WHSC test cycles, as described in paragraph 7, **however, for a hybrid engine**. 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 calculation 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 ≥ 0.75 dm³

In order for engines with a unit cylinder displacement of ≥ 0.75 dm³ 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 dm³

In order for engines with a unit cylinder displacement of < 0.75 dm³ 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) DeNOx system with selective reduction of NO_x (addition of reducing agent);

(d) Other DeNOx 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 (text inspired by 5.2 Engine family)

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

5.3.2 Special cases

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

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

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

5.3.3. Parameters defining the hybrid powertrain family

5.3.3.1. Internal combustion engine

See provisions and definition in section 5.2.3

5.3.3.2. Other component

5.3.3.3. Other component

5.3.3. . Other component

5.3.3.n. Last other component

5.3.4. Choice of the parent engine of a hybrid powertrain

5.3.4.1. Hybrid powertrain with compression ignition internal combustion engine
See section 5.2.4.1.

5.3.4.2. Hybrid powertrain with positive ignition internal combustion engine
See section 5.2.4.2.

5.4.4.3. Remarks on the choice of the parent engine of a hybrid powertrain

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

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

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

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

Turbocharged engines with or without cooling of the intake air:

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

(b) Positive ignition engines:

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

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. <u>Engine air intake system</u>

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. <u>Engine exhaust system</u>

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.

All following sections (also) remain valid. For HV, the calculated hybrid engine cycle shall apply instead of WHTC. Do WHSC references also need to be changed ?

6.6. <u>Engine with exhaust after-treatment system</u>

6.6.1. Continuous regeneration

6.6.2. Periodic regeneration

6.7. Cooling system

6.8. Lubricating oil

6.9. Specification of the reference fuel

6.10. Crankcase emissions

6.11. Paragraphs 6.11.1. and 6.11.2. shall apply to positive-ignition engines fuelled with petrol or E85.

6.11.1. The pressure in the crankcase shall be measured over the emissions test cycles at an appropriate location. The pressure in the intake manifold shall be measured to within ±1 kPa.

6.11.2. Compliance with paragraph 6.10. shall be deemed satisfactory if, in every condition of measurement set out in paragraph 6.11.1., the pressure measured in the crankcase does not exceed the atmospheric pressure prevailing at the time of measurement.

7. Test procedures

7.1. Principles of emissions measurement

7.1.1. Continuous sampling

7.1.2. Batch sampling

7.1.3. Measurement procedures

This annex applies two measurement procedures that are functionally equivalent. Both procedures may be used for both the WHTC and the WHSC test cycle **as well as the calculated WHVC hybrid engine test cycle**:

(a) The gaseous components are sampled continuously in the raw exhaust gas, and the particulates are determined using a partial flow dilution system;

(b) The gaseous components and the particulates are determined using a full flow dilution system (CVS system).

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

7.2. Test cycles

7.2.1. Transient test cycle WHTC

7.2.2. Ramped steady state test cycle WHSC

7.2.3. Transient test cycle WHVC (for HV only?)

The transient test cycle WHVC is listed in Appendix 1b as a second-by-second sequence of vehicle speed and normalized power values as well as mini-cycles for road load correction determination. In order to perform the test on an engine test cell, the cycle values need to be converted to the reference values for (rotational) speed and torque for the individual engine under test. The conversion is carried out according to the HILS method, and the test cycle so developed is the reference cycle of the engine to be tested. With those references speed and torque values, the cycle shall be run on the test cell, and the actual speed, torque and power values shall be recorded. In order to validate the test run, a regression analysis between reference and actual speed, torque and power values shall be conducted upon completion of the test.

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

For the gaseous pollutants, continuous sampling (raw or dilute exhaust gas) or batch sampling (dilute exhaust gas) may be used. The particulate sample shall be diluted with a conditioned diluent (such as ambient air), and collected on a single suitable filter. The WHVC is shown schematically in Figure 5.

Figure 5 (new)
WHVC test cycle
Include picture

7.3. General test sequence

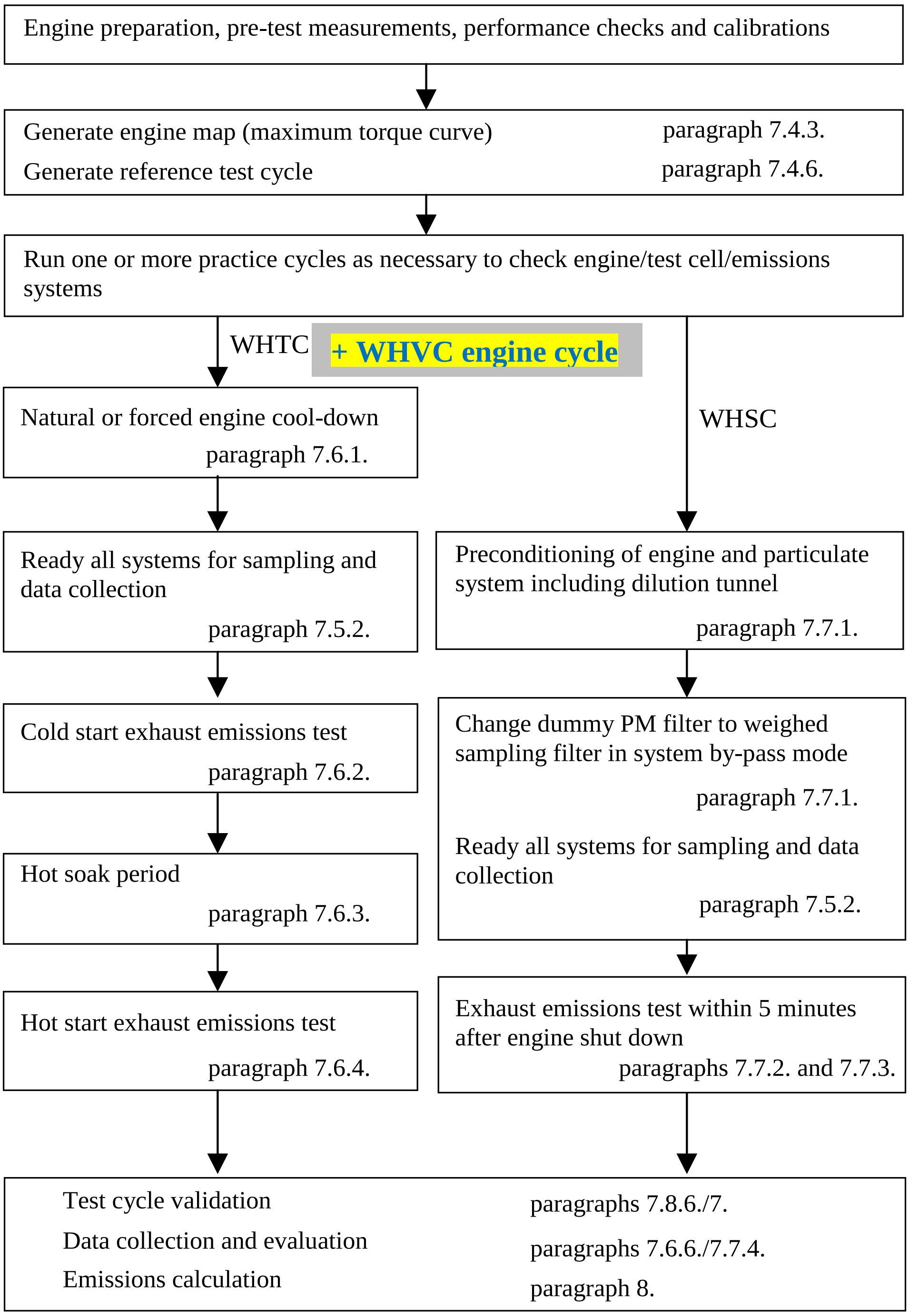
The following flow chart outlines the general guidance that should be followed during testing. The details of each step are described in the relevant paragraphs. Deviations from the guidance are permitted where appropriate, but the specific requirements of the relevant paragraphs are mandatory.

For the WHTC, the test procedure consists of a cold start test following either natural or forced cool-down of the engine, a hot soak period and a hot start test.

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

For the hybrid engine test cycle, the test procedure consists of a cold start test following either natural or forced cool-down of the engine, a hot soak period and a hot start test.

Include in flow diagram as third sequence in parallel to WHTC and WHSC, or together with WHTC ?



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 to determine the hybrid engine reference test cycle.

Should this refer to and/or is it different for Annex 8 (HILS method) or 9 (Powertrain method)?

Following sections may not be needed directly for HV engine testing, though can remain valid in general

7.4.1. Engine warm-up

7.4.2. Determination of the mapping speed range

7.4.3. Engine mapping curve

7.4.4. Alternate mapping

7.4.5. Replicate tests

7.4.6. Denormalization of engine speed

7.4.7. Denormalization of engine torque

7.4.8. Calculation of reference cycle work

Following section remain unchanged/valid for preparation of engine test cell testing

7.5. Pre-test procedures
7.5.1. Installation of the measurement equipment
7.5.2. Preparation of measurement equipment for sampling
7.5.3. Checking the gas analyzers
7.5.4. Preparation of the particulate sampling filter
7.5.5. Adjustment of the dilution system
7.5.6. Starting the particulate sampling system

7.6. WHTC cycle run
7.6.1
…
7.6.8

7.7. WHSC cycle run
7.7.1.
…
7.7.6.

7.8 "WHVC cycle run"
What reference name to use for derived HV engine cycle ? To be included, same as test execution as WHTC?)
7.8.1

…

7.8.8

7.9~~7.8.~~ Post-test procedures (check WHTC, WHSC, paragraph references)

7.9.1.~~7.8.1.~~

…

7.9.7~~7.8.7~~

8. Emission calculation

8.1. Dry/wet correction

…

8.6.2. Calculation of NMHC and CH_4

8.6.3. Calculation of the specific emissions

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

For the WHSC, hot WHTC, ~~or~~ cold WHTC, **or WHVC engine cycle,** the following equation shall be applied:

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

Where:

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

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

For the WHTC **and WHVC engine cycle**, the final test result shall be a weighted average from cold start test and hot start test according to the following equation:

$$e = \frac{(0{,}14 \times m_{\mathrm{cold}}) + (0{,}86 \times m_{\mathrm{hot}})}{(0{,}14 \times W_{\mathrm{act,cold}}) + (0{,}86 \times W_{\mathrm{act,hot}})} \quad (70)$$

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

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

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

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

9. Equipment specifications and verification

No changes expected for Hybrid / Electric as long as engine test is applied to determine emission values.

9.1. Dynamometer specification

9.2. Linearity requirements

9.3. Gaseous emissions measurement and sampling system

9.4. Particulate measurement and sampling system

9.5. Calibration of the CVS system

10. Particle number measurement test procedure
No necessary changes expected for Hybrid / Electric as long as engine test is applied to determine emission values.

10.1. Sampling
…
10.4.3. Determination of particle numbers with a full flow dilution system

10.4.4. Test result

10.4.4.1. Calculation of the specific emissions

For each individual WHSC, hot WHTC~~, and~~ cold WHTC **and WHVC engine cycle** the specific emissions in number of particles/kWh shall be calculated as follows:

$$e = \frac{N}{W_{act}} \quad (99)$$

Where:

e is the number of particles emitted per kWh,

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

10.4.4.2. Exhaust after-treatment systems with periodic regeneration

For engines equipped with periodically regenerating after-treatment systems, the general provisions of paragraph 6.6.2. apply. The WHTC **and WHVC engine cycle** start emissions shall be weighted according to equation 5 where $\bar{e}$ is the average hot number of particles/kWh without regeneration, and $\bar{e_r}$ is the average number of particles/kWh with regeneration. The calculation of the regeneration adjustment factors shall be done according to equations 6, 6a, 7 or 8, as appropriate.

10.4.4.3. Weighted average WHTC **and WHVC engine cycle** test result

For the WHTC **and WHVC engine cycle**, the final test result shall be a weighted average from cold start and hot start (including periodic regeneration where relevant) tests calculated using one of the following equations:

(a) In the case of multiplicative regeneration adjustment, or engines without periodically regenerating after-treatment

$$e = k_r \left(\frac{(0.14 \times N_{cold}) + (0.86 \times N_{hot})}{(0.14 \times W_{act,cold}) + (0.86 \times W_{act.hot})} \right) \quad (100)$$

(b) In the case of additive regeneration adjustment

$$e = k_r + \left(\frac{(0.14 \times N_{cold}) + (0.86 \times N_{hot})}{(0.14 \times W_{act,cold}) + (0.86 \times W_{act.hot})} \right) \quad (101)$$

Where:

N_{cold}	is the total number of particles emitted over the WHTC **or WHVC engine cycle** cold test cycle,
N_{hot}	is the total number of particles emitted over the WHTC **or WHVC engine cycle** hot test cycle,
$W_{act,cold}$	is the actual cycle work over the WHTC **or WHVC engine cycle** cold test cycle according to paragraph 7.8.6., in kWh,
$W_{act, hot}$	is the actual cycle work over the WHTC **or WHVC engine cycle** hot test cycle according to paragraph 7.8.6., in kWh,
k_r	is the regeneration adjustment, according to paragraph 6.6.2., or in the case of engines without periodically regenerating after-treatment k_r = 1

10.4.4.4. Rounding of final results

The final WHSC and weighted average WHTC test results **or weighted WHVC engine cycle test results** shall be rounded in one step to three significant figures in accordance with ASTM E 29–06B. No rounding of intermediate values leading to the final brake specific emission result is permissible.

10.5. Determination of particle number background

10.5.1. At the engine manufacturer's request, dilution tunnel background particle number concentrations may be sampled, prior to or after the test, from a point downstream of the particle and hydrocarbon filters into the particle number measurement system, to determine the tunnel background particle concentrations.

10.5.2. Subtraction of particle number tunnel background concentrations shall not be allowed for type approval, but may be used at the manufacturer’s request, with the prior approval of the Type Approval Authority , for conformity of production testing, if it can be demonstrated that tunnel background contribution is significant, which can then be subtracted from the values measured in the diluted exhaust.

<u>Annex 1</u>

a) WHTC ENGINE DYNAMOMETER SCHEDULE

b) WHVC VEHICLE SCHEDULE

Time, vehicle speed, norm.power (and/or road gradient?) for 1800s cycle

Time	*Vehicle Speed*	*Norm. Power*	*Road gradient ?*	*Time*	*Vehicle Speed*	*Norm. Power*	*Road gradient ?*	*Time*	*Vehicle Speed*	*Norm. Power*	*Road gradient ?*
s	*km/h*	*%*	*%*	*s*	*km/h*	*%*	*%*	*s*	*km/h*	*%*	*%*
0?	0	0	0	0	0	0	0	0	0	0	0
1											
…											
1800											

Annex 7

INSTALLATION OF AUXILIARIES AND EQUIPMENT FOR EMISSIONS TEST

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

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

Annex 8

REQUIREMENTS FOR ENGINES INSTALLED IN HYBRID VEHICLES USING HILS METHOD

1. SCOPE

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

2. TEST PROCEDURE

2.1 HILS method

The HILS method consists of running the internal combustion engine on the test bench **using the engine test cycle determined through:**

1) Construction of the HILS system
2) Definition of the HV model
3) Control the HV 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.
4) Calculate the engine operating conditions by performing a simulated running (referring to the running with the HDH model for approval, etc. actuated on the HILS system according to the reference vehicle speed pattern, as laid down in Annex 1, section b.

In Kokujikan No.281 following Chapters are mentioned:

(1) HILS system → section 3
(2) Test procedure(s) for components → section 4
(3) Test procedure for fuel consumption *(not applicable for GTR?)*
(4) Test procedure for exhaust emissions → section 5
(5) Verification test procedure for HILS system → section 6

Suggested to, here, include flow chart on the HILS method (ref: VTP1 final report or HDH-09-15e.pdf)

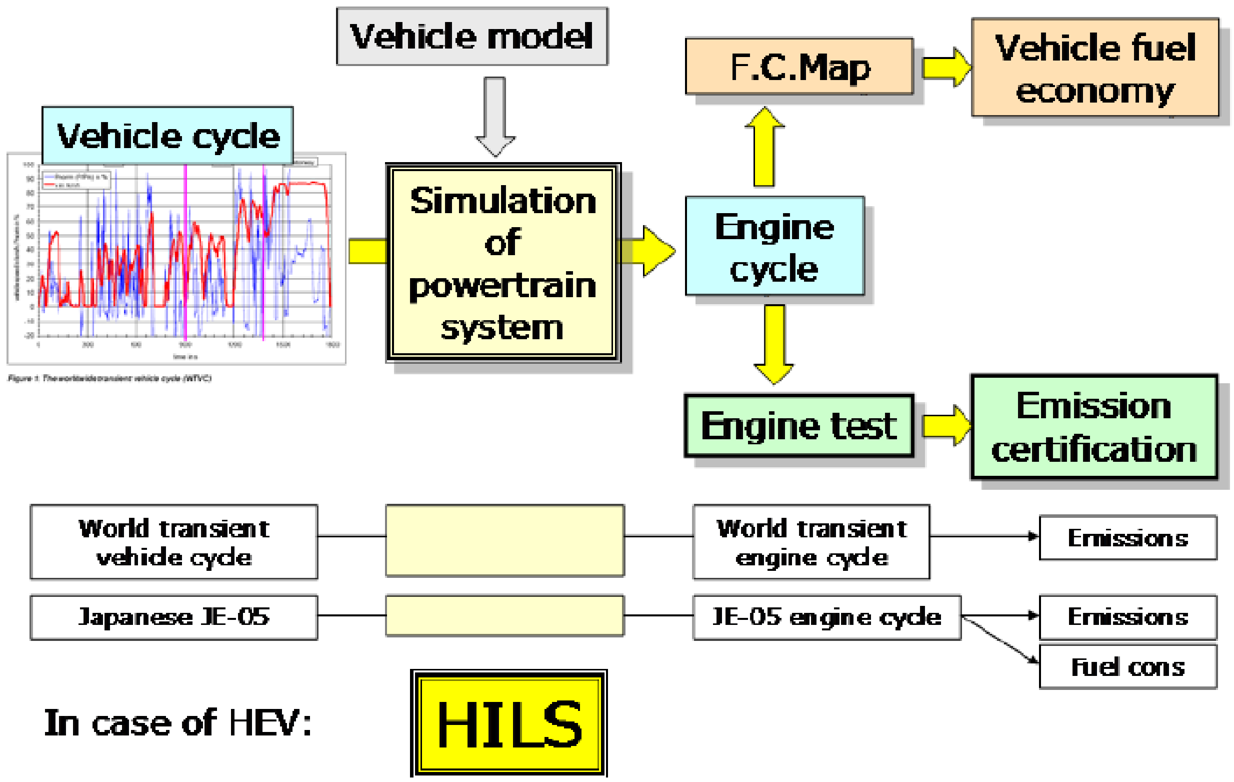


Figure 1 – Outline HILS method (ref: HDH-09-15e.pdf)

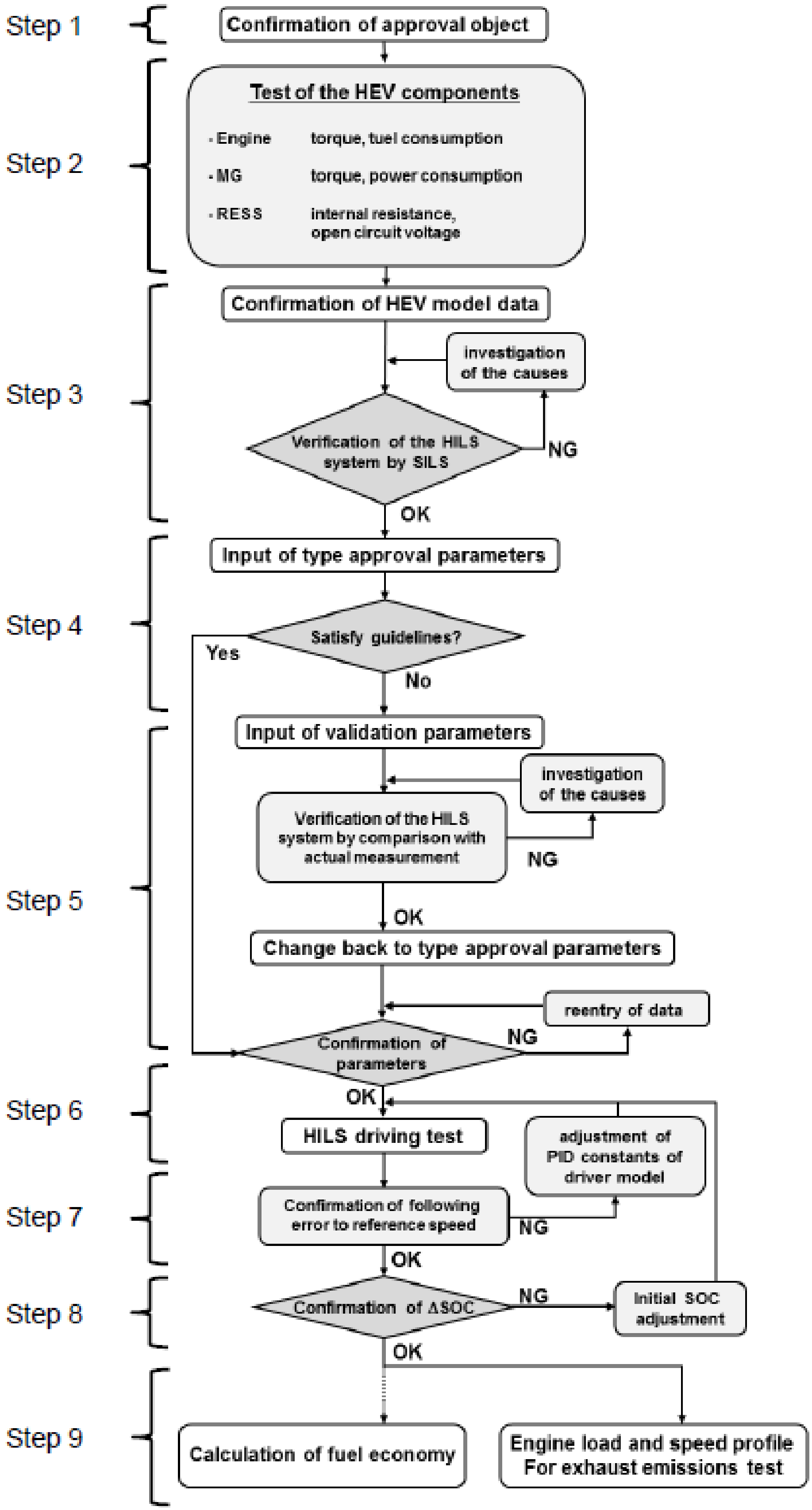


Figure 2 - Flow chart HILS method (ref: VTP1 final report) [to much detail, may need adaption?]

Step 1: Start of the approval of test object
Step 2: Component specific data for engine, electric machines and energy storage according to the test procedures including vehicle mass, inertias, transmissions and gear ratios are generated and implemented within the simulation models
Step 3: In order to ensure that the system and component models are working well, pre-check is done by using SILS (Software in the Loop) -simulation. SILS is a simplified predetermined control algorithm.
Step 4: Check if powertrain topology including their parameters has been certified before and analyse if additional verification is needed. If yes, system verification has to be done, otherwise go to step 6.
Step 5: Verification is done either using a "system test bench" or on a chassis dynamometer. If the model represents the real vehicle, go to step 6, otherwise investigation on causes has to be done.
Step 6: If verification process is passed, model parameters are used for running a full HIL-simulation. Step 6 includes an entire HIL-simulation run.
Step 7: Check if vehicle follows the reference speed (predefined driving cycle) If yes, go to step 8, otherwise adjust vehicle driver and redo HIL-simulation
Step 8: Check if energy level is within tolerances. If yes, go to step 9, otherwise adjust initial value of SOC and redo HILS-simulation
Step 9: Fuel consumption is calculated from fuel consumption map. In order to do exhaust emission test, the engine load and speed profile obtained from the simulation are used on engine dynamometer.

2.2 Powertrain method

The powertrain method consists of running the complete hybrid powertrain on the test bench.
This section to be deleted due to adoption as separate Annex 9

3. HILS ~~METHOD~~ **SYSTEM**

The HILS system consist of, as shown in Figure 3, the HILS hardware, the HV model and its input parameters (**for approval)**, 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.

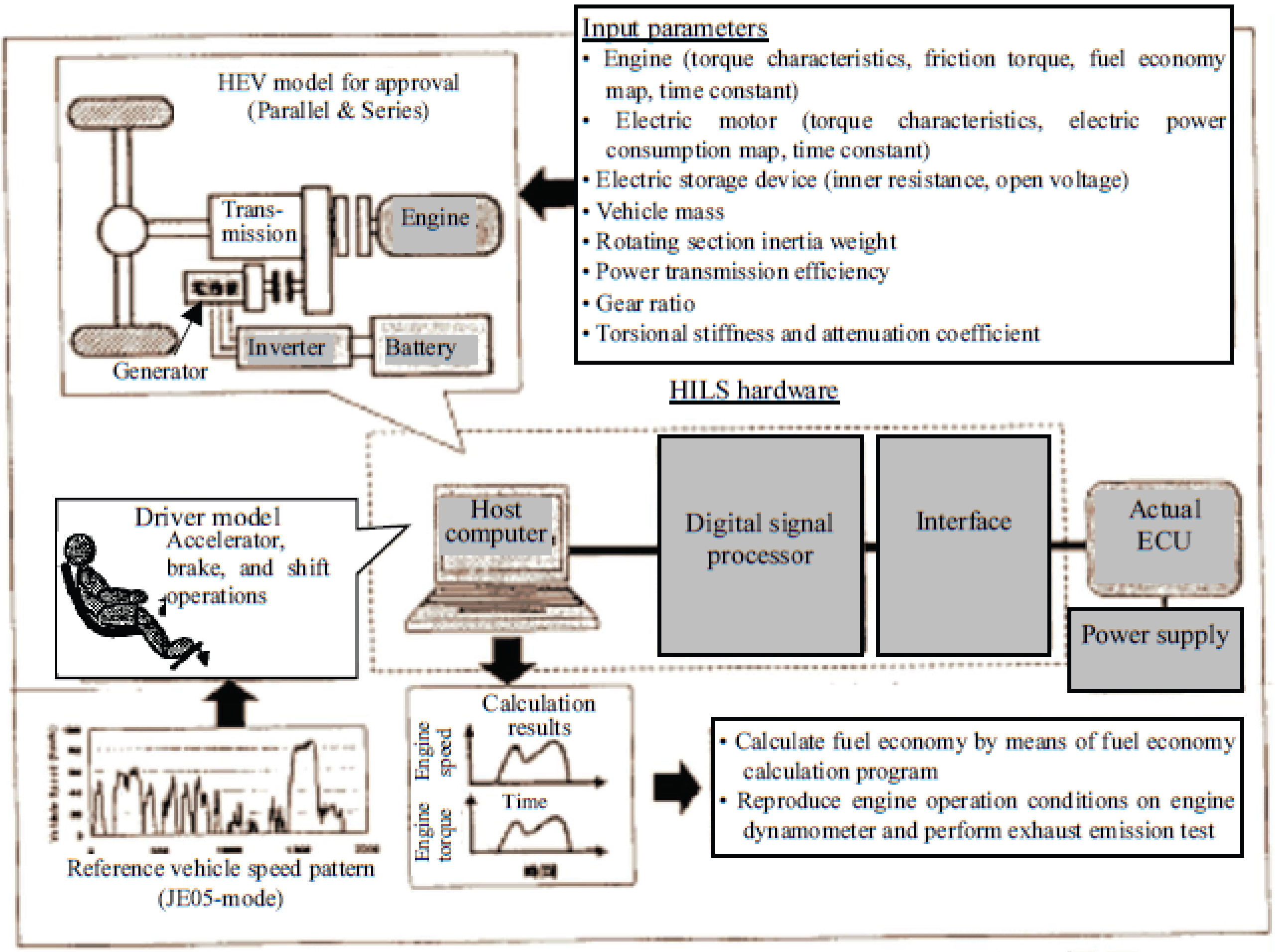


Figure 3 - Outline of HILS system for Heavy-Duty Hybrid Vehicles (may need some updating [TS-12-2-34 – 281.pdf])

The HV model for approval needs to be constructed from the available model components in HILS library, incl. driver model. For reference testing of the HILS system, a model should/is made available in the HILS library (does PHEV example model match with Japanese SILS reference model?).

OEM specific models possibly should not be allowed due to issues on verification of models. Suggested new structure for text becomes:

3.1 Software/models to be used *(ref: #281/Ch1/sect2)*

3.2 HILS hardware *(ref: #281/Ch1/sect3)*

3.3 Actual ECU *(ref: #281/Ch1/sect4)*

(ref: #281/Ch1/sect5 driver model part of HILS library, no need for separate section?)

3.4 HV Model for Approval (full HILS library description to be included) *(ref: #281/Ch1/sect6)*

3.4.1 Engine model

3.4.n … model

3.5 Reference ECU model for SILS *(ref: #281/Ch1/sect7)*

3.6 Operation check of HV model for approval *(ref: #281/Ch1/sect8)*

3.7 Construction of interface *(ref: #281/Ch1/sect9)*

3.8 Input parameters *(ref: #281/Ch1/sect10)*

3.1. Software/Models to be used

The **software/**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**~~ **is also used in** the simulated running using the HILS system, as well as a specific interpolation procedure (e.g. Hermite procedure, or other suggestions (VECTO?); may need comparison first) to be used when creating table data of the input parameters, etc. ~~**The models to be used are listed below:**~~

~~**• Standard parallel HEV model (section 3.5.)**~~

~~**• Standard series HEV model (section 3.6.)**~~

The software to be used is listed below:

- **HDH HILS library (section 3.4)**
- **Hermite interpolation program (to be described in an Appendix?)**

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 vehicle shall be used for the HIL simulation. In case the functionalities of the hybrid system are performed by multiple controllers, those controllers may be integrated via interface or software emulation. However, the key hybrid functionalities shall be available in the hardware controller(s).

3.3.1. Key hybrid functionalities

To be defined by HDH IWG

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.

NOTE: The following sections are copied from document HDH-DG-02-04 provided by Japan. They cover parallel hybrids, only. The sections and diagrams need to be updated based on input from the institutes. The provisions for serial hybrids will be added later.

3.5. Parallel HEV model

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

The parallel HEV model consists of the engine model, electric motor model, rechargeable energy storage system (RESS) model, and a driving model. The engine model calculates the engine torque from engine control signals such as the engine torque command, the motor model calculates the electric motor torque from electric motor control signals such as the electric motor torque command, and the RESS model calculates the RESS voltage from the electric motor current generated by the motor. The driving model determines rotational frequencies of shafts such as vehicle speed using the calculated engine and motor torques, and clutch stroke and gear shift position signals from ECU.

The parallel HEV model consists of three sub-systems: the engine model that calculates the engine torque, the electric motor model calculating the electric motor torque and current, the RESS model calculating the RESS voltage, and the driving model calculating the rotational frequencies of shafts such as vehicle speed. Section 3.5.1 describes the engine model, Section 3.5.2 the electric motor model, Section 3.5.3 the RESS model, and Section 3.5.4 the driving model.

3.5.1. Engine model

The engine model calculates the output torque of the engine from the engine torque command values, throttle valve opening or injection amount command values, and the torque map in relation to the engine rotational frequency. Then, it adds up the output torque of the engine, the starter toque, and the external torque loaded on the engine. Upon receiving the rotational frequency control or limit demand from the actual ECU, the PID control function inside the engine model controls the engine rotational frequency. The engine is stopped by the input of the Ignition OFF or Fuel Cut ON signal. A conceptual diagram of the engine model is shown in Figure 1

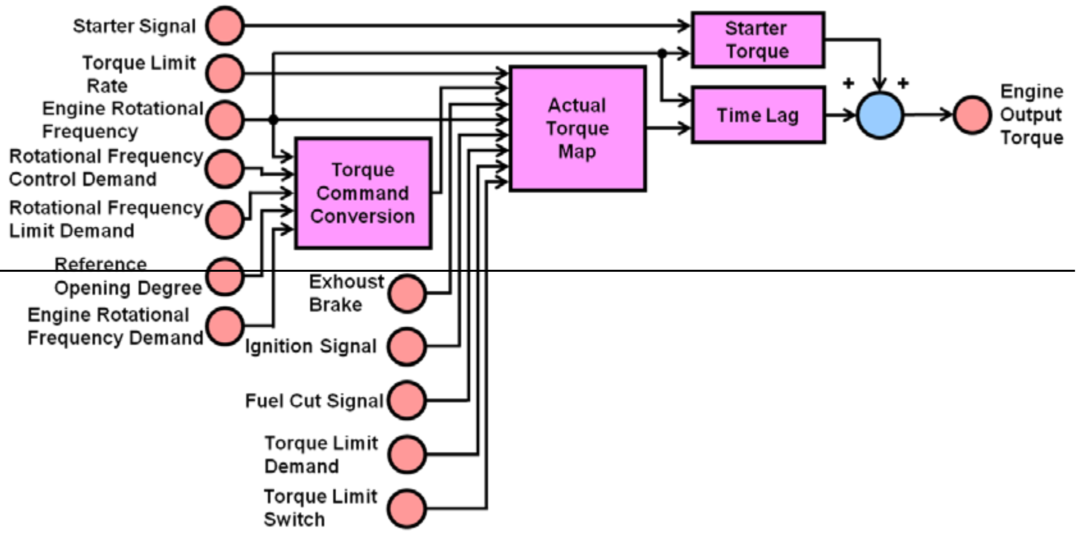


Figure 1: Diagram of engine model

3.5.2. Electric motor model

The electric motor model calculates the actual torque from the actual torque map developed from the toque command values from the ECU, the motor rotational frequency, and the measured RESS voltage values. Upon receiving the rotational frequency control demand from the ECU, it controls the motor rotational frequency using the control input calculated by the PI control as torque command. When the motor clutch is engaged, the motor rotational frequency is synchronized accordingly. A conceptual diagram of the electric motor model is shown in Figure 2.

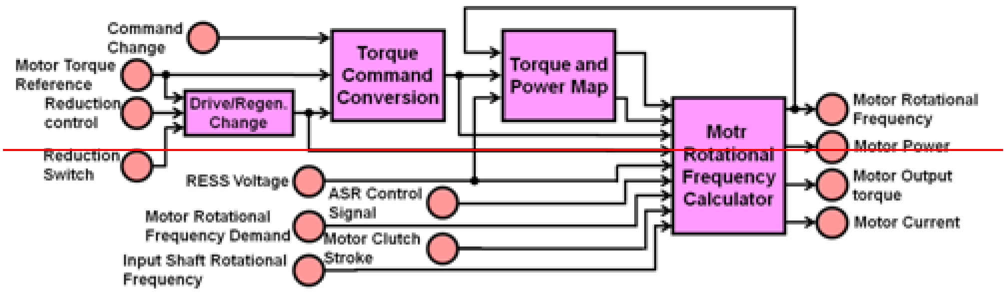


Figure 2: Diagram of electric motor model

3.5.3. Rechargeable Energy Storage System Model (TO BE CHECKED WITH SAE 1711 or is SAE 2711 meant?)

The rechargeable energy storage system (RESS) model calculates the RESS current by summing the input motor current and the auxiliary current calculated from the input of the RESS voltage to the map, and then determines the capacitor voltage and SOC, and the battery voltage and SOC using the RESS current. Depending on the vehicle model, either the output of the capacitor or that of the battery is used as the output of the RESS.

The model consists of two sub-systems: the capacitor model that calculates the capacitor voltage and SOC, and the battery model that calculates the battery voltage and SOC. Section 3.5.3.1 and 3.5.3.2 describe these two models. A conceptual diagram of the rechargeable energy storage system model is shown in Figure 3.

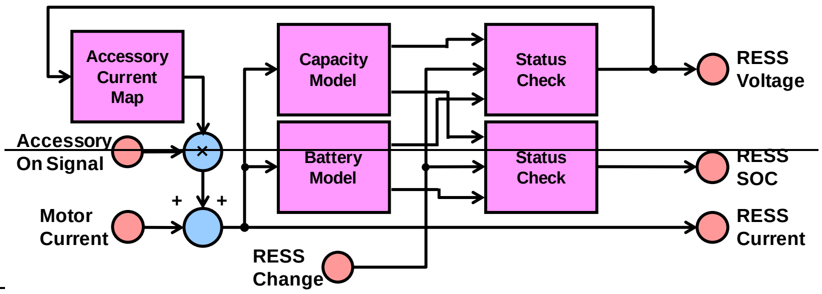


Figure 3: Diagram of the RESS model

3.5.3.1. Battery model

SOC and the charging/discharging power of the nickel hydride or lithium ion battery are calculated with the following equations (6) and (7); where SOC is calculated by current integration on the assumption that the Coulomb efficiency is 100%. Since the open voltage and internal resistance of the battery change with SOC, they should be calculated from their respective maps in relation to SOC. A conceptual diagram of the battery model is shown in Figure 4.

$$SOC = SOC_{initial} - \int_0^t \frac{I}{C_{nominal} \times 3600} \times 100 \quad \cdots \quad (6)$$

$$P = V_S I = (V_o - R_i I) I \quad \cdots\cdots\cdots\cdots \quad (7)$$

I : Motor current [A]

V_o : Battery open voltage [V]

V_S : Battery terminal voltage [V]

P : Battery power [W]

R_i : Internal resistance [Ω]

SOC : Battery SOC [%]

SOC_{initial} : Initial SOC [%]

$C_{nominal}$: Rated capacity [Ah]

t : Elapsed time [sec]

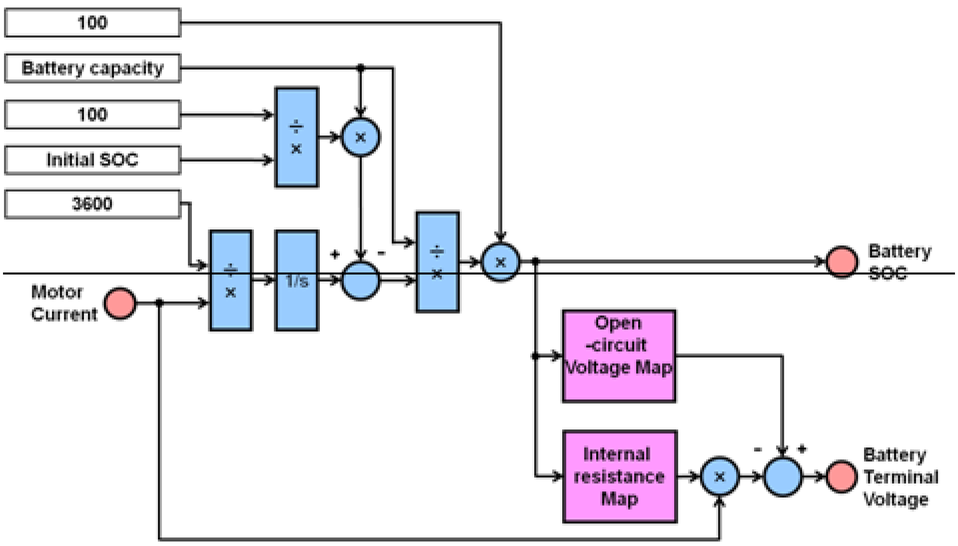


Figure 4: Diagram of the battery model

3.5.3.2. Capacitor model (TO BE CHECKED WITH SAE 1711 or is SAE 2711 meant?))

The terminal voltage and the state of charge (SOC) of the capacitor are calculated with the following equations: First, the charge of the capacitor is calculated by subtracting the electric current integrated value from the initial charge with equation (1). Then the resulting charge is divided by the nominal capacity to calculate the open voltage with equation (2). Finally with equations (3), (4) and (5), the terminal voltage and SOC are calculated using the open voltage. A conceptual diagram of the capacitor model is shown in Figure 5.

$$Q = \frac{C_{nominal} V_{\max}}{10}\sqrt{SOC_{initial}} - \frac{1}{s} I \quad \cdots\cdots (1)$$

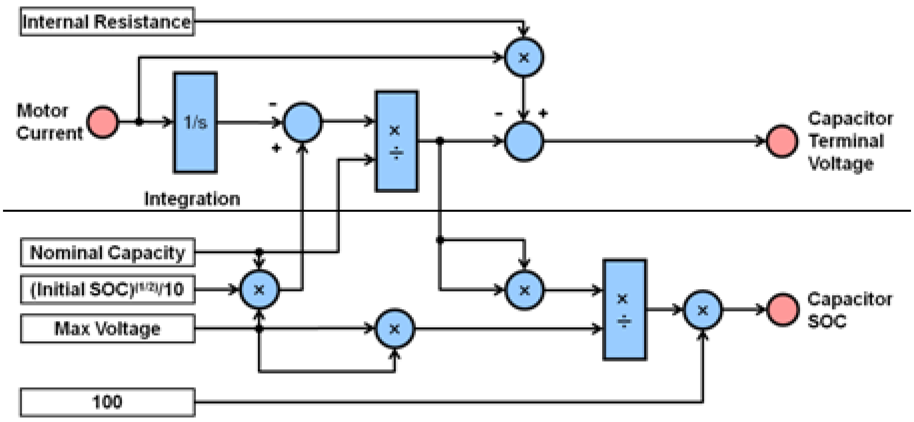
$$V_O = \frac{Q}{C_{nominal}} = \frac{V_{\max}}{10}\sqrt{SOC_{initial}} - \frac{1}{C_{nominal}}\frac{1}{s} I \quad \cdots\cdots (2)$$

$$V_S = V_O - R_i I = \frac{V_{\max}}{10}\sqrt{SOC_{initial}} - \frac{1}{C_{nominal}}\frac{1}{s} I - R_i I \quad \cdots\cdots (3)$$

$$P = V_S I \quad \cdots\cdots (4)$$

$$SOC = \frac{P}{P_{\max}} 100 = \frac{C_{nominal} V^2/2}{C_{nominal} V_{\max}^2/2} 100 = \frac{V^2}{V_{\max}^2} 100 = 100\left(\frac{V_{\max}}{10}\sqrt{SOC_{initial}} - \frac{1}{C_{nominal}}\frac{1}{s} I\right)^2 \Big/ V_{\max}^2 \quad \cdots (5)$$

I : Motor current [A]
V_S : Capacitor terminal voltage [V]
V_O : Capacitor open voltage [V]
V_{max} : Capacitor normal maximum voltage [V]
P : Capacitor power [W]
P_{max} : Maximum charging/discharging power [W]
SOC : Capacitor SOC [%]
$SOC_{initial}$: Capacitor initial SOC [%]
$C_{nominal}$: Capacitor nominal capacity [F]
Q : Charge [C]
R_i : Capacitor internal resistance [Ω]



~~Figure 5: Diagram of the capacitor model~~

~~3.5.3.3. Flywheel (exact location to be decided)~~

~~3.5.3.4. Hydraulic (exact location to be decided)~~

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.

NOTE: Compare with new Japanese proposal in HDH-DG-02-04, section 5. Further inout from institutes needed.

3.5.4.1. Running resistance model

This model calculates the running resistance, R, opposing vehicle movement that include rolling resistance, R_r, aerodynamic drag, R_a, and grading resistance, R_g, using the following formula:

$$R = R_r + R_g + R_a$$

Rolling resistance [N]:

$$R_r = f_r mg \cos\theta$$

where f_r is the rolling resistance coefficient, which is dimensionless and θ is the road angle (°), m is the vehicle mass (kg) and g is the gravity acceleration (m/s^2)

Grading resistance [N]:

$$R_g = mg \sin\theta$$

Aerodynamic drag [N]:

$$R_a = \frac{1}{2}\rho C_D A_f V^2$$

where ρ is the density of air (kg/m^3), A_f is the frontal area (m^2), V is the velocity (m/s) and C_D is the drag coefficient, which is dimensionless.

Eq. to be added (input from J.M. Lopez)

3.5.4.2. Transmission model

The transmission model calculates the input shaft load torque from the input differential load torque, differential acceleration resistance, input shaft rotational acceleration, and transmission gear ratio according to the gear shift position, transmission efficiency and rotary inertia. It also calculates the output rotational frequency by integrating the output shaft rotational acceleration determined by the multiplication of the input shaft rotational acceleration and the gear ratio, and the input shaft rotational frequency by integrating the input shaft rotational acceleration. A conceptual diagram of the transmission model is shown in Figure 6.

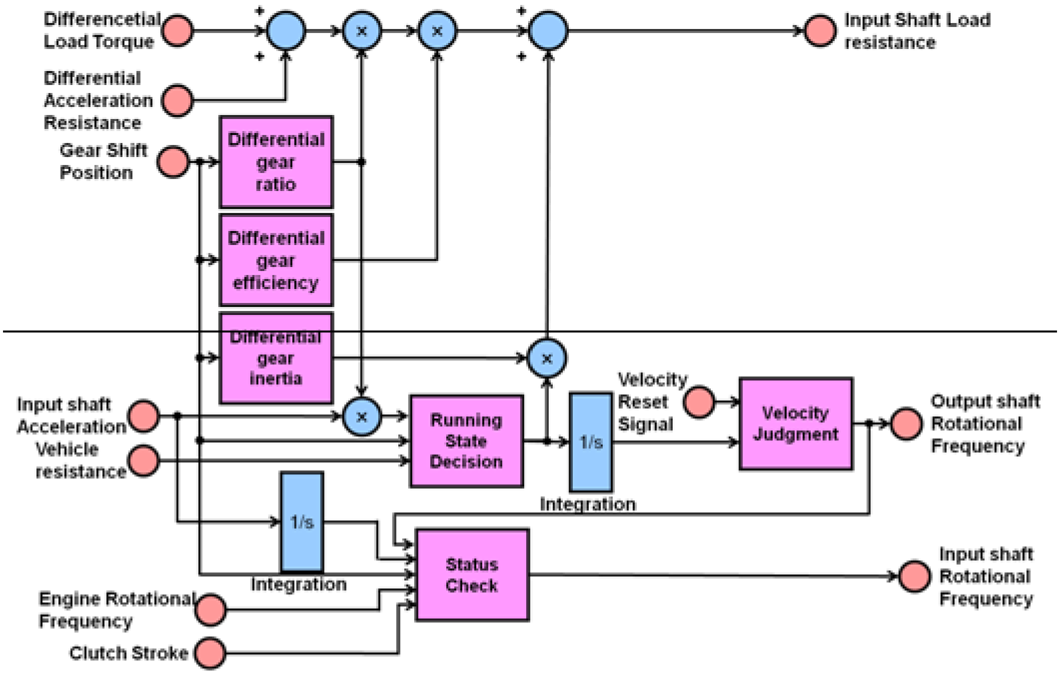


Figure 5: Diagram of the transmission model

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.

NOTE: Compare with new Japanese proposal in HDH-DG-02-04, section 5.2.4.2. Further input from institutes needed. Consideration of VECTO model needed.

3.6. Serial HEV model

3.4 HV Model for Approval

The HV model for approval shall be created based on the HILS library component models as specified in Paragraphs 3.4.1 through 3.4.n below. Thereafter, the input parameters pertaining to individual HV shall be inputted and the parameters settings for the input/output shall be performed according to the system of HV vehicles.

Reference to HILS library model description and manual ??? [ref: VTP1 final report (appendix A and B) or update through VTP2 or alike ?]

3.4.1 …

3.4.n …

Section 3.5 ~~(3.7)~~ and 3.6 ~~(3.8)~~ target the operational check of provided HV models. Is it still required to prescribe the procedure for verifying the OEM build model (using HILS library components) or will this be captured by HILS verification/validation as in #281/Ch5?

3.5 ~~3.7.~~ Reference ECU Model for SILS

The reference ECU model for SILS is used for the purpose of operation check of the HV model for approval. The signals given from the reference ECU model for SILS to the HV 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 HV 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.

3.6 ~~3.8.~~ Operation check of standard ~~HEV~~ HV Model

Following section may no longer apply as "standard HEV model", i.e. PHEV and SHEV, are no longer valid for HDH HILS library. Building of nHV model, ECU reference model (not needed?) and interface are all responsibility of OEM. Can interface parameter performance still be defined (interface signals are predefined/fixed when using HILS library)? In 281/Ch4/8-1-1 (intended for Annex8/sect5.8.1.1), the operational check for a (standard/default) HILS system is described to verify HILS system calculations and results/output are within the defined tolerances.

The operation check of the HV 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 HV model for approval, and control the HV 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 HV model for approval.

3.7 ~~3.9.~~ 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.

3.8. Input parameters

Input parameters for the HV model HILS library components shall be subjected to the applicable Paragraphs below.

3.8.1. Engine torque characteristics

The parameters for the engine torque characteristics shall be the table data obtained in ~~*Paragraph 3 "Test procedure for Engine" of Chapter 2*~~ section 4.2. However, values equivalent to or lower than the minimum engine revolution speed may be added. In addition, the engine model accessory torque map shall not be used at the time of the approval test.

3.8.2. Electric motor torque – electric power consumption characteristics

The parameters for the electric motor torque and electric power consumption characteristics shall be the table data obtained in ~~*Paragraph 4 "Test procedure for Electric Motor" of Chapter 2*~~ section 4.3. However, characteristic values at a revolution speed of 0 rpm may be added.

3.8.3. Battery

3.8.3.1. Resistor based model

The parameter for the internal resistance – open voltage of the electric storage device shall be the table data obtained in ~~*Paragraph 5 "Test procedure for Electric Storage Device" of Chapter 2*~~ section 4.4.1.

3.8.3.2. RC-circuit based model

The parameters for the RC-circuit battery model shall be the data obtained in section 4.4.2.

3.8.4 Transmission efficiency

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

(2) The transmission efficiency of the final reduction gear shall be 0.95.

3.8.5 Rolling and air drag resistance coefficients

The rolling resistance and air drag coefficient shall be calculated by the following formulas:

$$\mu_r = 0.00513 + \frac{17.6}{W}$$

$$\mu_a A = 0.00299 B \cdot H - 0.000832$$

where:

μ_r	:	Rolling resistance coefficient	(kg/kg)
$\mu_a A$	:	Air resistance coefficient × frontal projected area	$(kg/(km/h)^2)$
W	:	Vehicle mass at time of test	(kg)
		In the case of a truck, etc.: {Vehicle kerb mass + maximum loading capacity / 2 + 55}	(kg)
		In the case of a route bus or general bus: {Vehicle kerb mass + riding capacity × 55 / 2}	(kg)
		In the case of a tractor: {Vehicle kerb mass (tractor + trailer) + maximum loading capacity / 2 + 55}	(kg)
B	:	Overall width	(m)
H	:	Overall height	(m)

VTP1 comment:

- **Values obtained using these formulas need to be proofed against representativeness for heavy-duty vehicles.**
- **50% payload used**
- **55kg assumed as average mass of person (driver, passengers)**
- **Vehicle applications are distinguished**

Questions:

- **Are these relations derived from experimental/statistical evaluations ?**
- **What is validity for these relations ?**
- **Can these be determined from coast down experiments?**
- **Other alternatives for specification (tire testing, wind tunnel, …)?**
- **What is considered (sufficiently) representative and can be witnessed?**

3.8.6 Inertia moment of rotating section

Different inertia moment of the rotating sections shall be used for respective conditions for the HILS verification test pursuant to Chapter 5 and for the approval test, as specified below:

(1) At the time of the HILS verification test: the inertia moment of each rotating section shall be in accordance with the provisions of the test procedures provided for in *Paragraph 4-1 "Test procedure" of Chapter 5*.

VTP1 report: originates from conventional procedure (No.280); not needed for HDH vehicles as CAN signals from the vehicle control area allowed to calculate work delivered. (1) can be removed.

(2) At the time of approval test: the inertia moment of the section from the gear on the driven side of the transmission to the tyres shall be set in such a way that the mass equivalent to this rotating section becomes 7% of the vehicle kerb mass. The inertia moment of the section from the engine to the gear on the driving side of the transmission shall be the design value.

VTP1 report: value of 7% needs to be discussed and proven valid (seems very low for first gears of HD transmissions) for all hybrid topologies.

3.8.7 Maximum transmitted torque

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

~~**3.8.8 Torsional stiffness and attenuation coefficient**~~

~~**3.8.9 Engine model response delay block**~~

3.8.8 Gear change period

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

3.8.9 Gear change method

Gear positions at the start, acceleration and deceleration during the approval test shall be respective gear positions specified below according to the types of HV enumerated below:

(1) **Parallel (only?)** HV fitted with a manual shift transmission: gear positions as pursuant to the provisions of the calculation method applied in the European fuel consumption tool for conventional vehicles (VECTO).

(2) **Parallel (only**?) HV fitted with automated shift transmission (AMT) or automatic gear box (AT) with torque converter: gear positions according to the shift strategy of the actual transmission ECU control. However, the gear positions specified in (1) may be used.

(3) Series (only?) HV are assumed not to be equipped with any type of shift transmission, but can/should this be excluded or foreseen ? Low / high gear for city/highway operation or low/high speed manoeuvrability (can possibly be driver selected or automated/electronically controlled).

(4) Other HV topologies that need to be foreseen?

4. Test procedures for Energy Converter(s) and Storage Device(s) *(ref: No.281/Ch2)*

Following outline is suggested following No.281:

4.1. Scope

Definitions (not needed ?)

4.2. Internal Combustion Engine

4.3. Electric Motor / Generator

4.4. Battery

4.n. OTHER FORESEEN COMPONENTS ?

4.1. Scope

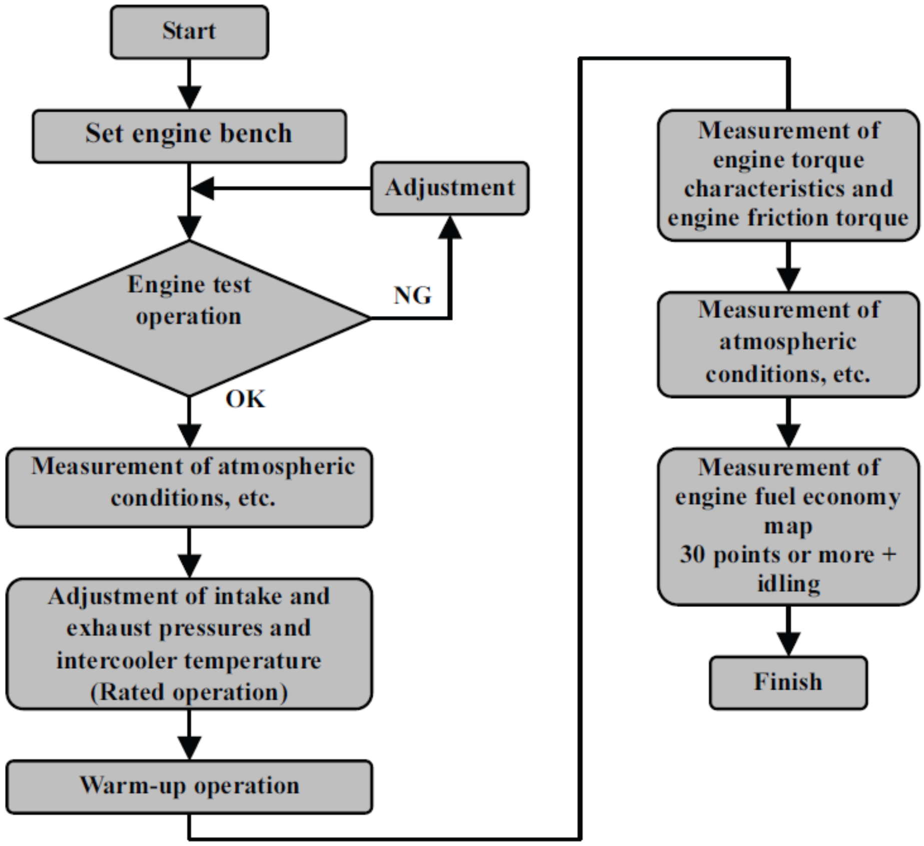
The procedures described below define testing protocols for obtaining parameters for the HILS system components that is used for the calculation of the engine operating conditions using the HV model.

Moreover, with respect to (internal combustion) engines, electric motors and storage devices of heavy-duty hybrid vehicles which cannot be tested according to this provision, provisions shall be laid down separately, as required, at the stage when motor vehicles equipped with the said devices are available for use.

4.2. Internal Combustion Engine

As the input parameters for the HILS system the engine torque characteristics, the engine friction loss, auxiliary brake, and engine fuel economy map shall be determined. The test method shall be as prescribed and schematically shown below **(remains scheme fully representative?)**:

1. Test Procedure for Engine Torque Characteristics • Fuel Economy Map for HILS System



4.2.1. Test engine

The test engine shall be in accordance with the provision of **~~Paragraph 4 "Test Engine" of the Measurement Procedure for Exhaust Emissions from Heavy-Duty Motor Vehicles~~** section 5.3.4**. (choice of hybrid parent engine)**.

4.2.2. Fuel

The test fuel shall be in accordance with the provision of Annex 4, section 6.9.

4.2.3. Accuracy, calibration, and so on, of measuring devices

The engine dynamometer, etc. shall be in accordance with the provision of Annex 4, section 9.

4.2.4. Test room and atmospheric conditions related to test

The test room and atmospheric conditions related to the test during the measurements of the engine torque characteristics provided for in Annex 4, section .

4.2.5. Measurement of engine torque characteristics

The engine torque characteristics of the test engine shall be obtained by the method provided for in Paragraphs 4.2.5.1 and 4.2.5.2 below:

4.2.5.1. Range of engine revolution speed for measurement

The range of engine revolution speed for measuring the engine torque characteristics shall be from the minimum engine revolution speed to the maximum engine revolution speed given below:

(1) The minimum engine revolution speed shall be the idling revolution speed of the engine in a warmed-up state.

(2) The maximum revolution speed shall be as follows:

1 In the case of engines without a governor, the maximum engine revolution speed shall be equal to or more than either 105 % of the revolution speed at which the maximum output was measured or the engine revolution speed exceeding the engine revolution speed at which the maximum output was measured and at which a drop of 3 % in relation to the said output took place, whichever is smaller.

2 In the case of engines with a governor, the maximum revolution speed shall be equal to or more than either the unloaded maximum revolution speed that was measured or the engine revolution speed at which the engine torque drops to zero in the condition where the engine torque command value and other command values related to the engine torque (hereinafter referred to as the “engine command values”) such as the throttle valve opening angle and fuel injection amount are full-open, whichever is smaller.

4.2.5.2. Measurement of engine torque characteristics

The engine torque characteristics in relation to the engine command values shall be measured after the test engine has been thoroughly warmed up until the coolant temperature, lubricant temperature and lubricant pressure stabilize. The measurement shall be carried out according to the following method:

(1) The engine torque shall be measured, after confirming that the shaft torque and revolution speed of the test engine have stayed around a constant value for one minute, by reading out the braking load or shaft torque of the engine dynamometer. If the test engine and the engine dynamometer are connected via a transmission, the read-out-value shall be divided by the transmission efficiency and gear ratio of the transmission.

(2) The engine revolution speed shall be measured by reading out the revolution speed of the crank shaft or the revolution speed of the engine dynamometer. If the test engine and the engine dynamometer are connected via a transmission, the read-out-value shall be multiplied by the gear ratio.

(3) The engine torque shall be measured under at least 80 conditions in total, for the engine revolution speed under 10 conditions within a range from the minimum engine revolution speed to the maximum engine revolution speed, and for the engine command values under 8 conditions within a range from the full-open to the full-close.

(4) In order to obtain the data of revolution speed at the same command values, all recorded data shall undergo the piecewise cubic Hermite (or other?) interpolation, and 100 or more table data shall be prepared in total, with 10 or more of the engine revolution speed and 10 or more of the engine command values. However, this provision shall not apply if Item (3) meets the condition of the said table data.

4.2.6. Measurement of engine friction torque

The friction torque of the test engine shall be measured by the method provided for in Paragraphs 4.2.6.1. and 4.2.6.2. below. Furthermore, this may be omitted if the measurement of the engine torque characteristics can simultaneously measure the engine friction torque.

4.2.6.1. Range of engine revolution speed for measurement

The range of engine revolution speed for measuring the friction torque of the engine shall be from the minimum engine revolution speed to the maximum engine revolution speed given below:

(1) The minimum engine revolution speed shall be the idling revolution speed of the engine in a warmed-up state.

(2) The maximum revolution speed shall be as follows:

1 In the case of engines without a governor, the maximum engine revolution speed shall be equal to or more than either 105 % of the revolution speed at which the maximum output was measured or the engine revolution speed exceeding the engine revolution speed at which the maximum output was measured and at which a drop of 3 % in relation to the said output took place, whichever is smaller.

2 In the case of engines with a governor, the maximum revolution speed shall be equal to or more than either the unloaded maximum revolution speed that was measured or the engine revolution speed at which the engine torque drops to zero in the condition where the engine command values are full-open, whichever is smaller.

4.2.6.2. Measurement of friction torque of engine

The measurement of the friction torque of the engine shall be performed, after the test engine has been thoroughly warmed up until the coolant temperature, lubricant temperature and lubricant pressure stabilize. The measurement shall be carried out by driving the test engine from the engine dynamometer and performing the measurement under at least 6 conditions within a range from the minimum engine revolution speed to the maximum engine revolution speed. Moreover, the friction torque when the auxiliary brake system such as an exhaust brake is operative shall be measured if that brake is needed in the HILS system in addition to the engine brake.

4.2.7. Measurement of engine fuel economy map

This section is not needed for pollutants related HILS, though may be needed when procedures for CO_2 are harmonized/use similar input data

The fuel economy map of the test engine shall be measured by the method provided for in Paragraphs 4.2.7.1. and 4.2.7.2.:

4.2.7.1. Range of engine revolution speed for measurement

The range of engine revolution speed for measuring the engine fuel economy map shall be from the minimum engine revolution speed to the maximum engine revolution speed given below:

(1) The minimum engine revolution speed shall be the idling revolution speed of the engine in a warmed-up state.

(2) The maximum revolution speed shall be as follows:

1 In the case of engines without a governor, the maximum engine revolution speed shall be equal to or more than either 105 % of the revolution speed at which the maximum output was measured or the engine revolution speed exceeding the engine revolution speed at which the maximum output was measured and at which a drop of 3 % in relation to the said output took place, whichever is smaller.

2 In the case of engines with a governor, the maximum revolution speed shall be the loaded maximum revolution speed.

4.2.7.2. Measurement of engine fuel economy map

The engine fuel economy map shall be measured, after the test engine has been thoroughly warmed up until the coolant temperature, lubricant temperature and lubricant pressure stabilize. The measurement shall be carried out according to the following method:

(1) After confirming that the shaft torque and revolution speed of the test engine have stayed around a constant value for one minute, read out the braking load or shaft torque of the engine dynamometer. If the test engine and engine dynamometer are connected via a transmission, divide the read-out-value by the transmission efficiency and the gear ratio of the transmission. In addition, the transitional period between the measurement points shall be approximately one minute.

(2) The engine revolution speed shall be measured by reading out the revolution speed of the crank shaft or the revolution speed of the engine dynamometer. Read out the indicated value if the measured value is within ±10 rpm in relation to the indicated value. In addition, when the measured value exceeds ±10 rpm, perform a resetting. If the test engine and engine dynamometer are connected via a transmission, the read-out-value shall be multiplied by the gear ratio.

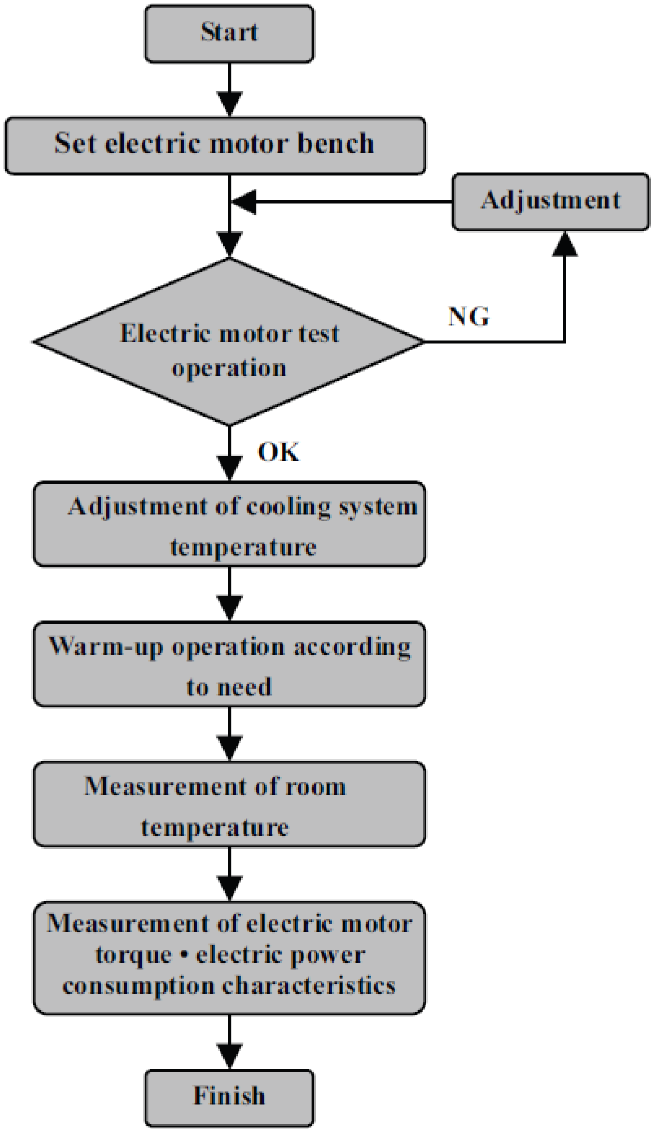
(3) The measurement of the amount of fuel consumption shall be carried out by measuring the flow rate of the fuel in term of volume or mass, which shall be, in principle, accumulated for at least 40 seconds. The measurement shall be conducted down to a unit of 0.0001 L or lower. The engine revolution speed shall be measured under at least 6 conditions including the maximum shaft torque engine revolution speed and maximum output engine revolution speed, within a range from 5 % normalizing engine revolution speed to the maximum engine revolution speed, and the shaft torque shall be measured under at least 5 conditions within a range from the torque equivalent to approximately 5 % load to the torque in the full-load operating condition. Therefore, the fuel flow rate shall be measured under a total of at least 30 conditions and at the minimum engine revolution speed. Moreover, the fuel flow rate shall be converted to the volume at the fuel temperature of 288 K (15 °C), using the Table 2B “Table Showing Coefficients for Volume Conversion in Relation to Temperature of Fuel and Oil” of Annexed Table II of JIS K 2249-1987. In addition, if any difficulty is encountered in controlling the engine revolution speed and torque due to the capabilities, etc. of the test facilities, the engine revolution speed and torque shall be set within a controllable range.

4.2.7.3. Additional/Optional measurements procedures
for e.g. warm-up, cold-start performance ???
Is anything required here because the models contain parameters for simulating this?

4.3. Electric Motor / Generator

As the input parameters for the HILS system, the torque map and electric power consumption map of the electric storage device (including those with a generator function. The same applies hereinbelow.) shall be determined. The test method shall be as prescribed and schematically shown below **(does scheme remain fully representative?)**:

2. Test Procedure for Electric Motor Torque • Electric Power Consumption Characteristics for HILS System



4.3.1. Test electric motor and controller

The test motor and controller shall be in the condition described below:

(1) The test motor and controller shall be serviced in accordance with the inspection and maintenance procedure, and thoroughly driven with the power absorber connected thereto.

(2) The power supply shall be a direct-current constant-voltage power supply or battery, which is capable of supplying sufficient electric power for the necessary input power to the controller at the maximum output of the electric motor.

(3) The voltage applied to the controller shall be ± 5 % of the nominal voltage of the electric storage device in a vehicle.

(4) If characteristics of the electric storage device change due to a large voltage variation in the voltage applied to the controller, the test shall be conducted by setting 3 conditions for the applied voltage: the maximum, minimum and medium in its control.

(5) The wiring between the electric motor and the controller shall be subjected to their in-vehicle specifications. However, if its in-vehicle layout is difficult, the wiring may be altered within a range not improving the electric motor performance. In addition, the wiring between the controller and the power supply need not be subjected to their in-vehicle specifications.

(6) The cooling system shall be subjected to its in-vehicle specifications. However, if its in-vehicle layout is difficult, the piping may be altered, or a cooling system exclusively used on a bench may be used, within a range not improving its cooling performance.

(7) No transmission shall be installed. However, in the case of an electric motor that cannot be driven if it is separated from the transmission due to the vehicle configuration, or an electric motor that has difficulty in being directly connected to the power absorber, a transmission may be installed. In such a case, a transmission whose gear ratio and transmission efficiency are clear shall be used.

4.3.2. Accuracy, calibration, and so on, of measuring devices

The applied equipment shall be in accordance with the provision of Annex 4, section 9. (for this Annex 4, section 9 needs to be expanded with hybrid measuring devices)

Measuring devices that have the following accuracies and have been checked, serviced and calibrated according to the predetermined handling procedures shall be used:

(1) The accuracy of the measuring device for the drive torque shall be ±1 % or less of the maximum torque of the test motor. The accuracy of the measuring device for the revolution speed shall be ± 0.5 % or less of the maximum revolution speed of the test motor.

(2) The measurement accuracy of the input power of the controller shall be ± 2 % or less of the maximum value of measured power.

(3) The accuracy of the voltmeter shall be ± 1 % or less of the maximum value of measured voltage, and the accuracy of the ammeter shall be ± 1 % or less of the maximum value of measured current.

(4) The accuracy of the thermometer shall be ± 1 K (1 ºC) for indoor types, and ± 2 K (2 ºC) for those other than indoor types.

4.3.3. Test room

The test shall be conducted at an appropriate place in the test room, taking into account the influence of direct sunlight, and of the radiant heat and exhaust heat from the electric motor and the controller.

4.3.4. Measurement of electric motor torque map

The test motor shall be driven according to the method in Paragraph 4.3.4.1, and the measurement shall be carried out in connection with the measurement items in Paragraph 4.3.4.2.

4.3.4.1. Driving method

The test motor shall be driven after the power absorber has been thoroughly warmed up under the warm-up operation conditions specified by the manufacturer.

(1) The output of the test motor shall be set under at least 6 conditions for the positive side and the negative side, respectively, within a range of the electric motor torque command values from the full-close (0 %) to the full-open (100 %).

(2) The test revolution speed shall be set within a range of ± 1 % or ± 10 rpm, whichever is larger, of the target revolution speeds that have been set under at least 6 conditions from the stopped state (0 rpm) to the maximum design revolution speed. Moreover, the torque may be measured at the minimum revolution speed for a stable operation of the power absorber if its measurement in the stopped state (0 rpm) is difficult.

(3) The driving shall be performed with the winding temperature and controller temperature during the test kept to the allowable values or lower. Furthermore, the motor may be driven with low-power or stopped for the purpose of cooling, as required

(4) The cooling system may be operated with its maximum cooling capacity.

4.3.4.2. Measurement items

(1) The shaft torque shall be measured, after confirming that the shaft torque and revolution speed of the test motor have been stabilized, by reading out the braking load or shaft torque of the power absorber. If the test motor and the power absorber are connected via a transmission, the read-out-value shall be divided by the transmission efficiency and the gear ratio of the transmission.

(2) The test revolution speed shall be measured by reading out the revolution speed of the test motor output shaft or the revolution speed of the dynamometer. However, if the test motor and the power absorber are connected via a transmission, it may be measured by reading out the revolution speed of the power absorber and multiplying the read-out-value by the gear ratio.

(3) The input power of the controller shall be measured with a wattmeter measuring the electric power as a multiplication of the voltage and current. However, it may be measured by multiplying the input voltage by the input current that are measured with a direct-current voltmeter and direct-current ammeter, respectively.

(4) In the operating condition prescribed in Paragraph 4.3.4.1., the winding temperature and temperature of each section of the controller shall be measured as reference values, simultaneously with the measurement of the shaft torque at each test revolution speed.

(5) The measurement method for the temperature at each section of the electric motor shall be the implanted thermometer method. The number of elements in the implanted thermometer shall be 3 to 6, which shall be appropriately distributed in circumferential direction, and implanted in axial direction at the sites where the temperature is expected to be the highest. However, if this method is difficult in terms of measurement, the thermometer method may be used.

(6) The ambient temperature shall be measured at the start and end of the test. The coolant temperature (in the case of liquid-cooling) shall be measured only at the start of the test.
VTP1 comment: seems to indicate coolant pre-conditioning before test start; it may be useful to define typical conditions like used in ECE R85 (paragraph 5.3.1.1) or Annex 4, section 6.7 (Cooling system with sufficient capacity).

4.3.5. Calculation formulas

The shaft output of the electric motor shall be calculated by means of the following formula:

$$P = \frac{2\pi \cdot T \cdot N}{60 \times 1000}$$

where:

P : Electric motor shaft output (kW)
T : Electric motor shaft torque (Nm)
N : Electric motor revolution speed (rpm)

4.4. Battery

VTP1 report: With the extension of the HILS model with a model for thermal behaviour of the electric storage there are two model versions for the electric storage device.
Questions:

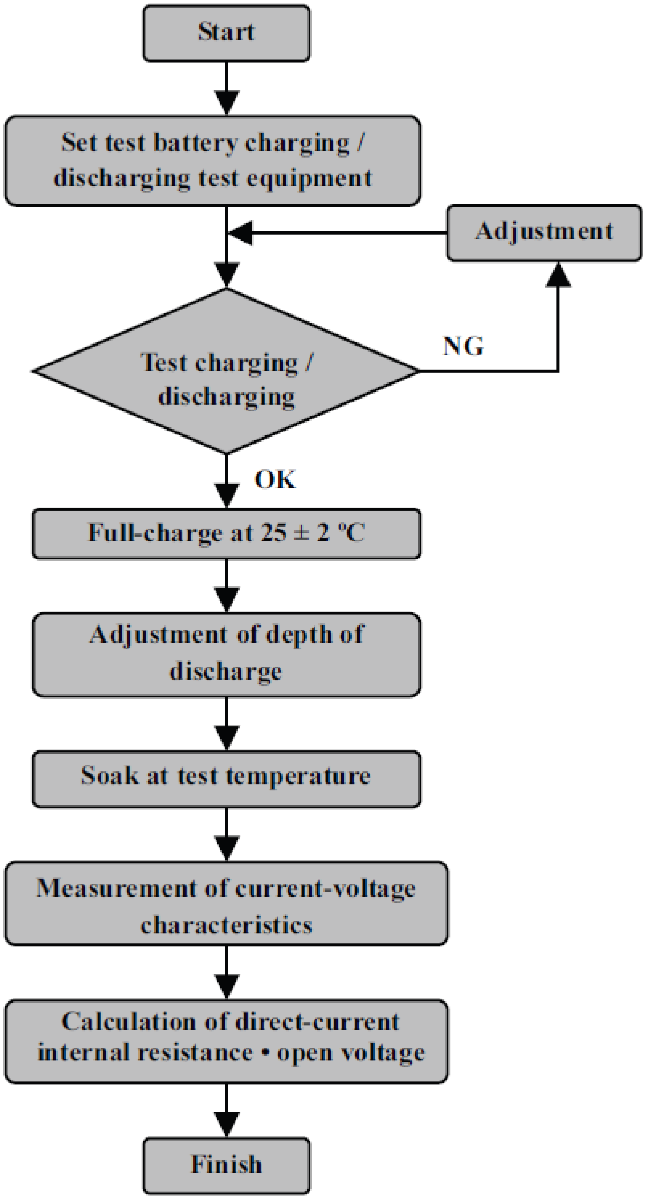
- **which model(s) is(are) to be maintained in the HILS library (simple resistor model or RC-circuit model incl. thermal) ?**
- **what test procedure for determining parameters to use?**

Included below:
4.4.1. Resistor based model as in No.281.
4.4.2. RC-circuit based model (VTP1)

4.4.1. Resistor based model test procedure for internal resistance - open voltage of nickel hydride battery and lithium-ion battery **(undesired restriction?)**

As the input parameters for the HILS system, the direct-current internal resistance - open voltage of the battery shall be obtained. The test method shall be as prescribed and schematically shown below **(does scheme remain valid?)**:

3. Test Procedure for Internal resistance • Open Voltage of Ni–MH / Li–ion Battery for HILS System



4.4.1.1. Test battery

The test battery shall be in the condition described below:

(1) The test battery shall be in in-vehicle condition, including unit batteries (module) or balancer, etc. If unit batteries are used for the test, the internal resistance - open voltage shall be calculated as follows:

• Inter-terminal internal resistance in in-vehicle condition = Inter-terminal internal resistance of a unit battery × number of unit batteries + connection resistance

• Inter-terminal voltage in in-vehicle condition = Inter-terminal voltage of a unit battery × number of unit batteries

Connection resistance: This refers to the resistance value to be added in in-vehicle condition, and the application value shall be used.

(2) As the test battery, one that has reached its rated capacity after repeating charging / discharging 5 times or less shall be used.

Rated capacity: The electric charge expressed in Cn (Ah) by the manufacturer. This is the electric quantity which can be released by the battery after fully charging it at an ambient temperature of 298 ± 2 K (25 ºC ± 2 ºC) according to the charging method specified by the manufacturer, then soaking it for 1 hour or more but not more than 4 hours under the said condition, and letting it discharge until it reaches the discharge termination condition which is, at 298 K (25 ºC) and with a constant current of In (A), 1.0 (V) per unit cell in the case of a nickel hydride battery, and a value specified by the manufacturer in the case of a lithium-ion battery.

$$I_n = \frac{C_n}{n}$$

Where

I_n : Standard charging / discharging current (A)
C_n : n-hour rate of rated capacity published by manufacturer of battery (Ah)
n : n=3 (h) in case of nickel hydride battery, and
n=1 (h) or n=3 (h) in case of lithium-ion battery

4.4.1.2. Accuracy, calibration, etc. of measuring devices

Measuring devices that have the following accuracies and have been checked, serviced and calibrated according to the predetermined handling procedures shall be used:

(1) The accuracy of the thermometer shall be ± 1 K (1 ºC) or less.

(2) The accuracy of the voltmeter shall be ± 1 % of the maximum value of measured voltage, and the accuracy of the ammeter shall be ± 1 % of the maximum value of measured current.

4.4.1.3. Test conditions

(1) The battery test environment shall be a place that is not influenced by direct sunlight from outside and by the radiant heat from other devices.

(2) The voltage shall be measured between the terminals of the unit battery or the terminals in the in-vehicle condition.

(3) The temperature measurement shall follow the method specified by the manufacturer. Or it shall be performed, as shown in Figures 1 and 2 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.

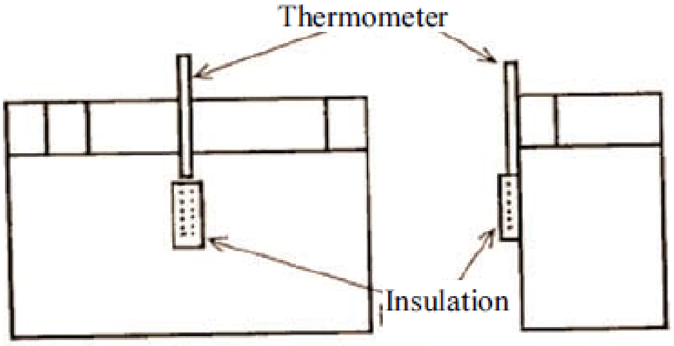


Fig. 1 Temperature Measurement Method for Rectangular Battery

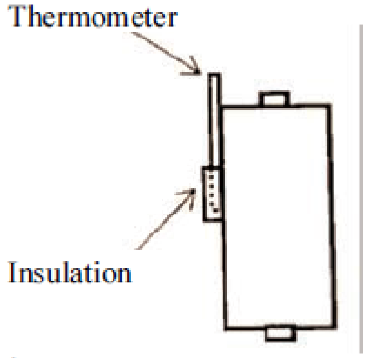


Fig. 2 Temperature Measurement Method for Cylindrical Battery

4.4.1.4 Current–voltage characteristic test

In this test, the voltage at the 10th second of discharging and charging with a constant current shall be measured by procedure given below:

(1) The test shall be conducted by changing the depth of discharge (100 % – state of charge %) within the range used for the **~~JE05 mode~~ WHVC**. The depth of discharge shall be level 3 or more, and shall be set in such a way as to allow for interpolation.

(2) As for the depth of discharge, after fully charging the battery at an ambient temperature of 298 ± 2 K (25 ºC ± 2 ºC) according to the charging method specified by the manufacturer, it shall be soaked under the same condition. The adjustment shall be started 1 hour or more but not more than 4 hours thereafter. The adjustment shall be performed by changing the discharge time with a constant current In (A). The depth of discharge (a %) is the state after discharging the battery at In (A) for (0.01 × a × n) hours. However, adjustment may be made by using the immediately preceding actually-measured battery capacity to calculate the discharge time for obtaining the targeted depth of discharge. Furthermore, if, after the completion of the current–voltage characteristic test at the first depth of discharge, an adjustment to the next depth of discharge is continuously performed, the adjustment may be made by calculating the discharge time from the present depth of discharge and the next depth of discharge.

(3) The battery temperature at the start of the test shall be 298 ± 2 K (25 ºC ± 2 ºC). However, 318 ± 2 K (45 ºC ± 2 ºC) may be selected by reporting in the application the actually-measured battery temperature at the time of the **~~JE-05 mode (city running mode)~~ WHVC** driving equivalent to the in-vehicle condition.

(4) After adjusting the depth of discharge, soak the battery at the prescribed battery temperature at the start of the test. The test shall be started 1 hour or more but not more than 4 hours thereafter, and 16 hours or more but not more than 24 hours thereafter in the case of 45ºC.

(5) The test shall be conducted according to the sequence shown in Fig.3:

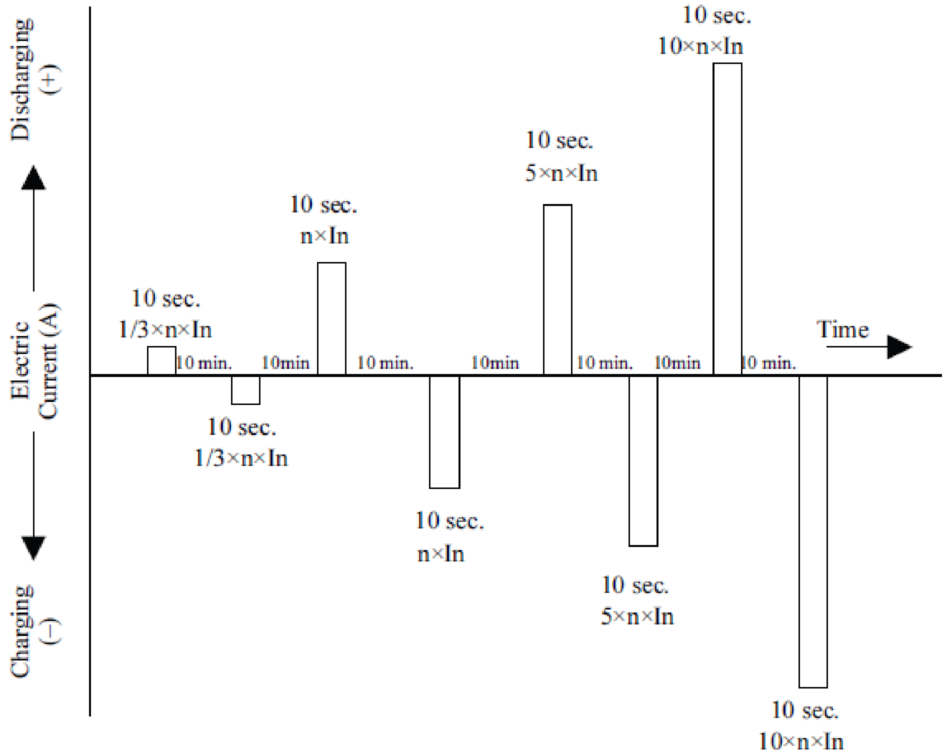


Fig. 3 Test Sequence of Current–Voltage Characteristic Test (Example: When rated capacity is less than 20 Ah)

(6) The battery voltage at the 10th second shall be measured by discharging and charging at each current specified for each category of the rated capacity posted in Table 1 below. The upper limit of the charging - discharging current shall be 200 (A). However, if the battery voltage at the 10th second exceeds the lower limit of discharging voltage or the upper limit of charging voltage, that measurement data shall be discarded.

Table 1 Charging • Discharging Current for Each Category of Rated Capacity

Category of rated capacity	Charging • discharging current (A)			
Less than 20 Ah	1/3 × n × In	n × In	5 × n × In	10 × n × In
20 Ah or more	1/3 × n × In	n × In	2 × n × In	5 × n × In

(7) During the rest period, the battery shall be cooled off for at least 10 minutes. It shall be confirmed that the change of temperature is kept within + 2 ºC before moving onto the next discharging or charging.

4.4.1.5. Calculation of direct-current internal resistance and open voltage

Use the measurement data to calculate the current–voltage characteristics that can be determined from each charging / discharging current (A) and their corresponding voltages ($V_{d1} - V_{d4}$), ($V_{c1} - V_{c4}$) by means of the least-square method. From Figure 4, calculate the absolute value of the slope (direct-current inner pressure on the output side R_d) and the intercept (open voltage on the output side V_{do}) of the regression line determined by means of the least-square method, and from Figure 5, determine the absolute value of the slope (direct-current inner pressure on the input side R_c) and the intercept (open voltage on the input side V_{co}) of the regression line determined by means of the least-square method.

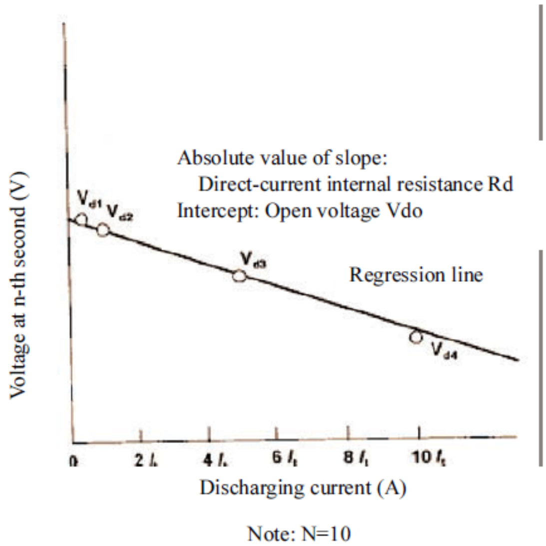


Fig. 4 How to Determine Internal Resistance and Open Voltage on Output Side

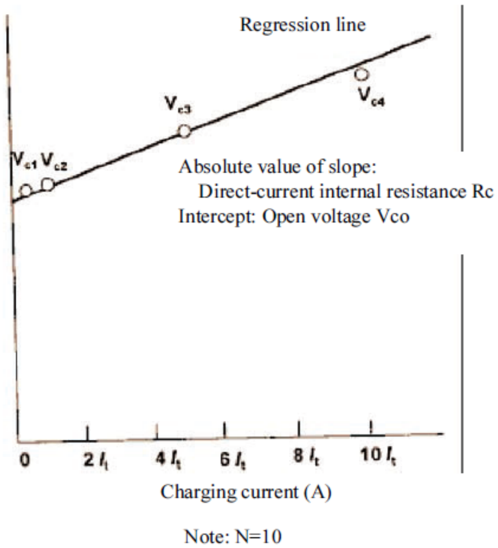
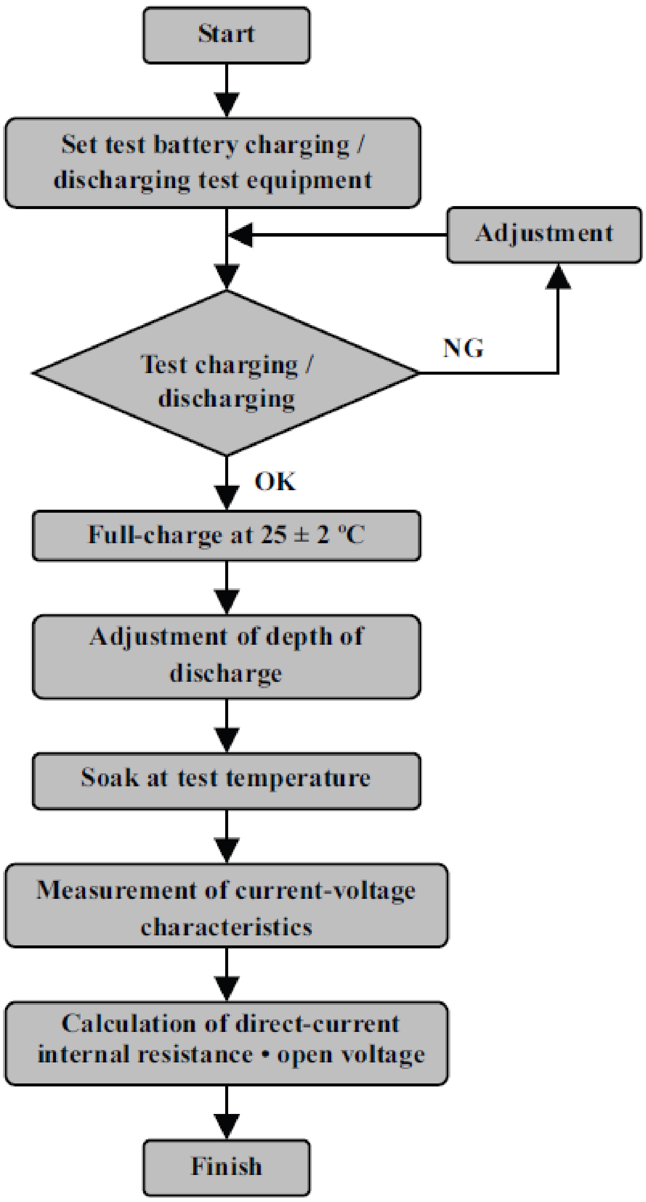


Fig. 5 How to Determine Internal Resistance and Open Voltage on Input Side

4.4.2. RC-based model **(VTP1 report)**

As the input parameters for the HILS system, the direct-current internal resistance - open voltage of the battery shall be obtained. The test method shall be as prescribed and schematically shown below **(does scheme remain valid?)**:

3. Test Procedure for Internal resistance • Open Voltage of Ni–MH / Li–ion Battery for HILS System



4.4.2.1. Test battery

The test battery shall be in the condition described below:

(1) The test battery shall be in in-vehicle condition, including unit batteries (module) or balancer, etc. If unit batteries are used for the test, the internal resistance - open voltage shall be calculated as follows:

• Inter-terminal internal resistance in in-vehicle condition = Inter-terminal internal resistance of a unit battery × number of unit batteries + connection resistance

• Inter-terminal voltage in in-vehicle condition = Inter-terminal voltage of a unit battery × number of unit batteries

Connection resistance: This refers to the resistance value to be added in in-vehicle condition, and the application value shall be used.

(2) As the test battery, one that has reached its rated capacity after repeating charging / discharging 5 times or less shall be used.

Rated capacity: The electric charge expressed in Cn (Ah) by the manufacturer. This is the electric quantity which can be released by the battery after fully charging it at an ambient temperature of 298 ± 2 K (25 ºC ± 2 ºC) according to the charging method specified by the manufacturer, then soaking it for 1 hour or more but not more than 4 hours under the said condition, and letting it discharge until it reaches the discharge termination condition which is, at 298 K (25 ºC) and with a constant current of In (A), 1.0 (V) per unit cell in the case of a nickel hydride battery, and a value specified by the manufacturer in the case of a lithium-ion battery.

$$I_n = \frac{C_n}{n}$$

Where

I_n : Standard charging / discharging current (A)
C_n : n-hour rate of rated capacity published by manufacturer of battery (Ah)
n : n=3 (h) in case of nickel hydride battery, and
n=1 (h) or n=3 (h) in case of lithium-ion battery

4.4.2.2. Accuracy, calibration, etc. of measuring devices

Measuring devices that have the following accuracies and have been checked, serviced and calibrated according to the predetermined handling procedures shall be used:

Question: are these accuracies realistic / resolution not equal to accuracy?

(1) The accuracy of the thermometer shall be ± **1 K (1 ºC) or less and resolution <0.1K**.

(2) The accuracy of the voltmeter shall be ± ~~**1 % of the maximum value of measured voltage**~~ **0.1% of the displayed reading**, and the accuracy of the ammeter shall be ± ~~**1 % of the maximum value of measured current**~~ **0.3% of the displayed reading. Moreover, the resolution of the voltmeter must be large (or small?) enough to measure the voltage drop during the smallest current pulse.**

4.4.2.3. Test conditions

(1) The battery test environment shall be a place that is not influenced by direct sunlight from outside and by the radiant heat from other devices.

(2) The voltage shall be measured between the terminals of the unit battery or the terminals in the in-vehicle condition.

(3) The temperature measurement shall follow the method specified by the manufacturer. Or it shall be performed, as shown in Figures 1 and 2 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.

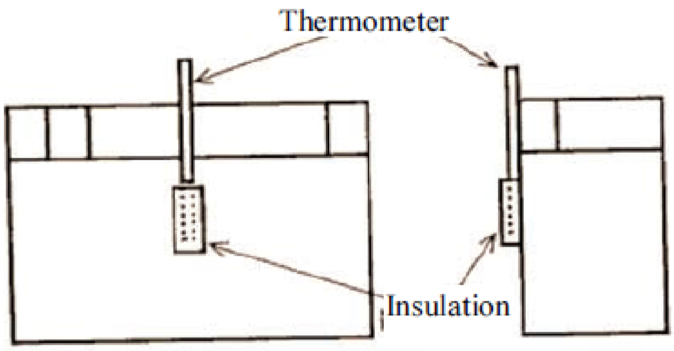


Fig. 1 Temperature Measurement Method for Rectangular Battery

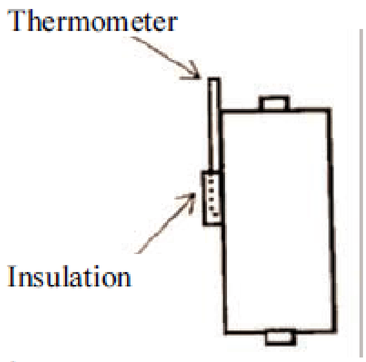


Fig. 2 Temperature Measurement Method for Cylindrical Battery

4.4.2.4 Current–voltage characteristic test

In this test, the voltage at the 10th second of discharging and charging with a constant current shall be measured by procedure given below:

(1) The test shall be conducted by changing the depth of discharge (100 % – state of charge %) within the range used for the ~~**JE05-mode**~~ **WHVC**. The depth of discharge shall be level 3 or more, and shall be set in such a way as to allow for interpolation.

(2) As for the depth of discharge, after fully charging the battery at an ambient temperature of 298 ± 2 K (25 ºC ± 2 ºC) according to the charging method specified by the manufacturer, it shall be soaked under the same condition. The adjustment shall be started 1 hour or more but not more than 4 hours thereafter. The adjustment shall be performed by changing the discharge time with a constant current In (A). The depth of discharge (a %) is the state after discharging the battery at In (A) for (0.01 × a × n) hours. However, adjustment may be made by using the immediately preceding actually-measured battery capacity to calculate the discharge time for obtaining the targeted depth of discharge. Furthermore, if, after the completion of the current–voltage characteristic test at the first depth of discharge, an adjustment to the next depth of discharge is continuously performed, the adjustment may be made by calculating the discharge time from the present depth of discharge and the next depth of discharge.

(3) The battery temperature at the start of the test shall be 298 ± 2 K (25 ºC ± 2 ºC). However, 318 ± 2 K (45 ºC ± 2 ºC) may be selected by reporting in the application the actually-measured battery temperature at the time of the ~~**JE-05 mode (city running mode)**~~ **WHVC** driving equivalent to the in-vehicle condition.

(4) After adjusting the depth of discharge, soak the battery at the prescribed battery temperature at the start of the test. The test shall be started 1 hour or more but not more than 4 hours thereafter, and 16 hours or more but not more than 24 hours thereafter in the case of 45ºC.

(5) The test shall be conducted according to the sequence shown in Fig.3:
But with altered current (should this be reflect in (1) or (2) already, or only in the figure here?): The highest charge $\hat{I}_{charge}$ and discharge pulse amplitudes $\hat{I}_{discharge}$ shall be the maximum pulse amplitudes of the in-vehicle use of the storage. The smaller pulses shall be calculated from this maximum values by successively dividing it by a factor of three for three times (e.g. $\hat{I}_{charge}$ = 27A gives a sequence for the charge current pulses of 1, 3, 9 and 27A).

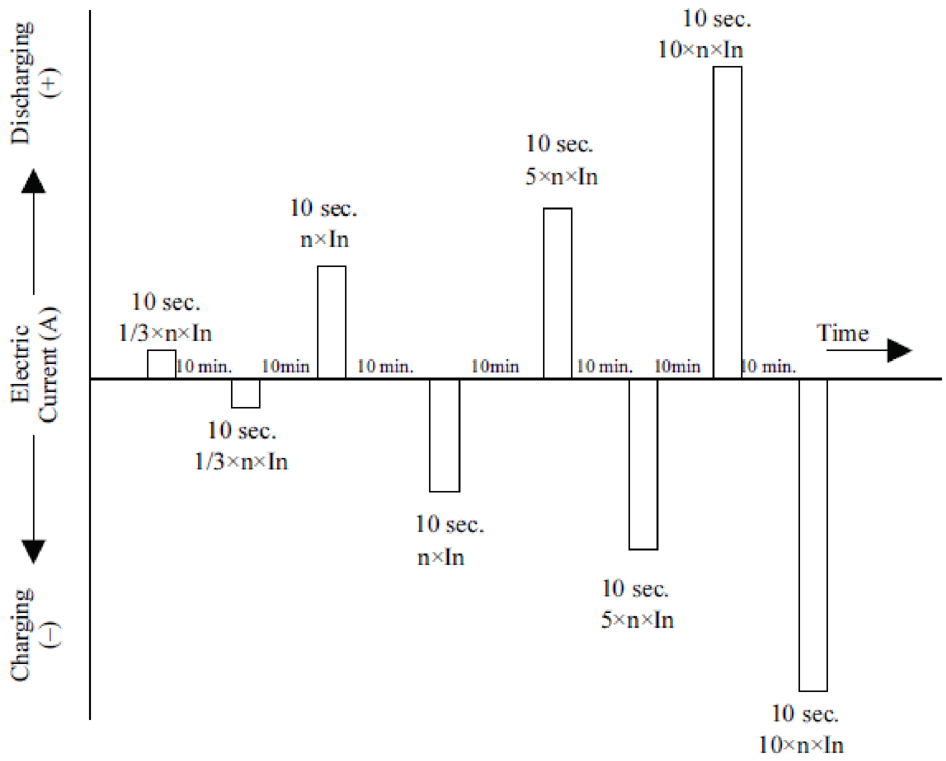


Fig. 3 Test Sequence of Current–Voltage Characteristic Test (Example: When rated capacity is less than 20 Ah)

(6) The battery voltage at the 10th second shall be measured by discharging and charging at each current specified for each category of the rated capacity posted in Table 1 below. The upper limit of the charging - discharging current shall be 200 (A). However, if the battery voltage at the 10th second exceeds the lower limit of discharging voltage or the upper limit of charging voltage, that measurement data shall be discarded.

Table 1 Charging • Discharging Current for Each Category of Rated Capacity

Category of rated capacity	Charging • discharging current (A)			
Less than 20 Ah	1/3 × n × In	n × In	5 × n × In	10 × n × In
20 Ah or more	1/3 × n × In	n × In	2 × n × In	5 × n × In

(7) During the rest period, the battery shall be cooled off for at least 10 minutes. It shall be confirmed that the change of temperature is kept within + 2 ºC before moving onto the next discharging or charging.

4.4.2.5. Calculation of direct-current internal resistance and open voltage

For each pulse with the pulse current I_{pulse} measure the ~~idle~~/open-circuit voltage before the pulse (V_{start} in Figure 4.1), and the voltage at 1, 5 and 9 seconds after the pulse has started (V1, V5 and V9).

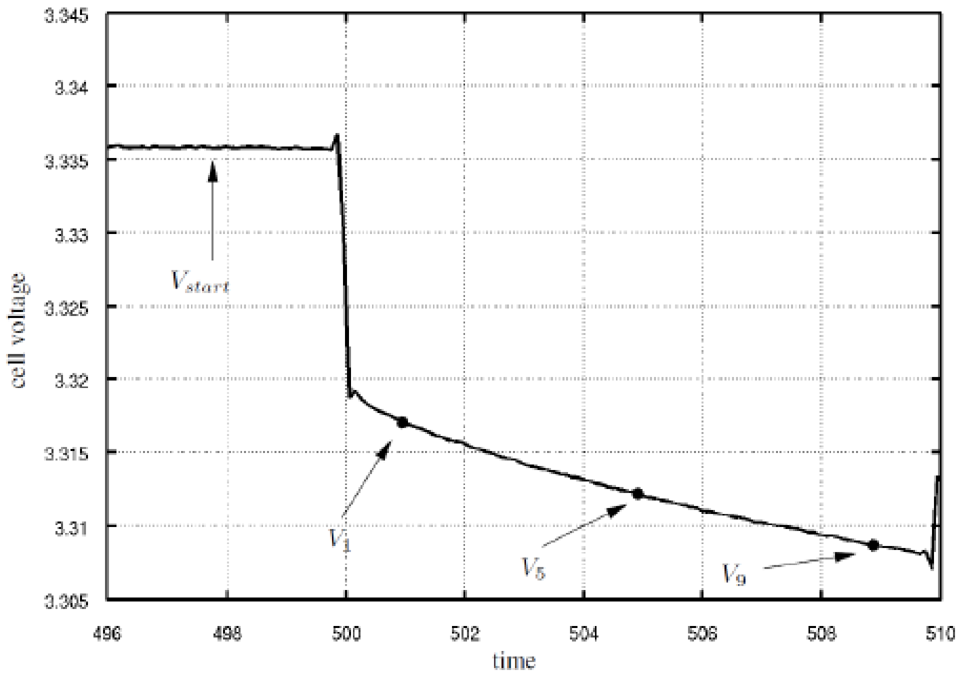


Figure 4.1: Example for a single voltage pulse during a discharge pulse

From this calculate:

$$V_\infty = \frac{V_1 \cdot V_9 - V_5^2}{V_1 - 2 \cdot V_5 + V_9}, \quad \tau = \frac{-4}{\ln(1 - (V_9 - V_5)/(V_\infty - V_5))}$$

Additionally for a charge pulse

$$K = -\tau \cdot \ln(1 - \frac{V_1}{V_\infty}), \quad V_0 = V_\infty \cdot (1 - e^{(1-K)/\tau})$$

Or a discharge pulse

$$V_0 = \frac{V_1 - V_\infty}{e^{-1/\tau}} + V_\infty$$

Now the values for $R_{0,pulse}$, R_{pulse} and C_{pulse} for a single pulse can be calculated as:

$$R_{0,pulse} = \frac{V_0 - V_{start}}{I_{pulse}}, \quad R_{pulse} = \frac{V_\infty - V_0}{I_{pulse}}, \quad C_{pulse} = \frac{\tau}{R}$$

Taking the mean values for all pulses leads to the desired values for R_0, R and C for the actual state of charge. The measurements shall be repeated for different values of the state of charge according to Annex 8, section 6. ~~***chapter 5, paragraph 5-1-4, sub item (1)***~~.

4.n. OTHER FORESEEN COMPONENTS ?

Will No.281/Ch3 on Fuel Consumption rate apply to this GTR?

~~3.11. Test procedure for exhaust emissions~~

5. Test procedure for exhaust emissions from heavy-duty hybrid vehicles

Following outline is suggested following No.281/Ch4:

5.1. Scope
5.2. Definitions
5.3. Test method for exhaust emissions from heavy-duty vehicles
5.4. Test engine
5.5. Test fuel
5.6. Measuring devices
5.7. Test room and atmospheric conditions related to test
5.8. Creation of exhaust gas measurement cycle
5.8.1. Conversion method to exhaust gas measurement cycle
5.8.1.1. Operation check of HILS system
5.8.1.2. Construction of HILS system and verification of compatibility
5.8.1.3. Calculation of exhaust gas measurement cycle by means of HILS system simulated running
5.8.1.4. Range of electricity balance for HILS system simulated running
5.8.2. Replacement of test torque value at time of motoring
5.9. Test procedure for exhaust emission from heavy-duty hybrid vehicles
5.9.1. Preparation prior to test
5.9.2. Running procedure for test engine
5.9.3. Verification of driving accuracy, and so on
5.9.3.1. Time correction of engine revolution speed and shaft torque
5.9.3.2. Calculation of integrated engine shaft output, and so on
5.9.3.2.1. Negative engine shaft torque
5.9.3.2.2. Range of integrated shaft output
5.9.3.3. Calculation of driving accuracy
5.9.3.4. Range of driving accuracy
5.10. Measurement of emission mass of CO, and so on, and PM
5.11. Calculation of integrated system shaft output

~~3.12. Verification test procedure~~

6. Verification test procedure for HILS system for heavy-duty hybrid vehicles

Following outline is suggested following No.281/Ch5:

6.1. Scope
6.2. Definitions
6.3. Cases requiring verification of HILS system
6.4. Actual vehicle test
6.4.1. Test procedure
6.4.2. Test conditions
6.4.3. Measurement items
6.5. HILS simulated running
6.5.1. Method for HILS simulated running
6.5.2. Test conditions
6.6. Comparison of actually measured values with HILS simulated running
6.6.1. Confirmation of correlation

6.6.2. Overall verification

6.6.2.1. Verification items and tolerances

6.6.2.2. Calculation method for verification items

6.6.2.3. Range of electricity balance

6.6.2.4. Conditions for verification by means of determination coefficient of engine torque

6.6.7. Others

Annex 9

REQUIREMENTS FOR POWERTRAIN INSTALLED IN HYBRID VEHICLES USING THE POWERTRAIN METHOD

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.