Power Determination GTR Version 21.11.2017

Style guidelines

- The *Concise Oxford English Dictionary* is the current authority for spelling in the United Nations. A United Nations spelling list supplements and indicates exceptions to the *Oxford English Dictionary*.
- The thousandths place in a number is indicated with a comma, e.g. four thousand five hundred and sixty seven milligrams is written as 4,567 milligrams.
- Numbers followed by a unit are written as a number and not as a word, i.e. 5 metres and not five meters.
- Numbering and formatting of section headings (e.g. 3.1.2, etc) should be established by using the appropriate Heading style. Refer to existing headings for examples.
- Numbering of tables and figures should be established by using the Word function "References: Insert caption"
- References to tables, figures, and section headings within the text should be established by using the Word function "References: Cross-reference"3

Tracking of open issues, expert input, and resolution

- All editing must be performed with Track Changes turned On.
- During early stages of drafting, Track Changes will be sufficient for tracking. However, the following convention was used in WLTP, and should be followed here in later stages of drafting:
  - Open issues for which comment is sought from experts should be flagged with a comment balloon and the text OPEN POINT and the date, followed by a description of the open point.
  - Expert contributions to an open point, or those independent of any specific open point, should similarly be marked EXPERT PROPOSAL.
  - Editorial changes should similarly be marked GTR CORRECTION
    - In the special case where a correction represents the final resolution of an open issue or expert proposal that requires approval by the IWG, it should be marked CONFIRMATION followed by the date and circumstances of its approval.
- If this convention is followed, all corrections, open points, and expert proposals may be found using the search function in Word.

Editorial changes since 1st meeting of Drafting Group, 21 November 2017

- Clause 7 restructured to separate discussion of TP1 and TP2.
- Equations in Annex A reformatted with Word equation editor.
- TP1 and TP2 added to definitions and abbreviations.
- Updated Figure 3 to show REESS instead of RESS
- Updated Figure 2 to remove extraneous green lines at border

Editorial changes since 2nd meeting of Drafting Group, 14 December 2017

- N/A

Editorial changes since EVE25, 8 January 2018 in Geneva

- Replaced "externally charged HEV" with "OVC-HEV" to align with definition in GTR No. 15 Amendment 3
- Revised definition of hybrid electric vehicle (HEV) to align with GTR No. 15 Amdt. 3
- Added definitions of terms cited in definition of HEV
- 5.1.3 cooling fan test condition replaced with analogous text from Annex 4 of GTR No 15 Amdt. 3 (6.5.1.6)
- 6.2.3 Chassis dynamometer warm-up replaced with analogous text from Annex 4 of GTR No 15 Amdt. 3 (7.2.2)
- Measurement item and accuracy – revised tolerances for electric voltage and electrical current to align with GTR No 15 Amdt. 3, Annex 8, Table A8/1
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Editorial changes since EVE26, 27-28 March 2018 in Tokyo

- Reworded 6.10 to more clearly describe option for manufacturer to specify a dynamometer speed or to identify the speed by testing.
- Revised 6.9.3.1 to refer to gearbox efficiency factors in Appendix, and modified equation to refer to the variable $\eta_{gearbox}$
- Under 2. Scope and Application, adopted Tripathy suggestion to adopt WLTP text, and also specified that it applies to PEVs with more than one propulsion motor.
- Added definitions of Pure Electric Vehicle and REESS from GTR No. 15 Amdt 3.
- In 6.5 Initial Charge of REESS, added suggested text to cover CS > CD (needs EVE review)
- In 6.5 Initial Charge of REESS, added suggested margin of within five percent of maximum SOC (needs EVE review)
- Replaced "motor" with "electric machine" which is the term used in GTR 15
- Significant rewording and clarification of 6.4 Preparation of Measurement Devices

Editorial changes since 4th meeting of Drafting Group, 24 April 2018

- Replaced "gtr" with "amendment to Global Technical Regulation No. 15".
- Added JAMA comments provided for 4th drafting group (DG) meeting 24 April 2018.
- Added definition of formula variables to abbreviations list (4.1)
- Replaced Ureess, etc with spelled-out versions in 6.4.1
- Modified 6.7 and 6.8.2 with temperature conditions from GTR 15
- Modified 5.1.2, pressure and humidity conditions of the test cell, to align with GTR 15
- Added humidity (5.1.2. and 5.2) to required measurement conditions, to align with GTR 15
- **Editorial changes since 4th meeting of Drafting Group, 24 April 2018**

Editorial changes since 5th meeting of Drafting Group, 7 May 2018

- Added language (6.7) from GTR 15 regarding dynamometer mode
- Modified 6.4.1 (Required measurement devices) to add fuel flow rate measurement for non-CI engines, to align with ISO FDIS 20762
- To title of document, added "pure electric vehicles having more than one electric machine for propulsion"
- Modified paragraph 5.2.1, Table 1, fuel flow rate line to include ICEs if the confirmation of fuel air ratio is necessary, to align with ISO FDIS 20762

- Modified 6.4.1, second passage, second sentence to specify "for 12V auxiliaries"
- Modified paragraph 6.8.2 (Vehicle conditioning) to clarify vehicle conditioning when performing measurement loop at different speeds, to align with ISO FDIS 20762
- Modified formula (b) in 6.9.2 to align with ISO FDIS 20762
- Modified formula for converted REESS power in 6.9.3.3 to align with ISO FDIS 20762
- Modified 7.2.2 (Fuel flow rate) exclusivity to CI engines to align with ISO FDIS 20762
- Added requirement in 7.2.3 to list $P_{auxiliaries}$ for the determination of converted REESS power
- Added paragraph to 5.2.2 on start and end recording of pressure and temperature to align with ISO FDIS 20762
- Added to 6.1, pure electric vehicles with more than one propulsion motor
- Added/deleted text in 6.1 to align with ISO FDIS 20762
- Miscellaneous edits to 6.4.1 to align with ISO FDIS 20762
- Added to 6.6 (Vehicle soak) a reference to soak conditions in 5.1.4
- Edits to 6.7 to align with ISO FDIS 20762
- Added to 6.8.4 (Vehicle operation) mention of driving mode switch, to align with ISO FDIS 20762, and other edits
- Renamed 6.8.5 (Pedal position) and other edits to align with ISO FDIS 20762
- Edits to 6.9.1 to align with ISO FDIS 20762
- Edits to 6.9.2 and 6.9.3.1 to align with ISO FDIS 20762
- Other miscellaneous edits to 6.9 and 7.1 to align with ISO FDIS 20762
- Updated Figure 3 per ISO FDIS 20762
- Updated Figure A.2 per ISO FDIS 20762 and minor edits to related formulas
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Item 3(b) of the provisional agenda
Light vehicles – Global Technical Regulation No. 15 on Worldwide harmonized Light vehicles Test Procedure (WLTP)

Proposal for determination of system power of hybrid vehicles or pure electric vehicles having more than one electric machine for propulsion for use with the Worldwide harmonized Light vehicles Test Procedure (WLTP)

Submitted by the Informal Working Group on Worldwide harmonized Light vehicles Test Procedure (WLTP)*

The text reproduced below was prepared by the Informal Working Group (IWG) on Worldwide harmonized Light vehicles Test Procedure (WLTP) in line with Phase 1B of its mandate (ECE/TRANS/WP.29/AC.3/39). A first draft of this proposal (GRPE-71-25 and GRPE-71-26) was introduced by the IWG on WLTP at the seventy-first session of GRPE (see report ECE/TRANS/WP.29/GRPE/71, paras. 14-16). The text is reproduced as a consolidated version.

* In accordance with the programme of work of the Inland Transport Committee for 2014–2018 (ECE/TRANS/240, para. 105 and ECE/TRANS/2014/26, programme activity 02.4), the World Forum will develop, harmonize and update Regulations in order to enhance the performance of vehicles. The present document is submitted in conformity with that mandate.

Draft proposal for determination of system power of hybrid vehicles or pure electric vehicles having more than one electric machine for propulsion

I. Statement of technical rationale and justification

A. Introduction

1. The WLTP test procedure requires information about the vehicle engine power rating to achieve certain purposes related to performing the test procedure. These purposes include classification of electrified vehicles into distinct Power-to-Mass ratio classes, based on the powertrain power rating; and application of the so-called "downscaling method" that enables the test reference cycles to be adapted for low powered vehicles, also based on the powertrain power rating.

2. For purposes of rating the motive power of light vehicles, the UNECE currently provides a regulation under the 1958 Agreement that can be used for approval of internal combustion engines (ICE) and pure electric drivetrains for M and N category vehicles. It focuses on the determination of engine power values and in many cases is sufficient to achieve the above purposes.

3. However, the technical description part of the regulation merely provides for the individual determination of the power of either an ICE or an electric machine. For vehicles with more than one power source, such as an engine and an electric machine that combine to provide a total combined system power, the regulation does not establish a method to determine this total power. The simple addition of individual power results from engine and electric machine is insufficient and can lead to incorrect estimations of the power performance of the vehicle. For example, in many cases (likely the majority), it is the propulsion battery system (also referred to as rechargeable electric energy storage system or REESS) and not the electric machine that limits and therefore determines the power of an electric powertrain. The specific way in which the control system combines the power of an engine and an electric machine (or multiple electric machines) under peak power demand can also affect the validity of simple addition. The situation may become worse in the future because more and more sophisticated hybrid vehicle concepts with distributed power sources are likely to gain market maturity (e.g. electrified vehicles with rim motor concepts, and all-wheel-drive configuration with separate electric machines powering each axle).

B. Procedural background and relation to WLTP

4. Currently, a clear demand for an improved power determination procedure comes from the members of the WLTP IWG, as the Electrified Vehicles subgroup is in need of a total system power specification for the purposes of classification and downscaling. Members of the EVE IWG have also acknowledged that system power ratings are also useful for other purposes. Among others, it may serve as customer technical information, may be used by regulators (as basis for taxation programs) or by insurance providers (as a classifier for determining premiums).

5. Accordingly, Part B of the second EVE mandate includes a subtask to develop an amendment to Global Technical Regulation No. 15 to establish a procedure for determining the powertrain performance of electrified vehicles for use with the WLTP test procedure.

6. Given the above described situation and according to its mandate under the UNECE, the EVE IWG established a subgroup “Determining power of EVs.” The goal was to clarify how an improved technical procedure for the determination of the system power of sophisticated powertrains, such as hybrid electric vehicles with multiple power sources, or pure electric vehicles driven by more than one electric machine, could be realized in an efficient and simple way.

7. The scope of the work covered light duty vehicles (passenger cars -M1 and light duty vehicles -N1) and aimed to develop a recommendation or regulation for determination of the performance criterion “system power.” It was agreed that the procedure shall cover all types of HEV (ordinary –NOVC-HEVs and plug-in –OVC HEVs), including the following configurations: Series HEV, Parallel HEV, and Power split HEV. The procedure shall also cover PEVs with one or more than one electric machine for propulsion (e.g. rim motor concepts, or all-wheel drive configurations driven by multiple electric machines). The system power rating, as a measure of vehicle performance, is intended to be comparable to the measure commonly used for conventional vehicles, i.e. the rated power of an ICE.

C. Background on test procedures considered

8. The EVE IWG recognized that activities with similar focus were currently being pursued by several standardization organizations. The EVE IWG was therefore able to consider several possible paths forward for which considerable research had already occurred. The Society of Automotive Engineers (SAE), the Korea Automobile Testing & Research Institute (KATRI), and the International Organization for Standardization (ISO) had all begun considering how the power of an electric or hybrid vehicle could be best measured. The EVE IWG received presentations from experts with these organizations and discussed the merits and drawbacks of some of the methods proposed by each.

9. The SAE J2908 Task Force led by Argonne National Laboratory (ANL) started a project in November 2014. The project was initially scheduled to be finalized towards end of 2015. Three primary methods of determining HEV system power emerged from the research (referred to as Method 1, Method 2, and Method 3). The EVE IWG agreed with the characterization of these three primary methods as reasonable approaches to measure system power. The three methods vary in terms of how well the measure can be compared to traditional power determination for ICEs, and in terms of the ability to verify a reported value. Method 1 is the sum of estimated engine power (estimated by an applicable standard) and measured DC power from the battery. This method is fairly compatible with existing vehicle power ratings and fairly straightforward to verify. Method 2 is the sum of estimated shaft powers from the engine and the electric machines. This method provides the best compatibility with existing vehicle power ratings but imposes a higher burden of instrumentation to verify. Method 3 is the measured power at the axle or wheel. This method is easily verifiable by dynamometer testing, but because it measures only power at the wheels, it is not as comparable to existing vehicle power ratings.

10. KATRI started a research project in July 2013 with the aim of developing a national standard for the determination of a representative power for (N)OVC-HEVs and EVs with in-wheel motors. It is intended for use in the national vehicle classification. It was finalized in June 2015 and the result will be harmonized with the research result on determining power of EVs in EVE IWG. Nominal rating and system power tests were studied using a powertrain dynamometer or a chassis dynamometer with added instrumentation. Under KATRI, the definition of the hybrid system power follows the same approach as the SAE procedure, namely that it involves a simple addition of the rated engine power and the electric power of the battery (Hybrid system power = Engine power + Electric power). The engine power is the rated power according UN-R85. The electric power is the measured power of the fully

charged REESS of the vehicle, determined by chassis dynamometer testing. Aside from this procedure and similar to the SAE methodology, a somewhat more sophisticated system power test provides not only accurate measurement of wheel or axle power but also useful information of system torque.

11. The International Organization for Standardization (ISO) has also conducted a project under New Work Item Proposal (NWIP) N3477 proposed by the Japan Automobile Research Institute (JARI), approved in June 2015. It started as a formal project of ISO/TC22/SC37/WG02. The ISO method includes two variations, referred to as Test procedure 1 (TP1) and Test procedure 2 (TP2). TP1 includes the definition of the hybrid system power as the arithmetic sum of engine power and battery power, as shown in previous cases (Hybrid system power = Engine power + Battery power). It is necessary to measure the battery output under the HEV system control. The engine power is the rated power determined by ISO 1585. The battery power should be measured when the hybrid system as a whole delivers maximum power on a chassis dynamometer. The exact point of maximum system power is determined by carrying out a series of test runs while driving the vehicle at different but constant speeds to find the maximum brake power of the chassis dynamometer that the vehicle is able to run against. The evaluation results in a power-versus-speed curve that shows a point of maximum power at a certain speed as shown in Figure 1.

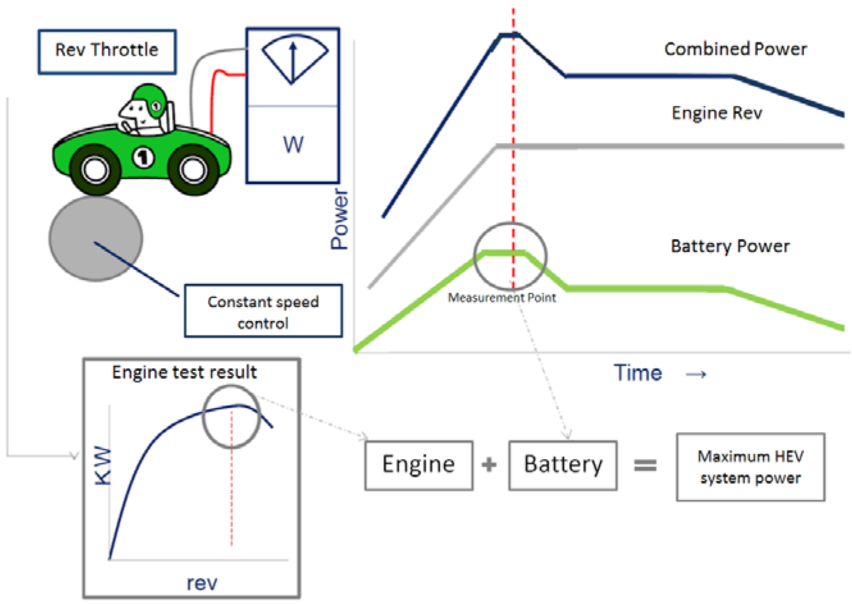

Figure 1. Measurement point for system power

12. During discussions among EVE members, Method 1 found the broadest acceptance since it showed to be quite similar to or the same as KATRI and ISO methodologies. The nominal rating Method 1 is based on determination of individual power at the component level (internal combustion engine, and battery power) and can therefore be considered as similar to current engine power ratings. ANL has investigated different test types (e.g. running a test vehicle at several fixed speeds vs. running a test vehicle with a speed sweep or ramp) in order to determine the maximum system power a vehicle can deliver.

13. Under Method 1, the definition of the hybrid system power follows a simple addition of the rated engine power and the electric power of the battery (Hybrid system power = Engine power + Electric power). The engine power is the rated power by SAE J1349. Electric power is a measured electric assist on the dynamometer.

14. At EVE-22, the contracting parties reached consensus that the ISO method presented the best option as a basis for development of a test procedure for system power determination. This method is very similar to the SAE Method 1. It shows good verifiability, and as a measure of vehicle performance it is comparable to ICE rated power, which makes comparisons between ICE ratings from conventional vehicles and maximum HEV system power ratings relatively straightforward.

15. The EVE IWG recognized that Method 3 is a sophisticated test, leading to highly verifiable results, e.g. for engineers to communicate power levels. However, Method 3 was not selected in part because, being based on a measurement of wheel or axle power rather than component power, it is not directly comparable to current measures of ICE vehicle power.

16. Similarly, Method 2 was not selected in part because it would pose a greater burden for verification due to the need for relatively complex and invasive instrumentation.

17. The ISO method includes two variations, referred to as Test procedure 1 (TP1) and Test procedure 2 (TP2). There was some debate as to whether the amendment to Global Technical Regulation No. 15 should select a single method or include both methods. It was generally decided that including two methods would be acceptable (as long as the results are the same given the correct inputs), because it provides the opportunity to choose the method that best fits the data or equipment that are available, or the powertrain architecture being tested.

D. Technical feasibility, anticipated costs and benefits

18. In designing and validating the ISO method, strong emphasis has been put on its practicability. While the methods are believed at this time to deliver equivalent results, this remains to be investigated in more detail. It could be said that both methods include some uncertainty in that both methods call for certain information to be estimated or assumed. TP1 relies on an estimated gear efficiency, while TP2 requires an assumed electrical component efficiency. The EVE IWG recognized that it would be necessary to perform testing to validate the ability of the method to effectively serve the purposes of WLTP as envisioned.

19. It was also recognized that the state of charge (SOC) of the REESS could affect measured power. After technical discussions with experts from the WLTP –IWG Subgroup EV, the members of the EVE IWG agreed on the concept to determine the maximum HEV system power with REESS fully charged unless otherwise specified by the manufacturer.

20. Another step to be taken is the validation of ISO test results, after review of the selected method(s). Several contracting parties volunteered to assist with such testing, including Environment and Climate Change Canada (ECCC), Joint Research Centre (JRC), U. S. Environmental Protection Agency (EPA), and possibly National Traffic Safety and Environment Laboratory (NTSEL) of Japan.

21. At EVE 22, the co-chair from Japan requested that EVE leadership take on the task of drafting the amendment to Global Technical Regulation No. 15, with initial priority placed on the reference method over the candidate method. Accordingly, a drafting group was formed to draft this document.

22. It was also suggested that at some point in the near future, a parallel effort should also be undertaken to further develop the candidate method by means of testing at laboratories of the contracting parties, but at this time this is considered a secondary goal.

23. The specification of a test procedure for power determination will remove significant uncertainty that manufacturers now face in communicating the power level of electrified vehicles both to the public and to regulating authorities. Initially the adoption of the procedure may bear some costs for vehicle manufacturers, technical services and authorities, at least considered on a local scale, since some test equipment and procedures may have to be upgraded. However, these costs should be limited since such upgrades are done regularly as adaptations to the technical progress. Related costs would have to be quantified on a regional level since they largely depend on the local conditions.

II. Text of the global technical regulation

1. Purpose

This amendment to Global Technical Regulation No. 15 aims at providing a worldwide harmonized method to determine a system power rating of electrified light-duty vehicles in a repeatable and reproducible manner and that is comparable to traditional measures of system power applicable to conventional vehicles. The results will provide a basis for consistent application of the classification and downscaling provisions of WLTP for the purpose of regional type approval and certification procedures.

2. Scope and application

This amendment to Global Technical Regulation No. 15 applies to vehicles of categories 1-2 and 2, both having a technically permissible maximum laden mass not exceeding 3,500 kg, and to all vehicles of category 1-1, which are either (a) hybrid electric vehicles, or (b) pure electric vehicles having more than one electric machine for propulsion.

The following document(s) are referenced in such a way that some or all of their content constitutes requirements of this document. The latest edition of the referenced document(s) (including any amendments) applies:

ISO 1585, *Road vehicles – engine test code – Net power*

3. Definitions

For the purposes of this document, the terms and definitions given in Global Technical Regulation No. 15, ISO 1585 (where applicable), and the following apply.

3.1 Powertrain

The total combination in a vehicle of propulsion energy storage system(s), propulsion energy converter(s) and the drivetrain(s) providing the mechanical energy at the wheels for the purpose of vehicle propulsion, plus peripheral devices.

3.2 Peripheral devices

Energy consuming, converting, storing or supplying devices, where the energy is not primarily used for the purpose of vehicle propulsion, or other parts, systems and control units, which are essential to the operation of the powertrain.

3.3 Auxiliary devices

Energy consuming, converting, storing or supplying non-peripheral devices or systems which are installed in the vehicle for purposes other than the propulsion of the vehicle and are therefore not considered to be part of the powertrain.

3.4 Drivetrain

The connected elements of the powertrain for transmission of the mechanical energy between the propulsion energy converter(s) and the wheels.

3.5 Energy converter

A system where the form of energy output is different from the form of energy input.

3.6 Propulsion energy converter

An energy converter of the powertrain which is not a peripheral device whose output energy is used directly or indirectly for the purpose of vehicle propulsion.

3.7 Electric machine

An energy converter transforming between electrical and mechanical energy.

3.8 Off-vehicle charging hybrid electric vehicle (OVC-HEV)

A hybrid electric vehicle that can be charged from an external source.

Note 1: External charge for the purpose of conditioning of the REESS is not included.

Note 2: OVC-HEVs are widely known as plug-in HEVs (PHEVs).

3.9 Not off-vehicle charging hybrid electric vehicle (NOVC-HEV)

3.10A hybrid electric vehicle that cannot be charged from an external source,Hybrid-electric vehicle (HEV)

A hybrid vehicle where one of the propulsion energy converters is an electric machine.

Note 3: This International Standard does not apply to fuel cell vehicles.

3.11Pure electric vehicle (PEV)

A vehicle equipped with a powertrain containing exclusively electric machines as propulsion energy converters and exclusively rechargeable electric energy storage systems as propulsion energy storage systems.

3.12Rechargeable electrical energy storage system (REESS)

The rechargeable electric energy storage system that provides electric energy for electrical propulsion. A battery whose primary use is to supply power for starting the engine and/or lighting and/or other vehicle auxiliaries systems is not considered as a REESS. The REESS may include the necessary ancillary systems for physical support, thermal management, electronic controls and casing.

3.13 Test procedure option 1 (TP1)

A test procedure, defined herein, for determining system power via measured REESS power and determined ICE power.

3.14 Test procedure option 2 (TP2)

A test procedure, defined herein, for determining system power via axle/wheel torque and speed measurement.

3.15 Charge depleting operating condition

An operating condition in which the energy stored in the REESS may fluctuate but decreases on average while the vehicle is driven until transition to charge-sustaining operation.

3.16 Charge sustaining operating condition

An operating condition in which the energy stored in the REESS may fluctuate but, on average, is maintained at a neutral charging balance level while the vehicle is driven.

[add definitions as needed and ensure consistency with WLTP]

4. Abbreviations

4.1 General abbreviations

[to be defined as necessary consistent with WLTP]

AWD	all wheel drive
HEV	hybrid-electric vehicle
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
ISO	International Organization for Standardization
REESS	rechargeable electrical energy storage system
SOC	state of charge
UN	United Nations
TP1	Test procedure option 1
TP2	Test procedure option 2
U_{REESS}	measured REESS voltage [V]
I_{REESS}	measured REESS current [A]
U_{DCDC}	voltage at DC/DC converter for 12V auxiliaries [kW]
I_{DCDC}	current to DC/DC converter for 12V auxiliaries [kW]

P_{DCDC}	power to DC/DC converter for 12V auxiliaries [kW]
K	conversion factor from electrical power to mechanical power
$P_{auxiliaries}$	power to auxiliaries except DC/DC converter for 12V auxiliaries [kW]

4.2 Chemical symbols and abbreviations

[to be defined as necessary consistent with WLTP]

5. Test conditions

5.1 Test instrumentation

5.1.1 Chassis dynamometer

The chassis dynamometer shall have the absorption capacity for the power of vehicle by fixed speed control.

5.1.2 Test room

The test cell shall have a temperature set point of 23 °C. The tolerance of the actual value shall be within ±5 °C.

Atmospheric pressure in the test cell shall be between 80kPA and 110 kPa.

The specific humidity H of either the air in the test cell or the intake air of the engine shall be such that:

$$5.5 \leq H \leq 12.2 \text{ (g } H_2O\text{/kg dry air)}$$

5.1.3 Cooling fan

A current of air of variable speed shall be blown towards the vehicle. The set point of the linear velocity of the air at the blower outlet shall be equal to the corresponding dynamometer speed above measurement speeds of 5 km/h. The deviation of the linear velocity of the air at the blower outlet shall remain within ±5 km/h or ±10 per cent of the corresponding measurement speed, whichever is greater.

5.1.4 Soak area

The soak area shall have a temperature set point of 23 °C and the tolerance of the actual value shall be within ±3 °C on a 5-minute running arithmetic average and shall not show a systematic deviation from the set point. The temperature shall be measured continuously at a minimum frequency of 0.033 Hz (every 30 s).

5.2 Measurement

5.2.1 Measurement item and accuracy

Measurement devices shall be of certified accuracy as shown in Table 1 traceable to an approved regional or international standard.

Table 1 — Measurement items and required accuracy

Item	Units	Accuracy	Remarks
Engine speed	min^{-1}	± 0.5 %	
Intake manifold pressure	Pa	± 50 Pa	Intake manifold pressure means inlet depression in ISO1585.
Atmospheric pressure	Pa	±0.3 kPa, with a measurement frequency of at least 0.1 Hz	
Humidity			
Fuel flow rate	g/s	± 3 %	For compression-ignition engines, and for other internal combustion engines if the confirmation of air-fuel ratio according to ISO 1585 is necessary.
Electrical voltage	V	±0.3 per cent FSD or ±1 per cent of reading	Whichever is greater. Resolution 0.1 V.
Electrical current	A	±0.3 per cent FSD or ±1 per cent of reading	Whichever is greater. Current integration frequency 20 Hz or more. Resolution 0.1 A.
Electrical energy	Wh	±1 per cent	Resolution 0.001 kWh. Equipment: static meter for active energy. AC watt-hour meter, Class 1 according to IEC 62053-21 or equivalent
Room temperature	K	±1 °C, with a measurement frequency of at least 0.1 Hz	
Chassis dynamometer roller speed	km/h	The roller speeds shall be controlled with an accuracy of ±0.2 km/h	

Time	s	± 10 ms; min. precision and resolution:10 ms	
Axle/wheel rotational speed	s^{-1}	± 0.05 s^{-1} or ± 1 %, whichever is greater	
Axle/wheel torque	Nm	± 6 Nm or ± 0.5 % of the maximum measured total torque, whichever is greater, for the whole vehicle, with a measurement frequency of at least 10 Hz	

5.2.2 Measurement frequency

All the items in Table 1 of 5.2.1, except atmospheric pressure, room temperature, and humidity shall be measured and recorded at a frequency equal to or greater than 10 Hz.

The items atmospheric pressure and room temperature shall be at least recorded as single measurement activity at start of vehicle operation (see 6.8.4) and after end of vehicle running (see 6.8.6).

The air temperature and humidity shall be measured at the test cell's cooling fan outlet at a minimum frequency of 0.1 Hz. Atmospheric pressure shall be measurable with a resolution of 0.1 kPa.

6. Test procedure

6.1 General

The purpose of the following test procedures is to determine the maximum system propulsion power of an HEV (maximum HEV system power), or of a pure electric vehicle having more than one electric machine for propulsion, on a chassis dynamometer at fixed speeds. Two optional and equitable test procedures are applicable, namely:

— a test procedure via measured REESS power and determined ICE power, consecutively named test procedure option 1 (TP1), and

— a test procedure via torque and speed measurement at the drive shaft(s) or wheel(s), consecutively named test procedure option 2 (TP2).

The test result for the maximum HEV system power shall be stated always in connection with the performed test procedure.

Note: Depending on the power transfer rate in series and power-split types, the results for the maximum HEV system power differ in TP1 and TP2.

6.2 Preparation of chassis dynamometer

6.2.1 Roller

The chassis dynamometer roller(s) shall be clean, dry and free from foreign material which can cause tire slippage.

6.2.2 Tire slippage

Additional weight may be placed on or in the vehicle to eliminate tire slippage. The use of any additional weight shall be recorded.

6.2.3 Chassis dynamometer warm-up

The chassis dynamometer shall be warmed up in accordance with the dynamometer manufacturer's recommendations, or as appropriate, so that the frictional losses of the dynamometer may be stabilized.

6.2.4 Chassis dynamometer control

The chassis dynamometer shall be controlled in fixed speed mode for the power test. Only for the requirements towards vehicle conditioning (6.8.2), the chassis dynamometer shall be controlled in road load mode.

6.3 Preparation of vehicle

The front and rear tires shall be inflated to the lower limit of the tire pressure range for the respective axle for the selected tire at the coastdown test mass, as specified by the vehicle manufacturer. The vehicle lubricants and levels specified by the manufacturer shall be used.

Fuel shall be in accordance with the vehicle manufacturer's recommendation or ISO 1585.

6.4 Measurement devices

6.4.1 Required measurement devices

The test vehicle shall be instrumented with measurement devices for measuring certain input values for the power calculation, depending on whether TP1 or TP2 is performed.

For TP1, measurement devices shall be used to measure ICE speed, intake manifold pressure, REESS current, REESS voltage, and fuel flow rate, if the confirmation of air-fuel ratio according to ISO 1585 is necessary. Optionally, current and voltage of the DC/DC converter for 12V auxiliaries may be measured to allow calculation of power to DC/DC converter for 12V auxiliaries.

For TP2, measurement devices shall be used to measure REESS current and REESS voltage. Wheel torque and rotational speed measurement may be provided either by means of appropriate, calibrated measurement device(s) for torque and rotational speed of the gearbox output shaft(s) or the driven wheel(s), or by traction force and speed measured by the chassis dynamometer.

Determination of REESS current and REESS voltage shall be subject to the requirements in Global Technical Regulation No. 15, Annex 8, Appendix 3.If wheel torque and rotational speed measurement is provided by measurement device(s), then if the driven axle is powered via differential and two wheels, it is sufficient to install only one torque and rotational speed measurement device on a drive shaft or wheel. In this case, the measured torque at a drive shaft or wheel shall be multiplied by 2 in order to get the sum of torque per driven axle.

If wheel torque and rotational speed measurement is provided by the chassis dynamometer, the accuracy of this measurement device must fulfills the same requirements as for the shaft/wheel measurement devices. If so, it is necessary that the measured values for traction force and speed be transformed, by calculation, to the required values for torque and rotational speed at drive shaft or wheel, taking into account the specific data of the tires and the proportional vehicle weight at the wheels used during the test (e.g.: rolling friction losses, dynamic rolling radius).

6.4.2 Preparation of measurement devices

The measurement devices shall be installed at suitable position(s) and warmed up as appropriate.

6.5 Initial charge of REESS

The initial SOC shall be set to obtain the maximum system power or as specified by the vehicle manufacturer. In the absence of manufacturer specification, the initial SOC shall be set to the maximum SOC achievable by regeneration. For OVC-HEVs, if the manufacturer indicates that the maximum power is achieved in a charge sustaining operating condition that does not operate near maximum SOC, the initial SOC shall be set to the SOC specified by the manufacturer.

After the SOC has been set, the current and voltage measurements shall be started.

The SOC shall be adjusted by regenerative braking or by charging from the external electric power supply or by discharging via electric driving.

The SOC adjustment may be carried out during vehicle soak (6.6) in case of OVC-HEVs.

6.6 Vehicle soak

The vehicle shall be soaked in the soak area for a minimum of 6 hours and a maximum of 36 hours with the engine compartment cover opened or closed. The soak area conditions during soak shall be as specified in 5.1.4.

6.7 Vehicle installation

The vehicle shall be installed on the chassis dynamometer roller in accordance with the dynamometer manufacturer's recommendation, or regional or national regulations.

Auxiliary devices shall be switched off or deactivated during dynamometer operation unless their operation is required by regional legislation.

If auxiliaries except DC/DC converter cannot be turned off, then the $P_{auxiliary}$ shall be measured or calculated and finally subtracted from the measured REESS power.

The vehicle's dynamometer operation mode, if any, shall be activated by using the manufacturer's instruction (e.g. using vehicle steering wheel buttons in a special sequence, using the manufacturer's workshop tester, removing a fuse).

The manufacturer shall provide the responsible authority a list of the deactivated devices and justification for the deactivation. The dynamometer operation mode shall be approved by the responsible authority and the use of a dynamometer operation mode shall be recorded.

The vehicle's dynamometer operation mode shall not activate, modulate, delay or deactivate the operation of any part that affects the emissions and fuel consumption under the test conditions. Any device that affects the operation on a chassis dynamometer shall be set to ensure a proper operation.

The test cell temperature at the start of the test shall be 23 °C ±3 °C. The engine oil temperature and coolant temperature, if any, shall be within ±2 °C of the set point of 23 °C.

6.8 Test sequence

6.8.1 General

The test shall be carried out in accordance with 6.8.2 to 6.8.6, and 6.9 to 6.10 (see Figure 3). The test shall be stopped immediately if warning indicator(s) with regard to the power train turns on.

Note: Warnings are coolant temperature and engine check lamp, for example.

6.8.2 Vehicle conditioning

In order to condition the vehicle, it shall run at the speed of 60 km/h at the vehicle road load for at least 20 minutes or with the vehicle manufacturer's recommendation.

If the vehicle conditioning has to be performed due to a measurement loop at various fixed dynamometer speeds (see 6.10), the time to run the vehicle for stabilization in the second or further loop may be shorter than 20 minutes according to the vehicle manufacturer's recommendation or if the temperature of components is measured and not higher than before the first test.

6.8.3 REESS adjustment

During vehicle conditioning according to 6.8.2, the SOC shall be monitored and adjusted at the end of vehicle conditioning according to the requirements specified in 6.5.

6.8.4 Vehicle operation

The measurement devices shall start collecting data. The driving mode switch shall be selected appropriately in order to obtain the maximum HEV power.

Run the vehicle at a fixed speed in accordance with the vehicle manufacturer's recommendation.

To be able to measure the maximum power value, a sufficient number of tests shall be carried out at appropriately varied speeds of the chassis dynamometer (see 6.10).

6.8.5 Pedal operation

The maximum accelerator pedal command shall be given by either the pedal position or by vehicle communication network for duration of at least 10 s.

Note: Prior to the maximum accelerator pedal command, it is possible to modulate the accelerator pedal position.

6.8.6 End of vehicle running

After the measurements according to 6.8.5, the vehicle and measurement devices, except those for the current and voltage, shall be stopped.

6.9 Calculation of HEV system power

6.9.1 General

The time series data obtained from 6.8 shall be analyzed to determine power. Regardless of TP1 or TP2, two power calculations shall be performed:

1) a 2-second "peak" power that applies a 2-second moving average filter for the 10-second measurement time; and

2) a "sustained" power that defines the average power within the measurement time window from 8 s to 10 s.

Note: In case of ICE power corrections according to ISO 1585, it is permissible to ask the vehicle manufacturer if necessary. It is possible that HEV power trains possess their own power compensation.

6.9.2 Calculation for TP1

The HEV system power is calculated as the sum of ICE power and converted REESS power:

$$HEV\ system\ power\ [kW] = ICE\ power\ [kW] + converted\ REESS\ power\ [kW]$$

a) ICE power [kW] shall be determined as follows: The test results of measurements according to ISO 1585 are necessary. ICE power is based on the measured engine speed, intake manifold pressure in inlet system and fuel flow rate if the confirmation of air fuel ratio according to ISO 1585 is necessary. It shall be determined by an engine dynamometer test specified in other international standards, or regional or national regulations. The engine dynamometer test fuel shall be the same as in 6.3.

The engine dynamometer test to obtain the ICE power can be conducted under the conditions specified in ISO 1585 using the above-measured engine speed, intake manifold pressure in inlet system and fuel flow rate if the confirmation of air fuel ratio according to ISO 1585 is necessary. If the intake manifold pressure or fuel flow rate deviates significantly from ISO 1585, conduct ISO 1585 under the conditions using the above-measured engine speed and intake manifold pressure in inlet system or fuel flow rate, ask the vehicle manufacturer, or conduct TP2.

b) converted REESS power [kW] shall be determined by the equation:

$$converted\ REESS\ power\ [kW] = \left(\frac{U_{REESS} \times I_{REESS}}{1000} - P_{DCDC} - P_{auxiliaries}\right) \times K$$

where

U_{REESS} is the measured REESS voltage [V]

I_{REESS} is the measured REESS current [A]

P_{DCDC} is the power to DC/DC converter for 12V auxiliaries (1.0kW or measured value) [kW]

$P_{auxiliaries}$ is the power to auxiliaries except DC/DC converter for 12V auxiliaries (measured value) [kW]

Note: If the power is measured, P_{DCDC} and $P_{auxiliaries}$ is equal to U_{DCDC} [V] and $U_{auxiliaries}$ [V] multiplied by I_{DCDC} [A] and $I_{auxiliaries}$ [A] divided by 1000 :$U_{DCDC} \times I_{DCDC}/1000$ and $U_{auxiliaries} \times I_{auxiliaries}/1000$, respectively.

$K$is the conversion factor from electrical power to mechanical power (0.85 or measured value).

Note: Conversion factor is defined as output power of electric machine divided by input power of inverter. 0.85 is applicable to permanent magnet synchronous (PMS) motor. In case of other types of motor, the K of the system at the maximum power shall be provided.

The HEV system power is calculated by adding the total of a) and b).

6.9.3 Calculation for TP2:

6.9.3.1 Calculation

The HEV system power at the wheels is calculated by multiplying individually the measured data of each drive shaft or wheel torque with the corresponding drive shaft or wheel speed to get the individual drive shaft or wheel power values and finally by the sum of each individual drive shaft or wheel power values according to the following formulas:

$$Drive\ shaft\ or\ wheel\ power\ [kW] = (2\pi \times \text{drive shaft or wheel speed } [s^{-1}] \times drive\ shaft\ or\ wheel\ torque\ [Nm])/1000$$

$$HEV\ system\ power\ at\ all\ axles\ or\ all\ wheels\ [kW] = Sum\ of\ drive\ shaft\ or\ wheel\ power\ of\ each\ driven\ drive\ shaft\ or\ wheel\ [kW]$$

In order to calculate the HEV system power value comparable to the engine or electric machine power value at the engine or electric machine output shaft, the measured HEV system power value at wheels shall be corrected by the gearbox system efficiency factor $\eta_{gearbox}$ according to the following formula:

$$P_{HEV\ system}\ [kW] = \frac{P_{HEV\ system\ at\ wheels}\ [kW]}{\eta_{gearbox}}$$

Where

$P_{HEV\ system}$ is the HEV system power [kW]

$P_{HEV\ system\ at\ wheels}$ is the HEV system power at wheels [kW]

$\eta_{gearbox}$ is the gearbox system efficiency factor

The gearbox system efficiency factor depends on individual gearbox system configurations. Therefore a value for this factor shall be used according to the vehicle manufacturer's recommendation or if not available, according to the gearbox system efficiency factor for the corresponding hybrid powertrain type under test, as provided in Appendix 1 to this Annex.

6.9.3.2 ICE power correction factors

The ICE power portion of the HEV system power shall be corrected according to the provision given in ISO 1585:1992 clause 6, if:

— the reference atmospheric and temperature conditions, given in ISO 1585:1992 clause 6.2.1; or

— the automatic control conditions according to ISO 1585:1992, clause 6.3

cannot be fulfilled.

If the ICE power portion needs to be corrected, follow 6.9.3.3, otherwise continue with6.10.

6.9.3.3 Corrected maximum HEV system power for TP2

TP2 does not deliver a measured value for the ICE power portion. If a correction of the ICE power portion according to 6.9.3.2 is required, the following additional actions for TP2 are required:

— Determine in addition to the already measured torque and speed values (see 6.8.5) the REESS power via DC voltage and current measurement at the REESS. Correct the measured power value at REESS with auxiliary power values, if necessary (e.g. power to DC/DC converter for 12V auxiliaries, equal to 1.0 kW or measured value). Multiply the corrected electrical power value with the conversion factor K valid for the tested HEV:

$$Converted\ REESS\ power\ [kW] = (U_{REESS}[V] \times I_{REESS}[A] \div 1000 - P_{DCDC}\ [kW] - P_{auxiliaries}\ [kW]) \times K$$

— Subtract the converted REESS power from the measured maximum HEV system power, the result is the measured ICE power:

$$P_{ICE}[kW] = P_{HEV\ system} - converted\ REESS\ power\ [kW]$$

— Correct the measured ICE power according to ISO 1585:

$$P_{ICE,\ corrected}[kW] = P_{ICE}[kW] \times Power\ correction\ factor$$

where Power correction factor is according to ISO 1585:1992, clause 6.

— The sum of corrected ICE power and converted REESS power is the corrected HEV system power:

$$P_{HEV\ system\ power,\ corrected}\ [kW] = P_{ICE,\ corrected}[kW] + converted\ REESS\ power\ [kW]$$

6.10 Determination of maximum HEV system power

The maximum HEV system power is the maximum value in the relation between power and speed (see Figure 2). If the vehicle manufacturer has specified a fixed vehicle speed at which maximum HEV system power occurs, the test shall be run with the dynamometer set to this vehicle speed. If the manufacturer has not specified a vehicle speed, the maximum HEV system power shall be identified by conducting the test procedure at a series of fixed vehicle speeds in order to identify the speed at which maximum power occurs.

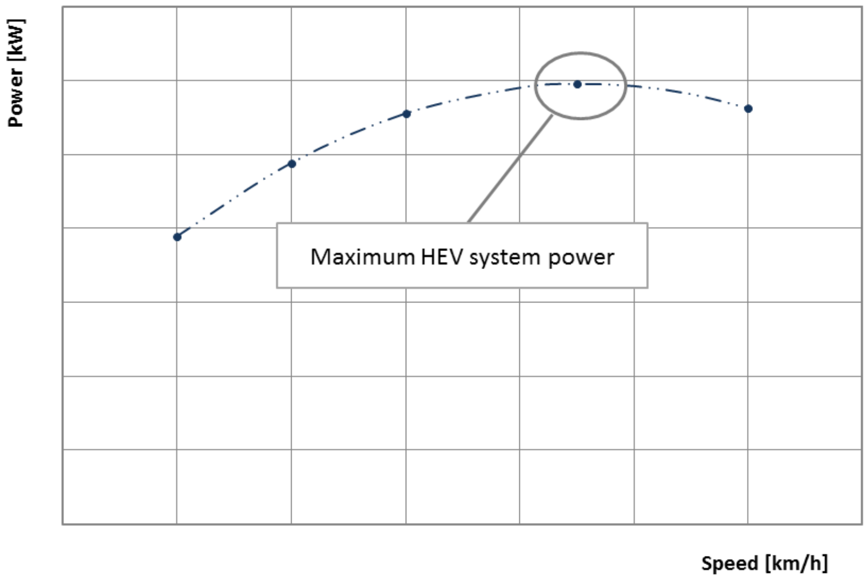

Figure 2 — Relation between power and speed

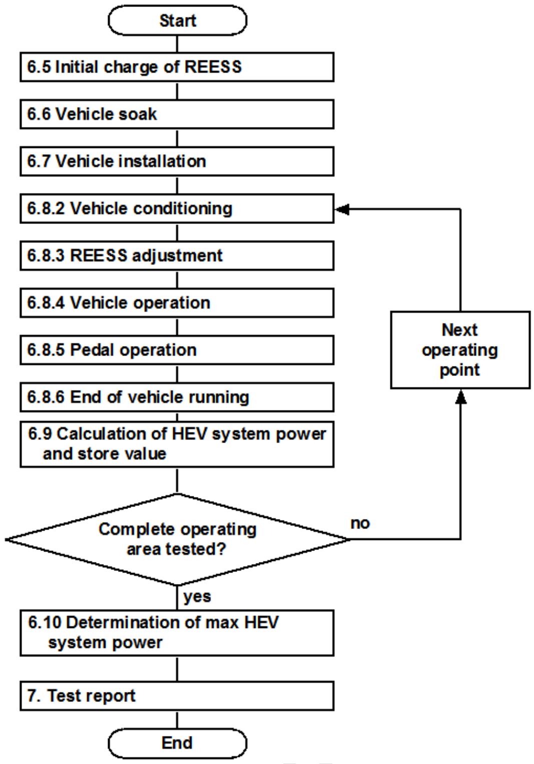

Figure 3 — Test sequence for determination of maximum HEV system power

The test sequence from 6.8.2 to 6.10 in Figure 3 shall be continued until the maximum HEV system power is determined.

Then, shut down the voltage and current measurement devices and continue with clause 7.

7. Test report

7.1 General

The test report and the statement of result shall indicate which test procedure (TP1 or TP2 in 6.1) was carried out and which power calculation 1) peak power or 2) sustained power in 6.9.1 was used. Depending on whether TP1 or TP2 was carried out, the test report shall also include at least the data listed in 7.2 or 7.3, respectively. The test report shall also include the environmental data listed in 7.4 and the general vehicle data listed in 7.5.

7.2 Test report data specific to TP1

7.2.1 Calculated values based on measured data

- Maximum HEV system power [kW]

- ICE power [kW]

- Converted REESS power [kW]

7.2.2 Measured data

- ICE speed [min^{-1}]
- Intake manifold pressure [Pa]
- Fuel flow rate (for compression-ignition engines, and for other engines if confirmation of air-fuel ratio according to ISO 1585 is necessary) [g/s]
- U_{REESS} [V]
- I_{REESS} [A]
- U_{DCDC} [V] and I_{DCDC} [A] (if measured)
- Axle/wheel rotational speed [s^{-1}]
- Conversion factor from electrical power to mechanical power, K, if measured

7.2.3 Assumed values

- P_{DCDC}...[1.0 kW]
- Conversion factor from electrical power to mechanical power, [*K*... 0.85]
- List of $P_{auxiliaries}$ (power of auxiliary devices is needed for the determination of the converted REESS power)

7.3 Test report data specific to TP2

7.3.1 Calculated values based on measured data

- Maximum HEV system power [kW]
- Maximum HEV system power at axle/wheel [kW]

7.3.2 Measured data

- HEV system power at axle/wheel, measured [kW]
- Chassis dynamometer roller speed at maximum HEV system power [km/h]
- U_{REESS} [V]
- I_{REESS} [A]
- U_{DCDC} [V] and I_{DCDC} [A] (if measured)
- Axle/wheel rotational speed [s^{-1}]
- Axle/wheel torque [Nm]
- Conversion factor from electrical power to mechanical power, K (if measured)
- Gearbox system efficiency factor (if measured)

7.3.3 Assumed values

- P_{DCDC}...[1.0 kW]
- Conversion factor from electrical power to mechanical power, [*K*... 0.85]
- Gearbox system efficiency factor

7.4 Environmental data

- Atmospheric pressure [Pa]

- Room temperature [°C]

7.5 General vehicle data based on the manufacturer's information

- Vehicle name & type

- Gearbox system

- REESS system

- Nominal voltage REESS system [V]

- REESS energy [kWh]

- ICE system

- ICE displacement [cm^3]

- Maximum ICE power at engine speed [kW @ min^{-1}]

- Type of electric machine

- Maximum power of the electric machine and the corresponding speed [kW @ min^{-1}]

Appendix 1

This Appendix provides examples for gearbox system efficiency factor (includes gearbox and differential) at maximum HEV system power.

This amendment to Global Technical Regulation No. 15 describes within clause 6, TP2, a measurement method to determine the maximum HEV system power via a torque and speed measurement at axle/wheel of HEVs. In order to be able to compare HEV power values with those by ICE or electric machine driven vehicles only, these HEVs measured power values at axle/wheel have to be transformed to a power level based on engine and/or electric machine shaft output level. In order to be able to perform this power transformation by calculation, it is necessary to take the gearbox system efficiency factor at maximum HEV system propulsion power into account. The gearbox system efficiency factor, $\eta_{gearbox}$, indicates the efficiency value for the mechanical power transfer for propulsion from input (P_{in}) to output (P_{out}) of the gearbox system representing the following equation:

$$\eta_{gearbox} = \frac{HEV\ system\ propulsion\ power\ at\ axle/wheel\ (P_{out})\ [kW]}{Sum\ of\ mechanical\ ICE\ and\ motor\ power\ at\ gearbox\ input\ (P_{in})[kW]}$$

The gearbox system efficiency value, $\eta_{gearbox}$, depends on the individual HEV system configuration and will be in a range typically between 0.95 and 0.98. The individual value for the tested HEV configuration shall be provided by the OEM. If this is not possible, the following typical gearbox system efficiency factors for the listed typical HEV configurations shall be used for the calculation of HEV system propulsion power according to clause 6.

A.1) Series hybrid-electric vehicle (Series HEV)

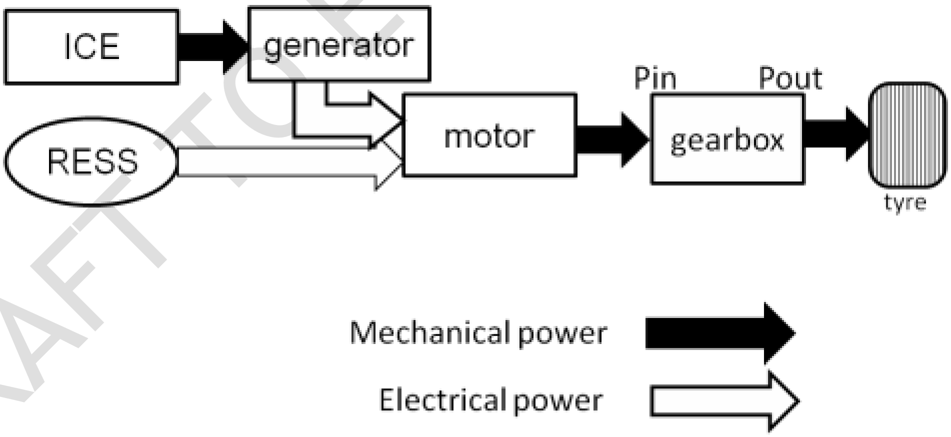

Figure A.1 — Series hybrid-electric vehicle configuration

For a series HEV, the gearbox system is typically a single or dual-speed transmission system with an gearbox system efficiency value of:

$$\eta_{gearbox}(Series\ Hybrid) = 0.98$$

A.2) Parallel hybrid-electric vehicle (Parallel HEV)

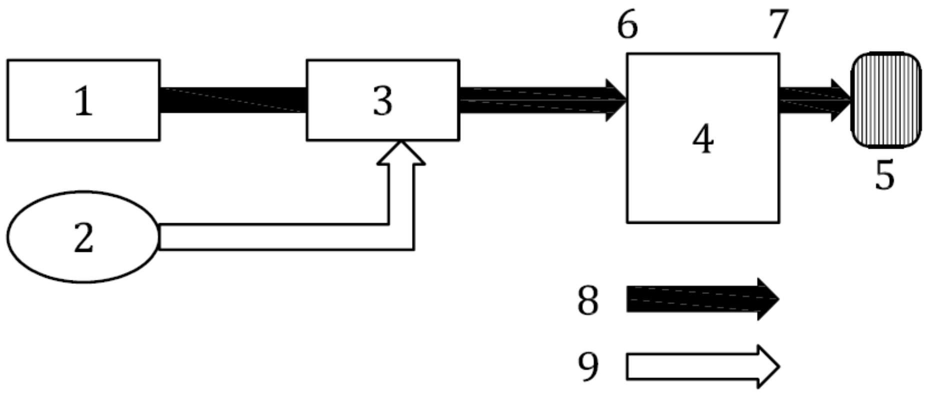

Figure A.2 — Single-shaft parallel hybrid-electric vehicle (Single-shaft parallel HEV) configurationKey

1 internal combustion engine (ICE)

2 rechargeable electrical energy storage system (REESS)

3 motor

4 gearbox

5 tire

6 P_{in} [kW]

7 P_{out} [kW]

8 mechanical power

9 electrical power

For a parallel HEV, the gearbox systems are typically a dual-clutch automatic transmission system or a multi-speed automatic transmission system with integrated electric machine instead of the converter and a starting clutch with the following gearbox system efficiency values:

$$\eta_{gearbox}(parallel\ hybrid, dual\ clutch\ automatic\ gearbox) = 0.97$$

$$\eta_{gearbox}(parallel\ hybrid, multispeed\ automatic\ transmission) = 0.96$$

For parallel HEVs with AWD, if the second axle is driven via a drive shaft from the hybrid drive system, the gearbox system efficiency factor for the second axle is the same as for the first axle.-

For parallel HEVs with AWD, if the second axle is driven via an additional electric machine connected to the hybrid drive system via electricity only, the gearbox system efficiency factor for the second axle is:

$$\eta_{gearbox}(parallel\ hybrid, second\ axle\ with\ separated\ electric\ machine) = 0.98$$

A.3) Power split hybrid-electric vehicle (Power split HEV)

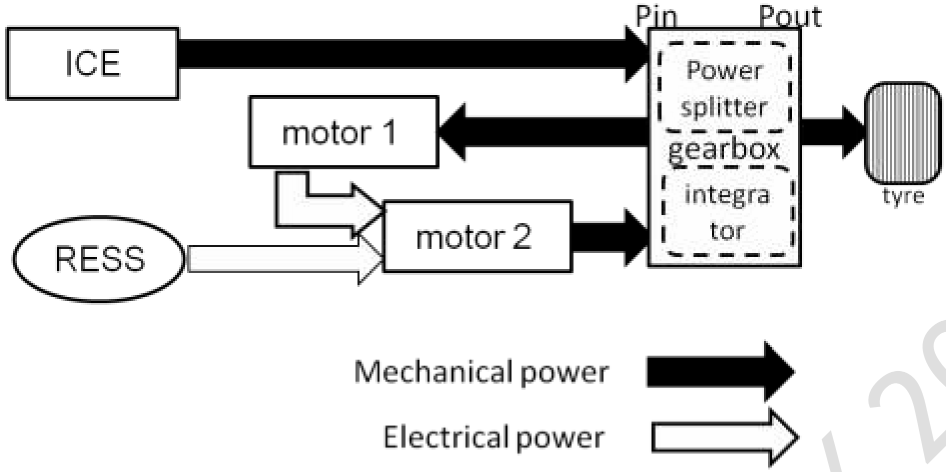

Figure A.3 — Power split hybrid-electric vehicle configuration

For a power split HEV, the gearbox system is typically a planetary gear transmission system, which performs a summation of the mechanical power from the parallel path (via ICE - power split device) and the mechanical power from the series path (motor 2 powered via REESS and motor 1 in generator mode), with the following typical gearbox system efficiency value:

$$\eta_{gearbox}(Power\ split\ HEV, planetary) = 0.93$$

$$\eta_{gearbox}(Power\ split\ HEV, planetary, with\ shift\ control\ device\ excluding\ oil\ pump) = 0.91$$

For power split HEVs with AWD, if the second axle is driven via a drive shaft from the hybrid drive system, the gearbox system efficiency factor for the second axle is the same as for the first axle.

For power split HEVs with AWD, if the second axle is driven via an additional electric machine connected to the hybrid drive system via electricity only, the gearbox system efficiency factor for the second axle is as follows:

$$\eta_{gearbox}(Power\ split\ Hybrid, second\ axle\ with\ separated\ motor) = 0.98$$

Bibliography

[1] UN Regulation No. 85, Uniform provisions concerning the approval of internal combustion engines or electric drive trains intended for the propulsion of motor vehicles of categories M and N with regard to the measurement of net power and the maximum 30 minutes power of electric drive trains