SAE INTERNATIONAL®

SURFACE VEHICLE INFORMATION REPORT

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(R) Vehicle Power and Rated System Power Test for Electrified Powertrains

RATIONALE

Power ratings provided for ICE vehicles are obtained from component-level tests of the engine (SAE J1349). However, electrified powertrains often consist of multiple power-producing components that may include an engine and one or more electric motors configured and integrated in a variety of ways. To find an objective determination of the powertrain power among all types of electrified vehicles, SAE J2908_201709 established a wheel power test (WPT) procedure. Because wheel power results incur losses in the drivetrain not present in traditional engine power ratings, SAE J1349 and wheel power are not suited for direct comparisons. This revision adds a methodology (with several options) building upon the established SAE J2908 WPT results to make a total propulsion system power determination (termed "rated system power"). Rated system power is defined as the maximum sum of the mechanical power outputs of the individual power-producing components used in propulsion. This method facilitates comparisons to existing engine power ratings established in SAE J1349 and to electric motor power ratings in SAE J2907. It provides common nomenclature, assumptions, conditions, and procedures for expressing electrified vehicle power ratings to consumers and the engineering community.

FOREWORD

This SAE Information Report is intended as a guide toward achieving common methods and practices and is subject to change in order to keep pace with added experience and technical advances.

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1. SCOPE

This SAE Information Report provides test methods and determination options for evaluating the maximum wheel power and rated system power of vehicles with electrified vehicle powertrains. The scope of this document encompasses passenger car and light- and medium-duty (GVW <10000 pounds) hybrid-electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel-cell electric vehicles (FCEVs). These testing methods can also be applied to conventional ICE vehicles, especially when measuring and comparing wheel power among a range of vehicle types.

This document version includes a definition and determination methodology for a rated system power that is comparable to traditional internal combustion engine power ratings (e.g., SAE J1349 and UN ECE R85). The general public is most accustomed to “engine power” and/or “motor power” as the rating metric for conventional and electrified vehicles, respectively. Wheel power will always be a lower-power result, owing to losses in the drivetrain that take power away from the power-producing components as it flows to the wheel. The methods in this document for determining rated system power were developed recognizing that no single approach is suitable for all powertrains without some variations specific to the powertrain type (e.g., BEV versus HEV) and the limits of test practicality.

Additional power-related tests are included to address unique operational capabilities of electrified vehicles.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.2 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1349 Engine Power Test Code - Spark Ignition and Compression Ignition - As Installed Net Power Rating

SAE J1715 Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) Terminology

SAE J1715/2 Battery Terminology

SAE J1798 Recommended Practice for Performance Rating of Electric Vehicle Battery Modules

SAE J2758 Determination of the Maximum Available Power from a Rechargeable Energy Storage System on a Hybrid Electric Vehicle

SAE J2907 Performance Characterization of Electrified Powertrain Motor-Drive Subsystem

2.3 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/.

ISO 20762 Determination of Power for Propulsion of Hybrid Electric Vehicle

2.4 United Nations Global Technical Regulation

Copies of these documents are available online at https://unece.org/transport.

UN GTR No. 21 Determination of Electrified Vehicle Power (DEVP)

3. TERMS AND DEFINITIONS

For terms and definitions not listed below relating to electrified vehicles, refer to SAE J1715.

3.1 ALL-ELECTRIC CHARGE-DEPLETING (CD) MODE

A particular PHEV charge-depleting mode wherein all driving, up to and including full performance, is satisfied by electric-only propulsion.

3.2 BLENDED CHARGE-DEPLETING (CD) MODE

A particular PHEV charge-depleting mode wherein the engine is used occasionally to blend with the electric motor(s) to provide vehicle propulsion power.

3.3 CHARGE-DEPLETING (CD) MODE

A PHEV operating mode in which the state of charge (SOC) of the rechargeable energy storage system (RESS) may fluctuate but, on average, decreases while the vehicle is driven until it transitions to a charge-sustaining mode.

3.4 CHARGE-SUSTAINING (CS) MODE

An operating mode where the HEV runs by consuming fuel energy while sustaining the electric energy of the RESS over time.

3.5 DC BATTERY POWER

The DC electric power flowing to or from the RESS terminals. This includes the power for propulsion, going to the DC/DC converter, and all other accessories powered on the DC bus.

3.6 DC/DC CONVERTER

The power converter device typically found on an electrified vehicle that converts power from the traction RESS bus to the low-voltage (12 V nominal) bus.

3.7 DC PROPULSION POWER

The DC electric power flowing to the propulsion system. It does not include power flowing to the DC/DC converter or any other accessory on the DC bus.

3.8 DRIVETRAIN

The rotating components of a vehicle mechanically connected to the driving wheels when the transmission is in neutral gear or mode. This includes the tires, wheels, brake disks/drums, drive shafts, differential, propeller shaft, transmission output shaft, and some components within the transmission. Because power-producing components are not part of the drivetrain, for electrified vehicles with no mechanical neutral state, the drivetrain does not include electric motors or engine.

3.9 ELECTRIFIED VEHICLE (also xEV)

A class of vehicles with a powertrain that includes an RESS used to power one or more electric motors used for vehicle propulsion. For purposes of this document electrified vehicles include the hybrid-electric vehicle (HEV), the plug-in hybrid-electric vehicle (PHEV), the fuel cell hybrid-electric vehicle (FCV, or FCEV), and the battery electric vehicle (BEV, or EV).

3.10 EFFICIENCY FACTORS (K1, K2)

Two efficiency factors (a value between 0 and 1) are established to describe the power losses from measurement locations in the powertrain to locations where rated system power is defined. Take note of the direction of power flow in the application of K1 and K2 in Figure 1 and see Equations 1 and 2. The K-factor equations below may account for the total system power, or only a portion of the total depending upon the propulsion system application.

$$P_{LOC1} * K1 = \text{Motor(s) shaft power} \quad \text{(Eq. 1)}$$

$$P_{LOC2} = \text{Rated system power} * K2 \quad \text{(Eq. 2)}$$

See Appendix C for more detail on measurement points as it pertains to auxiliary loads, the RESS, and motor/generator(s).

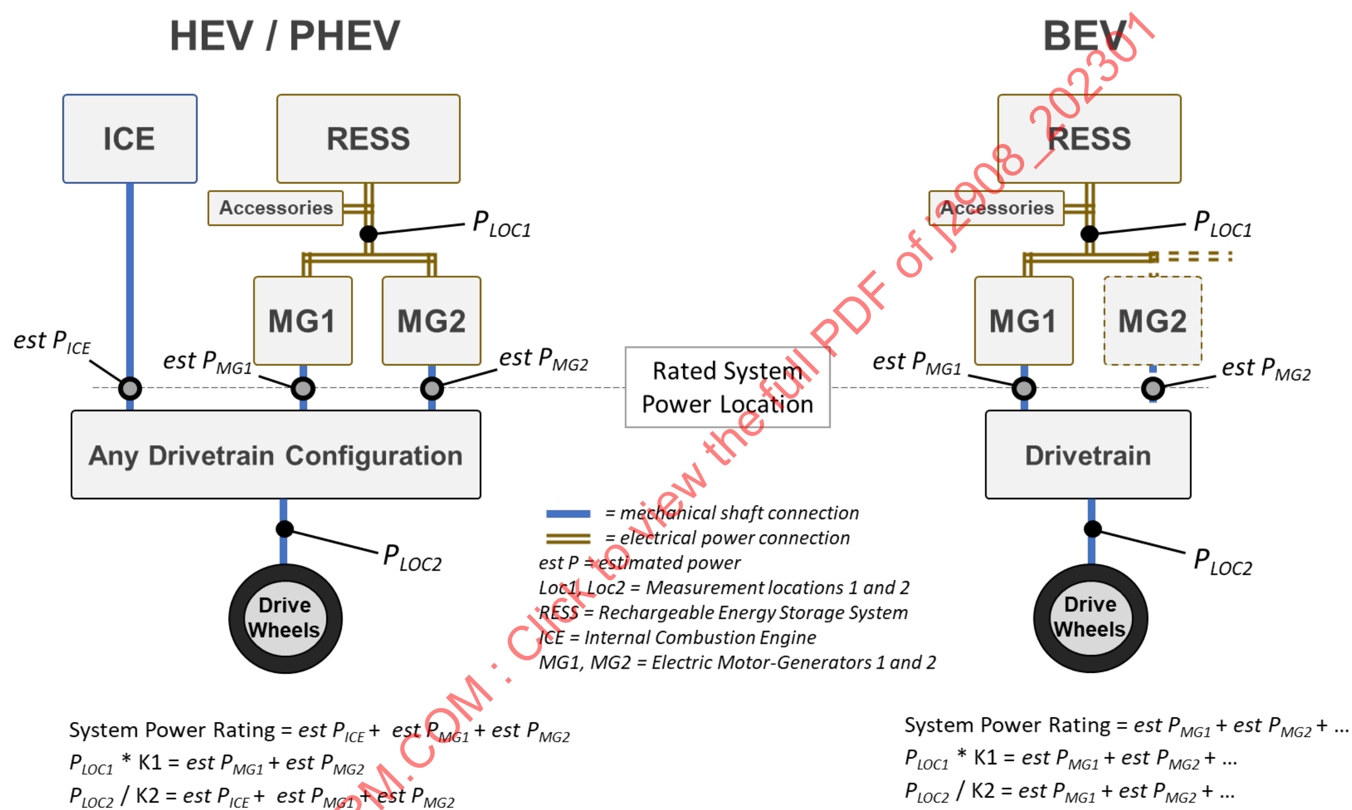

Figure 1 - Diagram relating system power, test points, and efficiency (K) factors

3.11 FULL CHARGE

For PHEVs and BEVs, the RESS state after the vehicle has completed recharging according to the manufacturer's recommended procedures. The recharging must be complete, as indicated by a vehicle recharging indicator light changing to the "off" state or other dash display indicating "full." If the vehicle has been at rest in a fully charged state for more than 36 hours, it is recommended that the operator repeat the recharge cycle to re-establish full charge.

3.12 MOVING AVERAGE FILTER

A moving mean, or rolling mean calculation applied to the raw collected data. This filter calculation creates a series of averages based on the raw data. The peak value from a moving average filter data set represents a peak in the context of a specific duration (the length of the moving mean window).

3.13 POWERTRAIN

The entire system of parts, components, and subsystems that produce and transmit rotational power to the wheels for vehicle propulsion (including the engine and/or electric motors).

3.14 RATED SYSTEM POWER

The sum of mechanical shaft power outputs of all components contributing to the propulsion of the vehicle at the condition of rated wheel power (maximum power). The precise determination is found by applying the appropriate signal processing as described in Section 9 to the system power signal estimated in Section 8.

3.15 RATED WHEEL POWER

The maximum power found by measuring torque and speed of the driven wheels, hubs, or axles and applying the appropriate signal processing in Section 9 to the power versus time signal acquired during the wheel power test (WPT) procedure in Section 7.

3.16 RECHARGEABLE ENERGY STORAGE SYSTEM (RESS)

A rechargeable storage system that provides electric energy for electrical propulsion, ancillaries, and accessories. The RESS may include subsystem(s) together with the necessary ancillary systems for physical support, thermal management, electronic control, and enclosures. It may also be referred to simply as "battery."

3.17 REPORTED STATE OF CHARGE

The RESS remaining charge state as reported by the vehicle's control computer(s), expressed in units of percentage. A high energy state corresponds to a high SOC value. Note: For the purposes of these procedures, 100% could mean usable energy, total energy, nominal energy, or any other logical choice made by the vehicle manufacturer. The reported value is useful in any of these cases, provided that the reported SOC level represents a consistent and reproducible RESS SOC.

3.18 STATE OF CHARGE (SOC)

The representation of the level of charge of the RESS relative to its referenced capacity. SOC is often expressed as a percentage based on a reference total capacity as determined by the manufacturer (for example, 0% = empty charge; 100% = full charge).

3.19 STATE-OF-CHARGE SET POINT

The SOC level established at the conclusion of the appropriate preconditioning procedure detailed in Section 6. It can be tracked and returned to that level for any necessary testing repeats by monitoring the vehicle-reported SOC % level or by tracking the RESS integrated A·h .

3.20 STATE-OF-CHARGE (SOC) CONDITIONING

Any series of steps taken with the test vehicle on the dynamometer that actively changes the SOC to a target SOC level by depleting the RESS or recharging the RESS using propulsion and/or regenerative braking functions. More details of SOC conditioning can be found in Appendix A.

3.21 TEST LOCATIONS (LOC1, LOC2)

These test locations are defined for use with efficiency factors K1 and K2. Test Location 1 ("Loc1") is the measured DC electrical power flowing to the traction drive motor(s). Test Location 2 ("Loc2") is the wheel (hub or axle) power measurement point from the wheel power test (WPT). See Figure 1.

NOTE: These test locations and efficiency factors are referenced in GTR-21 and provided here to harmonize references to K1 and K2 which are helpful in estimating rated system power.

3.22 VEHICLE SPEED AT MAXIMUM POWER (V_{MP})

The specific vehicle speed where wheel power is measured to be at the maximum. The value of V_{MP} is either provided to the tester by the manufacturer (or other third party) or determined using the procedures detailed in 7.1.

3.23 WHEEL ASSEMBLY

A pneumatic tire in combination with a wheel that can be mounted on a vehicle.

3.24 WHEEL HUB (OR HUB)

A rotating member that provides for wheel mounting.

3.25 WHEEL POWER

Total sum of all power-producing wheels measured at the wheels, axles, or wheel hubs using a dynamometer.

3.26 xEV

A vehicle with an "electrified" powertrain system. This document includes hybrid-electric, plug-in hybrid-electric, fuel cell hybrid-electric, and battery electric vehicles.

3.27 Acronyms and Abbreviations

4WD	Four-wheel drive
AWD	All-wheel drive
BEV	Battery electric vehicle
CAN	Controller area network
CD	Charge-depleting
CI	Compression ignition (engine)
CS	Charge-sustaining
DC	Direct current (electric power)
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GTR	Global technical regulation
HEV	Hybrid electric vehicle
HWY	Highway (drive schedule cycle)
IC, ICE	Internal combustion, internal combustion engine
K1, K2	Efficiency factor for location 1 and 2
LOC1, LOC2	Measurement location 1 and 2
MG1, MG2	Motor generator 1 and 2

mph Miles per hour

OEM Original equipment manufacturer

PHEV Plug-in hybrid electric vehicle

RESS Rechargeable energy storage system

SOC State-of-charge

UN United nations

V_{MP} Velocity (at) maximum power

WPT Wheel power test

xEV Any electrified vehicle type (HEV, PHEV, BEV, FCEV)

4. LABORATORY AND VEHICLE EQUIPMENT

4.1 Laboratory Conditions

Lab conditions when testing with an IC engine should broadly comply with SAE J1349 where applicable. Otherwise, conditions in Table 1 apply.

Table 1 - Laboratory conditions

Parameter	Standard Condition	Test Limits
Atmospheric pressure	100 kPa	90 to 105 kPa
Test area air temperature	25 °C	15 to 35 °C

4.2 Vehicle Condition

Before testing, a new vehicle shall have been properly broken in (mechanical run-in), according to the manufacturer's recommendations and/or sound engineering practice, to avoid additional frictional losses resulting from fresh bearings and wear surfaces in the powertrain components.

4.3 Dynamometer Systems

Dynamometer testing shall be conducted with the vehicle operating normally, as if it were driven on-road. This may require speed synchronization of front and rear axles and proper vehicle posture (among other vehicle testing properties). In some cases, proper vehicle operation may require a test mode to be activated that allows normal operation in a dynamometer facility. If the test vehicle has two driven axles, a synchronized 4WD (two-axle) dynamometer shall be used to measure power from all four wheels (both axles).

4.3.1 Hub Dynamometer

A hub dynamometer that directly measures torque and speed is suitable for all testing covered in this document. Because of low rotating inertia, special care needs to be taken to avoid oscillations, overshoots, or other transient problems that may interfere with measurement or could damage the test and measurement hardware or vehicle components. A hub dynamometer connects to the vehicle's hub (usually with the brake assembly remaining intact). Absorption mode is required for all tests in Sections 7 and 10, motoring capability is required for the peak electric regenerative braking power test in Section 10.

4.3.2 Chassis Dynamometer

Tests can also be conducted using a chassis dynamometer if appropriate wheel or axle torque sensors are installed and wheel tire/dynamometer surface slip at full power does not interfere with conducting the test procedures. Sensors must accurately measure all powertrain propulsion power (torque and speed) at the axles (using axle torque sensors) or the wheels (using wheel torque sensors). Absorption mode is required for all tests in Sections 7 and 10, motoring capability is required for the peak electric regenerative braking power test in Section 10.

4.3.2.1 Axle/Wheel Torque Sensors

When using a chassis dynamometer, total powertrain power (torque and speed) must be measured from axle torque sensors or wheel torque sensor assemblies that measure torque between the wheel hub and the tire. Direct measurement of wheel (axle) speeds are necessary, as chassis dynamometer roller speed will not reliably measure wheel rotational speed due to tire slip and deformation.

4.4 Fuel

Fuel energy content and specifications that affect IC engine power shall match what a customer would expect to use when following the manufacturer's recommendations. For more detailed information on fuel, refer to the reference gasoline and fuel specifications sections in SAE J1349.

4.5 Vehicle Network Diagnostic Scan Tool (for Indicated SOC %)

The driver and/or operator must be able to read the vehicle RESS SOC (or accurately track A·h) to achieve repeatable conditions for testing. Typically, the diagnostic scan tool provides this information (among many other vehicle parameters). Dashboard SOC readings can be used if OBD signals are not available for that model vehicle using standard industry OBD tools. In either case, the apparent resolution of the SOC should be at least 1%.

4.6 Exhaust Handling

Use common laboratory practice in routing exhaust out of the lab safely. Route exhaust to avoid generating backpressure or suction at the tailpipe from the lab exhaust system as this would affect engine peak power.

4.7 Cooling Requirements

Fans shall be used to cool the vehicle to maintain proper operating temperatures. However, excessive cooling is prohibited. The external cooling fan shall not generate air speeds higher than vehicle speeds encountered in the test. Use good engineering judgement to conduct the test safely without overheating powertrain components—this may include raising the hood to maintain normal temperatures.

5. MEASUREMENTS

5.1 Initial and Final Measurements

The lab conditions listed in Table 2 shall be recorded at the beginning and end of the test phase for each procedure. Test operator shall verify conditions are within the limits in 4.1 if the vehicle powertrain includes an IC engine.

Table 2 - Accuracy requirements of laboratory condition measurements

Parameter	Unit	Accuracy
Atmospheric pressure	kPa	±0.15
Test area air temperature	°C	±2
Relative humidity	RH%	±5%

5.2 Critical Measurements Logged During Testing

The following critical measurements listed in Table 3 shall be logged at 10 Hz (or faster) during the test phase of each procedure.

Table 3 - Critical measurements and accuracy requirements

Parameter	Unit	Accuracy	Note
Axle/wheel rotational speed	rev/s	±0.05 s^{-1} or ±0.5% of reading	All wheels that provide propulsion. Because of unknown wheel slip, chassis dynamometer speed shall not be used for wheel/axle speed measurements.
Axle/wheel rotational torque	N·m	1% of maximum measurement	All wheels that provide propulsion.
RESS terminal voltage	V	±0.5% of nominal voltage	For HEV, PHEV, BEV, or FCV.
RESS current	A	±0.3% of maximum measurement	For HEV, PHEV, BEV, or FCV.
Auxiliary current and/or Total traction drive unit(s) current	A	±0.3% of maximum measurement	All three DC bus current nodes should be logged: (1) RESS, (2) DC/DC current, and (3) traction drive unit(s) current. If all three currents cannot be accessed, measure two and calculate the third.

5.3 Other Measurements and Vehicle-Reported Parameters Logged During Testing

If rated power is to be determined from the WPT, the test operator shall have a means to log as much vehicle data (both direct measurements and vehicle-provided data) as appropriate for the specific rated power approach (see Section 8). Vehicle-reported data typically comes from reading the vehicle data network (such as CAN). The update rate of the vehicle network data should be 10 Hz or faster. Some or all vehicle-reported parameters listed in Table 4 may be logged as necessary during testing. Use good engineering judgment to determine which parameters are necessary to make the rated power determination.

If the vehicle is an HEV, data must also be collected to perform any necessary corrections to engine power (for temperature and pressure) in the manner defined in SAE J1349. In the case where engine operation from SAE J1349 engine dynamometer testing is matched to the chassis dynamometer WPT, refer to SAE J1349 for further guidance on engine-related parameters and measurements.

Table 4 - List of possible component signals needed for rated system power (requirements depend upon method used)

Component	Parameter	Note
(Each) Motor	Rotational speed	Reported rotational speed.
	Torque	Reported torque, and/or commanded value to component, and/or (measured or reported) DC current supplied.
	Temperature	If available, wherever this is measured or inferred. To establish thermal state and possibly be referenced in bench test.
IC Engine (refer to SAE J1349 for additional engine-related measurements)	Rotational speed	Reported rotational speed.
	Torque (or power)	Reported (crankshaft) torque, and/or power. Proxies for torque or power include command value to component and/or throttle position and/or manifold air pressure and/or reported intake mass airflow. Apply correction formulas where required or appropriate (see 5.4).
	Throttle angle	Reported engine throttle angle. Reported with same 0 to 100% reference used in engine dynamometer testing.
	Manifold air pressure	Measured or reported manifold air pressure.
	Mass air flow	If reported.
	A/F ratio	Reported air/fuel ratio.
	Exhaust backpressure	Measured backpressure at a location near the engine (refer to SAE J1349).
	Exhaust temperature	Measured exhaust temperature at a location near the exhaust port (refer to SAE J1349).
	Temperature	Coolant temperature (measured or reported), or wherever this is measured or inferred that can be used or referenced in bench test.
	State-of-charge %	Used when defining initial RESS state.
RESS	Terminal voltage	Reported values as a check on measured values.
	Current	Reported values as a check on measured values.
	Discharge power limit	Used to identify if vehicle is limiting power due to temperature, SOC, or other battery state.
	Charge power limit	Useful only in regenerative braking power test.
	Temperature	Measured or reported. Wherever this is measured or inferred that can be used or referenced in bench test.

5.4 Correction Formulas

(For HEVs) the applicable correction formulas for spark ignition and compression ignition engines are listed in 5.6 of SAE J1349. These correction formulas are designed for correction of net brake power at full throttle operation; however, for CI engines the formulas may also be used to correct partial power for the purpose of determining specific fuel consumption. These correction formulas are not intended for altitude de-rating. SAE J1349 includes all formulas necessary to correct observed engine power performance for deviations in inlet air and fuel supply conditions and when used correctly, can help to mitigate the environmental effects impacting the power production of the ICE engine used in a hybrid powertrain. Correction formulas should only be used to address the shaft brake power produced by the ICE (using methods described in Section 8).

6. VEHICLE WARMUP AND PRECONDITIONING PROCEDURES

For test-to-test and lab-to-lab uniformity, this section outlines specific procedures to follow to precondition the vehicle for maximum power testing. The reference preconditioning procedures listed below simultaneously provide the thermally warmed up state and the RESS initial energy state (SOC). Variations in warmup and preconditioning procedures depend on the specific powertrain types and modes. Additionally, PHEVs have different preconditioning steps for CS and CD modes.

To address possible OEM-designed user-selectable modes for maximum power, exceptions to the prescribed procedures are provided as follows.

a. Mode exception: The manufacturer (or third party tester) may choose to run the vehicle in a user-selectable mode other than “normal” or “default” if that mode is a “stock” feature, clearly indicated that it is for maximum power performance, and the mode is available to the customer. Invoking the mode shall not require special OEM tools, external computers, be hidden in a menu, nor require a special code to activate.

b. Prep exception: If the OEM-designed, user-selectable power mode includes an automatic prep phase or directions that include how to pre-condition the vehicle for maximum power, these directions can be followed instead of the pre-conditioning procedures below. However, these instructions shall be clearly stated in materials available to the customer.

6.1 Prior to Preconditioning

The RESS should be at a temperature similar to indoor test ambient conditions or as prescribed by the manufacturer for testing. The test vehicle should not be parked outdoors long enough to significantly alter the RESS temperature—especially if the outdoor temperatures are not similar to indoor test temperatures. For repeatability, it is suggested that battery temperatures be within ±10 °C of ambient test cell temperatures before preconditioning.

The test vehicle may require the operator to engage a special “dynamometer mode” to conduct testing on the dynamometer in order to avoid vehicle fault conditions that limit powers or otherwise causes the vehicle to operate abnormally. This mode shall not invoke capabilities or operational behavior that is not experienced in normal operation.

6.2 Preconditioning for HEVs and PHEVs in CS Mode

The objective of this preconditioning is to achieve thermal stability and to find a representative SOC for testing. This may be challenging given that engine operation may always be transient in nature. There are two options for pre-conditioning HEVs in CS mode based on the type of dynamometer used:

Option 1: Using typical emissions chassis dynamometer:

a. Drive two (or more if recommended by the OEM) HWY drive cycles in a row.

b. Check that the engine has warmed up and the SOC level is what is found during typical driving in CS mode.

c. Record the SOC; this set point may be used again if retests are desired.

Option 2: Using dynamometer systems without the ability to run drive cycles (no driver’s aid, etc.):

a. Drive at a constant speed (in road load simulation mode) best suited for warmup (keeping engine on, or in a steady on/off pattern, at 80 to 100 km/h is suggested) for at least 10 to 15 minutes (or longer if recommended by the OEM). Monitor vehicle-reported SOC level and engine speed during the warmup and pay attention to trends in SOC (more easily done if values are displayed on a graph in real time).

b. If SOC has stabilized, come to a stop at a modest rate (no more rapid than -4 km/h/s). Record SOC. The SOC at this point will be your SOC set point for any repeats or reruns.

c. If SOC has not stabilized, follow options i. or ii. accordingly:

   i. If the SOC does not follow a repeating pattern, then continue warmup only until the powertrain has achieved thermal stability. Come to a stop at a modest rate (no more rapid than -4 km/h/s). Record SOC. The SOC at this point will be your SOC set point for any repeats or reruns.

   ii. If the SOC repeats a pattern (e.g., a sawtooth pattern), identify the upper and lower bounds the SOC pattern, wait to end warmup until the SOC lays within the middle 1/3 of this SOC window. Record SOC. The SOC at this point will be your SOC set point for any repeats or reruns.

NOTE: One additional approach to avoid large SOC swings is to run the warmup preconditioning at a speed high enough to ensure continued engine operation (assuming there is a speed where engine-on/off operation transitions to continuous engine-on operation). The SOC swings will presumably be smaller without engine on/off transitions.

6.3 Preconditioning for PHEVs with Blended Charge-Depleting Mode

Because each vehicle's electric-only power capabilities can vary widely, specific instructions to accomplish both vehicle and engine warmup are not prescribed exactly. The following guidelines are presented to help the test operator find the best approach for preconditioning:

a. Recharge RESS to full charge (as specified in 3.11).

b. Select conventional road load dynamometer mode (or equivalent). Accelerate aggressively enough to invoke an engine start (either by speed or by acceleration rate). Modulate speed to 100 km/h and proceed at a steady speed until a total distance of 16.6 km (or roughly 10 minutes) has been traveled on the dynamometer.

c. If driving 16.6 km will reduce the SOC below 1/3 of the usable CD SOC, it is recommended to limit the driving and conclude preconditioning early to maintain the SOC within the middle 1/3 of the usable CD SOC range.

d. Come to a stop at a modest (no more rapid than -4 km/h/s) rate. Record SOC. The SOC at this point will be your SOC set point for any repeats or reruns.

6.4 Preconditioning for BEVs and PHEVs with All-Electric Charge-Depleting Mode

Follow these steps:

a. Recharge vehicle to full charge (as specified in 3.11).

b. SOC-condition and warm up powertrain by driving at 100 km/h for 10 minutes (16.6 km) at a representative load at that speed on level road (conventional road load dynamometer mode).

c. Come to a stop at a modest rate (no more rapid than -4 km/h/s). Record SOC. The SOC at this point will be your SOC set point for your tests, repeats, or reruns.

6.5 Preconditioning for Conventional ICE Vehicle

For conventional ICE vehicles, drive at a constant speed best suited for warmup (e.g.,100 km/h) at a representative load at that speed on level road (conventional road load dynamometer mode). Continue until temperature stability of the vehicle-reported engine coolant temperature (or other suitable engine temperature measurement) is observed.

7. WHEEL POWER TEST (WPT)

The test is a two-step process. The first test finds the vehicle speed at which peak power occurs (V_{MP}). The second test will hold the vehicle speed fixed at V_{MP} during the determination of maximum power. If necessary, mode selection and/or gear shifting may be used as appropriate to provide maximum power during the test.

7.1 Finding V_{MP} with Power Sweep Procedure

If V_{MP} is not known, a power sweep test can be run to find V_{MP}. If V_{MP} is known, skip to 7.2.

7.1.1 Power Sweep Test Procedure

The following steps shall be conducted if V_{MP} is unknown or the operator wishes to validate V_{MP}:

a. Warm up vehicle and precondition according to the applicable powertrain type in Section 6.

b. Set dynamometer to one of two modes: (1) road load, or (2) constant speed ramp rate.

c. Start from an initial speed assumed to be significantly lower than the expected peak power speed, depress accelerator pedal fully, and continue to a final vehicle speed assumed to be above the expected peak power speed.

Variations in how components combine to create full system power may necessitate some experimentation. The test operator may need to vary speed range, dynamometer settings, and accelerator pedal modulation initiating full power to properly locate the maximum-power speed range. V_{MP} may not be best found with one long sweep test. It may require two or more separate test sweep segments to accurately find V_{MP} (see Figure 2).

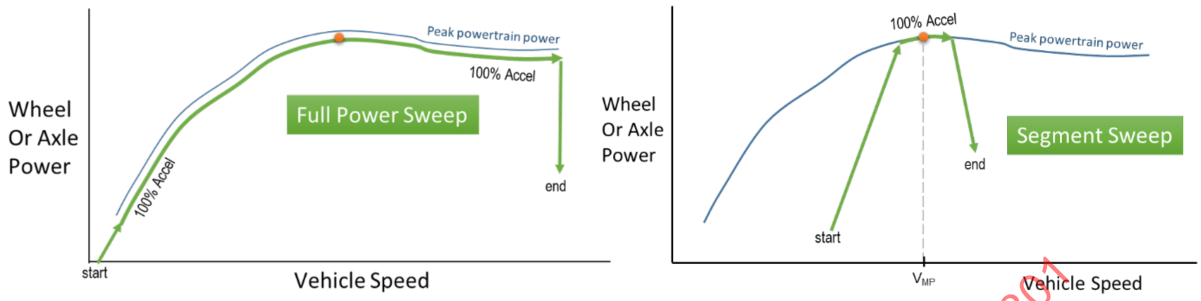

Figure 2 - Finding V_{MP} using power sweep procedure

Repeats of the power sweep procedure can be conducted without recharging the RESS to full charge and repeating the entire preconditioning procedure by repeating the sweep test at the target SOC. Care must be taken not to significantly alter critical vehicle temperature conditions achieved after preconditioning procedures. See Appendix A for SOC conditioning methods used to achieve a particular target SOC. Retests shall not be conducted with the aim to change the thermal state of the powertrain or drivetrain components.

7.1.2 Power Sweep Test Data Analysis

Analyze the data to locate the vehicle speed where peak power was achieved (V_{MP}). If a clear V_{MP} is not evident, use sound engineering judgment to identify a small, manageable set of speed points within a speed range where wheel power was highest and test the speeds separately.

7.2 Wheel Power Test (WPT) Procedure

The objective of conducting the WPT at a fixed speed is to measure the maximum powertrain power at the wheels/hubs while avoiding component and vehicle speed transients, which can impose additional loads due to the inertia of rotating components adding uncertainty to the final results.

Perform the WPT by following these steps:

a. Warm-up dynamometer as recommended by dynamometer manufacturer.

b. Warm up vehicle and precondition according to the applicable powertrain type in Section 6.

c. Set dynamometer mode according to the specific fixed-speed method that will be used. The three suggested test methods are: (1) fixed speed, (2) speed ramp, and (3) polynomial load curve for terminal velocity. See Appendix B for more details on each test method and guidance on which method may provide the best results.

d. Check that the SOC is at the target level. A short SOC conditioning (less than 4 minutes) is recommended to get back to the target SOC level if it has significantly changed after concluding the prep. See Appendix A for guidance on SOC conditioning for the various test methods.

e. Engage logging for all signals (see Section 5) needed later for rated system power (Section 8).

f. Depress accelerator pedal to maximum position quickly (within 1 second) unless other directions are given by the manufacturer. Hold pedal at maximum position and fixed speed (V_{MP}) for at least 10 seconds.

g. End data logging.

NOTE: Modulation of the accelerator pedal prior to maximum position may be necessary to achieve maximum power as recommended by the manufacturer.

Repeated testing (starting at step c) may be conducted without recharging the RESS to full charge and repeating the preconditioning procedure; however, the test must start at the target SOC and the battery temperature must not be significantly different than post-prep conditions. The object of retests is to make adjustments in V_{MP} with changes in dynamometer settings. Retests shall not be conducted with the aim to change the thermal state of the powertrain or drivetrain components.

7.2.1 Repeatability and Retests

This procedure does not require repeats at the same V_{MP}. However, if test-to-test variability in results are suspected, more robust results can be achieved using the average of several tests. Use good engineering judgment to decide if repeat testing is necessary.

8. RATED SYSTEM POWER

For this revision of SAE J2908, a flexible approach is used to determine the rated system power. Because powertrain architectures are so diverse, a single, consistent approach to determine the rated system power has not emerged from engineering practice. Presented here are different methodologies that are all pathways to the same objective: finding the sum total mechanical shaft power of all components providing vehicle propulsion during the WPT conducted in 7.2. The choice should be based upon which option provides the best chance of achieving the most accurate result within the limits of practicality for the application. All options shown below (8.1 through 8.4) should theoretically provide the same result because the desired rated system power signal (whether measured, estimated, or derived) is from the same WPT with the goal of determining the sum of mechanical shaft powers for components providing propulsion. In practice, each approach may yield a different result, again, the aim it to choose the most practical and accurate approach for the application.

It is assumed that this determination is performed by either the OEM for their own product, or a third-party test laboratory that has access to component data (efficiency maps or real-time data from a vehicle bus), or is able to perform bench tests like OEMs typically perform on their own subsystems while under development. Regardless of the process chosen from options in this section, the process is the same: for each time step of data collected in the WPT, generate a calculation/estimation of the sum of mechanical shaft power outputs of all powertrain components contributing to the propulsion of the vehicle. The final step in determination of rated system power is the time-series post-processing calculations described in Section 9. Figure 3 provides a descriptive workflow diagram for determination of rated system power.

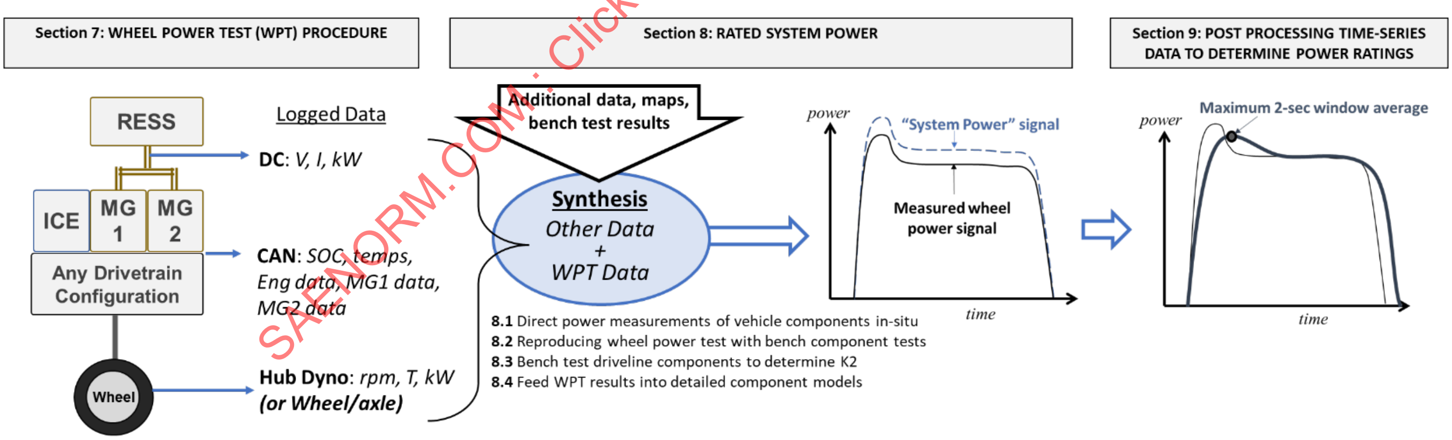

Figure 3 - SAE J2908 testing and post-processing workflow diagram

Sections 8.1 through 8.4 provide guidance to determine rated system power in order of most, to least accurate and verifiable. Specific examples illustrating these approaches are found in Appendix D.

8.1 Direct Power Measurements of Individual Components In-Situ

While this approach may provide the most accurate and verifiable data, it is the most costly, time consuming, and difficult among the options. This approach requires that power from each mechanical component contributing to the propulsion of the vehicle be instrumented to directly measure shaft output power in the vehicle during the WPT. To accomplish this, compact speed and torque measurement sensors would be installed at appropriate locations in the powertrain while maintaining normal operation during the WPT. Data from the sensors are logged and the rated system power is based on direct measurement of all propulsion component power outputs (all propulsion motors or propulsion motors + engine).

8.2 Reproduce WPT with Bench Component Tests

In this approach, first, the WPT is conducted with a comprehensive dataset logged from all the propulsion components. Subsequently, either the propulsion components are removed, or identical components are acquired for additional testing. Good engineering judgement is used to rig components individually or with other components - but power must always be accurately measured for the engine and/or motor(s) shaft(s). The components are individually "bench tested" by accurately recreating ("replaying") the WPT speeds, loads, and other conditions. Care must be taken to completely recreate the conditions (preconditions, speeds, temperatures, initial SOC, voltage, etc.) and the component commands given shall recreate the power/speed trajectory, and duration of the WPT. Like in 8.1, individual component powers are directly measured and summed to determine rated system power.

8.3 Bench Testing Drivetrain Components to Determine Efficiency Factor K2

Instead of testing the power-producing components, the drivetrain (the series of rotating components and gears between the power-producing components and the wheels) can be bench tested to determine their efficiency. This testing yields the factor K2. This method is most appropriate for powertrains where transmission power losses are more easily measured than the power of propulsion components themselves. Rated system power is determined by using Equation 2 with an accurate K2 (at maximum power) and measured wheel power (also see Figure 1). This method is not be appropriate for some configurations, including the power-split. Appendix D offers a few examples illustrating this approach

8.4 A Priori Component Data, Models, or Real-Time CAN Data

This approach leverages deep understanding of component operation, efficiency, and performance in the whole propulsion system. This knowledge is presumably gained during manufacturer development. Whereas the methods in 8.2 and 8.3 determine rated system power with results from additional, dedicated bench tests, this method uses pre-existing component performance data in the form of maps, models, and/or efficiency factors presumably from bench tests conducted a priori. The component data or models are applied to the signals, parameters, and states collected from the WPT. The accuracy of this method is the most difficult to verify by a third party because, unlike the other three methods, it relies upon additional data or information outside of what is gathered in this test procedure. Like the other approaches, the goal is to determine the actual shaft powers of the powertrain components during the WPT. The component models or data maps are applied to the WPT results in post-processing, or in real-time if the operator chooses to rely upon component power outputs broadcasted by the on-board computer controllers—which are running some form of a real-time model (or look up table).

9. POST-PROCESSING TIME-SERIES DATA TO DETERMINE POWER RATINGS

The time series data from the WPT and the resulting rated system power determination shall both be analyzed to determine rated wheel power and rated system power. These calculations are made after the processing detailed in Section 8. The entire testing and post-processing workflow is depicted in Figure 3.

The relationship between the duration and the measured peak power varies significantly from vehicle to vehicle. To provide consistent results, this post-processing procedure defines a standard way to calculate final rated power results. There are two separate power calculations: (1) a 2-second "impulse" power, and (2) a "sustained" power that finds the 2-second power after 8 seconds of full-power command is given.

9.1 Impulse Power (2-Second Maximum)

Impulse power is defined as the maximum average power over a 2-second period. To determine the numerical peak in the time series data, apply a moving average filter, 2 seconds in length, for the entire set of fixed speed power tests (7.2). The maximum value in the filtered power (Equation 3) set is the peak, 2-second rating:

$$\text{FilteredPower}(t) = \frac{1}{N}\sum_{i=0}^{N-1} x(t+i) \quad \text{(Eq. 3)}$$

where:

t = time

x = raw data of power measurement

N = number of points, for 2-second window, N = [data sample frequency in Hz] x [2 seconds]

FilteredPower(t) = filtered power at time t

9.2 Sustained Power (2-Second Window from t = 8 to 10 Seconds)

Sustained power is defined as the average power (actual measured power, not filtered power) over a 2-second period that starts at 8 seconds and ends at 10 seconds after the 100% full accelerator pedal command is given. The assumption is that the 2-second window from t = 8 to 10 seconds is lowest power segment the test; however, if this is not the case, to avoid gaming the sustained power shall be calculated from the lowest 2-second window average value in the 10 second period, starting at t = 2 seconds.

NOTE: When the accelerator pedal is depressed to full, t = 0 when the full pedal position (100%) is achieved.

10. MISCELLANEOUS xEV TESTS

This section outlines testing options that provide additional power rating data for specific xEV types. These additional tests are optional and not necessary for testing and reporting wheel power or rated system power.

10.1 PHEV Electric-Only Drive Power Test (PHEV Only)

This test shall only apply to PHEVs in charge-depleting mode. The objective of this test is to determine the mechanical axle/wheel power in charge-depleting mode under electric-only power.

NOTE: If necessary, the mode selection switch and/or gear shift may be used as appropriate.

10.1.1 Vehicle Warmup and SOC Preconditioning for PHEVs in Charge-Depleting Mode

Use the same warmup and preconditioning procedure detailed in 6.3.

10.1.2 PHEV Electric-Drive Power Test Procedure

A suitable procedure to quickly sweep through a large speed range for this test was not apparent at the time of SAE J2908 development. In the absence of other available information that can narrow the vehicle speed range of interest, the entire electric-only vehicle speed range may need to be tested.

The starting test speed should be the maximum electric-only speed (above this speed, the vehicle forces the engine on during steady-speed driving). This speed may be found from other testing or from manufacturer’s information. Starting from this high speed, vary speeds from high to low and repeat the procedure as follows.

Perform the following steps:

a. Select fixed-speed dynamometer mode.

b. Engage neutral gear on the test vehicle.

c. Engage the dynamometer to the desired speed

d. Condition SOC level.

   i. If the SOC level is below the target, engage the drive gear and wait until the vehicle-reported SOC rises to the target SOC level.

   ii. This assumes that there will be mild regenerative braking recharging the batteries. If the SOC is above the target, depress the accelerator pedal to discharge the RESS pack, assuming that the vehicle will be in an electric-only drive mode.

   iii. It may be advantageous to reduce speed first before depressing the accelerator pedal to discharge the RESS. The best speed depends upon the vehicle; 30 to 50 km/h is a sound suggestion.

e. Depress the accelerator pedal at a slow and steady rate from zero position until the engine powers up. The ramp rate of power (controlled by the accelerator pedal) should be sufficiently slow to find the precise limit of electric power before the engine is engaged.

f. Reduce the accelerator pedal level until the zero position is reached.

g. Reduce the dynamometer speed by 10 km/h. Repeat test starting at step b in this sequence.

   i. Use good engineering judgement to avoid excessive power regeneration to the batteries while the dynamometer is in fixed speed mode.

10.1.3 Post-Processing and Reporting PHEV Electric-Drive Power

The time series data shall be analyzed to determine the peak wheel/hub power while the engine is not powered (not spinning). Make a new data set with wheel power data removed at those instances in time when the engine is rotating. It is not necessary to define the peak over a specific time window; however, data must be filtered for noise and drivetrain dynamics. Use of a small moving average window (0.3 to 0.5 second) to process the data is suggested.

The results of this analysis should yield a set of peak wheel power values over the vehicle speed range tested. The peak value is the PHEV electric-drive powertrain power.

10.2 Peak Electric Assist Power Test (xEVs Only)

This test shall only apply to xEVs. This test shall determine the maximum electrical DC power flow from the RESS to the powertrain system during propulsion. For guidance in measurement location, see Appendix C.

10.2.1 Data Source

If the WPT has been previously completed, then a separate peak electric assist power test may not be necessary. The data used to determine peak electric assist power could be from any of the tests performed in Section 7. The data source must be a test that complies with the SOC and thermal conditions specified in Section 6. The three options presented below are suitable tests to source the data for peak electric assist power.

10.2.1.1 Option 1: Data from 7.1 (Power Sweep Test to Find V_{MP})

Existing DC electric power from the power meter collected during the power sweep test may be suitable for defining the maximum battery assist.

10.2.1.2 Option 2: Data from 7.2 (Fixed Speed Power Tests)

Existing DC electric power from the power meter collected during the fixed speed test may be suitable for defining the maximum battery assist.

10.2.1.3 Option 3: Dedicated Testing

A separate test dedicated to achieving maximum RESS power can be performed on a dynamometer or on a test track or on the road without the use of torque sensing elements. A DC electric power meter is required. A preconditioning procedure similar to that of Section 6 is required.

10.2.2 Post-Processing and Reporting Peak Electric Assist Power Rating

To determine the numerical peak in the time series data, choose a window filter of 2 seconds in length for the entire set of data. See Section 9 for details of applying the window average filter. The peak electric assist power rating is the maximum value in the set of processed data (moving average window).

10.3 Peak Electric Regenerative Braking Power Test (HEV, PHEV, and BEV only)

This test shall determine the maximum electrical DC power flow from the drive system to the RESS during vehicle braking. For guidance in measurement location, see Appendix C.

Maximum regenerative braking power levels can be found during “normal” driving, and thus may not require high-power testing. The data used could be from existing chassis dynamometer cycle testing. However, if those data are not adequate, then a dedicated test is appropriate.

10.3.1 Option 1: Speed Drive Cycles in Dynamometer Road Load Mode

Standard cycles for fuel economy, emissions or custom speed cycles with progressively higher deceleration rates may contain the braking rates and conditions required to determine the peak electric regenerative braking power rating. Standard drive cycles performed according to those described in SAE J1711 or SAE J1634 may be adequate.

10.3.2 Option 2: Fixed Speed Braking Testing

The dynamometer can also be operated in a fixed speed mode, as prescribed in 7.2. At varying vehicles speeds, enact varying levels of regenerative braking force by depressing the brake pedal. Take care not to brake for too long, too hard, or too often, as the friction of braking may generate excessive heat. It is advisable to periodically check the rotor temperatures using an IR temperature gun. It is advisable for the operator to view a real-time plot of the DC RESS power to witness the saturation of power with increasing brake effort.

10.3.3 Post-Processing and Reporting Peak Electric Regenerative Braking Power

The time series data shall be analyzed to determine the peak DC RESS power, as measured at the terminals, and flowing to the RESS during braking. Peak electric regenerative braking power is not valid if a portion of the electrical energy flowing to the RESS was derived from converting engine shaft power. All power generated shall only come from vehicle inertia. Apply a moving window average filter of 2 seconds in length to the entire set of DC RESS power. The peak value from the set of filtered data is the peak electric regenerative braking power.

11. NOTES

11.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

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