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Development and Validation of a Test Procedure for Determining the System Power of Hybrid and Plug-In Hybrid Electric Vehicles

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Summary

The World Harmonized Light Vehicles Test Procedure (WLTP) determines vehicle classification and cycle downscaling based on engine power rating. However, it does not specify a method for determining an equivalent system power rating for electrified vehicles that have more than one source of propulsion, such as an internal combustion engine and one or more electric motors. This paper describes the development and initial validation of a draft test procedure being considered by the United Nations Economic Commission for Europe (UN ECE) Informal Working Group (IWG) on Electric Vehicles and the Environment (EVE). This paper reports on a first exploratory phase of testing, in which hybrid vehicles were tested at laboratories in North America and Europe to support initial assessment of the draft procedure and to generate relevant information and experience to assist its further development by the EVE IWG.

Keywords: testing processes, power, vehicle performance, regulation, HEV (hybrid electric vehicle)

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1 Introduction

The United Nations Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29) is a regulatory forum within the UNECE Inland Transport Committee. Several working parties exist under WP.29, including the Working Party on Pollution and Energy (GRPE) which develops emission and energy requirements for vehicles. Several informal working groups (IWGs) exist under GRPE, including the Electric Vehicles and the Environment (EVE) IWG. Under the second of two mandates, the EVE IWG has been tasked with several initiatives related to vehicle electrification, one of which is the development of a test procedure for determining the combined system power of hybrid electric vehicles (HEVs) and pure electric vehicles (PEVs) with more than one propulsion motor.

This paper outlines the structure of the draft test procedure and preliminary results of HEV testing performed in 2018 at the U.S. Environmental Protection Agency (EPA), Environment and Climate Change Canada (ECCC) and European Commission Joint Research Centre (JRC).

1.1 Background

Passenger vehicles are commonly assigned a maximum power rating, which is useful for comparing the performance of different vehicles. This rating is sometimes also used for other purposes, such as for certification or taxation.

Traditionally, vehicle power ratings are based on the maximum rated power of the internal combustion engine (ICE) as measured on a test stand. This is straightforward and convenient, because the power rating may be applied to any vehicle that uses the same engine. Although it neglects the losses between the engine and the road, this metric is generally suitable for comparison if one assumes that the engine is the sole power source, that the engine will generate the same maximum power when installed in a vehicle as it generates on a test stand, and that most vehicles will experience similar losses between engine and road.

These assumptions begin to break down for HEVs that have more than one propulsion source, such as an ICE and one or more electric motors, or PEVs with multiple electric motors. For these vehicles, the maximum power output depends on how the control system combines the power outputs of the propulsion sources when the driver demands maximum power. Summing the bench test results from each source is not reliable because there is no guarantee that all of the propulsion components will be delivering their maximum rated power under this condition. A further complication is that the available battery power may constrain the power output of a motor independently of its bench power rating.

For these reasons, maximum vehicle power should be measured while the components are in operation within the vehicle during a maximum power demand event. Also, in order for the measured power to be qualitatively comparable to the engine-based power rating of a conventional vehicle, it should represent the power as it would be measured at a reference point that is mechanically analogous to the output shaft of a conventional engine (as opposed to being measured at the wheels, or some other point in the powertrain).

The most direct approach would be to instrument the output shafts of each propulsion source with torque and speed meters. However, this requires invasive instrumentation and may not be physically possible in many cases. A more practical approach would measure power flow at alternative points along the drivetrain that are easier to instrument, and convert these measurements to shaft output power (the reference point) by accounting for the energy losses between the measuring points and the reference point. The measuring points could either be upstream or downstream of the shaft reference point. Options for measuring power at an upstream point might include measuring battery output power, engine speed, and intake manifold pressure or fuel flow rate. Options for measuring at a downstream point might include measuring wheel power using any of: a hub dynamometer, wheel torque and speed sensors, or the dynamometer rollers. Shaft output power could then be estimated by using an efficiency factor representing electric motor and inverter efficiency, or gearbox efficiency, respectively.

1.2 Relation to WLTP

The World Harmonized Light Vehicles Test Procedure (WLTP) [1] specifies that test vehicles be classified into one of several distinct power-to-mass ratio classes [2], and that low-powered vehicles that cannot follow the standard reference cycle be tested on a modified cycle that has been downscaled [3]. Both of these provisions require the power rating of the vehicle as an input.

In the case of conventionally powered vehicles, the power is an engine power rating determined according to ISO 1585 [4] or UN Regulation 85 [5]. However, in the case of HEVs, or PEVs having more than one motor, WLTP recognizes the difficulty of determining a system power and places all such vehicles into Class 3. A standard test procedure for determining the system power of hybrid electric vehicles would thus be a useful addition to WLTP.

According to its mandate under the UNECE, in 2015 the EVE IWG formed a subgroup to investigate options for developing a test procedure for this purpose, applicable to UNECE class M1 and N1 light duty HEVs and pure electric vehicles (PEVs) with more than one propulsion motor. Because conventional vehicles under WLTP are classified and downscaled by reference to engine power, the system power rating is intended to be comparable and so should represent the power at a similar reference point within the powertrain as discussed previously.

1.3 Procedures considered

The EVE IWG examined several approaches being pursued by various organizations at the time [6]. The Society of Automotive Engineers (SAE) was developing SAE J2908 [7]; the Korea Automobile Testing & Research Institute (KATRI) was investigating its own standard [8]; and the International Organization for Standardization (ISO) was developing ISO Standard 20762 [9]. The EVE IWG consulted with and hosted presentations from these organizations, discussing the merits of each of the methods. Consensus was reached that the ISO method presented a suitable structure as a basis for developing a power determination test for WLTP purposes. The basic structure of the draft procedure is therefore similar to the ISO procedure, with modifications as necessary to align with WLTP requirements and the needs of a regulatory application.

1.4 Overview of draft procedure

The first challenge in developing a test procedure for system power determination is to identify a reliable way to elicit a maximum power demand event in a laboratory setting. The second challenge is to specify how to take power measurements during this event at an appropriate point in the powertrain and convert the measurements to a total system power metric.

1.4.1 Eliciting maximum power demand

In the draft procedure, measurements are taken when the hybrid system delivers maximum power on a chassis dynamometer. This condition is created by operating the dynamometer in constant speed mode at the speed at which maximum power is developed on full and rapid depression of the accelerator pedal. If this speed is not specified by the manufacturer, or for verification, the draft procedure recommends testing over a range of different dynamometer speeds and issuing full accelerator pedal command at each speed.

1.4.2 Power measurement points

The draft procedure defines two equivalent methods to determine system power.

In the first method, called Test Procedure 1 (TP1), measurement occurs upstream of the reference point. System power is the sum of engine power and motor power. Engine power is the rated power by ISO 1585 at the observed operating point. Motor power is based on measured battery power, adjusted by a factor that represents efficiency of the inverter(s) and motor(s).

In the second method, called Test Procedure 2 (TP2), measurement occurs downstream of the reference point. System power is measured at the drive axles or wheels, and adjusted by a factor that represents the efficiency of the transmission/gearbox (and corrected for tire losses, if applicable).

Calculations are then performed to determine the system power according to TP1 or TP2. In each, a “peak” power is derived from a 2-second moving average over a 10 second window from the start of maximum accelerator depression, and a “sustained” power is the average power between the 8th and 10th seconds.

By defining both TP1 and TP2, the draft procedure accommodates variations in vehicle instrumentation possibilities and differing laboratory capabilities or preferences. In theory, both TP1 and TP2 should deliver the same result if the source measurements and the efficiency factors are accurate. It is desirable to minimize the degree of variation. Likewise, results under either TP should be consistent and repeatable to minimize the need for repeated testing.

1.4.3 Outline of TP1

TP1 calls for measurement of engine speed, intake air pressure or fuel flow rate, battery output voltage ($U_{battery}$), and battery output current ($I_{battery}$). Optionally, power to the DC-DC converter (P_{DCDC}) and 12V auxiliaries ($P_{auxiliaries}$) are also measured, or a default value specified in the draft procedure can be used. An efficiency factor (K1), which represents the energy efficiency between the electrical measurement point and the output shaft(s) of the electric motor during maximum vehicle power, is also needed. This may be provided by the manufacturer, or if not available, the draft procedure suggests a default value.

$$P_{HEV\ system}\ [kW] = ICE\ power\ + \left(\frac{U_{battery} \times\ I_{battery}}{1000} -\ P_{DCDC} -\ P_{auxiliaries} \right) \times K1$$

ICE power is derived from the measured engine speed by reference to engine test results of ISO 1585, which reports engine output power, intake air pressure, and fuel flow rate at wide-open throttle (WOT) over the full range of engine operating speed. WOT is confirmed by comparing the measured intake air pressure or fuel flow rate to the test result at the observed engine speed. If WOT is not confirmed, options are to ask the manufacturer for the engine power output under the measured conditions, perform ISO 1585 under the measured conditions, or perform TP2. The procedure also provides for correction of engine power for environmental conditions under ISO 1585.

1.4.4 Outline of TP2

TP2 calls for measurement of power at the wheels (P_{wheels}), as measured by wheel torque and speed at each driven wheel or axle shaft. An efficiency factor (K2), representing the mechanical efficiency between the reference point and the measurement point during maximum vehicle power (essentially, the gearbox or transmission efficiency), is also needed. This may be provided by the manufacturer, or if not available, the draft procedure suggests a variety of default values based on gearbox architecture. Ideally, battery current and voltage, and power to DC-DC converter and auxiliaries, should also be measured (as in TP1) to allow the contribution of electric motor power to be separated from the engine power, in case the latter requires correction for environmental conditions.

$$P_{HEV\ system}\ [kW] = \frac{P_{wheels}}{K2}$$

The draft procedure allows for instrumentation by torque and speed sensors on each driven wheel or axle, or dynamometer-recorded roller torque and speed with a correction for tire losses.

1.4.5 Vehicle conditioning and SOC adjustment

Prior to the test, the vehicle undergoes a soak period, and then is conditioned by operating on the chassis dynamometer in road load mode at 60 kilometers per hour (kph) for a period of at least 20 minutes. The intent is to allow the powertrain components to reach a stable operating temperature that will be maintained throughout the test. Each power pulse takes place at the maximum normal operating SOC of the battery (or an applicable SOC specified by the manufacturer) with regeneration of the SOC between pulses by coasting or light regenerative braking.

2 Testing

ISO 20762 was carefully and extensively validated as part of its development process. Although the draft procedure is structurally similar, the EVE IWG recognized that the modifications necessary to align with WLTP and to fit a regulatory application would call for similar validation of the new procedure. Validation testing would also serve to bring useful information and experience into the drafting process.

The testing described in this paper primarily sought to generate information regarding: (a) the general practicability of implementing the draft procedure as written at the time, (b) the repeatability of identifying the speed of maximum power, (c) generating examples of specific sources of potential variation between TP1 and TP2 in addition to those that had already been discussed in EVE IWG, and (d) the repeatability of a given TP result for a given vehicle at a given laboratory.

At the EPA National Vehicle and Fuel Emissions Laboratory (NVFEL), the draft procedure was applied to a 2013 Malibu Eco mild hybrid and a 2013 Chevrolet Volt plug-in hybrid. At the Environment and Climate Change Canada (ECCC) laboratory, the procedure was applied to a 2016 Chevrolet Volt and a 2018 BMW 530e. At EU JRC the procedure was applied to a pure hybrid and a plug-in hybrid vehicle.

2.1 Instrumentation

Test vehicles at each laboratory were instrumented to provide the data required by TP1 and TP2. At EPA, all signals except intake manifold pressure were collected from CAN signals at approximately 10 Hz. At ECCC and JRC, battery power was measured by current clamps and voltage meters. Other relevant signals such as vehicle speed, accelerator position, and component temperatures were also collected through CAN and/or physical instrumentation. As the testing was focused on variation for a given vehicle (rather than absolute accuracy or comparison across vehicles), variations in instrumentation do not impact the findings.

2.2 Test plan

Prior to testing, the high-voltage battery was charged to full SOC (plug-in vehicles only). A conditioning cycle was then run at the start of each test session. Component temperatures were monitored and recorded during the test. For all tests, the vehicle was secured by rigid restraints and/or chains at front and rear, and the exhaust was connected to the building exhaust system.

An initial test session was devoted to identifying the speed of maximum power by conducting a speed sweep from 50 to 130 kph in 10 kph increments in dynamometer constant speed mode. At each speed, two pulses of maximum power were performed for up to 15 seconds each, by rapidly pressing the accelerator to the floor. The state of charge (SOC) of the battery was restored after each pulse by light regenerative braking or by allowing the dynamometer to coast the vehicle. After the initial ("coarse") speed sweep was completed, the wheel power measured at the dynamometer rollers was analysed to identify the speed range where maximum power was generated. A second test session was devoted to a second ("fine") sweep to identify the speed more precisely, again with two pulses at each speed but within a narrower range of speeds. Assuming that the second sweep includes the speed of maximum power, this sweep yields the data necessary to perform TP1 and TP2 calculations.

2.3 Results

2.3.1 Observations on general practicability

The 20-minute conditioning cycle was sufficient to warm up most of the relevant components. However, as shown in Figure 1, the transmission oil temperature of the Malibu Eco reached approximately 70 deg C during the 20-minute conditioning cycle, but continued to rise further as the test sequence was conducted.

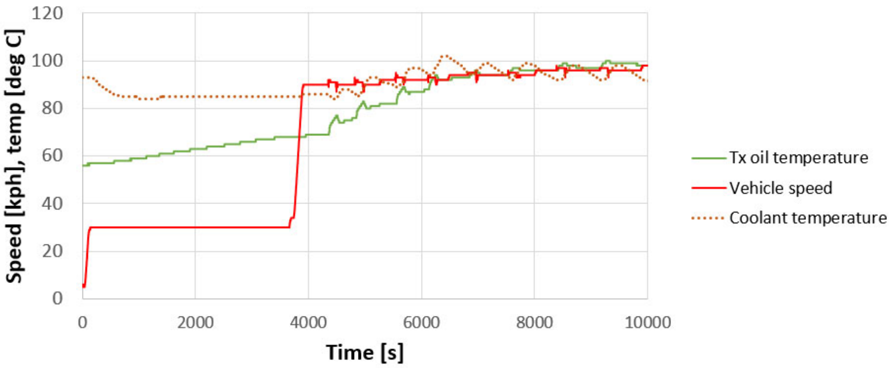

Figure 1: Warmup of engine coolant and transmission oil temperature, 2013 Malibu Eco

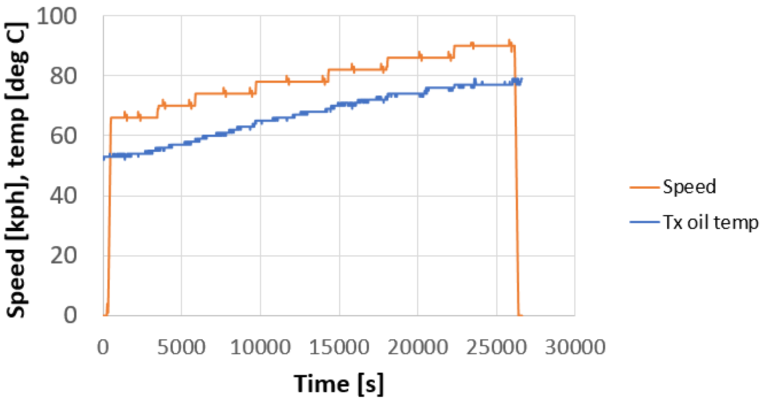

Figure 2: Continued warmup of transmission oil temperature, 2013 Volt

As shown in Figure 2, this also affected the 2013 Chevy Volt, which was operated in Hold mode during the conditioning cycle, a mode that reduces depletion of the battery SOC by operating in a charge-sustaining mode. Transmission oil temperature had reached only about 55 deg C at the end of the conditioning cycle and continued to rise during the test sequence.

This suggests that the 20-minute conditioning cycle is sufficient for most components, but may not be sufficient to ensure a stable transmission operating temperature. This would particularly impact TP2, which relies on an accurate assessment of transmission efficiency.

In conducting the test procedure, it was noted that the draft procedure does not specify the rate at which SOC should be regenerated between test pulses (although it does specify regeneration as a permissible technique). In order to avoid inadvertently derating the battery, test personnel felt that it would be helpful to specify a target C-rate or provide similar guidance.

It was noted by ECCC that the recommended process of cycling through a range of dynamometer speeds to identify the speed of maximum power is time consuming and requires constant-speed mode capability of the dynamometer, which not all laboratories may possess. ECCC also observed some momentary variation in dynamometer speed at the start and end of each power pulse, as the dynamometer requires a finite amount of time to adjust. JRC had earlier reported their experience conducting acceleration runs in road load mode, in part to determine the gear shift strategy using speed variation. ECCC then investigated the feasibility of identifying the speed of maximum power by this means. As shown in Figure 3, the power measured during a series of free acceleration runs of the 2016 Chevy Volt at ECCC matched well with the power measured during steady-state runs at fixed dynamometer speeds. This experience at ECCC and JRC suggests that acceleration runs might provide an alternative way to identify the speed of maximum power.

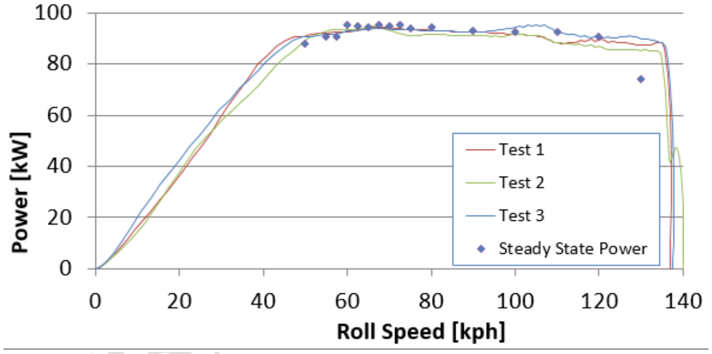

Figure 3: 2016 Chevy Volt acceleration runs vs. steady state

2.3.2 Identifying the speed of maximum power

The initial coarse sweep for the 2013 Malibu Eco is shown in Figure 4. The plot shows the power measured at the dynamometer rolls. It can be seen that the power output increases at each speed up to 90 kph, until a gear shift intervenes at 100 kph, causing the power output to decline. A finer speed sweep was conducted in this region and identified the speed of maximum power as occurring at 93 kph, with a maximum power of about 111 kW at the wheels.

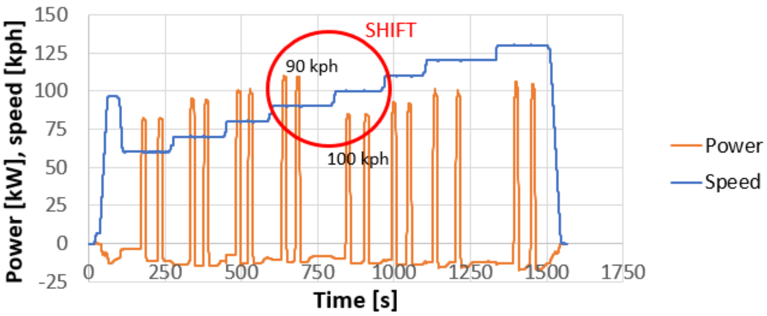

Figure 4: Initial coarse speed sweep for 2013 Malibu Eco

For the 2013 Chevrolet Volt (Figure 5), which was powered solely by electric drive during the test, the coarse sweep showed very little variation in power output. A finer sweep conducted between 66 and 90 kph identified a slight peak at 86 kph, with 93.5 kW measured at the wheels. The shape and magnitude of each pulse was highly uniform, as illustrated for the Volt in Figure 6.

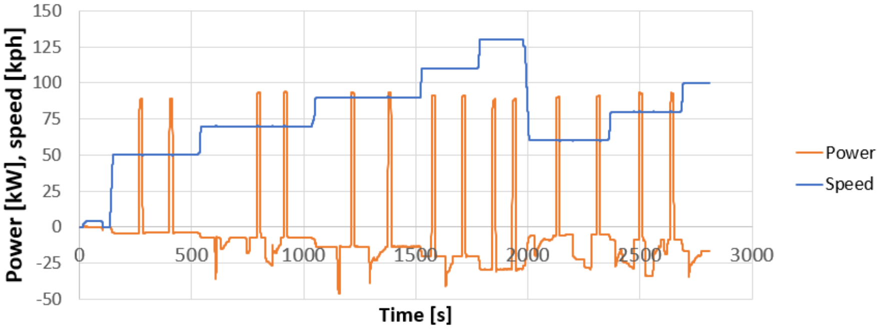

Figure 5: Initial speed sweep for 2013 Chevrolet Volt

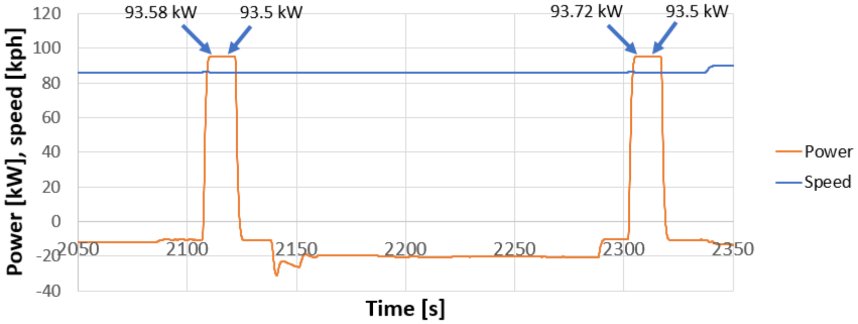

Figure 6: Repeatability of maximum power measured at 86 kph, 2013 Chevrolet Volt

Testing at ECCC was similarly successful at identifying a speed of maximum power for both the 2016 Chevy Volt and the 2018 BMW 530e. As shown in Figure 7, for the 2016 Chevy Volt, two observations of power at the dynamometer rolls were conducted at each of a variety of speeds, with only a small variation between each observation being observed within the range of peak power. As with the 2013 Volt, a near-maximum power output was observed over a range of speeds rather than at a single specific speed, making it difficult to identify a single speed value.

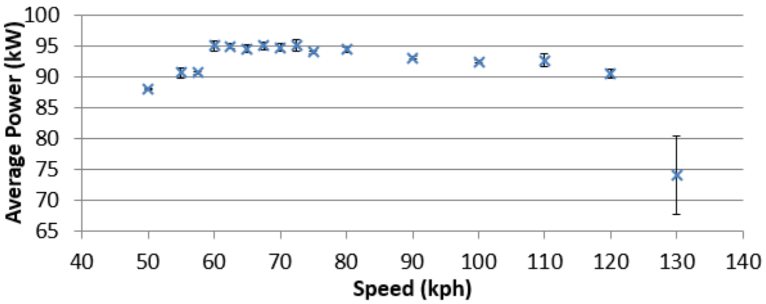

Figure 7: 2016 Volt average steady state power at the dynamometer rollers

As shown in Figure 8, ECCC also found that the maximum power at the rolls was consistent at each speed for the BMW 530e.

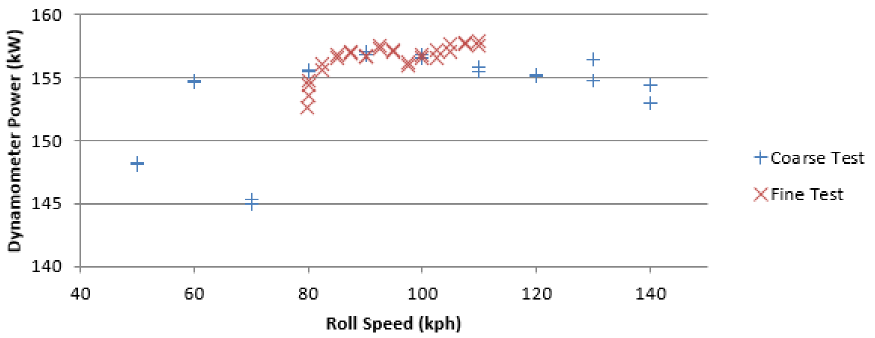

Figure 8: Repeatability of maximum power at the dynamometer rollers, BMW 530e

2.3.3 Variation and repeatability

The EVE IWG has discussed a number of potential sources of variation between TP1 and TP2. This paper presents initial observations regarding two of the sources, which are the estimation of tire losses in TP2, and the use of default K factors.

The draft procedure allows TP2 data to be measured by torque and speed meters installed on the gearbox output shaft or wheels, or measured at the dynamometer rolls. In the latter case, a correction is to be applied to account for losses in the tires, but a method is not specified.

Tire rolling resistance coefficient (RRC) data was not available for any of the tested vehicles. For the 2013 Volt, because the vehicle was tested in four-wheel drive mode of the dynamometer, the dynamometer recorded a power drag on the rear roller resulting from tire rolling resistance and bearing losses of the rear wheels. This made it possible to estimate an equivalent RRC that includes tire and bearing losses.

At 86 kph, the rear roller drag was 1.8 kW. The weight on the rear axle, as measured on a platform scale, was 1704 lb (773 kg). The nominal wheel radius was 0.334 m based on rim and tire specifications. At 86 kph the wheel rotational speed was 11.38 rev/s. Using these figures, the equivalent RRC was calculated as approximately 0.01.

Assuming this RRC for the front tires (only the front wheels are powered on the Volt) and a scale weight on the front axle of 2465 lb, the drag force on the two driven wheels together would be about 110 N. At 87 kph (as measured by the CAN rather than the dynamometer, to include the speed change due to any slippage), the rotational speed of the wheel would be 11.51 rev/s. Tire losses in the two driven wheels together were therefore calculated as approximately 2.65 kW.

For the 2013 Malibu Eco, the weight on the front axle was 2250 pounds (1020.6 kg) and on the rear axle, 1744 lb (791.1 kg). Only the front wheels were in operation on the dynamometer. At 93 kph roller speed, the onboard system indicated a vehicle speed of 94 kph (possibly due to wheel slippage). Assuming a rolling resistance coefficient of 0.01 at 94 kph, the total tire losses on both driven wheels would be 2.6 kW.

EPA and ECCC saw some evidence of wheel slippage on the dynamometer rolls. Figure 9 shows that the recorded dynamometer speed varied slightly from the reported speed on the CAN bus, only during the high power pulse. The resolution of the signal was not sufficient to precisely identify the amount of slippage but its presence during the pulse is clear. This effect was seen for both the 2013 Malibu Eco and the 2013 Volt. Figure 10 shows a similar effect on the 2016 Chevy Volt as recorded by ECCC. Similar slippage was reported for the vehicles tested at JRC.

While the tire losses were estimated at about 2.6 kW for the 2013 Volt and Malibu, this remains uncertain because the weight on the rollers may differ from the platform scale weight due to unknown forces imposed by the tie down method, and the estimated dynamic rolling radius of the tire may also be prone to inaccuracy. The impact of wheel slippage on tire losses is also uncertain, and may increase the tire loss by an unknown amount that is difficult to quantify.

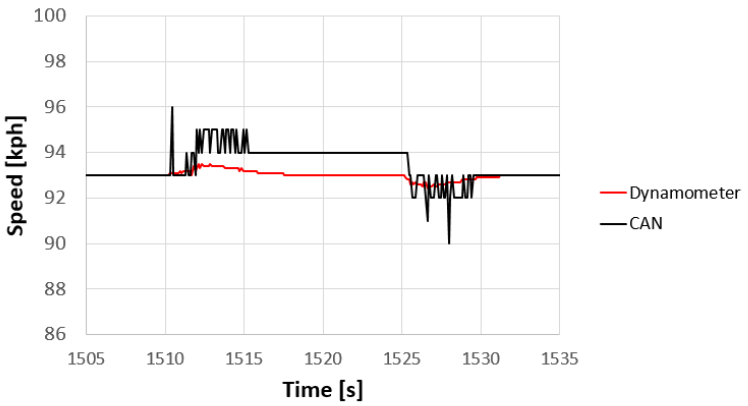

Figure 9: Wheel slippage indicated by measured speed differences, 2013 Malibu Eco (EPA)

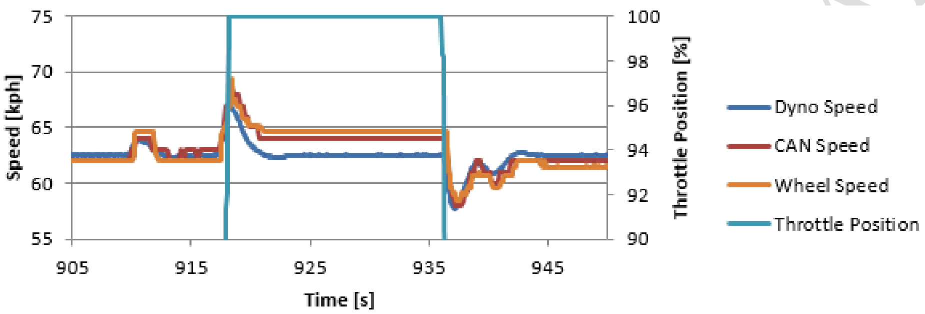

Figure 10: Wheel slippage indicated by measured speed differences, 2016 Chevy Volt (ECCC)

Another anticipated source of variation is the influence of K factors. The draft procedure provides default values for efficiency factors K1 and K2 to be used in the case that an accurate value is not available from the manufacturer. The results of TP1 and TP2 are each individually sensitive to the accuracy of the K factor with respect to the vehicle being tested. In other words, the expectation that TP1 and TP2 should deliver the same result is less likely to be met if the respective K factors are not of similar accuracy for a given vehicle. In such a case, this can produce variation between TP1 and TP2.

As an example, results of EPA testing of the 2013 Volt and 2013 Malibu are shown in Table 1 and Table 2. TP1 was calculated using measurements from CAN bus voltage and current, while TP2 utilized dynamometer roller data and includes a correction for tire losses as previously described. The results indicate that using the default factors may have different implications for different vehicles. As shown in Table 1, in the case of the 2013 Volt, TP1 delivered a significantly smaller result than TP2. However, as shown in Table 2, in the case of the 2013 Malibu Eco, TP2 delivered a smaller result than TP1.

Table 1. Peak and sustained power, TP1 and TP2, 2013 Chevrolet Volt

	Peak power			**Sustained power**		
	TP1	**TP2**	**Difference**	**TP1**	**TP2**	**Difference**
First pulse	94.31 kW	103.29 kW	+8.98 kW	92.91 kW	101.00 kW	+8.09 kW
Second pulse	93.21 kW	102.31 kW	+9.10 kW	92.67 kW	101.19 kW	+8.51 kW
Difference	-1.10 kW	-0.98 kW		-0.24 kW	+0.18 kW	

Table 2. Peak and sustained power, TP1 and TP2, 2013 Malibu Eco

	Peak power			Sustained power		
	TP1	**TP2**	**Difference**	**TP1**	**TP2**	**Difference**
First pulse	130.73 kW	121.07 kW	-9.66 kW	129.57 kW	120.15 kW	-9.42 kW
Second pulse	130.04 kW	119.87 kW	-10.17 kW	129.54 kW	118.99 kW	-10.55 kW
Difference	-0.69 kW	-1.2 kW		-0.03 kW	-1.16 kW	

In the case of the 2013 Volt, the electric share of the power as tested is 100 percent. The TP1 result is smaller than the power that was actually measured at the wheels, suggesting an underestimation. Assuming that the CAN battery signal data is accurate, TP1 might be indicating a lower power because the default efficiency factor for the electrical powertrain (0.85) may be relatively conservative for this vehicle. Changing to a factor of 0.92, which might also be a reasonable figure for this vehicle, would bring the TP1 result very close to that of TP2. In the case of the Malibu Eco, the potential electric share of the power is on the order of 10 percent, which means that the effect of any inaccuracy of the default 0.85 K1 factor on the result is much smaller. Here, it is TP2 that delivers a smaller result than TP1. For both vehicles, the differences between Pulse 1 and Pulse 2 are small, illustrating the repeatability of the measurement.

The results from the 2016 Chevrolet Volt at ECCC are presented in Table 3. ECCC utilized data from voltage and current sensors for TP1, and dynamometer roller data (without tire loss correction) for TP2. The sustained power results agree quite closely, suggesting that the respective K factors used had comparable accuracy with respect to their characterization of the respective portions of the vehicle powertrain. As with the 2013 Volt, the peak power calculations for TP1 and TP2 showed a significant difference. This may be due to power variations near the beginning of the pulse that were detected by the TP2 instrumentation but not by the TP1 instrumentation. The differences between Repeat 1 and Repeat 2 are small, illustrating repeatability.

Table 3. Peak and sustained power, TP1 and TP2, 2016 Chevrolet Volt (ECCC)

	Peak power			Sustained power		
	TP1	**TP2**	**Difference**	**TP1**	**TP2**	**Difference**
Repeat 1	103.9 kW	115.6 kW	+11.7 kW	103.3 kW	104.3 kW	+1.0 kW
Repeat 2	103.2 kW	113.6 kW	+10.4 kW	102.9 kW	103.0 kW	+0.1 kW
Difference	-0.7 kW	-2.0 kW		-0.4 kW	-1.3 kW	

It is important to note that the observed variation between the TP1 and TP2 results for these vehicles would likely be much smaller if the K factors used in the calculations were measured values specific to each vehicle being tested, rather than generic default factors. In a type approval or certification situation, a manufacturer would likely provide accurate and verifiable K factors, thus reducing or eliminating this variation. The testing did not seek to assess the variation applicable to that case. The variation observed here merely illustrates variation that may accompany the use of default K factors for these specific vehicles using these specific measurement methods, and that the direction of this variation may vary by powertrain architecture.

3 Conclusions

This paper has presented the background and structure of a draft procedure being developed by the EVE IWG and has presented a subset of results generated at EPA, ECCC and JRC. Additional results continue to be generated and discussed within the EVE IWG. The results presented here represent the experience of the authors with respect to the specific vehicles tested under the available conditions. The tests did not seek to assess absolute accuracy of either TP, nor to assess the variation when vehicle-specific K factors are supplied.

Results suggest that attaining a stable transmission oil temperature may call for a longer conditioning cycle. TP2 could be affected because it depends on an accurate assessment of transmission efficiency. However, if the speed of maximum power is known in advance, it would reduce the duration of the test procedure, reducing the potential variation in oil temperature during the test.

For the vehicles tested at EPA and ECCC, a speed of maximum power was straightforward to identify by means of repeated constant-speed maximum acceleration runs in constant speed mode of the dynamometer. For the 2013 and 2016 Volt, identifying a specific speed required some judgement due to the relatively flat power curve. It also made it difficult to identify, from the coarse results, a speed range to conduct the finer sweep. The magnitude of the maximum power at the wheels showed good repeatability. ECCC and JRC found that the speed of maximum power might alternatively be identified by acceleration runs in road load mode instead of incremental steady state runs, based on testing of the 2016 Chevy Volt, a pure hybrid vehicle, and another plug-in hybrid vehicle. More evaluation would be needed to confirm this possibility.

For TP2, the testing presented here evaluated only the use of dynamometer roller data and not the use of wheel torque and speed sensors. The approximate magnitude of tire losses was found to be estimable by observing the tire drag on undriven wheels in 4WD mode, deriving a rolling resistance coefficient from this data, and using this coefficient along with approximate axle loading to estimate tire losses on the driven wheels. The tire losses for these vehicles were estimated in the range of 2 to 3 kW. Evidence of tire slippage was observed but the effect was not accounted for. JRC is exploring possibilities for the assessment of tire slippage for the JRC-tested vehicles by applying empirical tire models from literature.

Ideally, if the respective K factors for both TP1 and TP2 are accurate, and the measurements are also accurate, TP1 and TP2 should deliver the same result. Experimentally verified K factors were not available for the tested vehicles, so calculations were performed with default K factors. Variation was observed when the default K factors were used. The observed variation might be attributable to any of several sources, including relative measurement accuracy, and differences between the actual losses in these specific vehicles and the losses assumed by the respective default K factors.

The validation activity discussed here is one of many sources of information being considered in discussions among members of the EVE IWG, which continues its work to develop and validate the draft procedure to promote its effective and practical implementation as a potential method of establishing the combined system power of electrified vehicles with more than one propulsion source.

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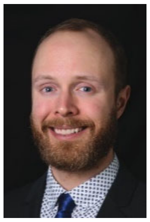

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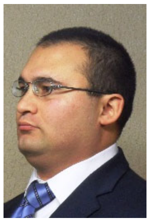

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