2016 Report on a Study Commissioned by the Japan Automobile Manufacturers Association (JAMA)

Study on Measuring Methods of HEV System Power Output

March 2017

Japan Automobile Research Institute

Group in charge: Hybrid Group, Electronic Vehicle Subcommittee, JAMA

Study project members

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Overview

1. Objectives

With various hybrid electric vehicles (HEV) being developed and their use becoming widespread, there is a growing need for HEV system power measurement. For this reason, testing methods to measure HEV system power are starting to be researched and studied in Western countries. In Japan, the HEV Group HEV System Power Testing Working Group, consisting of members from automobile manufacturers and supported by JARI as its managing office, is studying HEV system power measuring methods with the issues below in mind, and is proposing a method to calculate HEV system power by combining combustion engine power and battery power to ISO/TC22/SC37.

1) Provision of accurate information to customers
   - No misleading information (combustion engine maximum power + electronic motor maximum power ≠ system maximum power)
2) Establishment of fair parameters that make comparative evaluations possible
   - comparison between automobile manufacturers and between HEV systems
   - comparison with internal combustion engine vehicles, electric vehicles and other electric motor vehicles
3) Avoidance of risks posed by standardization led by other countries (with adverse features for Japan)

This study was conducted for the purpose of facilitating the development of methods to measure HEV systems' maximum power. Measuring methods for HEV system power that are technologically reasonable, and the results of which can be compared with measurements of internal combustion engines without modifying the conventional testing methods, were studied and examined. The study results will be used for the development of HEV system power measuring methods.

2. Items studied

(1) Study of effects that different facilities have on power measurements of HEV systems
   This study:
   - examined HEV system power output on roads and rollers and reviewed the effect of different facilities and devices using three types of facilities, which are a real road (test course), chassis dynamometer, and axle-hub chassis dynamometer, and three vehicles with different system configurations.
   - analyzed factors of measurement errors in each type of facility and evaluated the effect of counter measures.

(2) Measurement of operating conditions of HEV systems at the time of maximum power output
   This study:
   - measured operating conditions of the engines, motors and batteries.
   - calculated power output of the engines and motors based their operating conditions.

(3) Study of effects that testing conditions have on power measurements of HEV systems
   - Testing conditions (warm-up methods, state of charge at the beginning of the test, testing speed, power output duration, etc.) are used as parameters, and the effect of each of them

on HEV systems were quantitatively reviewed.

(4) Trend research on HEV system power measuring methods in different countries (done in 2015)
- Research on testing and analysis being done in different countries
- Research on usage of HEV system power measurements in different countries
- Research on standardization of HEV system power measuring methods

3. Results obtained

(1) Study of effect that different facilities have on power measurements of HEV systems

Considering that different testing facilities and different locations where measurements are taken can affect replicability of resulting maximum power measurements, a study was conducted using three types of facilities: a real road, a chassis dynamometer and an axle-hub chassis dynamometer. To evaluate replicability, differences from the average value (deviation) were examined. The JARI HEV System Power Working Group expects to study methods for judging the significance of differences in the future, but the minimum display unit for practical use of measuring methods is assumed to be one kilowatt (kW), in which case the minimum precision required is thought to be one kilowatt or smaller. Also, factors such as tire losses can impact measurements taken with three types of facilities, and depending on the locations where measurements are taken, measurements can vary. Therefore differences in power measurements between different facilities were examined and their contributing factors and solutions were considered. Table 1 shows the effects of different types of facilities on power measurements of the HEV systems of tested vehicles A, B and C. Vehicle A uses a series-parallel powertrain, vehicle B uses a parallel powertrain and vehicle C is a four-wheel drive series-parallel vehicle and is chargeable from outside power sources.

On a real road, when road surface power output was measured, the maximum deviation was 1.4 kW with vehicle A, 7.9 kW with vehicle B and 2.7 kW with vehicle C. Errors in acceleration measurements taken during acceleration, tire losses and testing temperature are some of the factors thought to have contributed to the measurement errors. Because the testing environment cannot be improved, to eliminate tire losses and errors in acceleration measurements, wheel driving power was measured. The result showed a maximum deviation of 0.3 kW with vehicle A, 8.6 kW with vehicle B and 4.3 kW with vehicle C. While the deviation decreased with vehicle A, there was no improvement with vehicles B and C, and therefore it is surmised that other factors contributed to deviations. When HEV system power was calculated using the sum of engine power and battery electric power, which is being proposed to ISO, vehicle A showed a maximum deviation of 0.4 kW, which is about the same as the result of the above-mentioned method, but vehicle B recorded a maximum deviation of 1.6 kW, and vehicle C recorded a maximum deviation of -0.5 kW, which were significantly smaller than deviations of other methods, proving that this calculation method can yield stable measurements.

Next, the roller surface power output was measured using a chassis dynamometer. The result showed a maximum deviation of 0.7 kW with vehicle A, 1.9 kW with vehicle B and 0.4 kW with vehicle C, and relatively stable measurement was possible. The effect of tire losses is considered to be a likely factor contributing to errors. To eliminate errors due to tire losses, wheel driving power was measured. Results are a maximum deviation of 0.8 kW with vehicle A, 1.9 kW with vehicle B and 1.3 kW with vehicle C, showing no improvement on deviations, and therefore other factors are to be considered. When HEV system power was calculated using the method being proposed to ISO, the maximum deviation was 0.3 kW with vehicle A, 0.4 kW with vehicle B and 0.2 kW with vehicle C, which were significant reductions, and it was proven that stable measurement is possible with this method.

When wheel-driving power was measured with an axle-hub chassis dynamometer, the maximum deviation was 0.8 KW with vehicle A, 0.3 kW with vehicle B and 0.7 kW with vehicle C, and relatively stable measurement was possible. When HEV system power was calculated using the method being proposed to ISO, the maximum deviation was 0.1 kW with vehicle A, 1.0 kW with vehicle B and 0.2 kW with vehicle C, which were significant reductions, and it was proven that stable measurement is possible with this method.

These results show that HEV system power measurement based on the method proposed to ISO, using a chassis dynamometer or an axle-hub chassis dynamometer, can suppress deviations to one kW or smaller. Calculation of HEV system power based on the method proposed to ISO directly uses engine power determined from the rotation speed of the engine and measurement of battery power. It is surmised that this method can generate stable measurements because it is not affected by varied losses occurring on tires or transmissions.

Table 1 Effects of different facilities on power measurements of HEV systems

<table>
<tr><th colspan="2"></th><th colspan="3">Real road</th><th colspan="3">Chassis dynamometer</th><th colspan="3">Axle-hub chassis dynamometer</th></tr>
<tr><td colspan="2">Tested vehicle</td><td>A</td><td>B</td><td>C</td><td>A</td><td>B</td><td>C</td><td>A</td><td>B</td><td>C</td></tr>
<tr><td rowspan="4">Road surface power output (real road)

Roller surface power output (chassis dynamometer)</td><td>Average measurement of HEV system power</td><td>58.1 kW</td><td>72.6 kW</td><td>131.6 kW</td><td>61.2 kW</td><td>84.8 kW</td><td>123.6 kW</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Power measured</td><td colspan="3">Acceleration</td><td colspan="3">Power output on chassis dynamometer</td><td colspan="3">–</td></tr>
<tr><td>Deviation</td><td>-0.7 – 1.4 kW (-1.2 – 2.4%)</td><td>-7.9 – 7.9 kW (-10.9 – 10.9%</td><td>-2.7 – 2.5 kW (-2.1 – 1.9%)</td><td>-0.4 – 0.7 kW (-0.7 – 1.1%)</td><td>-1.9 – 1.7 kW (-2.2 – 2.0%</td><td>-0.3 – 0.4 kW (-0.2 – 0.3%)</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Contributing factors to errors</td><td colspan="3">Tire losses, testing environment, acceleration measurement</td><td colspan="3">Tire losses</td><td colspan="3">–</td></tr>
<tr><td rowspan="4">Wheel-driving power</td><td>Error-alleviating measures</td><td colspan="3">Wheel torque measurement;
others issues are hard to deal with</td><td colspan="3">Wheel torque measurement</td><td colspan="3">–</td></tr>
<tr><td>Average measurement of HEV system power</td><td>62.8 kmW</td><td>73.3 kW</td><td>131.3 kW</td><td>63.9 kW</td><td>88.7 kW</td><td>137.0k W</td><td>64.0 kW</td><td>88.0 kW</td><td>131.6 kW</td></tr>
<tr><td>Power measured</td><td colspan="3">Wheel-driving power</td><td colspan="3">Wheel-driving power</td><td colspan="3">Power output on axle-hub chassis dynamometer</td></tr>
<tr><td>Deviation</td><td>-0.3 – 0.3 kW (-0.5 – 0.5%)</td><td>-8.6 – 8.5 kW (-11.7 – 11.6%</td><td>-4.3 – 3.7 kW (-3.3 – 2.8%)</td><td>-0.8 – 0.5 kW (-1.3 – 0.8%)</td><td>-1.9 – 1.6 kW (-2.1 – 1.8%</td><td>-1.3 – 0.8 kW (-0.9 – 0.6%)</td><td>-0.8 – 0.5 kW (-1.3 – 0.8%)</td><td>-0.3 – 0.2 kW (-0.3 – 0.2%</td><td>-0.7 – 0.6 kW (-0.5 – 0.5%)</td></tr>
<tr><td rowspan="3">Method proposed to ISO</td><td>Average measurement of HEV system power</td><td>73.8 kW</td><td>91.8 kW</td><td>146.4 kW</td><td>73.2 kW</td><td>92.6 kW</td><td>147.3k W</td><td>73.1 kW</td><td>92.6 kW</td><td>147.3 kW</td></tr>
<tr><td>Power measured</td><td colspan="3">Engine + battery</td><td colspan="3">Engine + battery</td><td colspan="3">Engine + battery</td></tr>
<tr><td>Deviation</td><td>-0.4 – 0.3 kW (-0.5 – 0.4%)</td><td>-1.6 – 0.9 kW (-1.7 – 1.0%</td><td>-0.5 – 0.3 kW (-0.3 – 0.2%)</td><td>-0.3 – 0.3 kW (-0.4 – 0.4%)</td><td>-0.3 – 0.4 kW (-0.3 – 0.4%)</td><td>-0.2 – 0.2 kW (-0.1 – 0.1%)</td><td>-0.1 – 0.1 kW (-0.2 – 0.2%)</td><td>-0.7 – 1.0 kW (-0.8 – 1.1%</td><td>-0.2 – 0.2 kW (-0.1 – 0.1%)</td></tr>
</table>

(2) Measurement of operating conditions of HEV systems at the time of maximum power output

Topics of study included whether or not measurements that are necessary to determine operating conditions of engines, motors and batteries at the time of maximum power output can be taken the same way on differently-structured HEV systems without significantly modifying the vehicles; where some measurements could not be taken, whether or not operating conditions could be determined based only on measurements that could be obtained; and where operating conditions could be measured, the differences between the calculated HEV system power based on those measurements and the manufacturers' listed power values.

The results showed that, with regard to engine operating conditions, the power output of the engine could be calculated by measuring the engine's rotation speed and intake pipe pressure. With motors, neither motor rotation speed nor motor torque could be measured, and only input voltage and electric current could be measured. It was difficult to determine operating conditions solely with these data. With batteries, both voltage and electric current could be measured.

Following the method proposed to ISO, a test was done using a chassis dynamometer. For engine power, thanks to support from manufacturers, data on engine rotation speed and power generation output curve were provided and used for calculation. The results were 73.1 kW at the vehicle speed of 160 km per hour with vehicle A, which was 100% of the value listed by the manufacturer, and 95.3 kW at the speed of 115 km per hour and on the fourth gear with vehicle B, which was 94%of the manufacturer's listed value. With vehicle C, the result was 147.3 kW at 160 km per hour, but since its system power output is not published by the manufacturer, the replicability of the measurement is not known.

(3) Study of effects that testing conditions have on power measurements of HEV systems

In developing measuring methods, the possibility of testing conditions affecting HEV systems' power output should be considered. For this reason, testing conditions including warm-up methods, state of charge at the beginning of the test, testing speed, gear position, and power output duration were treated as parameters, and the effect of changes in each of them on HEV systems are shown in Table 2.

Because the maximum deviation was 0.4 kW when vehicles were tested under the same conditions on a chassis dynamometer, this value was used as the baseline to evaluate the effects of differences in parameters.

Using the case where vehicles were warmed up at a steady speed of 60 km per hour as the basis, a cold condition and a JC08 mode warm-up condition were compared. When power output was obtained by adding up engine power output and battery power, which method is proposed to ISO, compared with the average values in the cases where vehicles were warmed up at a steady speed of 60 km per hour, the maximum difference was 0.4 kW with vehicle A, 1.4 kW with vehicle B and 1.2 kW with vehicle C, showing that the effect was great with vehicles B and C. Based on this result, it is deemed necessary to specify the warm-up method, and a specification such as "warm up at a steady speed of 60 km per hour for 20 minutes or longer" would be considered appropriate.

To examine the effect of the state of charge (SOC) at the beginning of the test, two values of SOC, i.e. the SOC at the time of maximum power output and the SOC within the regular range of usage, were used as the SOC at beginning of the test. The difference in power output between the two SOCs was 0.4 kW with vehicle A, 0.2 kW with vehicle B and 1.7 kW with vehicle C, showing that, with some vehicles, this difference can be larger than the deviation under the same condition. When the SOC at the beginning was very low and outside the range of regular usage, the power output was significantly decreased.

To examine the effects of the speed of the vehicles, two methods were evaluated: the method proposed to ISO in which different speed levels are set in each test, and the method that is being considered by the SAE in which the speed at which the vehicle reaches maximum power output is sought under running resistance control. The testing speed in the SAE method was sometimes different from that of the ISO method, and the SAE method recorded lower power output compared with the ISO method: 0.8 kW lower with vehicle A, 0.7 kW lower with vehicle B and 2.0 kW lower with vehicle C, which were larger differences than deviations under the same conditions. Based on this, it is thought that, while the method considered by the SAE has the advantage of giving speed measurements easily, it cannot appropriately evaluate vehicles that can increase power output for a short period of time like vehicle A, and that therefore a method in which different speed settings are used to determine the maximum power output speed, like the one proposed to ISO, is more appropriate.

Regarding the effect of the gear position, with vehicle B, in the second gear, the power output was 5.5 kW lower than that in the fourth gear, and it became clear that it is necessary to consider the gear position when testing vehicles.

To evaluate the effect of repeating tests, one set of tests was conducted with 20 minutes of warm-up time (at the steady speed of 60 km per hour) between them, and another set was done without warm-up time in between, and the differences between the results of test 1 and test 4 were compared. When warm-up time was inserted between tests, the difference between tests 1 and 4 was 0.5 kW with vehicle A, 1.0 kW with vehicle B, and 0.2 kW with vehicle C; the differences with vehicles A and B were larger than deviations under the same conditions. When tests were repeated without warm-up time in between, the difference between tests 1 and 4 was 1.0 kW with vehicle A, 1.2 kW with vehicle B, and 1.9 kW with vehicle C, which were larger than those in the set where warm-up time was inserted. This indicates that more highly replicable results can be obtained when warm-up time is inserted between tests.

For the examination of the effect of power output duration, moving averages for one second and three seconds were compared. The moving average output for three seconds was lower than that of one second by 1.6 kW with vehicle A and by 0.2 kW with vehicle B, and they were the same with vehicle C. With vehicles B and C, the differences were smaller than deviations recorded under the same conditions, but the difference was large with vehicle A. This is because with vehicles that can increase power output for a short period of time like vehicle A, when the period over which moving average is taken is longer, the power output goes down from the peak.

These results show that differences in certain conditions can result in differences in power measurements that are larger than deviations in measurements obtained under same conditions. These conditions include the warm-up method, the method to determine the vehicle's running speed, the gear position, the way the tests are repeated and the duration for which power output is measured. Therefore these conditions have to be specified definitively when tests are conducted.

Table 2 Effects of testing conditions on power measurements of HEV

Tested vehicle		A	B	C	Remarks
System		Series-parallel	Parallel	Series-parallel	
Deviation under the same condition		-0.3 – 0.3 kW	-0.3 – 0.4kW	-0.2 – 0.2 kW	Four tests with chassis dynamometer
Effect of testing facilities	Power output calculated with the method proposed to ISO	-0.1 – 0.6 kW	-0.8 – 0.0 kW	-3.5 – 0.0 kW	Difference from power output measured with chassis dynamometer
Effect of warm-up method	Method that warms up batteries faster	JC08 mode	Steady at 60 km/hour	Steady at 60 km/hour	Comparison between steady 60 km/hr and JC08 mode
	Range of power output variation	-0.3 – 0.4 kW	-1.0 – 1.4 kW	-1.2 – 0.6 kW	Difference from power output measured after warm-up steady at 60 km/hr
Effect of SOC at the beginning of the test	Within the range of normal usage	-0.4 kW	-0.2 kW	-1.7 kW*	Difference from power output measured with the SOC of maximum power output
	Low SOC	13.3 kW (SOC: 35%)	-0.7 kW (SOC: 30%)	-47.8 kW (SOC: 20%)	Difference from power output measured with fully charged batteries
Effect of testing speed	Power output calculated through the method of the SAE	-0.8 kW	-0.7 kW	-2.0 kW	Difference from power output calculated through the method proposed to ISO
	Speed condition calculated through the method of the SAE	-20 km/hr	-3 km/hr	0 km/hr	Difference from speed condition proposed to ISO
Effect of gear position		Unknown because of the continuously variable transmission	-5.5 kW (2nd gear)	Unknown because of the continuously variable transmission	Difference from power output in 4th gear

Effect of repeating tests	Warming up + SOC adjustment + test	+0.5 kW	+1.0 kW	+0.2 kW	Power output in the 4th test compared with the 1st test
	SOC adjustment + test	+1.0 kW	+1.2 kW	-1.9 kW	Power output in the 4th test compared with the 1st test
Duration of power output	Duration of measurement	-1.6 kW	-0.2 kW	0.0 kW	Difference from power output measured for one second

* -4.1 kW when SOC was 100%

(4) Trend research on HEV system power measuring methods in different countries (done in 2015)

At present, as far as available information indicates, for those in categories M and N of European vehicle classification, there is no testing method to measure HEV system power output in other countries.

The SAE in the US started discussions regarding the development of testing methods for the purpose of presentations in product catalogues.

At ISO, a project on HEV system power output testing methods was started in June 2015 based on Japan’s proposal, for the purpose of developing a presentation system in catalogues that can be used for comparison with internal combustion engine vehicles.

The major uses of HEV system power output measurements are presentation in catalogues, vehicle classification in the WLTP (Worldwide harmonized Light vehicles Test Procedure) and calculation of downscaling ratios.

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4. Testing methods

4.1 Definition of HEV system power output

When HEV system power output is evaluated, depending on where measurements are taken, resulting values vary. In this study, four roughly divided locations were chosen for measurement of HEV system power output. As shown in Figure 4.1, the engine, batteries and inverter are the main components, and the power output of each of them is defined first. To obtain the engine power output indicated with "A," the engine rotation speed is measured and calculation is done based on the engine rotation speed and the power output curve. The motor input electric power, indicated with "B," is defined as the power calculated from the AC voltage and electric current between the motor and the inverter. The batteries' power, indicated with "C," is defined as the power calculated from the DC voltage and electric current between the batteries and the inverter. Table 4.1 shows definitions of power output at four places. Of these four, the most downstream power output is the driving power on the road or the rollers of a chassis dynamometer through tires. On the road, it is defined as (1) road surface power. On the chassis dynamometer, it is defined as (1) roller surface power. The power at the axle, where power output excluding tire losses is measurable, is defined as (2) wheel driving power. On the road and the chassis dynamometer, the power measured with the six-component force meter is used for the wheel driving power. On the axle-hub chassis dynamometer, since the axle and the dynamometer are directly connected, the power measured by the dynamometer is the wheel driving power. The combined power of motor input electric power (B) and engine power output (A), which are situated more upstream, is defined as (3) motor input electric power + engine power output. The combined power of battery power (C) and engine power output (A), which are even further upstream, is defined as (4) battery power + engine power output, and this is the power output defined in the proposal that has been submitted to ISO. Depending on the testing facilities, road surface power and roller surface power (1) and wheel driving power (2) are measured in different ways. For this reason, measuring methods and calculation methods are defined for each facility.

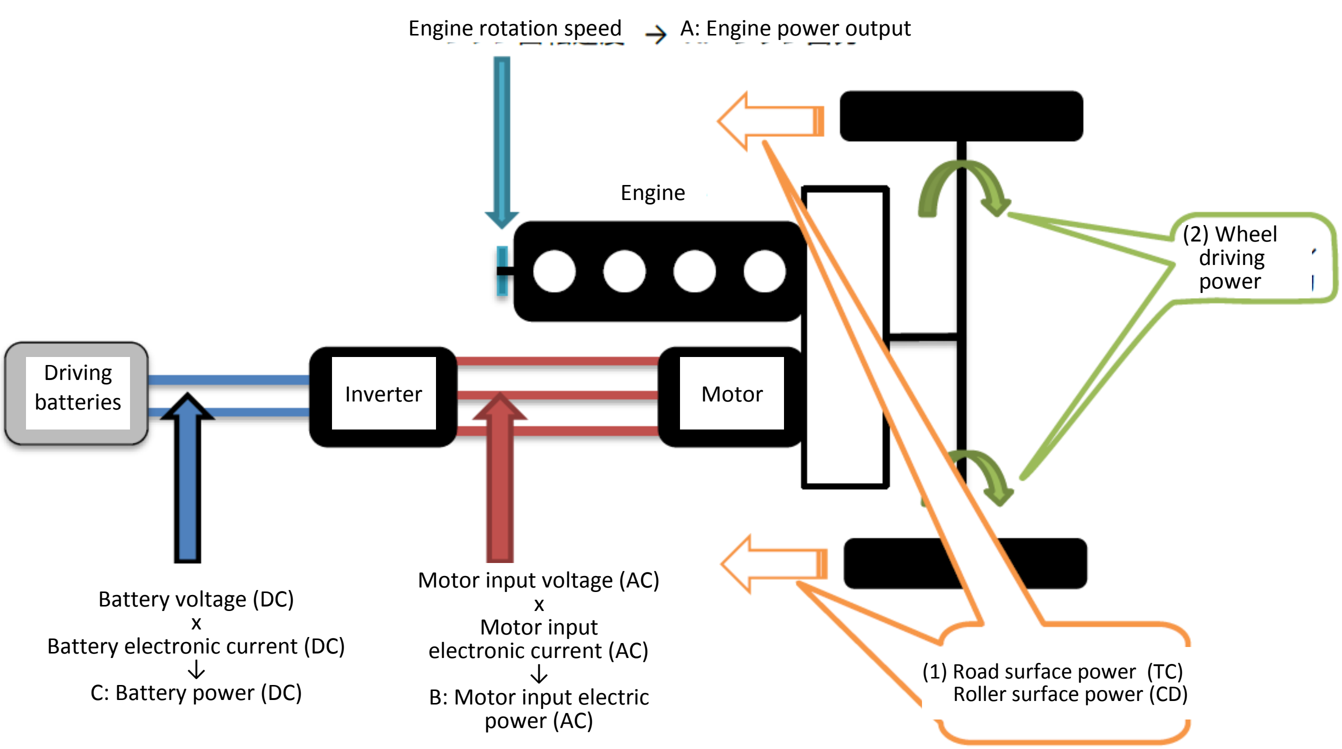


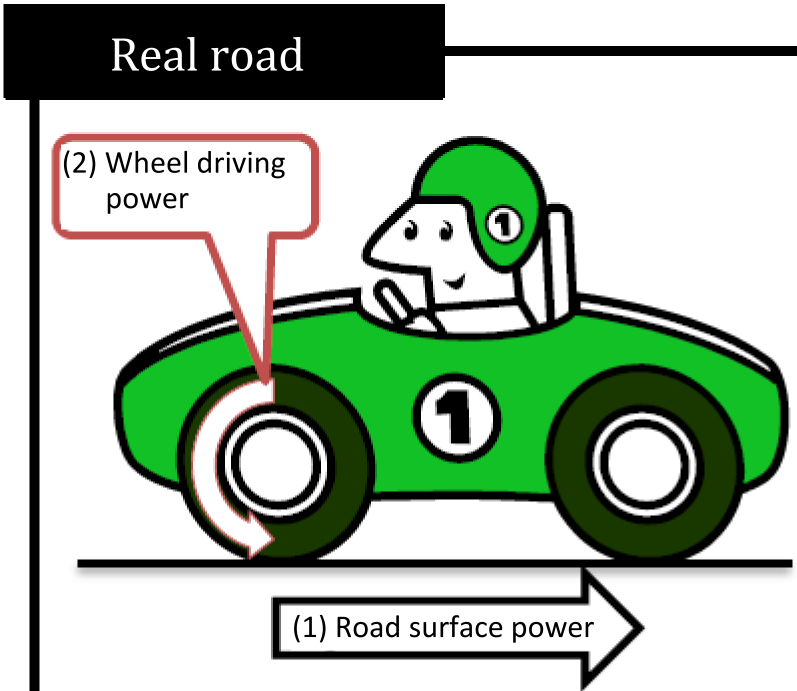
Figure 4.1 Locations where power output is measured

Table 4.1 Definition of power output at four locations

	Road	Chassis dynamometer	Axle-hub chassis dynamometer
(1) Driving power on tires on road or rollers	Road surface power	Roller surface power	NA
(2) Power output at wheel excluding tire loss	Wheel driving power		
(3) Power obtained by combining motor input electric power and engine power	Motor input electric power + engine power output		
(4) Power obtained by combining battery power and engine power	Battery power and engine power output		

Figure 4.2 shows how power output on a road is measured and calculated. Road surface power output (1) on a real road can be calculated by multiplying the vehicle speed by road surface driving force. Vehicle speed was measured with a speedometer that utilized GPS. The road surface driving force was defined as the mass of the testing vehicle multiplied by the acceleration of the vehicle, and the formula F=m x a was used for its calculation. Acceleration of the vehicle was measured with an accelerometer. Also, since the acceleration used in this study is intermediate acceleration from a certain speed, the driving force for the travelling resistance at the speed and the driving force for the equivalent inertia mass of the rotating part were taken into consideration. The equivalent inertia mass was defined as 3.5 per cent of the kerb mass of the vehicle, as defined by TRIAS.

Wheel driving power (2) was measured with a six-component force meter attached to the driving wheel. The distortion measured with the six-component force meter was converted to wheel driving torque by a memory recorder. In addition, since the six-component force meter can measure the rotating speed of each wheel, with testing vehicles and A and B, the rotating speed of each of the right and left wheels was multiplied by the corresponding wheel driving torque, and the total of the products for the right and left wheels was defined as the wheel driving power. With testing vehicle C, because the six-component force meters were attached only to the right front wheel and the right rear wheel, the driving torque of the right front wheel was multiplied by 2, and the product was defined as the front wheel driving torque; similarly, the driving torque of the right rear wheel was multiplied by 2, and the product was defined as the rear wheel driving torque. The product of the front wheel driving toque multiplied by the rotating speed of the right front wheel was added to the product of the rear wheel driving torque multiplied by the rotating speed of the right rear wheel, and the sum was defined as the wheel driving power.



(1) Road surface power (GPS speedometer and accelerometer)
Power output = vehicle speed x road surface driving force
Road surface driving force = (rotation part equivalent inertia mass + testing vehicle mass) x vehicle acceleration + target travelling resistance

(2) Wheel driving power output (six-component force meter)

<u>Testing vehicles A and B</u>

Power output = right wheel rotating speed x right wheel driving torque
+ left wheel rotating speed x left wheel driving torque

<u>Testing vehicle C</u>

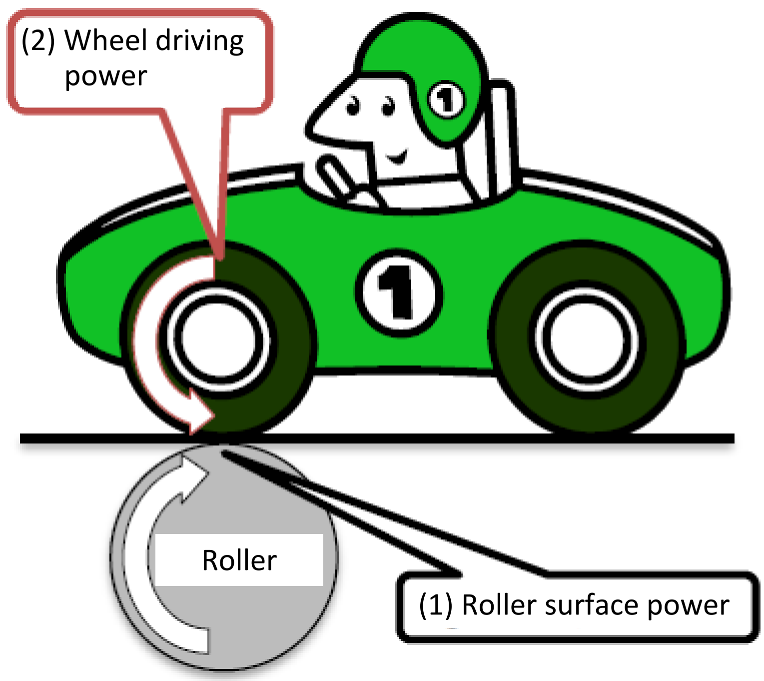
Power output: right front wheel rotating speed x right front wheel driving torque x 2
+ right rear wheel rotating speed x right rear wheel driving torque x 2

Figure 4.2 Measurement and calculation of power output on real road

Figure 4.3 shows how power output on a chassis dynamometer is measured and calculated. The roller surface power output (1) on a chassis dynamometer can be calculated by multiplying the roller speed by the roller surface driving force measured with the dynamometer.

The wheel driving power output (2) was calculated with measurements of the wheel rotation speed and the wheel driving torque obtained with the six-component force meter attached to the driving wheels, using the same method as the road testing.

Chassis dynamometer (CD)



(1) Roller surface power (CD speed and CD driving force)
Power output = roller speed x roller surface driving force

(2) Wheel driving power output (six-component force meter)

<u>Testing vehicles A and B</u>

Power output = right wheel rotating speed x right wheel driving torque
+ left wheel rotating speed x left wheel driving torque

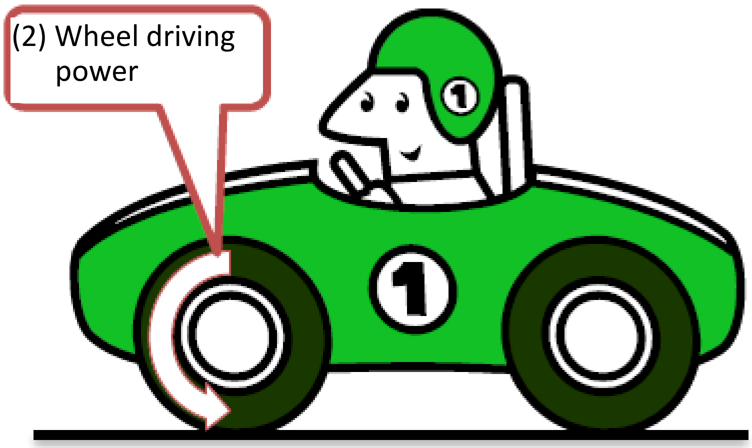
<u>Testing vehicle C</u>

Power output: right front wheel rotating speed x right front wheel driving torque x 2
+ right rear wheel rotating speed x right rear wheel driving torque x 2

Figure 4.3 Measurement and calculation of power output on chassis dynamometer

Figure 4.4 shows how power output on an axle-hub chassis dynamometer was measured and calculated. Because the vehicle on an axle-hub chassis dynamometer is not driven through tires, there is no equivalent of the roller surface driving force (1). For this reason, the only power output that can be measured on an axle-hub chassis dynamometer is the wheel driving power output (2). Using dynamometers attached to the right and left driving wheels, rotation speed and driving torque were measured. While rotation speed was measured separately on the left and right wheels, because the rotations are synchronized, the power output was calculated based on the product of average rotation speed on the left and right multiplied by the sum of driving torque on the left and right. With vehicle C, because it is a 4WD vehicle, power output of the front and rear axles was obtained and added.

Axle-hub chassis dynamometer (CD)



(2) Wheel driving power output (axle-hub dynamometer)

Testing vehicles A and B

Power output = right/left average wheel rotating speed x sum of right and left wheel driving torque

Testing vehicle C

Power output: average rotating speed of right and left front wheels x sum of wheel driving torque of right and left front wheels + average rotating speed of right and left rear wheels x sum of wheel driving torque of right and left rear wheels

Figure 4.4 Measurement and calculation of power output on axle-hub chassis dynamometer

4.2 Testing procedure

The testing procedure was based on the testing method Japan is currently proposing to ISO , as shown in Figure 4.5. In the procedure proposed to ISO, there is a step at the beginning where HEVs that are chargeable with external power supplies are charged to the level of state of charge for the test. After the initial step, whether or not they are externally chargeable, all the HEVs are tested using the same procedure. First, the vehicle is soaked and after charging is complete, it is set up on the chassis dynamometer. Next, the vehicle is warmed up. Warming up the vehicle after soaking might seem like a wasteful step, but without being soaked beforehand, the vehicle might not be adjustable to the normal condition solely through the recommended warming method due to the effects of pre-testing conditions (such as high temperature after previous testing or cold storage). In particular, vehicles with large batteries might need a long period of time before the temperature stabilizes because of the batteries' large heat capacities. After the warm-up, the vehicle's state of charge is adjusted through regeneration. Then, the vehicle is run on the chassis dynamometer at a constant speed and the accelerator pedal is pressed to the full open position. This concludes the test, and the HEV system power output is calculated. If the maximum value is not obtained, the procedure is repeated from the warm-up stage.

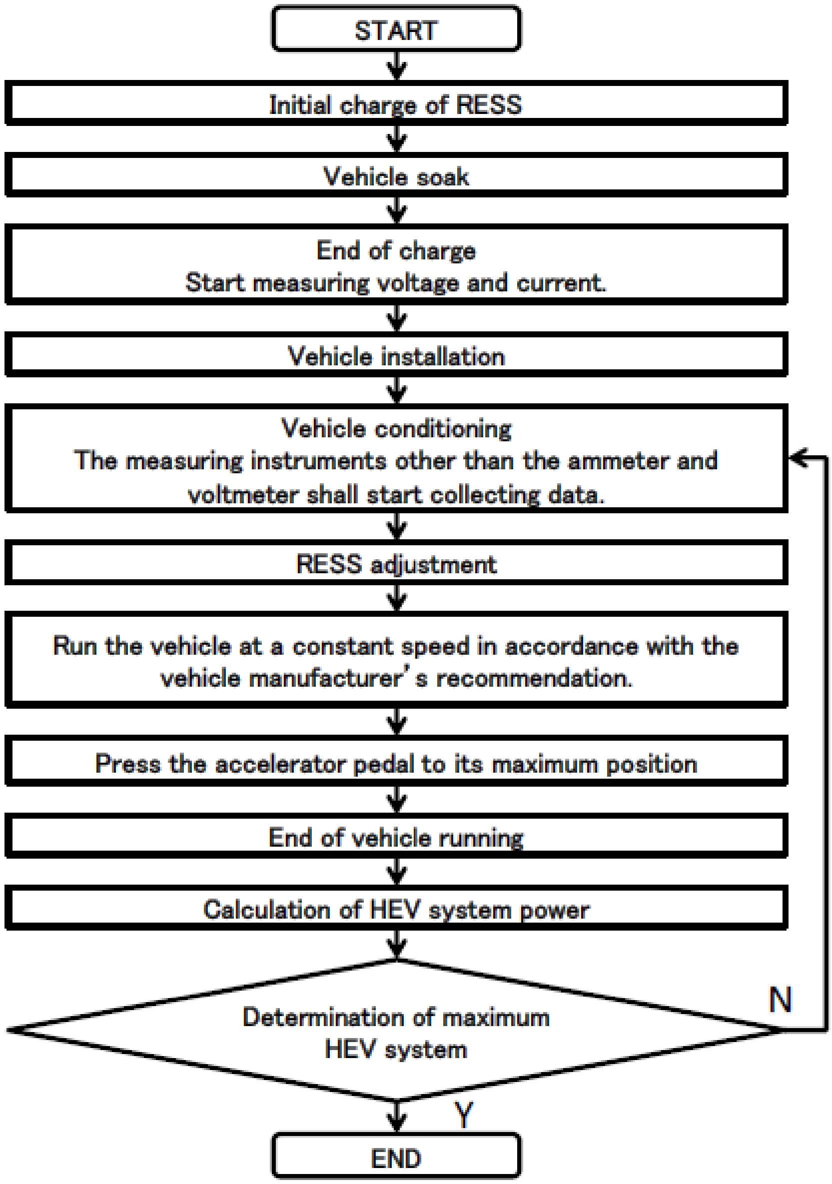


Figure 4.5 Testing procedure being proposed to ISO

As shown above, the procedure being proposed to ISO does not specify details such as warm-up conditions or testing speed so that it can be applied to different types of vehicles. Therefore, to actually carry out the tests of this study, details of the procedure, from the warm-up to the completion of the tests, were determined and implemented following a study on conditions that work for the characteristics of testing vehicles based on existing expertise.

For testing vehicle A, the basic flow of the test was:

1. Warm up the vehicle (chassis dynamometer running resistance control; 20 minutes at 60 km/hr)
2. Adjust the SOC (chassis dynamometer speed control; regenerated to 80% SOC at 60 km/hr)
3. Using the chassis dynamometer's speed control, accelerate to 160 km/hr, which is the maximum power generation speed
4. Press the accelerator to full open (after the engine rotation has risen, maintain it for 10

seconds)

5. Release the accelerator → Press the accelerator to full open again (measurement of the maximum power output)
6. Stop the vehicle
7. Cool down the vehicle
8. Repeat from 1.

For testing vehicle B, the basic flow of the test was:

1. Warm up the vehicle (chassis dynamometer running resistance control; 20 minutes at 60 km/hr)
2. Adjust the SOC (chassis dynamometer speed control; regenerated to 93% SOC at 60 km/hr)
3. Using the chassis dynamometer's speed control, accelerate to the maximum power generation speed
4. Shift the gear down and press the accelerator to full open (maintain for 10 seconds)
5. Stop the vehicle
6. Cool down the vehicle
7. Repeat from 1.

For testing vehicle C, the basic flow of the test was:

1. Warm up the vehicle (chassis dynamometer running resistance control; 20 minutes at 60 km/hr)
2. Adjust the SOC (chassis dynamometer speed control; regenerated to 90% SOC at 60 km/hr)
3. Using the chassis dynamometer's speed control, accelerate to the maximum power generation speed
4. Press the accelerator to full open (maintain for 10 seconds)
5. Stop the vehicle
6. Cool down the vehicle
7. Repeat from 1.

4.3 Calculating procedure

The procedure being proposed to ISO simply states "calculation of HEV system power." The calculation is to be done by combining the battery power and engine power output, but specifics of the data processing method are not provided. In this study, the calculation was done using the procedure below.

1. Cull data from all measurements (500 Hz sampling) and convert them to equivalents at 10 Hz
2. Obtain engine power output based on the engine rotation speed data (at every 10 Hz) and the engine power output curve
3. Add battery power and engine power output and obtain HEV system power
4. Perform one-second sample moving average processing on all the measurement data
5. Determine the maximum value of the HEV system output in the test.

4.4 List of testing conditions

In this study, the procedure being proposed to ISO, as well as methods studied and/or used for testing in other countries and possible testing conditions, were used as parameters for evaluation. The testing conditions are listed in Table 4.2. For comparison of facilities, measurements of running conditions, effects of warm-up methods, effects of SOC (within the range of normal usage), each test was repeated four times and the average and the difference from the average (deviation) were calculated.

Table 4.2 List of testing conditions

Tested vehicle	A	B	C
Comparison of facilities	Real road, chassis dynamometer and axle-hub chassis dynamometer		
Measurement of running conditions	160 km/hr	115 km/hr in fourth gear	160 km/hr
Effects of warm-up method	Cold, 60 km/hr steady for 20 min, JC08 mode		
Effects of SOC (within range of normal usage)	55% and 80%	70% and 93%	29% and 90%
Effects of SOC (within range of possible SOC)	35%, 45%, 55% and 65%	30%, 50% and 70%	20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%
Effects of the vehicle's speed (method proposed to ISO)	140 km/hr, 145 km/hr, 150 km/hr, 155 km/hr, 160 km/hr, 165 km/hr and 170 km/hr	5400 rpm, 5500 rpm, 5600 rpm, 5700 rpm, 5800 rpm, 5900 rpm and 6000 rpm	30 km/hr, 40 km/hr, 50 km/hr, 60 km/hr, 70 km/hr, 80 km/hr, 90 km/hr, 100 km/hr, 110 km/hr, 120 km/hr, 130 km/hr, 140 km/hr, 145 km/hr, 150 km/hr, 155 km/hr, 160 km/hr, 165 km/hr and 170 km/hr
Effects of vehicle speed (SAE)	0 to 170 km/hr, 100 to 170 km/hr and 145 to 170 km/hr	0 to 170 km/hr, 60 to 170 km/hr, 80 to 170 km/hr	0 to 170 km/hr and 140 to 170 km/hr
Effects of gear position	NA	Second, third and fourth	NA
Effects of repeating tests	Repeated four times with warm-up in between and repeated four times without warm-up in between		

5. Test results and discussion

5.1 Study of effects that different types of testing facilities have on power output measurements of HEV systems

5.1.1 Overview of the tests

Considering that different testing facilities and different locations where measurements are taken can affect replicability of resulting maximum power measurements, a study was conducted using three types of facilities: a real road, a chassis dynamometer and an axle-hub chassis dynamometer. Also, factors such as tire losses can impact measurements taken with three types of facilities, and depending on the locations where measurements are taken, measurements can vary. Therefore differences in power measurements between different facilities were examined and their contributing factors and solutions were studied.

5.1.2 Testing vehicle A

With testing vehicle A, the effect of differences between three types of facilities on the measurements of HEV system power output was studied. The on-road test was conducted as shown in Figure 5.1. The test on the chassis dynamometer was conducted as shown in Figure 5.2, and the test with the axle-hub chassis dynamometer was conducted as shown in Figure 5.3. Tests were carried out following the procedure described in section 4.2, but since it is impossible to measure the full-open power output while driving at a steady speed on a real road, measurements were taken during acceleration. In the tests on the chassis dynamometer and the axle-hub chassis dynamometer, the testing speed was set at 160 km/hr, which was given to us by the manufacturer as the speed at which the maximum power output is obtained, but in the on-road test, for the above reason, measurements were taken when the vehicle reached 160 km/hr through the full-open acceleration from 155 km/hr. For the SOC, data from the scan tool connected to the vehicle's diagnostic connector were used. The SOC at the beginning of the tests was set at 80 per cent, which is considered full charge, but because it is difficult to fully charge the vehicle just before the on-road test, an SOC of 50 per cent or more within the regular usage range was used for the on-road test.

Figure 5.1 On-road test (testing vehicle A)

Figure 5.2 Chassis dynamometer test (testing vehicle A)

Figure 5.3 Axle-hub chassis dynamometer test (testing vehicle A)

A comparison of the results of power output tests on vehicle A conducted with the three facilities is shown in Figure 5.4 and Table 5.1. In the figure and the table, results on real road are marked with "A.TC," those on the chassis dynamometer are marked with "B.CD," and those on the axle hub chassis dynamometer are marked with “C.HCD.” The bar chart shows the average value and the range of results of each test repeated four times.

The road surface power output measured on real road was 3.1 kW smaller than the roller surface power output measured in the chassis dynamometer test. One factor that can be pointed out is that this vehicle has a function of getting temporarily increased power when the accelerator is released and re-pressed. In the on-road test, it is difficult to activate this function at 160 km/hr, which is when the maximum power is generated, and the measured power output value turned out to be lower. In addition, there is a difference in friction coefficient on the on-road surface and on a chassis dynamometer, and the effects of tire losses are thought to be different. As for the deviation, the maximum deviation on the chassis dynamometer was approximately 0.7 kW, but it was around 1.4 KW on the road. The JARI HEV System Power Working Group expects to study the difference in the degrees of deviation in the future, but the minimum display unit for the operations of the tests is thought to be one kW. In that case, the precision required is thought to be at least one kW or smaller. Considering this, the deviations in the road surface power output and the roller surface power output on the chassis dynamometer were somewhat large.

With this issue in mind, to avoid the effects of tire losses, wheel driving power output was measured. On the road and on the chassis dynamometer, a six-component force meter was used. On the axle hub chassis dynamometer, the power measured by the dynamometer was directly taken as the result. The power output measured in the on-road test was approximately one kW lower than that of the chassis dynamometer and axle hub chassis dynamometer tests because of different conditions, such as the fact that the function that temporarily increases the power output was not utilized and the measurements were taken during acceleration. On the other hand, it was found that the power output was about the same on the chassis dynamometer and on the axle hub chassis dynamometer. Also, compared with the road surface power output and the roller surface power output, the wheel driving power output was 4.7 kW higher on the road and 2.7 kW higher on the chassis dynamometer, revealing that effects of tire losses are different with different testing facilities. Deviations were ±0.3 kW in the on-road test, and -0.8 to 0.5 kW in the chassis dynamometer and axle hub chassis dynamometer tests, and it is thought that, while there are some deviations, they are smaller than 1.0 kW with any of the facilities, and it is believed that stable measurements are possible.

For the comparison with the power of internal combustion engine vehicles, the power output of the vehicle was calculated by adding the motor input electric power and the engine power output, which are further upstream than the transmission gear and the reduction drive. The engine power output is the value derived from the engine power curve, and if the throttle is fully open, it can be determined directly based on the rotation speed. For the motor input electric power, the alternating current power between the inverter and the motor was measured. The sum of the motor input electric power and the engine power output was 1.0 kW higher on the road than on the chassis dynamometer, and 0.8 kW higher on the axle hub chassis dynamometer than on the chassis dynamometer. Differences among testing facilities were 1.0 kW or less, which means that the effects of different facilities were small. Deviations were ±0.1 kW on the road, ±0.2 kW on the chassis dynamometer and -0.5 – 0.2. kW on the axle hub chassis dynamometer, which were smaller than deviations in results of wheel driving power output measurements; therefore, it is believed that more stable measurements are possible this way.

Further, the power output was calculated as the sum of battery power and the engine power output, which is the method proposed to ISO. For the battery power, the direct current electric power between the batteries and the inverter was measured. This sum of battery power and engine power output was, compared with that of the chassis dynamometer, 0.6 kW higher on the road and 0.1 kW lower on the axle hub chassis dynamometer. Differences among testing facilities were less than 1.0 kW, and the effects of different facilities were very small. Deviations were -0.4 – 0.3 kW on the road, ±0.3 kW on the chassis dynamometer and ±1.0 kW on the axle hub chassis dynamometer, and therefore it is believed that more stable measurements are possible, as is the case with the method of adding the motor input electric power and the engine power output.

7. Conclusion

7.1 Study of effects that differences in facilities have on measurements of HEV system power output

Considering that the effects of different testing facilities and different locations where measurements are taken can lead to differences in replicability of resulting maximum power measurements, the study was conducted using three types of facilities: a real road, a chassis dynamometer and an axle-hub chassis dynamometer. To evaluate replicability, each of the tests was conducted four times, and differences from the average values (deviation) were examined. The JARI HEV System Power Working Group expects to study methods for judging the degree of differences in the future, but the minimum display unit for the practical use of measuring methods is expected to be one kilowatt (kW), in which case, the minimum precision required is thought to be one kilowatt or smaller. Also, factors such as tire losses can impact measurements taken using three types of facilities, and difference in locations where measurements are taken can result in different measurements. Therefore, differences in power measurements between types of facilities were examined and their contributing factors and solutions were studied.

On the road, when road surface power output was measured, it was observed that deviations tended to be large. Errors in acceleration measurements taken during acceleration, tire losses and testing temperature are some of the factors thought to have contributed to the measurement errors. Because the testing environment cannot be improved, to eliminate tire losses and errors in acceleration measurements, wheel driving power was measured. While the deviation decreased with vehicle A, there was no improvement with vehicles B and C, and it was surmised that other factors were contributing to the errors. When HEV system power was calculated using the method of adding engine power output and battery electric power, which is being proposed to ISO, deviations decreased significantly, proving that this calculation can yield stable measurements.

Next, roller surface power output was measured using a chassis dynamometer, and results showed that relatively stable measurement was possible. The effect of tire losses was thought to be contributing to measurement errors, and to address the issue, wheel driving power output was measured. The results did not show any improvements, and it was thought that other factors were contributing to the errors. When HEV system power was calculated using the method being proposed to ISO, deviations decreased greatly, and it was proven that stable measurement is possible with this method.

When wheel-driving power was measured with an axle-hub chassis dynamometer, results showed that relatively stable measurement was possible. When HEV system power was calculated using the method being proposed to ISO, it was found that stable measurement is possible with this method.

These results showed that power measurement of HEV systems based on the method proposed to ISO, using a chassis dynamometer or an axle-hub chassis dynamometer, can suppress deviations to one kW or smaller. Calculation of HEV system power based on the method proposed to ISO directly uses engine power determined from the rotation speed of the engine and measurement of battery power, and it is surmised that this method can generate stable measurements because it is not affected by varied losses occurring on tires or in transmissions.

7.2 Measurement of operating conditions of HEV systems at the time of maximum power output

Topics of study included whether or not measurements that are necessary to determine operating conditions of engines, motors and batteries at the time of maximum power output can be taken the same way on differently-structured HEV systems without significantly modifying the vehicles; where some measurements could not be taken, whether or not operating conditions could be determined based only on measurements that could be obtained; and where operating conditions could be measured, the differences between the calculated HEV system power and the manufacturers' listed values.

The result showed that, with regard to engine operating conditions, the power output of the engine could be calculated by measuring the engine's rotation speed and intake pipe pressure. With motors, neither motor rotation speed nor motor torque could be measured, and only input voltage and electric current could be measured. It was difficult to determine operating conditions solely with these data. With batteries, both voltage and electric current could be measured.

Following the method being proposed to ISO, tests were conducted using a chassis dynamometer. The results were 73.1 kW at the vehicle speed of 160 km per hour with vehicle A, which was 100% of the value listed by the manufacturer, and 95.3 kW at the speed of 115 km per hour and in the fourth gear with vehicle B, which was 94% of the manufacturer's listed value. With vehicle C, the result was 147.3 kW at 160 km per hour, but since its system power output is not published by the manufacturer, the replicability of the measurement is not known.

7.3 Study of effects that testing conditions have on power measurements of HEV systems

In developing measuring methods, the possibility of testing conditions affecting HEV systems' power output should be considered. For this reason, to study testing conditions, the warm-up method, states of charge (SOC) at the beginning of the test, testing speed, gear position, and power output duration were treated as parameters, and the effects of changes in each of them on HEV systems were examined.

Because the maximum deviation was 0.4 kW when vehicles were tested under the same conditions on the chassis dynamometer, this value was used as the baseline to evaluate the effects of changes in parameters.

Regarding warm-up methods, it was found that the differences in results when vehicles were warmed up at 60 km/hr and when they were warmed up in the JC08 mode were larger than the deviations under the same condition with vehicles B and C. Based on this result, it is deemed necessary to specify the warm-up method, and a specification such as "warm up at a steady 60 km per hour for 20 minutes or longer" is considered appropriate.

To examine the effects of the SOC at the beginning of the test, the full charge and an SOC within a normal range of use were compared. The results showed that depending on the vehicle, the difference in the SOC at the beginning of the test can result in larger differences than deviations under the same condition. When the SOC at the beginning was very low and outside the range of normal usage, the power output was significantly decreased.

To examine the effect of the speed of the vehicles, two methods were evaluated: the method proposed to ISO, in which different speed levels are set, and the method being considered by the SAE, in which the maximum power output was sought with running resistance control. The maximum power output speed in the SAE method was sometimes different from that of the ISO method, and the differences in power output measurements were larger than the deviations under the same conditions. Based on this, it is thought that, while the method considered by the SAE has the advantage of giving speed measurements easily, it cannot appropriately evaluate vehicles that can increase power output over a short period of time like vehicle A, and therefore it is believed that a method in which different speed settings are used to determine the maximum power output speed, like the one proposed to ISO, is more appropriate.

Regarding the effect of the gear position, with vehicle B, in the second gear, the power output was 5.5 kW lower than in the fourth gear, and it became clear that it is necessary to consider the effects of the gear position when testing vehicles.

Regarding the effect of repeated tests, when 20 minutes of warm-up (at a steady speed of 60 km per hour) was inserted between tests, vehicles A and B recorded larger differences between the first test and the fourth test than the deviation under the same conditions. Also, when no warm-up was inserted between tests, larger differences were recorded between the first and the fourth tests than when warm-up was inserted. This indicates that more highly replicable results can be obtained when warm-up is inserted between tests.

For the examination of the effect of power output duration, moving averages for one second and three seconds were compared. While the differences between one second and three seconds with vehicles B and C were about the same as the deviation under the same conditions, vehicle A recorded a large difference between one and three seconds. This is because with vehicles that can increase power output for a short period of time like vehicle A, when the period over which moving average is taken is longer, the power output goes down from the peak.

These results show that differences in certain conditions can result in differences in power measurements that are larger than deviations in measurements obtained under same conditions. These conditions include the warm-up method, the method to determine the vehicle's running speed, the gear position, the way the tests are repeated and the duration for which power output is measured. Therefore these conditions have to be specified definitively when tests are conducted.

7.4 Trend research on HEV system power measuring methods in different countries (done in 2015)

At present, as far as available information indicates, for those in categories M and N of European vehicle classification, there is no testing method to measure HEV system power output (criteria or standards) in other countries.

The SAE in the US started discussions regarding the development of testing methods for the purpose of presentations in product catalogues.

At ISO, a project on HEV system power output testing methods was started in June 2015 based on Japan's proposal for the purpose of presentation in catalogues that can be used for comparison with internal combustion engine vehicles.

The major uses of HEV system power output measurement are presentation in catalogues, vehicle classification in the WLTP (Worldwide harmonized Light vehicles Test Procedure) and calculation of downscaling ratios.