Study on Measuring Methods of HEV System Power Output

1. Background and purposes

1.1 Background

With regard to hybrid electronic vehicles (HEV), which are now widely used by the general public, not only the fuel economy but also the maximum power output is becoming a subject of evaluation when different models are being compared. However, the maximum power output of HEVs is hard to define, and currently, each manufacturer is presenting it in its own way.

The difficulty of defining it stems from the fact that simply adding the engine's maximum power output and the motor's maximum power output does not yield the total power output of an HEV system.

In addition to the mismatch between the speed at which the engine generates maximum power and the speed at which the motor generates maximum power, limitations caused by electricity supply from the batteries are a factor. Also, because the power supply from batteries is limited, a motor cannot sustain its maximum power output for a long period of time like an engine.

For this reason, as shown in Table 1.1, not only in Japan but also in other countries, HEV system power output is not presented as specification values, and in catalogues, etc., it is presented by each manufacturer in its own way. To overcome these challenges and measure HEV systems' maximum power output in a fair manner, research and studies on measuring methods are starting.

Table 1.1 Current HEV system power output presentations in different countries

	Japan	US	Europe
Specification values	Not presented (power output values of engine and motor are presented separately)	Not presented (power output values of engine and motor are presented separately)	Not presented (power output values of engine and motor are presented separately)
Presentation in product catalogues, etc.	Each company using its own way	Each company using its own way	Each company using its own way

In terms of the current situation with respect to studying standard-related matters, for the WLTP (Worldwide Harmonized Light vehicles Test Procedure), a study on HEV system power output testing methods has started for the purpose of classifying test cycles of electronic vehicles and downscaling. With respect to Drafting G, Heavy Duty Hybrids Informal Group meeting (HDH-IG), a calculation method of HEV system maximum power output was established as a Global Technical Regulation (GTR) in March 2015. This method calculates the system power output based on the engine's power output and motor's power output when the system is accelerated to full force on a Hardware In the Loop Simulator (HILS) model.[i]

As for studies in other countries, South Korea's Korea Automobile Testing & Research Institute (KATRI) presented a system power output testing method that measures wheel axle power using the axle-hub chassis dynamometer in October 2013 at the Beijing meeting of Electronic Vehicle Environment (EVE)-GTR of the United Nations. The Society of Automotive Engineers (SAE) is studying methods to measure HEV system power output using the axle-hub chassis dynamometer, after switching from the method that uses the chassis dynamometer, for the purpose of presentation in product catalogues in a way that would allow comparison between different HEV models.

In Japan as well, the HEV System Power Testing Working Group of the HEV 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 output by combining combustion engine power output and battery power to the International Organization for Standardization (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 parameters that will make fair comparative evaluations possible
    - Between automobile manufacturers; between HEV systems
    - Comparison with internal combustion engine vehicles, electric vehicles (EVs) and other electric motor vehicles
3) Avoidance of risks posed by standardization led by other countries (with adverse features for Japan)

1.2 Challenges in developing HEV system power output testing methods

The most important purpose of the HEV system measuring method proposed to ISO is to establish a method that makes comparison of HEVs with internal combustion engine vehicles possible. In the case of internal combustion engine vehicles, only engine power output values are presented; their performance specifications and the vehicles' power output is not presented. Therefore, for proper comparison, with HEVs, the system power output that corresponds with engine power output has to be measured. Figure 1 shows an example of methods used to measure the engine power output of internal combustion engine vehicles. The engine on its own is directly connected to an engine dynamometer and the axle power output is measured. Next, Figure 1.2 shows an example of methods to measure HEV system power output. The example shown here is for the parallel drivetrain, but generally speaking, the motor is placed within a transmission case and the combined axle power output of the engine and the motor can be measured only at the exit of the transmission. This means that, depending on the system composition, the efficiency of the transmission can affect the power measurement and fair comparison with internal combustion engine vehicles is not possible. For fair comparison, there is a way to reverse calculate the efficiency of the transmission. However, with systems like the power-split type, in order to reverse calculate the efficiency of the transmission at the time of the maximum power output, complicated power paths need to be taken into consideration and in reality, the reverse calculation is difficult to perform.

For this reason, a method to simply measure the power output of the engine and that of the motor of HEVs separately, without taking into account the efficiency of the transmission, is being proposed to ISO. An example of this type of measuring method of HEV system output is shown in Figure 1.3. This method runs the system on devices such as a chassis dynamometer under conditions that generate the maximum system power and measures values that indicate the operating conditions of the engine, including the rotation speed. Based on the conditions obtained, the engine power output is read from the known engine power output curve. Similarly, the battery power at the time of maximum system power output is measured. The HEV system power output is calculated as the total of the engine power output and the battery power output.

In addition to power output values of the HEV system, the effect of factors unique to HEVs, such as the duration of the power output and the SOC at the start of testing, needs to be studied.

ED: Engine dynamometer

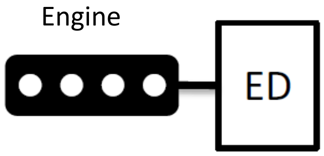


Figure 1.1 Example of methods used to measure the engine power output of internal combustion engine vehicles

ED: Engine dynamometer
TM: Transmission
CD: Chassis dynamometer

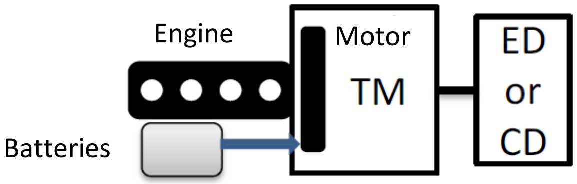


Figure 1.2 Example of methods to measure the system power output of HEVs

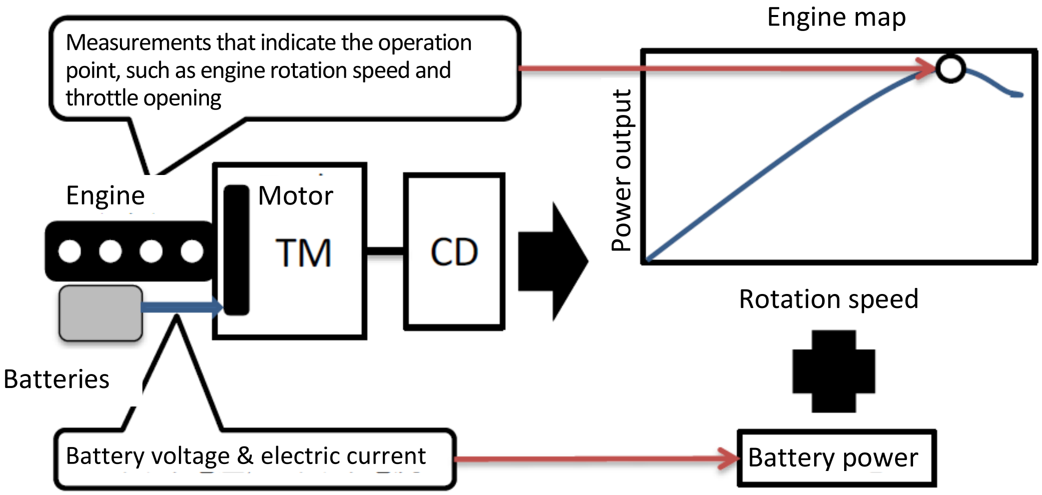


Figure 1.3 Example of the configuration of the HEV system power output measuring method proposed to ISO

1.3 Purpose

To respond to the background and challenges discussed above, this study is being conducted for the purpose of facilitating the development of methods to measure and calculate HEV systems' maximum power output. Measuring methods for HEV system power that are technologically reasonable are studied and examined. Methods yielding results that can be compared with measurements of gasoline-fueled vehicles without modifying the conventional testing methods of gasoline-fueled vehicles are studied and examined. Information obtained from results of these examinations will be used as reference in the process of developing HEV system power measuring methods.

2. Items to be studied

2.1 Study of effects that different types of testing devices have on power measurements of HEV systems

This study will:

- examine HEV system power output on road and on a roller and review the effect of different facilities and devices using three types of facilities/devices, which are a real road (test course), chassis dynamometer, and axle-hub chassis dynamometer, and three vehicles with different system configurations;
- analyze factors of measurement errors in each of the facility/device types and evaluate the effect of counter measures.

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

This study will:

- measure operating conditions of the engines, motors and batteries;
- calculate power output of the engines and motors based on their operating conditions.

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

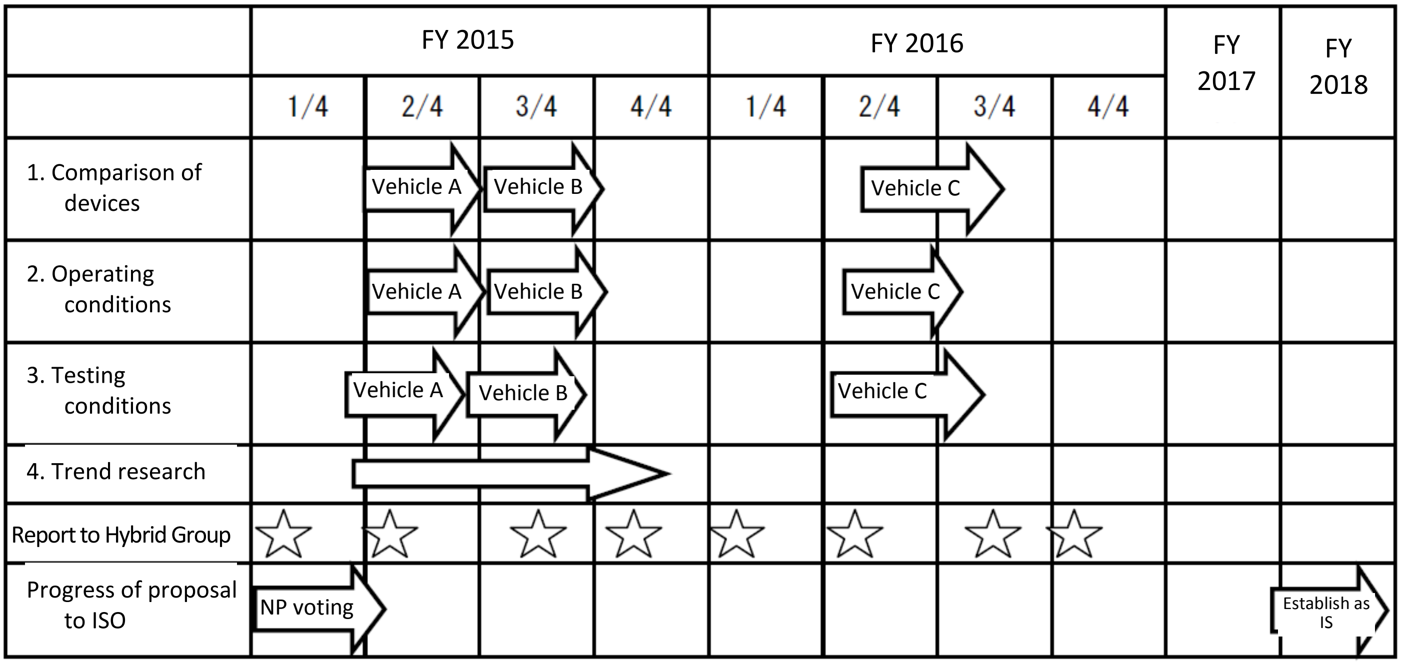
- Testing conditions (warming-up methods, state of charge at the beginning of the test, testing speed, power output duration, etc.) are used as parameters and the effect of each of them on HEV systems are quantitatively compiled.

2.4 Trend research on studies conducted in different countries on HEV system power measuring methods (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

2.5 Study schedule

Figure 2.1 shows the schedule of the study over two years. In the first year, FY 2015, testing vehicles A and B will be tested. These two vehicles are small-sized HEVs, one with a series-parallel drivetrain and the other with a parallel drivetrain. In the second year, FY 2016, as testing vehicle C, a four-wheel-drive plug-in hybrid vehicle will be tested.



NP: New work item proposal IS: (establishment as) International Standard

Figure 2.1 Two-year study schedule

3. Testing facilities and devices

3.1 Real road

Testing on real road was conducted in the high speed circuit of the JARI Shirosato Testing Centre shown in Figure 3.1. The overview of the circuit is shown in Table 3.1. The surface is paved with asphalt and the course is oval-shaped with a bank designed for 190 km/hr in the curves. One lap is 5500 m and as shown in Figure 3.2, the 1112-metre straight section running south-north was used to take measurements.

Figure 3.1 High speed circuit of Shirosato Testing Centre

Table 3.1 Overview of the high speed circuit

Pavement	Asphalt
Circumference	5500 metres
Width	12 metres
Length of the straight section	1112 metres
Radius of the semicircular section	400 metres
Design speed of the curved section	190 km per hour
Maximum angle of the semicircular section	45.2 degrees
Gradient (in the straight section)	1 % cant
Design wheel load	8000 kg
Run-off zone width	Straight section: 10 metres Curved section: 18 metres

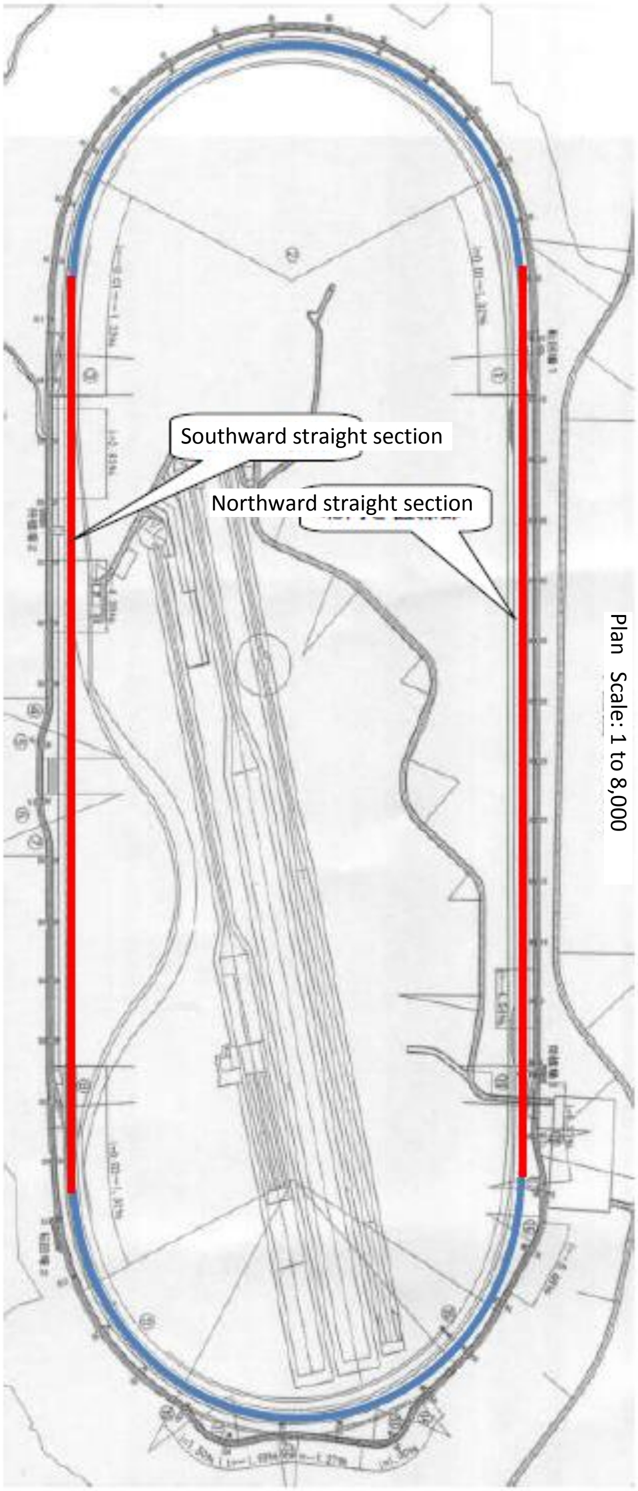


Figure 3.2 Plan of the high speed circuit

3.2 Chassis dynamometer

For tests on chassis dynamometers, 4WD chassis dynamometers owned by JARI were used. With testing vehicles A and B, the one set up in the fuel cell research building was used. It is shown in Figure 3.3. With testing vehicle C, the one in the engine research building was used;specifications are shown in Table 3.2. Testing vehicle C was expected to generate the maximum power output at a speed higher than 160 km/hr, and therefore the chassis dynamometer in the engine research building, which has the capacity to test vehicles at speed higher than 160 km/hr, was used. These chassis dynamometers are equipped with single-roller alternating current dynamometers at the front and back, and can be used to test not only two-wheel drive vehicles, which may be front-wheel-drive or rear-wheel-drive vehicles, but also four-wheel-drive vehicles, without being modified to a two-wheel driving mechanism. In addition, they can handle vehicles that are two-wheel-drive but whose controlling systems such as ABS or stability control make it necessary for driven wheels to rotate at the same speed as the driving wheels. Their inertia compensation systems are all-electric type and equivalent inertia weight can be set in one kilogram increments.

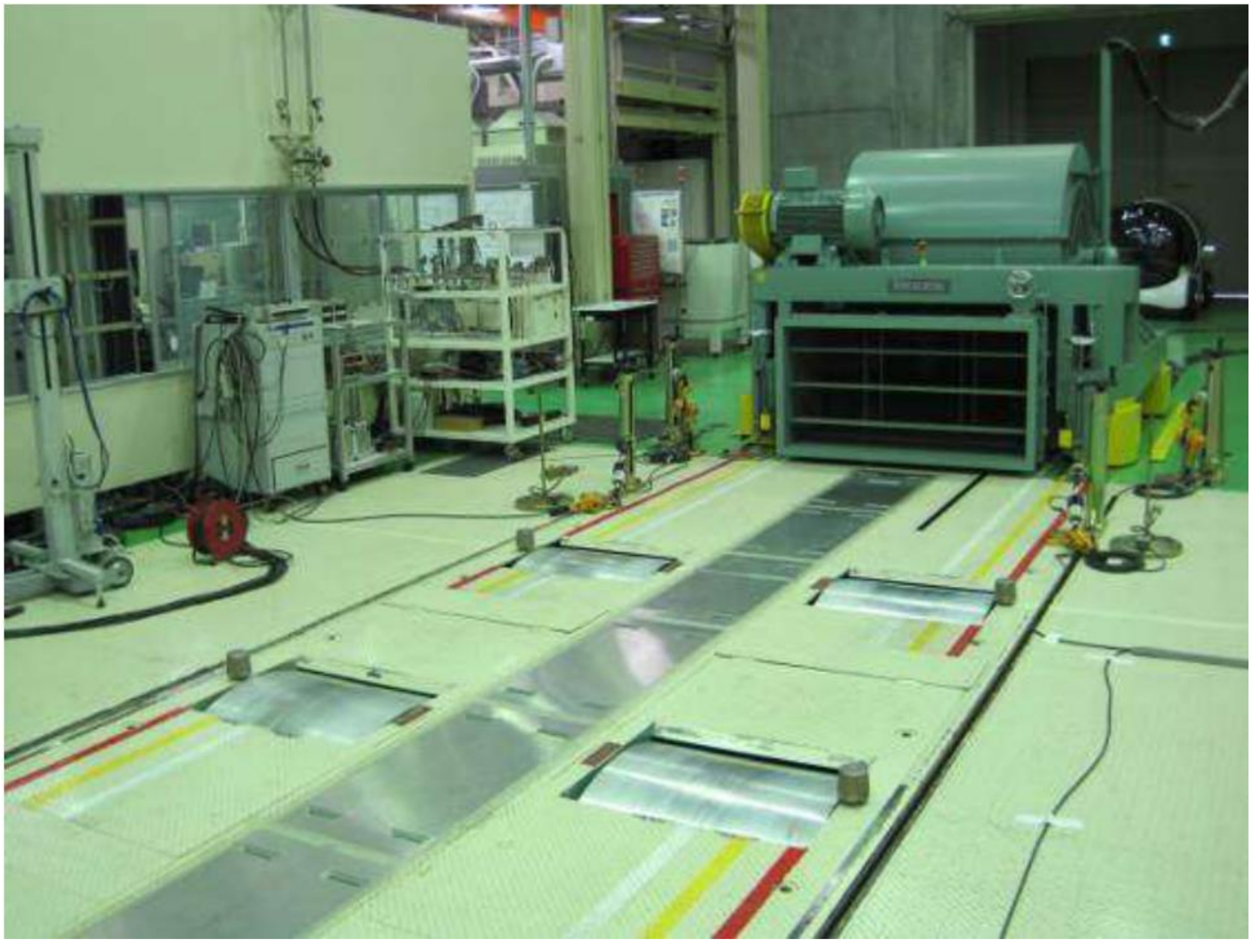


Figure 3.3 Appearance of the chassis dynamometer

Table 3.2 Specifications of the 4WD chassis dynamometers

Location		Fuel cell research building	Engine research building
Vehicles tested		A and B	C
Manufacturer		Meidensha Corporation	
Dynamometer	Model type	FC-DY	
	Max speed	160 km/hr	200 km/hr
	Max. wheel load	25 kN	
	Short-time rating	Absorption: 190 kW Drive: 160 kW	Absorption: 220 kW Drive: 200 kW
Rollers	Material	Aluminum Alloy	Steel
	Diameter	1219.2 mm	
	Roller width	700 mm	800 mm
	Inner distance between the rollers	800 mm	
	Surface finish	Smooth	Tungsten carbide thermal-sprayed
	Wheelbase	1850 – 4000 mm	2100 – 4100 mm
Inertia compensation	System		
	Mechanical inertia moment	Front wheels: 835 kg Rear wheels: 835 kg	Front wheels: 1000 kg Rear wheels: 1000 kg
	Electric inertia simulation range	2WD: -381 – 1887 kg 4WD: -990 – 2840 kg	Front wheels: -545 – 2500 kg Rear wheels: -545 – 2500 kg
	Total inertia moment	2WD: 454 – 2722 kg 4WD: 680 – 4510 kg	2WD: 455 – 3500 kg 4WD: 800 – 3500 kg
Cooling fan	Wind speed	9 – 90 km/hr	4 – 160 km/hr
	Wind speed control system	Vehicle speed tracking system	
	Discharge opening dimensions	1500 mm wide x 750 mm high	1000 mm wide x 700 mm high

3.3 Axle-hub chassis dynamometer

Testing on an axle-hub chassis dynamometer was conducted at Utsunomiya Technical & Product Centre of Ono Sokki, Co. Ltd. Figure 3.4 shows the dynamometer's appearance and Table 3.3 shows its specifications. Figure 3.5 is a layout drawing of the dynamometer. This dynamometer is equipped with a low-inertia dynamometer, which is used for the engine dynamometer, on each of the four wheels, and therefore is capable of testing not only two-wheel-drive vehicles, which are front-wheel-drive or rear-wheel-drive vehicles, but also four-wheel-drive vehicles, without them being modified to a two-wheel driving mechanism. In addition, it can handle vehicles that are two-wheel-drive but whose controlling systems such as ABS or stability control make it necessary for driven wheels to rotate at the same speed as the driving wheels during tests. For controlling the dynamometer on each wheel, MATLAB/Simulink is used, and each control is completely independent of others and therefore their behaviour during turning can be simulated by controlling the rotation speed and torque of each wheel without any steering operation. The maximum speed with the equivalent of tires 650 mm in diameter is 294 km/hr on the front wheels and 245 km/hr on the rear wheels. The rated absorption power is a total of 1000 kW for front wheels and a total of 400 kW for rear wheels, and for one minute, a total of 1500 kW for front wheels and a total of 600 kW for rear wheels. The cooling fan is a vehicle speed tracking type and can generate wind equivalent of up to 130 km/hr.

While axles and wheels are normally fixed to each other with wheel nuts, in this device, as shown in Figure 3.6, wheels and axles are separated, and the device is structured in such a way that allows the axles to be connected to dynamometers with the wheels fixed.

Figure 3.4 Appearance of the axle-hub chassis dynamometer

Table 3.3 Specifications of the axle-hub chassis dynamometer

Manufacturer		Ono Sokki Co. Ltd.
Vehicles that can be tested	Driving system	Front-wheel drive, rear-wheel drive, 4-wheel drive
	Axle load	76.5 kN
	Wheelbase	1800 – 3100 mm
	Axle track	1200 – 1700 mm
Alternating current dynamometer	Maximum speed	Front axle: 294 km/hr Rear axle: 245 km/hr (under conditions equivalent to tires 650 mm in diameter installed)
	Continuous rated power output	Front axle: 500 kW x2 Rear axle: 200 kW x2
	Short-time rating (one minute)	Front axle: 750 kW x2 Rear axle: 300 kW x2
	Maximum absorption torque	Front axle: 3995 Nm x2 Rear axle: 3995 Nm x2

Cooling fan	Wind speed	Up to 130 km/hr
	Wind speed control system	Vehicle speed tracking
	Airflow rate	1440 m^3/min
Automated gauging control system	System	FAMS-8000
	Control	Digital PID arithmetic function (2 ch) Learning and predictive control Service load control External instrument control (exhaust gas analyzer, micro soot sensor)
	Gauge	Counter (pulse) input: 4 ch Universal analog input: 16 ch Temperature: 22 ch Pressure: 12 ch
Air conditioning		18 – 30 C^{o}
Torque sensor		High rigidity torquemeter TQ-1000 series
Battery simulator		BTS: 750 W, 450 A, 200 kW
Exhaust gas analyzer	Analyzer	Diluted exhaust gas analyzer MEXA-ONE-C2 CVS instrument CVS-ONE-MV Diluted air cleaner DAR-2200 Measurement object: gasoline engines
Micro soot sensor		AVL-483

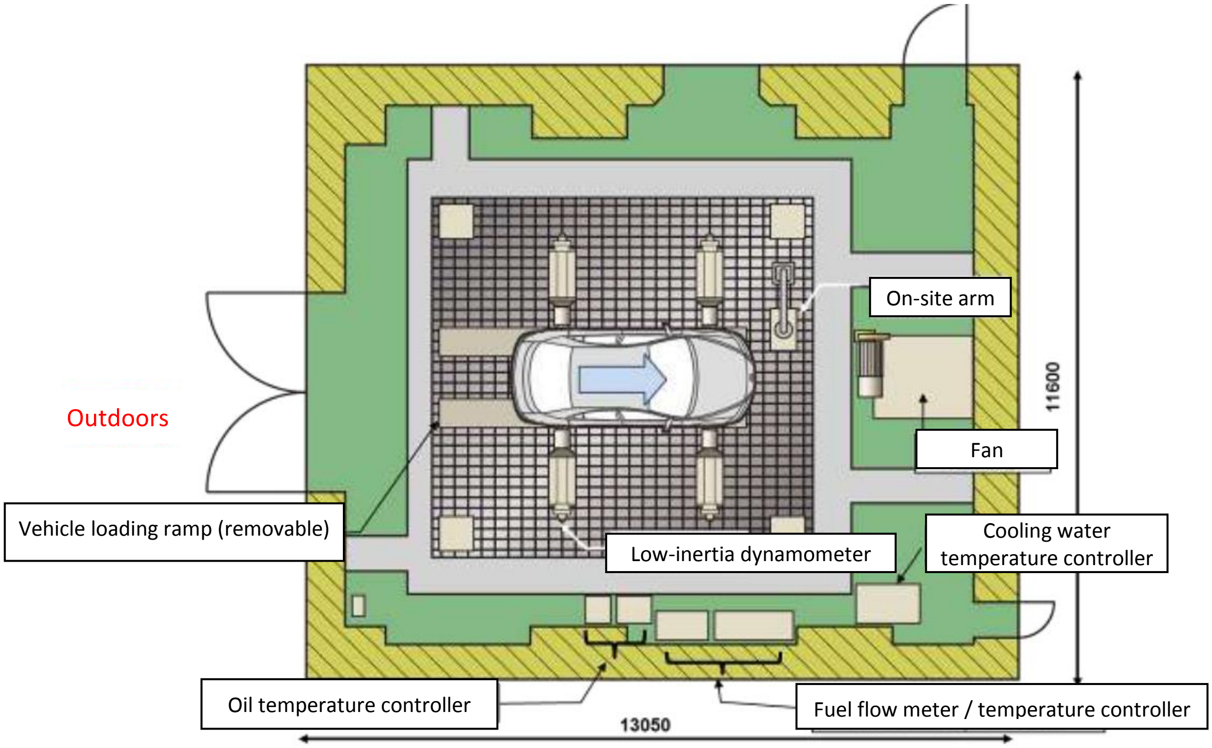


Figure 3.5 Layout of axle-hub chassis dynamometer

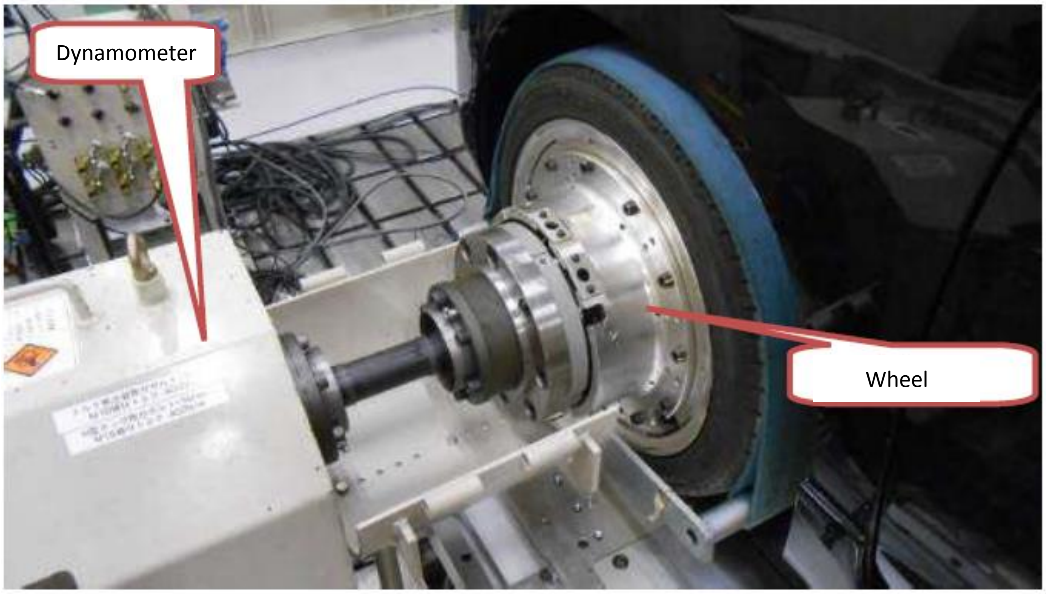


Figure 3.6 Connection between tire type bearing and dynamometer

3.4 Measuring devices

3.4.1 Six component force meter

To measure wheel driving power output, a wheel six component force measuring system (hereafter “six component force meter”) was used. The definition of the six component forces is shown in Figure 3.7. The six component force meter can measure six component force: three forces in the directions of three orthogonal axes (Fx, Fy, and Fz) that work on the axle (at the point where the wheels are attached) of the tested vehicles and moments around each axle (Mx, My and Mz); the wheel rotation angle and the sensor section temperature can be also measured. Each force registers as positive output when load is applied in the direction of the arrow on the hub’s side on which the sensor is fixed. The composition of the six component force meter is shown in Figure 3.8. The sensor is mounted on a special wheel and the transmitter unit wirelessly sends data to a receiver antenna. Table 3.4 shows specifications of the six component force meter. Rated capacities of forces measured with the six component force meter are ±8 kN in the longitudinal direction, ±4 kN for side force and ±8 kN for load. Rated capacities of moments are ±1.5 kNm for overturning moment, ±0.5 kNm for rolling resistance and ±1.5 kNm for self-aligning.

In the present study, because testing vehicles A and B were front-wheel drives, the driving wheels on the left and right were used for measurements and six component force meters were affixed to them. Dummy sensors, rims, hub adaptors, etc. were mounted on the non-driving wheels to balance the mass of front and rear wheels. Because testing vehicle C was a four-wheel drive vehicle, six component force meters were affixed to the right front wheel and the right rear wheel and driving power of the front and rear was measured. Dummy sensors, rims, hub adaptors, etc. were mounted on the left front wheel and the left rear wheel [TB1]to balance the mass of left and right wheels.

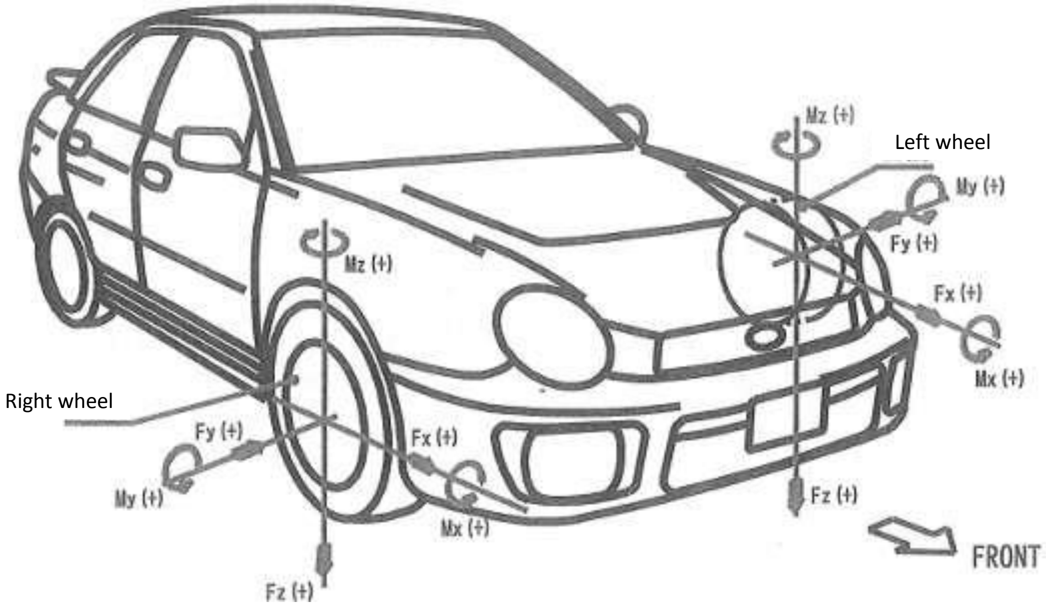


Figure 3.7 Definition of six component forces

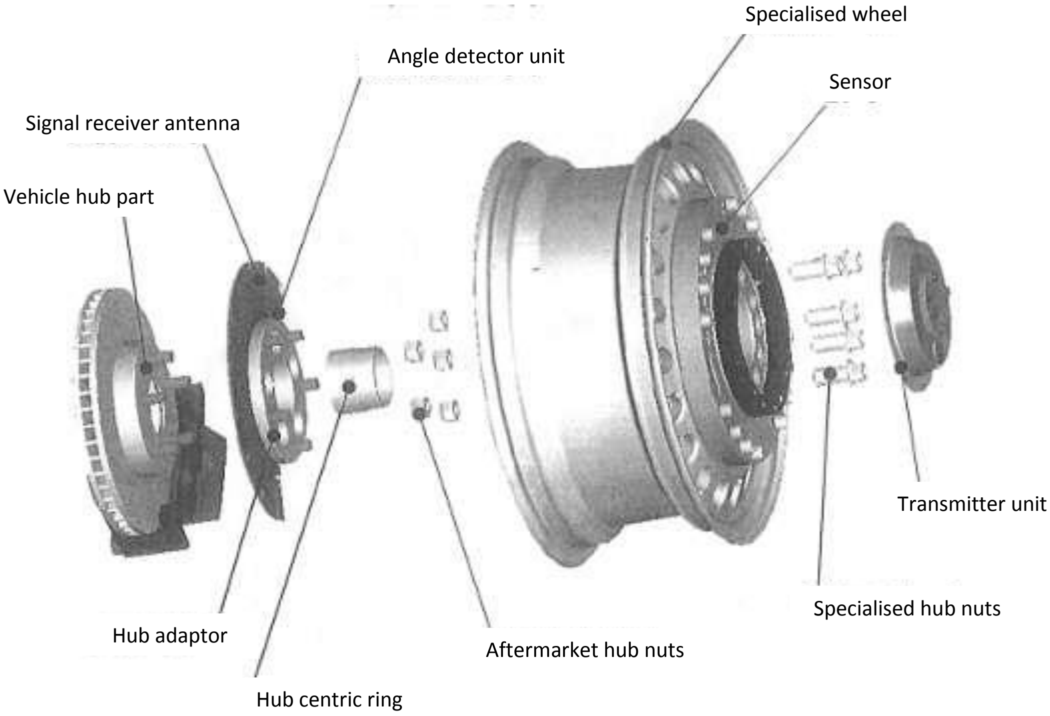


Figure 3.8 Composition of the six component force meter

Table 3.4 Specifications of the six component force meter

Manufacturer		Kyowa Electronic Instruments
Signal transmission system		Telemeter system
Rated capacity	Fx (force in longitudinal direction)	±8 kN
	Fy (side force)	±4 kN
	Fz (load or load reaction)	±8 kN
	Mx (overturning moment)	±1.5 kNm
	My (rolling resistance)	±0.5 kNm
	Mz (self-aligning torque)	±1.5 kNm
System precision		±3 % RO
Allowable overload		120 %
Temperature range	Sensor section	Compensation range: 0 – 70 C° Permissible range: -10 – 80C°
	Telemeter transmission unit	Permissible range: -10 – 50C°
Temperature effect	Zero-point drift	±0.01 % RO
Rotation speed measurement	Resolution	720 p/rev
	Maximum rotation speed	2000 min^{-1}
Wheel size		6.5 J-16

3.4.2 Engine rev counter

Engine rotation speed was measured with a digital fibre sensor. Figure 3.9 shows the appearance of the digital fibre sensor and Table 3.5 shows its specifications. Reflective tape was affixed to a part of the engine crank pulley, and by counting flashes of the reflected light from it with the digital fibre sensor, the number of revolutions was determined. Because the output of the digital fibre sensor was pulse signals, they were converted by a digital-analog converter to analog signals. Because the engine speed was over 6000 min^{-1} and less than 10 millisecond per revolution with the tested vehicles of this study, in order to obtain enough resolution, the response time was set at 250 micro second for counting.

Figure 3.9 Appearance of the digital fibre sensor

Table 3.5 Specifications of the digital fibre sensor

Manufacturer	Keyence Corp.
Light source LED	Red four-element LED (wavelength: 630 nm)
Response time	50 µs – 16 ms (range setting available)
Power source voltage	DC 12 – 24 V ± 10 %
Rated power	Under regular condition: 900 mW or lower
Ambient operating light	Incandescent lamp: 20000 lm or lower Sun light: 30000 lm or lower
Ambient operating temperature	-20 – 55 C^o
Ambient operating humidity	35 – 85% RH

3.4.3 Thermometer

Temperature was measured with a type-T thermocouple. Table 3.6 shows specifications of the type-T thermocouple. Depending on the place where it was used, one with appropriate sheath diameter and length and the end appropriately processed was selected.

Table 3.6 Specifications of type-T thermocouple

Manufacturer	Yamari Industries, Ltd.
Sheath thermocouple type	T
Material	SUS315L
Precision	JIS class 1
Logarithm	Single
Hot junction	Type II (non-grounded type)

3.4.4 Manometer

Intake pipe pressure was measured with a compound-pressure type manometer. Figure 3.10 shows the appearance of the manometer and Table 3.7 shows its specifications. The rated pressure range is ±101.3 kPa. The vacuum piping of the engines was split and the intake pipe pressure was measured. Since the manometer was a separate-amplifier type, the amplifier and the display were set up inside the vehicles.

Figure 3.10 Appearance of the manometer

Table 3.7 Specifications of the manometer

Manufacturer	Keyence Corp.
Rated pressure range	-101.3 – +101.3 kPa
Pressure tolerance	500 kPa
Measurable fluids	Air, non-corrosive gas
Pressure type	Gauge pressure
Temperature characteristics	Within ±2% of FS
Ambient operating temperature	0 – +50 C^o
Ambient operating humidity	35 – 85% RH

3.4.5 Accelerometer

To measure the acceleration of the vehicles, a triaxial acceleration transducer was used. The acceleration transducer's appearance is shown in Figure 3.11 and its specifications are shown in Table 3.8. Its rated capacity is defined as ±9.807 m/s^2, which is enough to measure acceleration when a vehicle is accelerating. The accelerometer was fixed around centre in the interior of the vehicle being tested.

Figure 3.11 Appearance of the acceleration transducer

Table 3.8 Specifications of the acceleration transducer

Manufacturer	Kyowa Electronic Instruments
Rated capacity	±9.807 m/s^2 (±1G)
Nonlinearity	Within ±0.1% RO
Hysteresis	Within ±0.1% RO
Rated output	0.5 mV/V (1000 x 10^{-6} strain) or higher
Operating temperature range	-10 to 60 °C
Safe overload rating	1000 % (equipped with stopper)
Frequency range	DC to 40Hz at 23 °C , sensitivity deviation ±5%

3.4.6 Voltmeter and ammeter

To measure voltage and electric current, a wattmeter was used for both direct and alternating currents. The appearance of the wattmeter is shown in Figure 3.12 and its specifications are shown in Table 3.9. When taking measurements on testing vehicles A and B, the range of direct current voltage was set at 300V and the current range at 200A. The range of alternating current voltage was set at 600V and the current range at 200A. With testing vehicle C, because one wattmeter did not have enough channels to measure electric power of the front and rear motors, this device was used only to measure alternating currents, and the alternating current voltage range was set at 600V and the current range at 500A. To measure voltage, the terminal of the vehicle's high voltage cable was directly connected to the wattmeter. For measurement of electric currents, a switch current transducer was clamped to the electric current line. The electric power was determined to be the value calculated by the wattmeter based on the voltage and the electric current.

Figure 3.12 Appearance of the wattmeter

Table 3.9 Specifications of the wattmeter

Manufacturer	Hioki E. E. Corp.
Measurement lines	Single-phase 2-wires, single-phase 3-wires, 3-phase 3-wires, 3-phase 4-wires
Measurement items	Voltage, current, voltage and current waveform peak values, active power, reactive power, apparent power, power factor, phase angle,

	frequency, current integration, power integration, load factor and efficiency
Measurement range	Voltage: 6/ 15/ 30/ 60/ 150/ 300/ 600V Current: 5/ 10/ 20/ 50/ 100/ 200A
Accuracy	DC: ±0.1% reading ±0.2% FS
Operating ambient temperature	-10 to 50 ^{o}C
Operating ambient humidity	80% RH or lower

With regard to testing vehicle C, because it has motors at the front and back, the number of channels of the above wattmeter was not enough. For this reason, another wattmeter was used to measure direct currents. The appearance of this wattmeter is shown in Figure 3.13 and its specifications are shown in Table 3.10. The range of direct current voltage was set at 600V and the direct current range at 200A. To measure voltage, the terminal of the vehicle's high voltage cable was directly connected to the wattmeter. For measurement of electric currents, a switch current transducer was clamped to the electric current line. The electric power was determined to be the value calculated by the wattmeter based on the voltage and the electric current.

Figure 3.13 Appearance of the wattmeter

Table 3.10 Specifications of the wattmeter

Manufacturer	Hioki E. E. Corp.
Measurement lines	Single-phase 2-wires, single-phase 3-wires, 3-phase 3-wires, 3-phase 4-wires
Measurement items	Voltage, current, voltage and current waveform peak values, active power, reactive power, apparent power, power factor, phase angle, frequency, current integration, power integration, and efficiency
Measurement range	Voltage: 15/ 30/ 60/ 150/ 300/ 600/ 1500V Current: 4/ 8/ 20/ 40/ 80/ 200A
Accuracy	DC: ±0.05% reading ±0.05% FS

Operating ambient temperature	0 to 40 °C
Operating ambient humidity	80% RH or lower

3.4.7 Fuel flow meter

To measure the fuel flow, a displacement flow meter was used. The appearance of the flow meter is shown in Figure 3.14 and its specifications are shown in Table 3.11. Because a flow meter of small flow-type was used, the flow range was 0.06 to 60 L/hr. The testing vehicles used in the present test had a returnless fuel system, and therefore the flow meter was inserted in the hose between the fuel pump and the fuel rail.

Figure 3.14 Appearance of the displacement flow meter

Table 3.11 Specifications of the displacement flow meter

Manufacturer	Ono Sokki
Acceptable liquid	gasoline, light oil, kerosene
Flow	0.06 to 60 L/hr
Precision	Within ±0.5%
Accuracy	DC: ±0.05% reading ±0.05% FS
Pressure loss	0.01 kPa or less
Minimum resolving power	0.01 mL
Maximum operating pressure	980 kPa
Operating temperature range	0 to 60 °C

3.4.8 Vehicle speed measuring device

To measure vehicle speed in the high-speed circuit, a GVS speed and distance meter based on GPS was used. The appearance of the speed and distance meter is shown in Figure 3.15 and its specifications are shown in Table 3.12. The measurable speed range is posted as 0.1 to 999.9 km/hr.

Figure 3.15 Appearance of the GVS speed and distance meter

Table 3.12 Specifications of the GVS speed and distance meter

Manufacturer	Vios System
Speed update	100 Hz
Measurable speed range	0.1 to 999.9 km/hr
Analog output	Vehicle speed 0 to 4V (0 - 100 km/hr, 0 - 200 km/hr, 0 - 300 km/hr, 0 – 500 km/hr)

3.4.9 Data storage device

To store data generated by measuring instruments, a memory recorder/analyzer was used. The appearance of the memory recorder is shown in Figure 3.16 and its specifications are shown in Table 3.13. This device is designed in a way that allows it to be connected to a six-component force meter and has the function to convert strain signals to driving torque. Also, it allows analog inputs and thermocouple inputs and can measure at the maximum speed of 50 kHz. In this study, sampling was done at a cycle of 500Hz, and analog signal data were recorded all together.

Figure 3.16 Appearance of the memory recorder

Table 3.13 Specifications of the memory recorder

General	Manufacturer	Kyowa Electronic Instruments
	Sampling frequency	1 Hz to 50 kHz
	Operating temperature range	0 to 40°C
	Operating humidity range	20 to 80% RH (no condensation)
	Storage temperature range	-20 to 60°C
Strain measurement	Input resistance	Approx. (10MΩ + 10 MΩ)
	Applied gauge factor	2.00
	Bridge power supply	DC 2.00 ± 2% (120 to 1 kΩ)
	Balance adjustment range	Resistance ± 2.4% (±12000 x10^{-6} strain)
	Measurement range	500, 1 k, 2 k, 5 k, 10 k, 20 k, 50 k x10^{-6} strain
Voltage measurement	Input resistance	Approx. 1 MΩ
	Measurement range	0.1, 0.2, 0.5, 1, 2, 5, 10 V
Common to strain and voltage	Range precision	each range ±0.2% FS
	Calibration value	each range ±100% and ±50%
	Nonlinearity	±0.1% FS
	Resolution	16 bits
Thermocouple	Applicable thermocouples	K and T
	Measurement range	K: -200 to 1230°C, -200 to 480°C, -200 to 240 °C T: -200 to 400 °C, -200 to 210 °C
	Overall precision	Within ± (0.5% of reading + 1) °C; ambient temperature 20 ± 3 oC Within ± (0.5% of reading + 2) °C; ambient temperature 0 to 40oC
	Calibration value	50% and 100% in each range at 0ºC
	Resolution	16 bits

3.4.10 Testing vehicles

Two testing vehicles were used in 2015 and one testing vehicle in 2016. It was decided to test small-sized hybrid vehicles in 2015, and testing vehicle A (Figure 3.17), which runs on a series-parallel powertrain and testing vehicle B (Figure 3.18), which runs on a parallel powertrain were selected. In 2016, a four-wheel drive series-parallel vehicle that is chargeable from outside power sources was used as testing vehicle C (Figure 3.19). Specifications of each vehicle are shown in Table 3.14. Testing vehicles A and B are both small-sized vehicles with a 1.5L engine and are less than 4 meters in length. Testing vehicle C is 4.7 meters long and has a 2.0L engine. While the *Test Requirements and Instructions for Automobile Standards* [of the National Agency for Automobile and Land Transport Technology of Japan] defines the vehicle weight for fuel economy and emission tests as the vehicle curb weight plus 110 kg,[ii] since the subject of the present tests is power output, it was determined that the vehicle weight would not affect test results. However, when necessary devices are all loaded onto the vehicles, their weight increased significantly, so unnecessary seats such as the passenger seat and rear seats were removed to minimize the weight increase. The weight of testing vehicle A in the test was 1340 kg, 260 kg heavier than its curb weight. Testing vehicle B weighed 1360 kg in the test, which was 200 kg heavier than its curb weight, and testing vehicle C weighed 1933 kg, 113 kg heavier than its curb weight. The posted engine power of testing vehicle A is 54 kW, the posted motor power output is 45 kW and the posted HEV system power output is 73 kW. For testing vehicle B, the posted engine power output is 81 kW, the posted motor power output is 22 kW and the posted HEV system power output is 101 kW. Testing vehicle C has an engine power output of 87 kW and a 60 kW motor in the front and rear, and its HEV system power output is not disclosed. All the three vehicles used for the tests were used, and the mileages at the end of the tests were 5187 km on testing vehicle A, 12768 km on testing vehicle B and 8119 km on testing vehicle C. Because six component force meters were to be attached to tires, 16-inch wheels were used, and the tire size of testing vehicles A and B were 195/50R16, which is equivalent to their genuine tires, and testing vehicle C's tire size was that of its genuine tires, which was 251/70R16.

Figure 3.17 Appearance of testing vehicle A

Figure 3.18 Appearance of testing vehicle B

Figure 3.19 Appearance of testing vehicle C

Table 3.14 Specifications of testing vehicles

		2015		2016
Testing vehicle		A	B	C
Body	Length x Width x Height	3.99 m x 1.69 m x 1.44 m	3.95 m x 1.69 m x 1.52 m	4.69 m x 1.80 m x 1.71 m
	Curb weight	1080 kg	1160 kg	1820 kg
	Gross vehicle weight	1355 kg	1435 kg	2095 kg
	Test weight	1340 kg	1360 kg	1933 kg
Engine	Total engine displacement	1.496 L	1.496 L	1.988 L
	Maximum power	54 kW	81 kW	87 kW
Motor	Type	Alternating current synchronous motor	Alternating current synchronous motor	Alternating current synchronous motor
	Maximum power	45 kW	22 kW	60 kW/60 kW
HEV	System	Series parallel	Parallel	Series parallel
	System power	73 kW	101 kW	Not disclosed
Mileage at the end of the test		5187 km	12768 km	8119 km
Test tire size		195/50R16		215/70R16

3.4.11 Overall view of the measuring instruments

The overall view of the measuring instruments and data recorder installed on the testing vehicles is shown in Figure 3.20. Data generated by all the instruments are recorded as analog data in the memory recorder, which is a data recording device. The sampling speed was set at 2 milliseconds. In addition to what is shown in the figure, general-purpose scan tools connected to the vehicles' diagnostic connectors were used to take measurements, such as the SOC of the driving batteries and vehicle speed, as reference data.

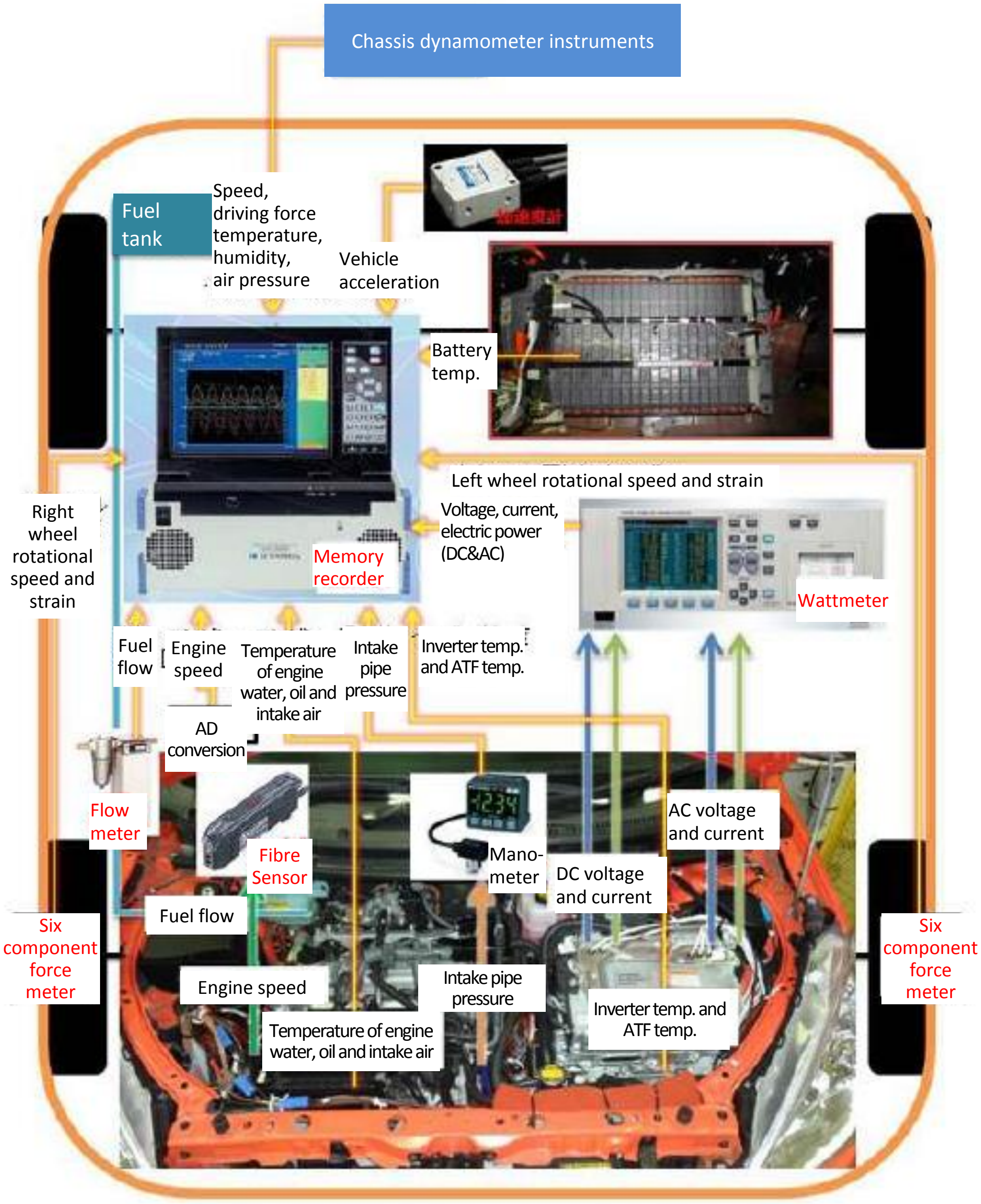


Figure 3.20 Overall view of the measuring instruments

References

[i] Global technical regulation (GTR) No. 4: Test procedure for compression ignition (C.I.) engines and positive-ignition (P.I.) engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG) with regard to the emission of pollutants, A. 9.6.3   Hybrid system rated power determination.

[ii] TRIAS 99-006-01 Fuel economy test (JC08 mode) Annex 4 Methods of measuring driving resistance and setting loads to the chassis dynamometer (5. related), p. 18