Working Paper No. **HDH-DG-01-02e**
(1st HDH Drafting Group meeting, 19 to 20 March 2013)

Overview of Test Procedure of HILS in Japan

Heavy Duty Hybrids GTR Drafting Meeting
Date.19-20,March,2013
JASIC

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Official Notifications for HILS SYSTEM

Notification of HILS SYSTEM

- TEST PROCEDURE FOR FUEL CONSUMPTION RATE AND EXHAUST EMISSIONS OF HEAVY-DUTY HYBRID ELECTRIC VEHICLES USING HARDWARE-IN-THE-LOOP SIMULATOR SYSTEM, Kokujikan No. 281 of March 16, 2007

Notifications regarding HILS SYSTEM

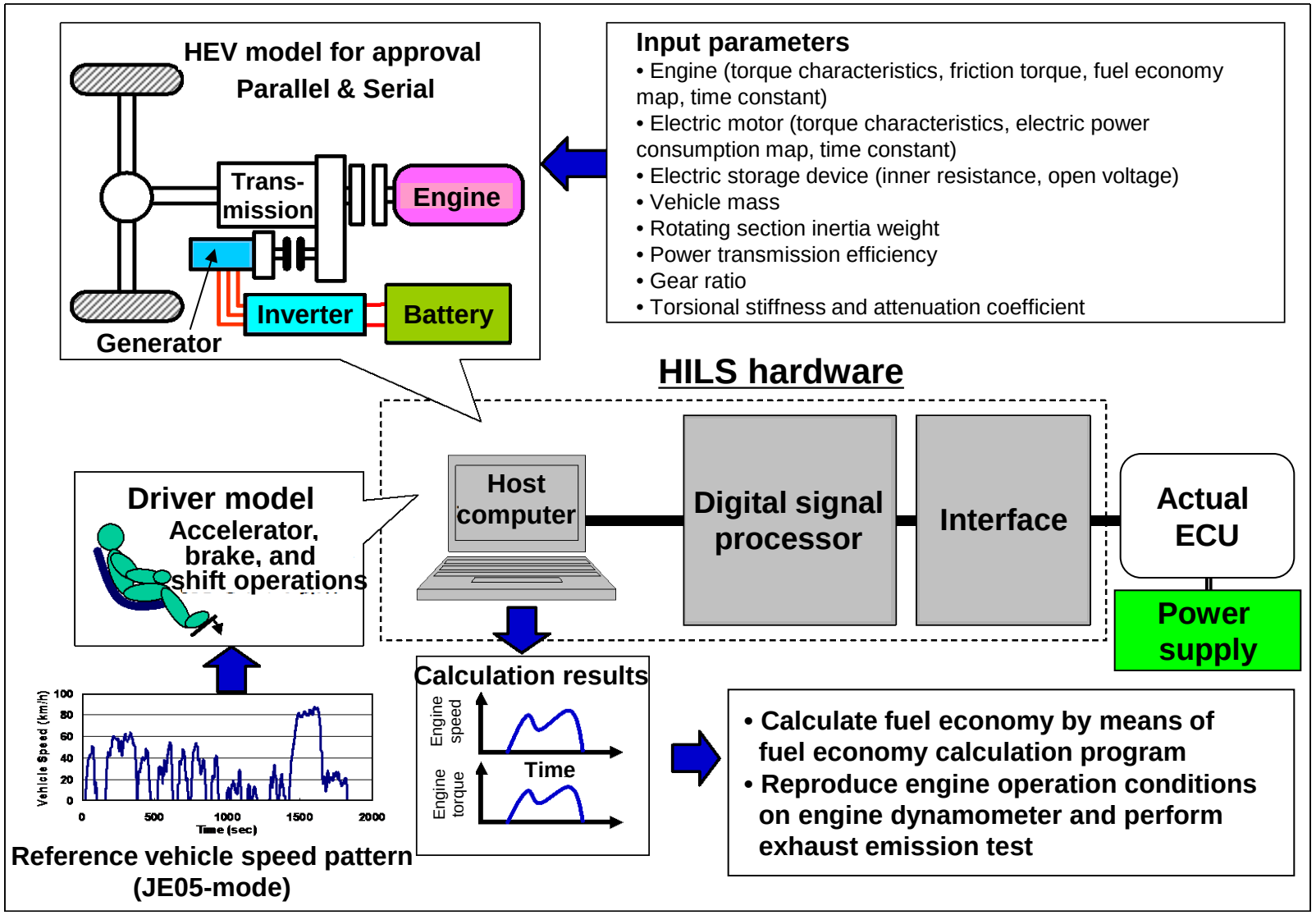
- TEST PROCEDURE FOR HILS SYSTEM PROVISIONAL VERIFICATION FOR HEAVY-DUTY HYBRID ELECTRIC VEHICLES, Kokujikan No.282 of March 16, 2007
- Measurement Procedure for JE05-Mode Exhaust Emissions by Means of Chassis Dynamometer, Kokujikan No. 280 of March 16, 2007

Guidelines regarding HILS SYSTEM (April 9, 2007)

- Guideline of Verification of HILS SYSTEM, Shinsajoho No.2007-9
- Appendix (Guideline of System bench test procedure, Shinsajoho No.2007-7/ Guideline of HILS SYSTEM Shinsajoho No.2007-8)

Chap.1 HILS SYSTEM for HDH

1. Overview of HILS SYSTEM for HDH



Chap.1 HILS SYSTEM for HDH

2. Softwares to be used

- Parallel HEV model for approval
- Series HEV model for approval
- Fuel efficiency calculation-assisting program
- Hermite interpolation program: can be used when a map is produced. (correspond three dimensions map)

3. Actual ECU

- The hybrid ECU of the test motor vehicle shall be used as the actual ECU.
- in the case of a motor vehicle equipped with a transmission ECU, this may be used as the hybrid ECU at the same time.

4. Driver Model, etc.

- The driver model makes the HEV model for approval to operate in such a way as to achieve the reference vehicle speed by generating accelerator, brake and shift signals, and is actuated by the PID control, etc.
- In addition, the driver model may be replaced by dot-sequential data of accelerator, brake and shift signals.

Chap.1 HILS SYSTEM for HDH

5. Operation Check of HEV Model for Approval

- Input the SILS reference parameters in the HEV model for approval, and control the HEV model for approval using the ancillary reference ECU model for SILS.
- Confirm that the calculation result of each parameter satisfies the criterion shown in Table 1 in relation to the SILS reference calculation result.
- However, this provision shall not apply if changes have been made in the construction and constant of each component model of the HEV model for approval.

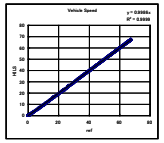
Table1. Criterion for Operation Check of HEV Model for Approval by Means of Reference ECU Model for SILS

Verification items	Criterion		
	Slope	Intercept	Determination
Vehicle speed, electric motor revolution speed • Torque, electric storage device voltage •current • state of charge, engine revolution speed • Torque	0.9995 – 1.0005	±0.05 % or less of the maximum value	0.995 or more

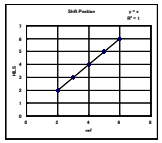
Chap.1 HILS SYSTEM for HDH

5. Operation Check of HEV Model for Approval

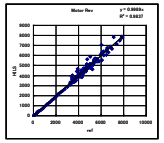
Result of SILS CHECK



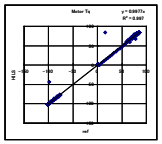
Vehicle Speed
y=x-0.0002
R^2=1.000



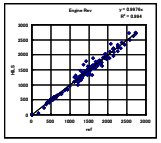
Shift position
y = 0.9954x + 0.0218
R^2=0.998



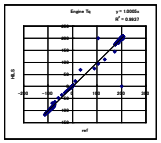
Motor revolution
y = 1.0001x + 0.0043
R^2=0.999



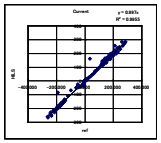
Motor torque
y = x + 0.0008
R^2=1.000



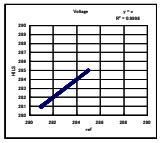
Engine revolution
y = 0.9998x + 0.3434
R^2=0.999



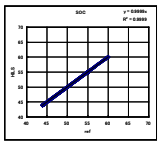
Engine torque
y = x + 0.0421
R^2=1.000



Battery current
y = 1.0001x - 0.0143
R^2=0.999



Battery voltage
y = 0.9999x + 0.0204
R^2=1.000



Battery SOC
y = 0.9999x + 0.007
R^2=1.000

Chap.1 HILS SYSTEM for HDH

6. Gear Change Method

- Gear positions at the start, acceleration and deceleration during the approval test shall be the respective gear positions specified below according to the types of heavy-duty hybrid electric vehicles enumerated below:
- Furthermore, since heavy-duty series hybrid electric vehicles have no transmission, no gear positions are specified for them.

(1) Heavy-duty parallel hybrid electric vehicles fitted with a manual transmission and an automatic transmission with torque converter (AT):

➢ Gear positions pursuant to the provisions of the calculation program for the fuel consumption rate of heavy-duty motor vehicles provided for in Attached Table 6 (8), Test Procedure for Fuel Consumption Rate of Heavy-Duty Motor Vehicles (TRIAS 5–8–2006) of the “Type Approval Test Procedures” (Jisha No. 669 of October 20,1971), or to the provisions of the “Measurement Procedure for Exhaust Emissions from Heavy-Duty Hybrid Electric Vehicles” (Kokujikan No.60 of June 30, 2004).

Chap.1 HILS SYSTEM for HDH

6. Gear Change Method

(2) Heavy-duty parallel hybrid electric vehicles fitted with an automated manual transmission (AMT):

- Gear positions of the automatic gear shifting by means of the actual transmission ECU control. However, the gear positions specified in Item (1) may be used.

Chap.2 Test procedure for Engine, Electric Motor and Electric Storage Device

Test Procedure for Engine

- Engine torque characteristics
  N-T characteristics against accelerator and against EV_ECU Command values
- Engine friction torque
- Fuel economy map

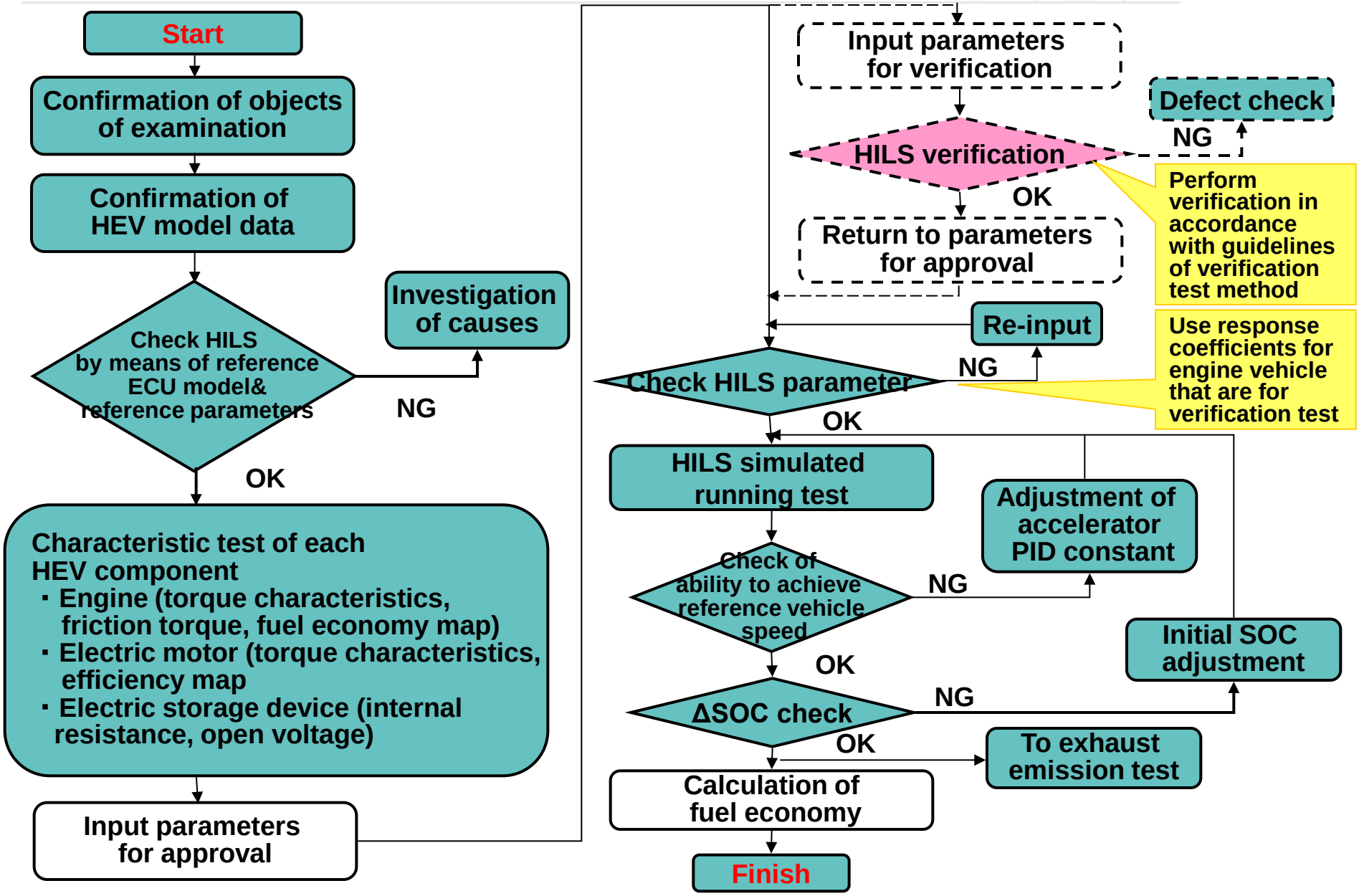
Test Procedure for Electric Motor

- Electric Motor torque characteristics
  -revolution speed, torque command values, shaft torque, output shaft,
  electric power, temperature at each section

Test Procedure for Electric Storage Device

- Current-voltage characteristics test.
- Calculate Internal resistance Open voltage.

Chap.3, Chap.4 Test Procedure for Fuel Consumption Rate and Exhaust Emissions of HDH



Chap.3, Chap.4 Test Procedure for Fuel Consumption Rate and Exhaust Emissions of HDH

Allowable errors in speed and time during the simulated running

- shall be, at any point during each running mode, within ± 2.0 km/h in speed and within ± 1.0 second in time, and shall be within the range of the colored section in Figure 1.
- Moreover, if deviations are within the tolerance corresponding to the setting items posted in the left column of Table 1, they shall be deemed to be within the allowable errors. Time deviations at the times of start and gear change operation, however, shall not be included in the total cumulative time. In addition, this provision shall not apply to motor vehicles incapable of attaining the speeds of each running mode during the accelerations with their accelerator pedals fully depressed.

Fig.1

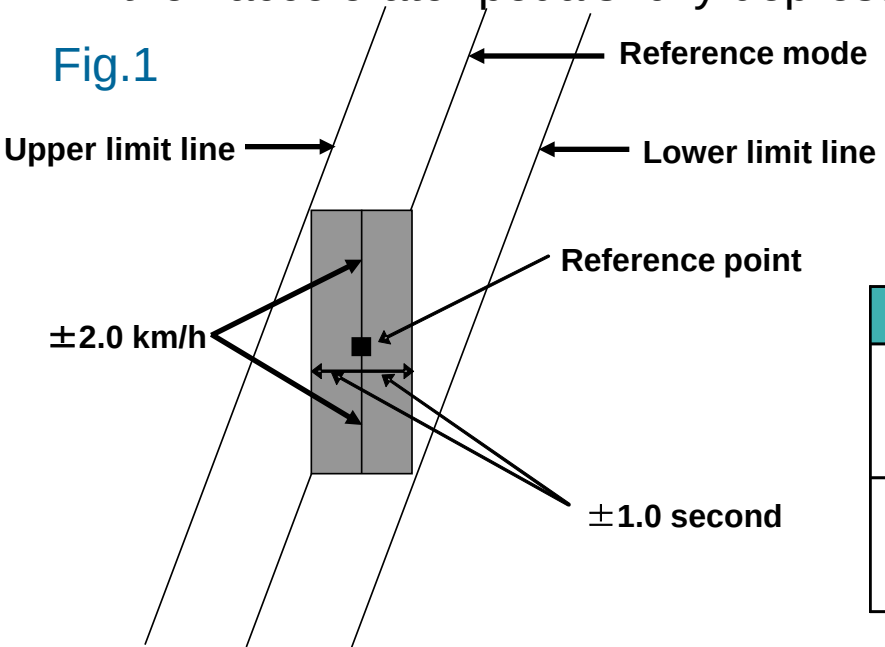


Table.1

Setting item Tolerance	Tolerance
1. Tolerable time range for one deviation	1.0 second
2. Tolerable time range for the total cumulative value of time deviations	2.0 seconds

Chap.3, Chap.4 Test Procedure for Fuel Consumption Rate and Exhaust Emissions of HDH

Range of electricity balance for HILS system simulated running

➢Fuel consumption

$$\left|\Delta E / C\right| < 0.003$$

$$\Delta E = \Delta Ah \times V_{\text{nominal}} \times 3600$$

$$C = Q \times \rho \times Hu$$

ΔE: Energy conversion value of electricity balance (J)

C: Energy conversion value of cumulative amount of fuel consumption (J)

ΔAh : Electricity balance (Ah)

Vnominal: Rated voltage (V)

Q: Cumulative amount of fuel consumption (L)

ρ: Specific gravity (kg/L)

Hu: Lower calorific value (J/kg)

➢Exhaust emission

$$\left|\Delta E / W_{eng\_ref}\right| < 0.03$$

$$\Delta E = \Delta Ah \times V_{\text{nominal}}$$

ΔE: Energy conversion value of electricity balance (kWh)

ΔAh: Electricity balance (Ah)

Vnominal: Rated voltage (V)

Weng_ref: Integrated positive engine shaft torque (kWh)

Chap.3, Chap.4 Test Procedure for Fuel Consumption Rate and Exhaust Emissions of HDH

Calculation of fuel consumption rate of heavy-duty motor vehicles

$$E = \frac{1}{\frac{1-\alpha/100}{E_u} + \frac{\alpha/100}{E_h}}$$

E: Fuel consumption rate heavy-duty motor vehicle (km/L)

Eu: City running fuel consumption rate (km/L)

Eh: Intercity running fuel consumption rate (km/L)

α: Intercity running ratio (%)

In the case of a motor vehicle equipped with an automatic transmission with torque converter (AT), the fuel consumption rates of the said motor vehicle shall be determined by multiplying the calculated fuel consumption rate by 0.91 in the case of the city running mode, by 0.96 in the case of the intercity highway running mode, and by 0.91 in the case of the urban running mode.

Chap.3, Chap.4 Test Procedure for Fuel Consumption Rate and Exhaust Emissions of HDH

Calculation of fuel consumption rate of heavy-duty motor vehicles

Table.1 Standard Specifications and Intercity Running Ratio of Trucks, etc.

Fuel economy category No.	Category		Standard vehicle specifications					
	Range of gross vehicle weight (ton)	Range of maximum loading capacity (ton)	Vehicle weight (kg)	Maximum loading capacity (kg)	Riding capacity (person)	Overall height (m)	Overall width (m)	Intercity running ratio (%)
T1	3.5 < & ≤ 7.5	≤ 1.5	1,957	1,490	3	1.982	1.695	10
T2		1.5 < & ≤ 2	2,356	2,000	3	2.099	1.751	
T3		2 < & ≤ 3	2,652	2,995	3	2.041	1.729	
T4		3 <	2,979	3,749	3	2.363	2.161	
T5	7.5 < & ≤ 8	–	3,543	4,275	2	2.454	2.235	
T6	8 < & ≤ 10	–	3,659	5,789	2	2.625	2.239	
T7	10 < & ≤ 12	–	4,048	7,483	2	2.541	2.350	
T8	12 < & ≤ 14	–	4,516	7,992	2	2.572	2.379	
T9	14 < & ≤ 16	–	5,533	8,900	2	2.745	2.480	
T10	16 < & ≤ 20	–	8,688	11,089	2	3.049	2.490	
T11	20 <	–	8,765	15,530	2	2.934	2.490	30

Table.2 Standard Specifications and Intercity Running Ratio of Trucks (tractors)

Fuel economy category No.	Category	Standard vehicle specifications					
	(Tractor head) Range of gross vehicle weight (ton)	Vehicle weight (kg)	Maximum loading capacity (kg)	Riding capacity (person)	Overall height (m)	Overall width (m)	Intercity running ratio (%)
TT1	≤ 20	10,525	24,000	2	2.927	2.490	20
TT2	20 <	19,028	40,000	2	2.890	2.490	10

Chap.3, Chap.4 Test Procedure for Fuel Consumption Rate and Exhaust Emissions of HDH

Calculation of fuel consumption rate of heavy-duty motor vehicles

Table.3 Standard Specifications and Intercity Running Ratio of Passenger Vehicles (Route Buses)

Fuel economy category No.	Category	Standard vehicle specifications				
	Range of gross vehicle weight (ton)	Vehicle weight (kg)	Riding capacity (person)	Overall height (m)	Overall width (m)	Intercity running ratio (%)
BR1	6 < & ≤ 8	5,186	39	2.88	2.072	0
BR2	8 < & ≤ 10	6,672	46	2.947	2.301	
BR3	10 < & ≤ 12	7,324	62	2.949	2.304	
BR4	12 < & ≤ 14	8,654	77	2.969	2.385	
BR5	14 <	9,790	79	2.962	2.490	

Table.4 Table 4 Standard Specifications and Intercity Running Ratio of Passenger Vehicles (General Buses)

Fuel economy category No.	Category	Standard vehicle specifications				
	Range of gross vehicle weight (ton)	Vehicle weight (kg)	Riding capacity (person)	Overall height (m)	Overall width (m)	Intercity running ratio (%)
B1	3.5 < & ≤ 6	3,543	29	2.593	2.027	10
B2	6 < & ≤ 8	5,622	29	3.019	2.197	
B3	8 < & ≤ 10	6,608	49	3.105	2.314	
B4	10 < & ≤ 12	8,022	58	3.160	2.399	
B5	12 < & ≤ 14	9,774	60	3.168	2.490	
B6	14 < & ≤ 16	12,110	62	3.320	2.490	35
B7	16 <	14,583	51	3.668	2.490	

Chap.3, Chap.4 Test Procedure for Fuel Consumption Rate and Exhaust Emissions of HDH

Calculation of Integrated System Shaft Output

The integrated shaft output (hereinafter referred to as “Wsys”) that is used to calculate the emission mass of the exhaust gas per unit work done shall be calculated using the integrated shaft output of the hybrid system obtained by means of the HILS system, as shown below:

(1) Cases where Weng_act < Weng_ref:

$$W_{sys} = W_{sys\_ref} \times W_{eng\_act} / W_{eng\_ref}$$

(2) Cases where Weng_act ≥ Weng_ref:

$$W_{sys} = W_{sys\_ref}$$

Wsys: Integrated positive shaft output of hybrid system (kWh)
Wsys_ref: Integrated positive shaft output of hybrid system by means of HILS system (kWh)
Weng_act: Integrated measured positive engine shaft output (kWh)
Weng_ref: Integrated measured positive test engine shaft output (kWh)

Chap.5 Verification Test Procedure for HILS SYSTEM for HDH

Purpose of Verification Test

To verify the reproducibility for the behavior of the actual vehicle (or system).
For this purpose, following two verifications are developed.

1. Verification of correlation within a short-period vehicle operation

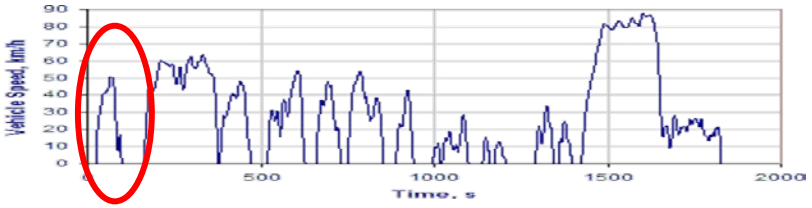


Table.1 Tolerance in Correlation (Determination Coefficient) of Actually-Measured Verification Values and HILS Simulated Running Values

Test condition	Vehicle speed or engine revolution speed	Electric motor		Engine		Electric storage device output
		Torque	Output	Torque	Output	
One heap in JE05-mode	**0.97 or more**	**0.88 or more**	**0.88 or more**	**0.88 or more**	**0.88 or more**	**0.88 or more**

Chap.5 Verification Test Procedure for HILS SYSTEM for HDH

2. Verification of correlation for the load and fuel efficiency of whole test cycle

Table 2 Tolerances in Overall Verification

Test condition	Vehicle speed or engine revolution Speed	Engine torque	Positive engine work	Fuel economy value
	Determination coefficient	Determination coefficient	W_{eng_HILS} / $W_{eng\_vehicle}$	FE_{HILS} / $FE_{vehicle}$
Entire JE05-mode	**0.97 or more**	**0.88 or more**	**0.97 or more**	**1.03 or less**

Weng_HILS : Integrated positive engine shaft output in HILS simulated running (kWh)

Weng_vehicle: Integrated positive engine shaft output in actual vehicle test (kWh)

FEHILS : Fuel economy value in HILS simulated running (km/L)

FEvehicle : Fuel economy value in actual vehicle test (km/L)

In test for fuel consumption, engine torque verification is not necessary.
(engine torque verification is necessary in the case of verification for Exhaust emission with HILS)

Guideline of Verification of HILS SYSTEM

Requiring verification of HILS system shall be applied in cases as follows;

1) First case to use HILS system

it shall be required both verifications in case of GVW more than 12 ton and in case of GVW 12ton or less even if using same hybrid system.

2) Cases to change hybrid system layout consists of engine, electric motor, transmission (TM) and clutch (CL),

for example ; even if using same components,

- change vehicle model from parallel hybrid to series hybrid
- change the installation of electric motor from in-engine to in-TM

Guideline of Verification of HILS SYSTEM

3) Cases to change the structure of components or constant

for example ;

- change the structure of engine model or increase the input parameters in order to make the engine model suitable for manufacture's characteristic of real engine

4) Cases to change sort of components

for example ; even if using same components,

- change sort of TM model from manual shift type to Automated mechanical type
- change sort of CL model from without fluid coupling to with fluid coupling

Guideline of Verification for HILS SYSTEM

5) Cases to change delay time of engine model, time constant of engine/electric motor models

for example ;

- change delay time* of engine model, time constant *of engine/electric motor models in order to make the engine/electric motor models suitable for manufacture's characteristic of real engine/electric motor

*chapter1, 10-9 prescribes both delay time and time constant of engine model shall be 0.01second.

Guideline of Verification of HILS SYSTEM

6) Cases of other reasons

for example ;

- change software of hybrid ECU (electronic control unit) of series hybrid from one point constant driving of engine for electric generator to multi points driving

In case of certificated hybrid system, it is not needed to be required verification test to change only input data of

-Engine torque characteristic

-Electric motor torque, electricity characteristic

-Battery internal resistance, voltage characteristic

-Vehicle specification except changing GVW cross over 12ton

END