6 January, 2011

Subject: Release of HILS Open source model for HD Hybrid Vehicle using rigid model

Japan has been working for the full open source of the standardized HEV model in Japan for the purpose of international harmonization of HILS test procedure.

Nevertheless, current HILS Certification Model used in Japan can not be provided due to the intellectual property right.

To get over this difficulty, JAMA/JARI is now under development of another model which can be disclosed. The model which we release today is a rigid model for parallel hybrid vehicle, which was reported at #3 HDH-IG.

As explained above, this is not the same model which is currently certified as HILS test procedure in Japan, however, the accuracy is almost verified by experts from HEV WG of JAMA.

We have also started the development of fluid coupling model and toque converter model. and the verification is also now underway, with a target of receiving approvals as HILS test procedure in Japan during fiscal year 2012.

We are ready to consider the support to the research laboratories in member countries of HDH-IG for their operation of the model if required.

Sincerely,

Japan Automobile Standards Internationalization Center (JASIC)

6 Jan. 2011 JARI

HILS SYSTEM FOR HEAVY-DUTY HYBRID ELECTRIC VEHICLES

1. Outline of HILS System for Heavy-Duty Hybrid-Electric Vehicles

The HILS system consist of, as shown in Figure 1, the HILS hardware, the HEV model for approval and its input parameters, the driver model and the reference vehicle speed pattern, and the hybrid ECU of the test motor vehicle (hereinafter refereed to as the "actual ECU") and its power supply.

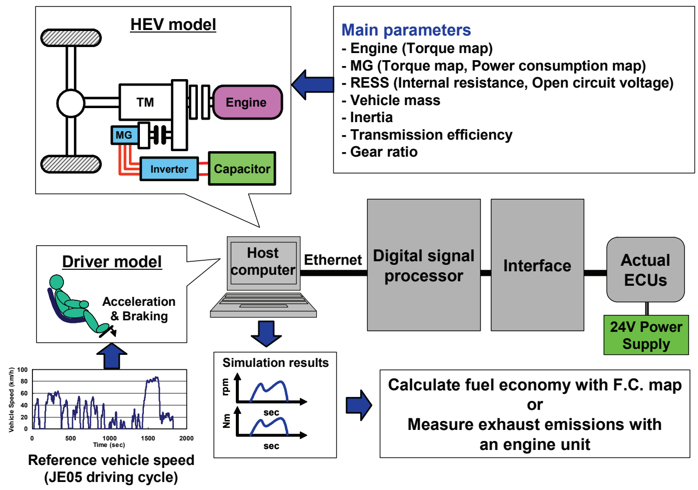

Fig. 1 Outline of HILS System for Heavy-Duty Hybrid Electric Vehicle

2. Softwares to be Used

The softwares necessary for this test method are, in addition to an HEV models for approval (including the reference ECU model for the Software-in-the-Loop Simulator (hereinafter referred to as the "SILS")) corresponding to parallel and series heavy-duty hybrid electric vehicles, a fuel economy calculation-assisting program capable of calculating fuel economy based on the engine revolution speed and torque that are obtained from the simulated running using the HILS system, as well as the Hermite interpolation program that can be used when creating table data of the input parameters, etc. The softwares to be used are enumerated below:

- Parallel HEV model for approval
- Series HEV model for approval
- Fuel efficiency calculation-assisting program
- Hermite interpolation program

3. HILS Hardware

The HILS hardware shall have the signal types (ADIO, PULSE, CAN) and number of channels that are sufficient for constructing the interface between the HILS hardware and the actual ECU, and shall be checked and calibrated.

4. Actual ECU

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

5. 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.

6. HEV Model for Approval

The HEV model for approval shall be created based on the specifications specified in Paragraphs 6–1 through 6–4 below. Thereafter, the input parameters pertaining to individual test motor vehicles shall be inputted and the parameter setting for the input / output shall be performed according to the system of heavy-duty hybrid electric vehicles.

6–1 Engine model

The engine model calculates the generated torque of the engine from the engine torque command value, throttle valve opening angle or injection amount command value and the torque map in relation to the revolution speed. The torque generated by the engine, the starter torque and the torque loaded on the engine from outside are combined. The revolution speed is determined from the combined torque and the inertia moment of the engine's rotating sections. If the actual ECU required revolution control or revolution limit, the PID control function inside the engine model controls the engine revolution speed. In addition, the idle revolution speed can be adjusted by the input for adjustment. It stops by the input of Ignition OFF or Fuel Cut ON signal (Fig. 2).

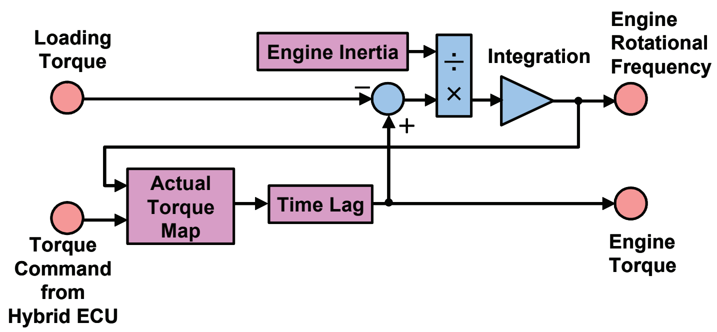

Fig. 2 Conceptual Diagram of Engine Model

6–2 Electric motor model

The electric motor model has the voltage as its parameter. It has the torque map and the electric power consumption map in relation to the electric motor torque command value and the revolution speed. While driving or controlling the vehicle based on the electric motor command value inputted from the actual ECU, it calculates electric power consumption. The electric motor torque command value corresponds to the switching of power running / regeneration (Fig. 3).

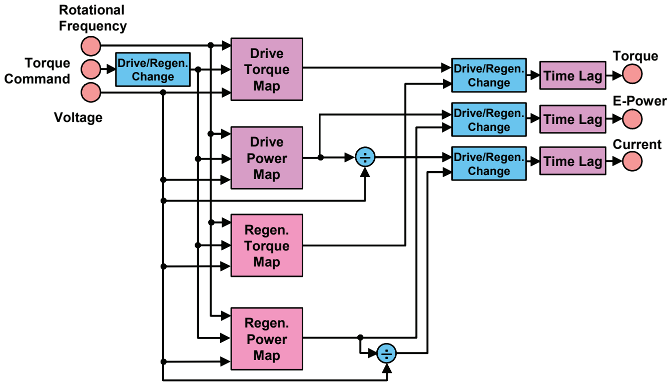

Fig. 3 Conceptual Diagram of Electric Motor Model

6–3 Rechargeable energy storage system (RESS) model

The charged / discharged power and the state of a charge of the nickel hydride battery or lithium-ion battery shall be calculated by using the following formulas: In this case, the state of charge shall be calculated by current integration assuming that the Coulomb efficiency is 100 %. Both the open voltage and internal resistance of the battery shall be calculated from the map in relation to the state of charge, since they change according to the state of charge (Fig. 4).

$$P = V_s I = (V_o - R_i I) I$$

$$SOC = SOC_{initial} - \int_0^t \frac{I}{C_{nominal} \times 3600} dt \times 100$$

where:

P : Charged / discharged power (W)

Vs : Terminal voltage (V)

I : Electric current (A)

Vo : Open voltage (V)

Ri : Internal resistance (Ω)

SOC : State of charge (%)

SOCinitial: Initial state of charge (%)

Cnominal : Rated capacity (Ah)

t : Elapsed time (s)

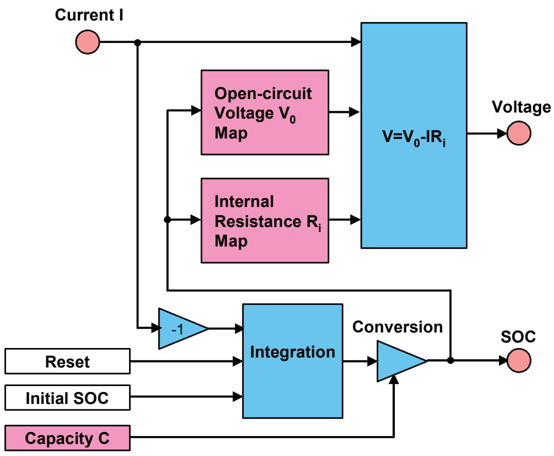

Fig. 4 Conceptual Diagram of Battery Model

6–4 Vehicle / power train system model

The vehicle / power train system model consist of the running resistance model, the transmission / vehicle model and the clutch for electric motor model. This not only calculates the running resistance but also gives and receives the torque between the engine model and the electric motor model, generating the vehicle speed.

(1) Running resistance model

This model calculates the running resistance from the vehicles speed, using the following formula:

$$R = \mu_r mg + mg\sin\theta + \mu_a AV^2 g$$

where:

R : Running resistance (N)

μr : Rolling resistance coefficient (kg/kg)

m : Vehicle mass at time of test (kg)

μaA : Air resistance coefficient × frontal projected area(kg/(km/h)^2)

V : Vehicle speed (km/h)

g : Acceleration of gravity (m/s^2)

θ: Longitudinal gradient (rad)

Here, the acceleration of gravity is assumed to be 9.80665 (m/s^2).

(2) Transmission • vehicle model

This model calculates the torque transmitted to the vehicle from the engine torque, electric motor torque, reduction ratio at each speed, final reduction ratio, gear efficiency and inertia moment of each component. From this torque and the load torque consisting of the running resistance of the vehicle, vehicle mass, inertia moment of the tyres and axles, the acceleration of the vehicle shall be determined. The torque transmitted from the transmission input shaft to its output shaft is calculated from the clutch stroke and gear transmission efficiency, and inertia moment is set for each speed.

(3) Clutch model

This model simulates the clutch operation between the engine and transmission, and calculates the transmission (including the electric motor) / input shaft revolution speed, and the load torque to the engine. It adds the torque inputted from the electric motor and calculates the input shaft revolution speed from the inertia of the clutch section including the electric motor.

7. Reference ECU Model for SILS

The reference ECU model for SILS is used for the purpose of operation check of the HEV model for approval. The signals given from the reference ECU model for SILS to the HEV model for approval are command values of the torques of the engine and electric motor, of the gear change, clutch, lock up of hydraulic coupling, etc. Moreover, the reference ECU model for SILS shall be ancillary to the HEV model for approval, and shall be arranged in such away that it can be used by switching from the actual ECU with a selector switch.

8. Operation Check of HEV Model for Approval

The operation check of the HEV model for approval shall be performed by the following method:

Input the SILS reference parameters (Attached Sheet 1 in the case of the parallel type, and Attached Sheet 2 in the case of the series type) 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 (Attached Sheet 3 in the case of the parallel type, and Attached Sheet 4 in the case of the series type). 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

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Table 1 Criterion for Operation Check of HEV Model for Approval by Means of Reference ECU Model for SILS

Verification items	Tolerance		
	Slope of the Regression Line	Y Intercept of the Regression Line	Coefficient of Determination (r^2)
Vehicle speed, MG rev/torque, RESS voltage/current/SOC, Engine rev/torque	0.9995-1.0005	+/-0.05% and below of Maximum value	0.995 and above

9. Construction of Interface

In the HILS system, where the actual ECU, driver model and HEV model for approval are stored, connection is made by means of the interface shown in Table 2 for parallel heavy-duty hybrid electric vehicles, respectively. In addition, level tuning of the signal and the fail release correspondence, etc. can be handled by using a unique interface conversion model according to the system of the heavy-duty hybrid electric vehicle.

Table 2 Interface Specifications of Parallel HEV Model for Approval

Model	Input/Output (from model)	Symbol	Meaning of signal	Unit	Remarks
Transmission and vehicle model	Input-1	BR_TQ_N	Mechanical brake force	N	Tire surface
	Input-2	CL_q_1	Clutch stroke	%	
	Input-3	shift_p	Shift position command	-	
	Input-4	Motor_CL	MG clutch	-	ON/OFF
	Input-5	Clutch_position	Clutch (MG) position	-	
	Input-6	F_coup_on	Fluid-coupling switch	-	ON/OFF
	Input-7	Lock_up	Lock-up switch	-	ON/OFF
	Input-8	koubai	Longitudinal gradient	%	
	Output-1	Speed_Out	Vehicle speed	km/h	
	Output-2	RL_N_Out	Road load	N	
	Output-3	Distance	Driving distance	km	
	Output-4	KASOKUDO	Acceleration	m/s^2	
	Output-5	Ni_rpm	counter shaft revolution	r/min	
	Output-6	Nc_rpm	Input shaft revolution	r/min	
	Output-7	Eg_Fuka_Nm	Loading torque	Nm	incl. MG control
	Output-8	No_rpm	Output shaft revolution	r/min	
	Output-9	Nt_rpm	Turbine revolution	r/min	
	Output-10	shift_p	Shift position	-	
RESS model	Input-1	RESS_change	RESS change switch	-	
	Input-2	Accessory1_ON	Accessory 1 switch	-	ON/OFF
	Input-3	Accessory2_ON	Accessory 2 switch	-	ON/OFF
	Output-1	RESS_SOC	RESS_SOC	%	
	Output-2	RESS_Voltage	RESS_Voltage	V	
	Output-3	RESS_Current	RESS_Current	A	
	Output-4	RESS_Power	RESS_Power	W	
Engine model	Input-1	Sireikaido	Torque Command	Nm	%, mm^3/st, etc.
	Input-2	ACCkaido	Accelerator opening	%	
	Input-3	ACC_switch	Command-signal-change switch	-	0/1
	Input-4	IG_In	Ignition	-	ON/OFF
	Input-5	ST_In	Starter	-	ON/OFF
	Input-6	Fuel_cut	Fuel cut	-	ON/OFF
	Input-7	EXHB_In	Exhaust brake	-	ON/OFF
	Input-8	Rev_demand	Reference revolution	rpm	
	Input-9	Rev_control_demand	Revolution control demand	-	ON/OFF
	Input-10	Rev_limit_demand	Revolution limit demand	-	ON/OFF
	Input-11	Tq_limit_demand	Torque limit demand	-	ON/OFF
	Input-12	Tq_limit_rate	Torque limit rate		
	Input-13	Tq_limit_switch	Torque limit switch	-	ON/OFF
	Input-14	Idle_rpm_adjust	Idle revolution adjust		
	Output-1	Ne_out	Engine revolution	r/min	
	Output-2	Fuel_Consumption	Fuel consumption	L	
	Output-3	EgDriveTq	Engine positive torque	Nm	
	Output-4	EgLossTq	Engine friction torque	Nm	
	Output-5	EgMaxTq	Engine maximum torque	Nm	
	Output-6	Eng_Tq	Engine torque	Nm	
	Output-7	Eng_Tq_rate	Engine torque rate		
	Output-8	Eng_Tq_rate2	Engine torque rate 2		
	Output-9	Loss_Tq_rate	Engine friction rate		
	Output-10	Loss_Tq_rate2	Engine friction rate 2		
	Output-11	Driver_demand_rate	Driver demand torque rate		
	Output-12	DRV_demand_Inj	Driver demand Injection		
	Output-13	ISC	Idle speed control		
	Output-14	EgDriveTq_woLoss	Engine torque without accessory	Nm	
	Output-15	Eg_Tq_map_sirei	Engine torque map command		
MG model	Input-1	Tq_Ref	Torque command	Nm	%, etc.
	Input-2	Ref_Rev	Reference revolution	r/min	
	Input-3	Command_change	Torque command change	-	0/1
	Input-4	Reduction_SW	Regeneration switch	-	0/1
	Input-5	Reduction_ON	MG mode change	-	0/1/2/3
	Output-1	Motor_Tq	MG torque	Nm	
	Output-2	Motor_Tq_fb	MG feedback torque	Nm	
	Output-3	Motor_Rev	MG revolution	r/min	
	Output-4	Motor_Current	MG current	A	discharge + / charge -
	Output-5	Motor_Power	MG electric power	W	discharge + / charge -
	Output-6	MotorDriveTqMax	MG maximum drive torque	Nm	
	Output-7	MotorRegenTqMax	MG maximum regenerative torque	Nm	

Total: 66 (Input:30, Output: 36)

10. Input Parameters

Input parameters for engine torque characteristics, electric motor torque / electric power consumption characteristics and battery internal resistance / open voltage shall be subjected to Paragraphs 10–1 through 10–3 below. Input parameters for those other than these shall be subjected to Paragraphs 10–4 through 10–10

10–1 Engine torque characteristics

The parameter for the engine torque characteristics shall be the table data obtained by engine unit test. However, values equivalent to or lower than the minimum engine revolution speed may be added. In addition, the engine model accessory torque map shall not be used at the time of the approval test.

10–2 Electric motor torque / electric power consumption characteristics

The parameter for the electric motor torque / electric power consumption characteristics shall be the table data obtained by electric motor unit test. However, characteristics value at a revolution speed of 0 min^{-1} may be added

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10–3 Internal resistance / open voltage of RESS

The parameter for the internal resistance / open voltage of RESS shall be the table data obtained by RESS unit test.

10–4 Transmission efficiency

(1) The transmission efficiency of the transmission shall be 0.98 for a direct transmission, and 0.95 for others.

(2) The transmission efficiency of the final reduction gear shall be 0.95.

10–5 Rolling resistance coefficient and air resistance coefficient

The rolling resistance coefficient and air resistance coefficient shall be calculated by the following formulas: Here, the rolling resistance coefficient and air resistance coefficient of route buses or general buses shall be the value obtained by multiplying by 0.680 the value calculated using the following formulas:

$$\mu_r = 0.00513 + \frac{17.6}{W}$$

$$\mu_a A = 0.00299 B \cdot H - 0.000832$$

where:

μr : Rolling resistance coefficient (kg/kg)

$\mu a A$: Air resistance coefficient × frontal projected area $(kg/(km/h)^2)$

W : Vehicle mass at time of test (kg)

In the case of a truck, etc.: {Vehicle kerb mass + maximum loading capacity / 2 + 55} (kg)

In the case of a route bus or general bus: {Vehicle kerb mass + riding capacity × 55 / 2} (kg)

In the case of a tractor: {Vehicle kerb mass (tractor + trailer) + maximum loading capacity / 2 + 55} (kg)

B : Overall width (m)

H : Overall height (m)

10–6 Inertia moment of rotating sections

Different inertia moment of the rotating sections shall be used for respective conditions for the HILS verification test and for the approval test, as specified below:

(1) At the time of the HILS verification test: The inertia moment of each rotating section shall be in accordance with the provisions of the test procedures.

(2) At the time of the approval test: The inertia moment of the section from the gear on the driven side of the transmission to the tyres shall be set in such a way that the mass equivalent to this rotating section may become 7 % of the vehicle kerb mass. The inertia moment of the section from the engine to the gear on the driving side of the transmission shall be the design value.

10–7 Engine model response delay block

The delay time in the engine model response delay block shall be 0.01 second, and its time constant shall be 0.01 second.

10–8 Gear-change period

The gear-change period for a manual transmission shall be one second.

11. 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).

(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.