Developmental Status of HEV Model without "Intellectual Property of Developer"

THE THIRD MEETING OF THE GRPE INFORMAL GROUP ON HEAVY DUTY HYBRIDS (HDH)
in Brussels on October 25th-26th, 2010

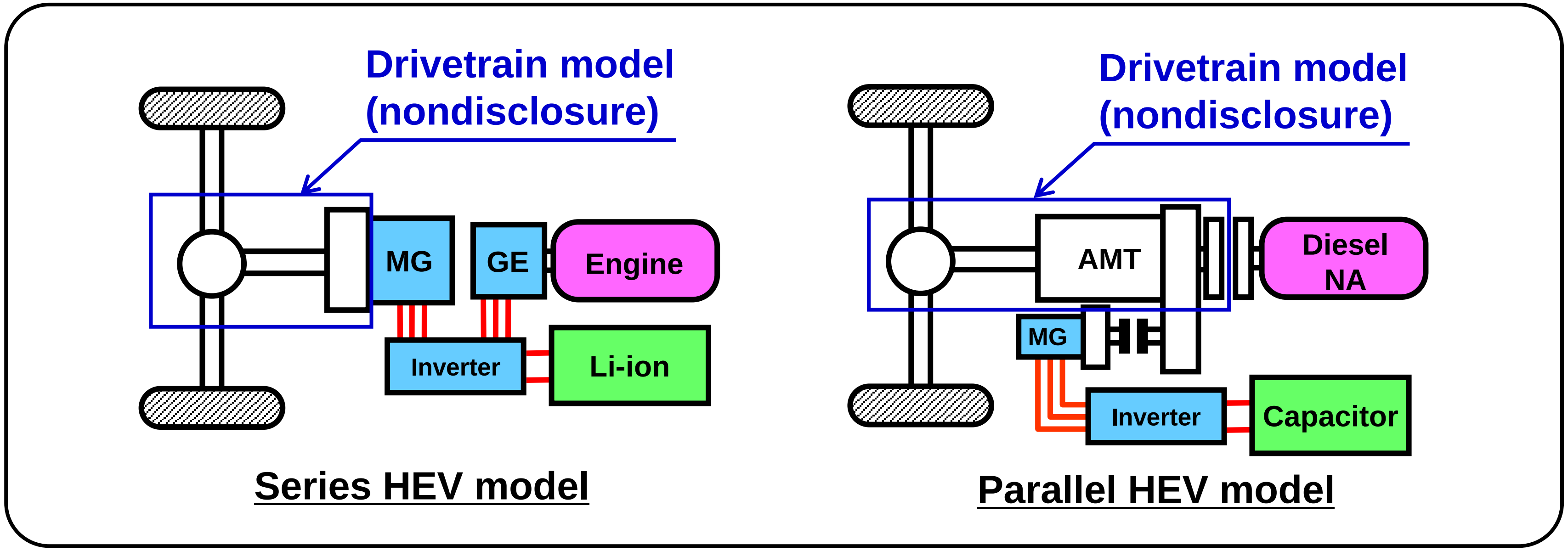
Japan Automobile Standards Internationalization Center (JASIC)

Contents

Background and Objective

To use HILS method as global technical regulation (gtr), it is **preferable to standardize HEV model**, which can be applied for each nation's new HEVs.

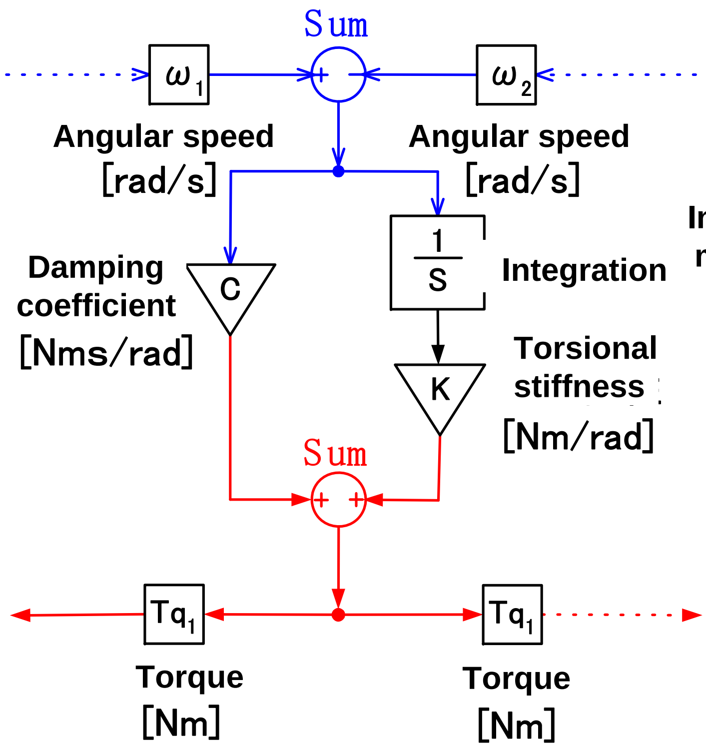
However, **today's Japanese HEV model** for the certification **includes non-disclosure drivetrain model** with elastic elements because of "Intellectual Property of Developer".

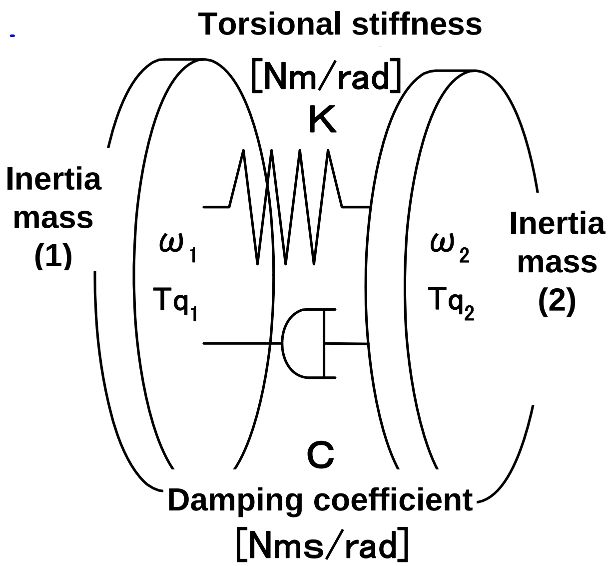


Background and Objective (continued)

Current clutch model with spring-mass System

$$Tq_1 = C(\omega_1 - \omega_2) + K \cdot \int [(\omega_1 - \omega_2)\, dt$$





Amount of torque transferred is calculated by difference between input and output shaft revolution.

Input of "appropriate" torsional stiffness and damping coefficient is required to avoid vibration. ⇒Not fit with certification test.

Objective: Develop disclosure drivetrain model

Select Drivetrain Model Type to be Developed

Comparison of drivetrain model type

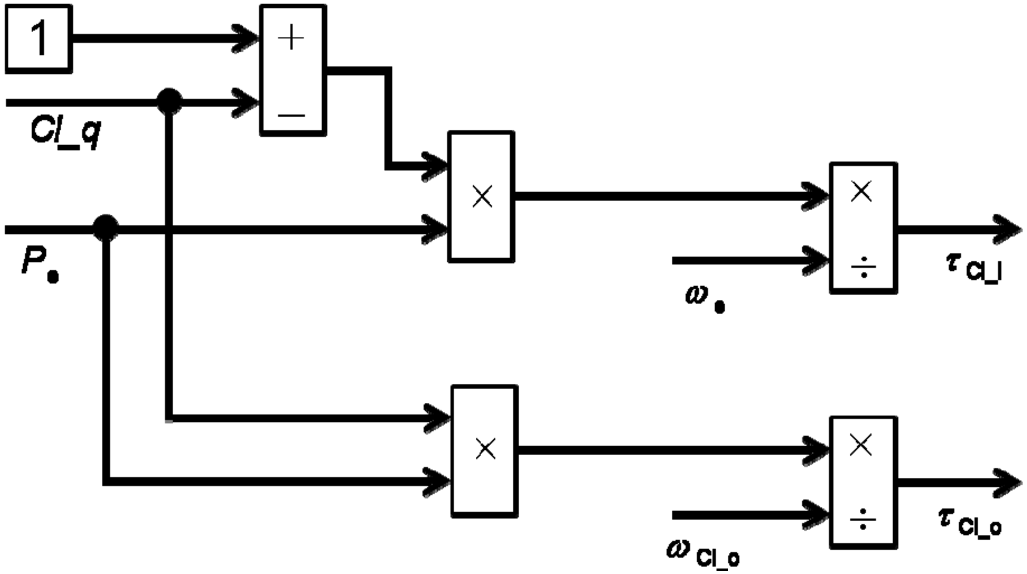
	Spring-mass system	Rigid-body system
Input of torsional stiffness	necessary	unnecessary
Input of damping coefficient	necessary	unnecessary
Reproducibility of clutch system	++	+
Difficulty level of model development	-	+

++: very good, +: good, -: bad

Develop rigid-body powertrain model.

Outline of Rigid-Body Model (1)

【Flow of torque in the clutch system】



Engine power is transferred to clutch-output-shaft depending on clutch connection rate, then converted to torque, because of the difference between engine revolution and clutch-output-shaft revolution.

$$P_{Cl\_i} = (1 - Cl\_q) \times P_e$$

$$\tau_{Cl\_i} = \frac{P_{Cl\_i}}{\omega_e}$$

$$P_{Cl\_o} = Cl\_q \times P_e$$

$$\tau_{Cl\_o} = \frac{P_{Cl\_o}}{\omega_{Cl\_o}}$$

Cl_q	: Clutch stroke ($0 \leqq Cl\_q \leqq 1$)
Pe	: Engine power
P_{Cl_i}	: Excess engine power
P_{Cl_o}	: Delivered clutch power
τ_{Cl_i}	: Excess engine torque
τ_{Cl_o}	: Delivered clutch torque
ω_e	: Engine revolution
ω_{Cl_o}	: Clutch-output-shaft revolution

Outline of Rigid-Body Model (2)

【Calculation method of revolution of rotating body】

Torque $\tau(t)$ and revolution $\omega(t)$ of rotating body is given as follows:

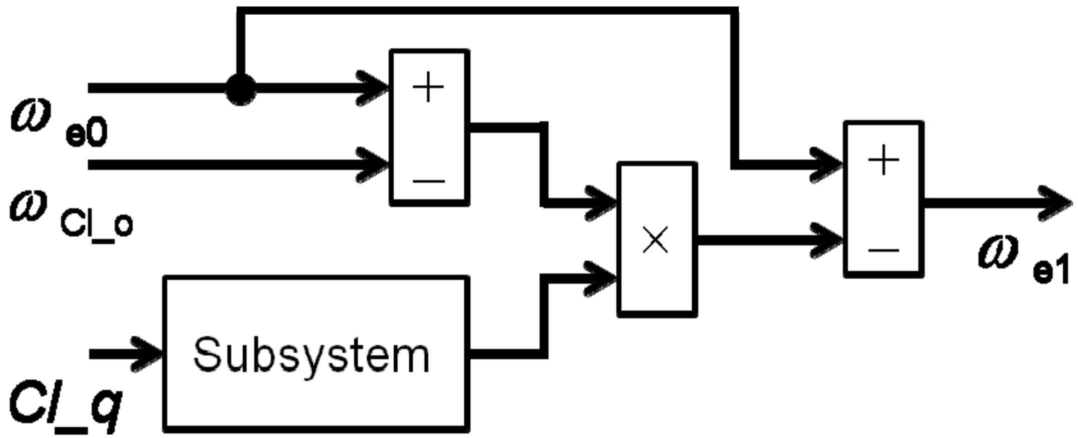
$$\tau(t) - D\omega(t) = J\frac{d}{dt}\omega(t)$$

Where, *J* is moment of inertia, *D* is viscous friction coefficient. When *D* is adjusted to 0, the following expression is obtained.

$$\frac{d}{dt}\omega(t) = \frac{1}{J}\tau(t)$$

Outline of Rigid-Body Model (3)

【Calculation method of engine revolution】

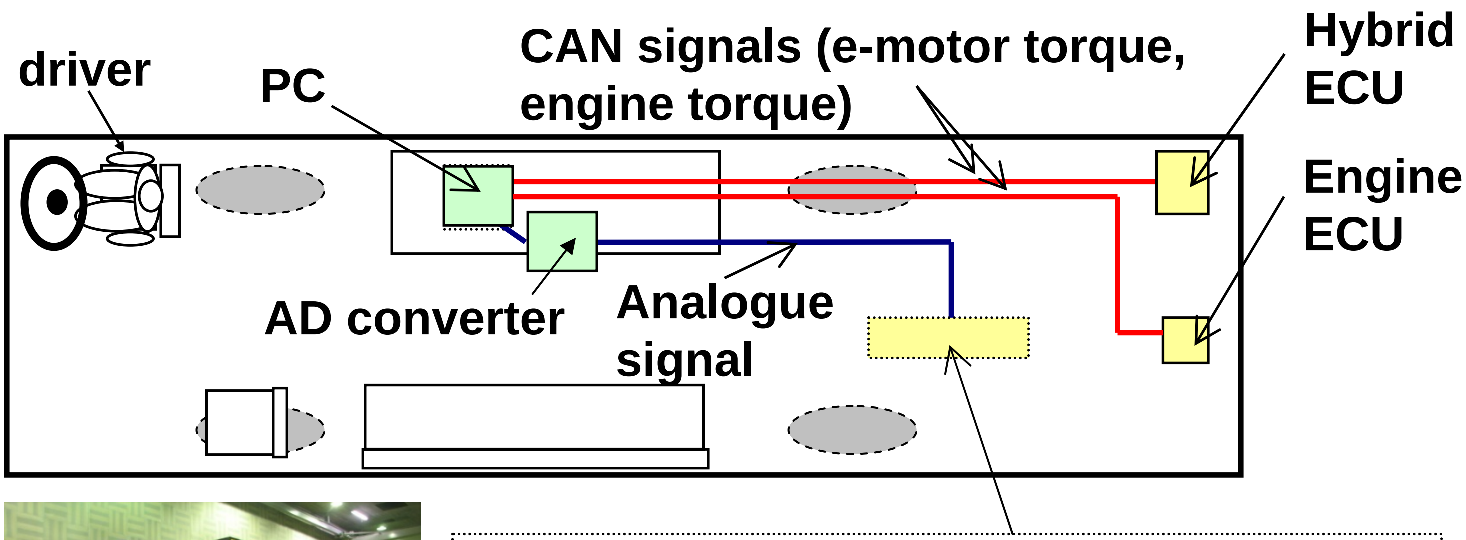


Cl_q	**: Clutch stroke (0 ≦ *Cl_q* ≦ 1)**
ω_{e0}	**: Engine revolution**
ω_{e1}	**: Engine revolution**
ω_{Cl_o}	**: Clutch-output-shaft revolution**

•Engine revolution is same with clutch-output-shaft revolution when clutch connects. synchronize engine revolution with clutch-output-shaft revolution depending on clutch connection rate when half clutch.
•In the subsystem, set up synchronize timing not to synchronize until clutch connection rate reaches given value

Verification Method of HILS Accuracy (1)

It seems basically available for the chassis dyno test for the verification of HILS accuracy in today's Japanese HILS certification in the case of using WHVC vehicle speed profile if possible to track on it.



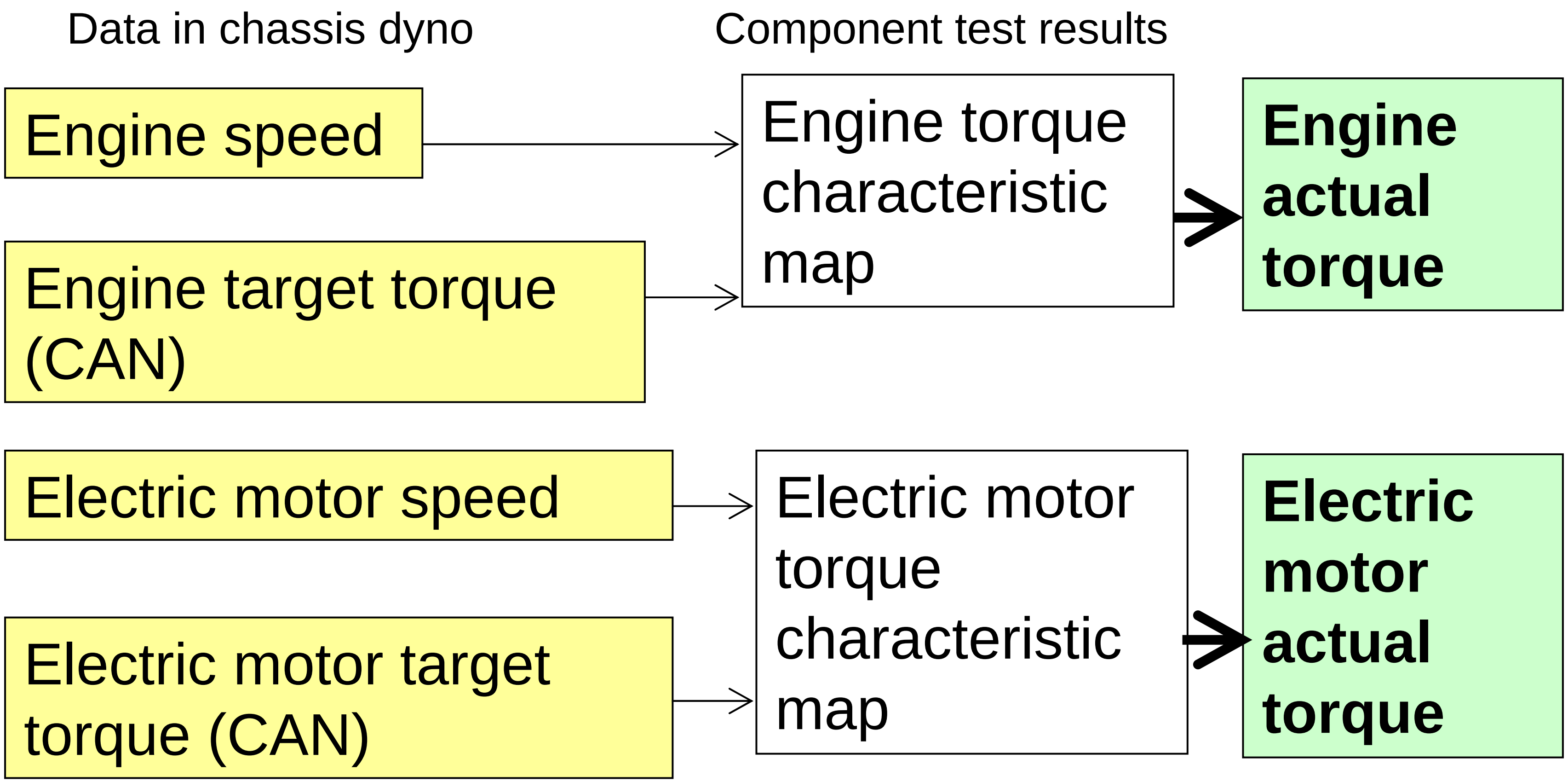
Sensors;

engine speed, electric motor speed, battery current, battery voltage, accelerator position, brake position

Measuring data in Chassis dyno test (for example)

Verification Method of HILS Accuracy (2)

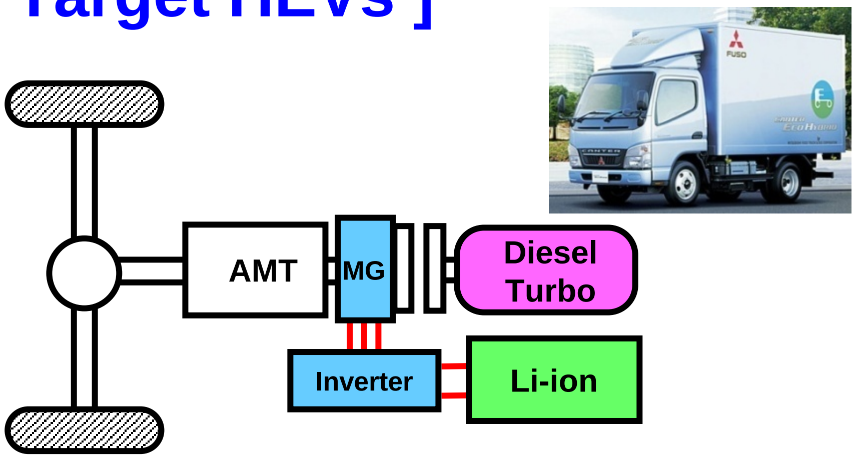
There might be nothing to be changed for the translation method from CAN data of engine, e-motor torque in chassis dyno test to actual data in today's Japanese HILS certification in the case of using WHVC vehicle speed profile.



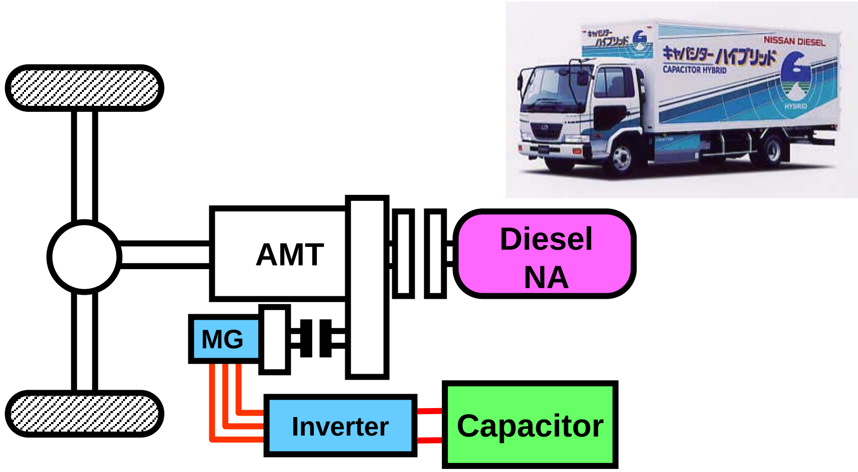
Translation diagram from CAN signal in Chassis dyno test to actual data of engine/e-motor torque

Verification of Parallel HEV Model with Rigid-Body (1)

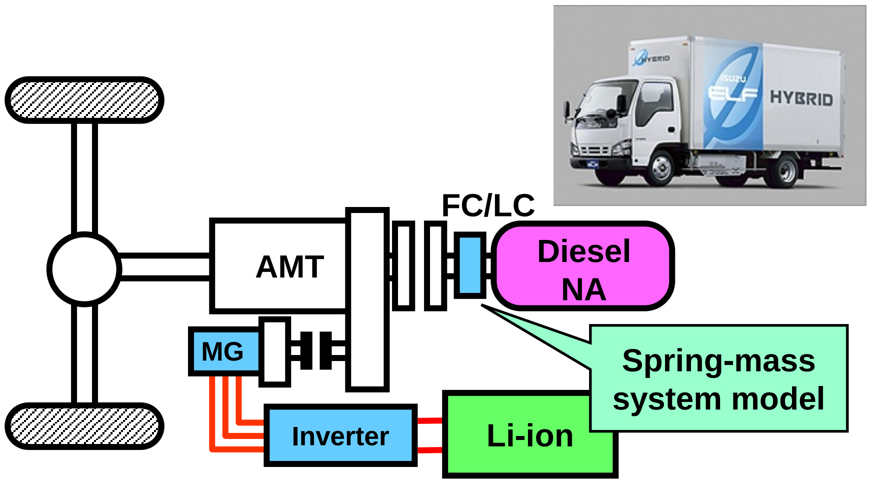
[Target HEVs]



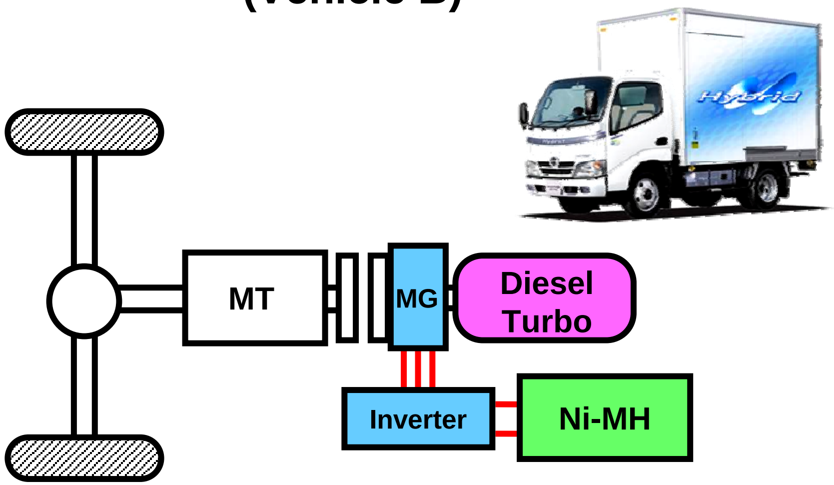
MG-TM Direct Connecting Type
(Vehicle A)



PTO Use Type
(Vehicle B)



PTO Use Type with FC/LC
(Vehicle C)

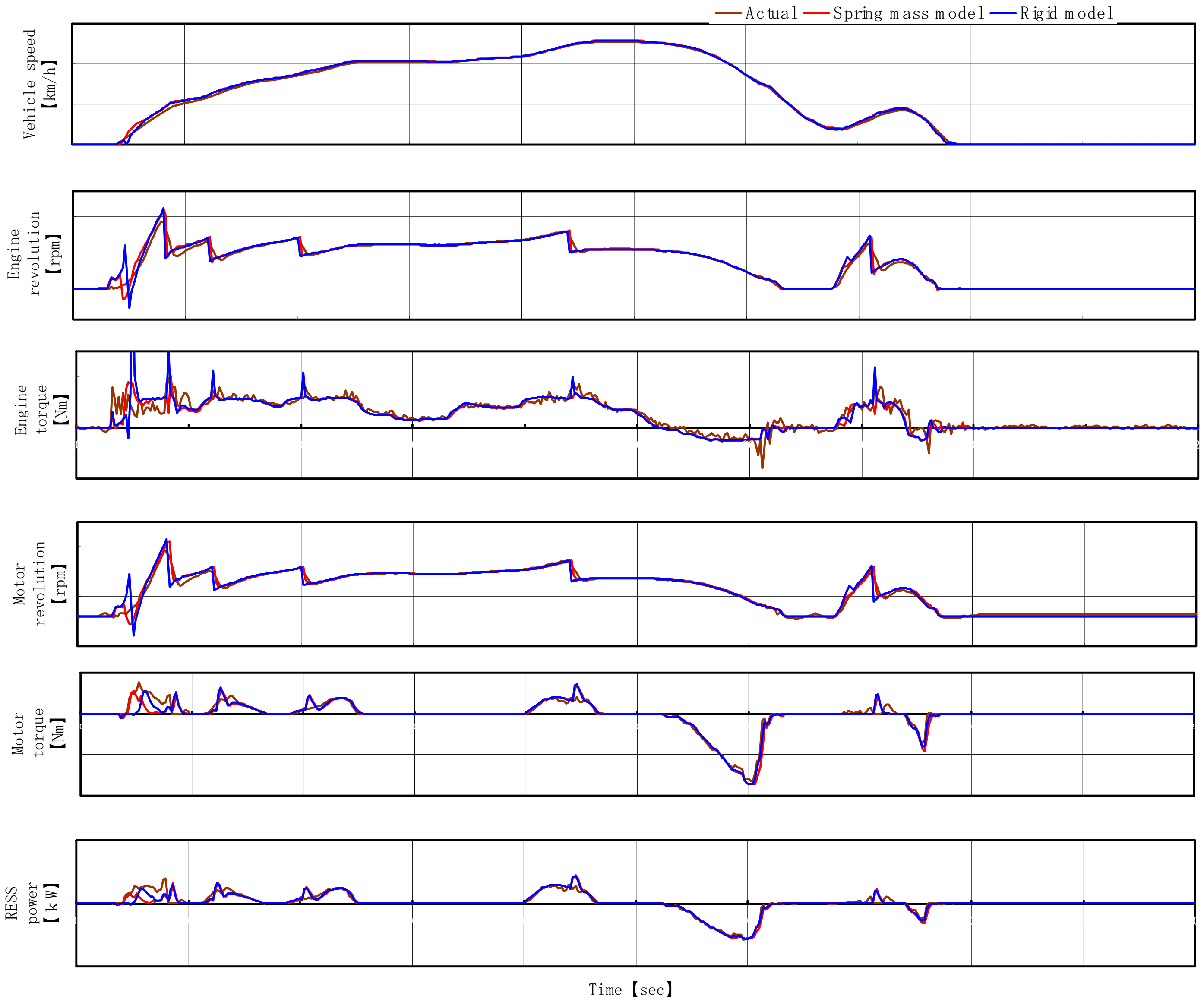


MG-Engine Direct Connecting Type
(Vehicle D)

Verification of Parallel HEV Model with Rigid-Body (2)

[Verification results: Example of vehicle D]

- JE05 one trip verification: Comparison of HILS data with actual data



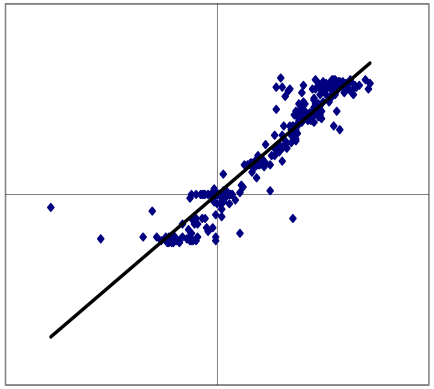
Verification of Parallel HEV Model with Rigid-Body (3)

[Verification results: Example of vehicle D]

- JE05 one trip verification: Comparison of HILS data with actual data

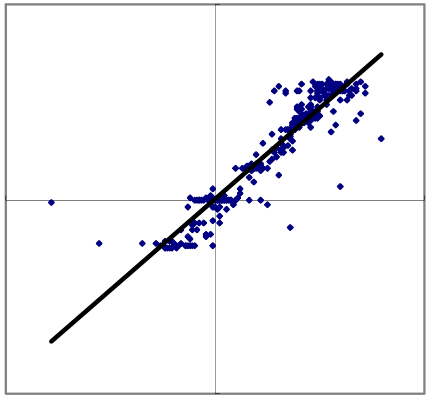
	Vehicle speed or Engine rev.	MG		Engine		RESS power
		Torque	Power	Torque	Power	
Tolerance	0.97 ≦	0.88 ≦	0.88 ≦	0.88 ≦	0.88 ≦	0.88 ≦
Spring mass model	0.994	0.949	0.937	0.908	0.928	0.923
Rigid model	0.996	0.981	0.978	0.892	0.931	0.972

Actual - Spring mass model



Engine Torque

Actual - Rigid model



Engine Torque

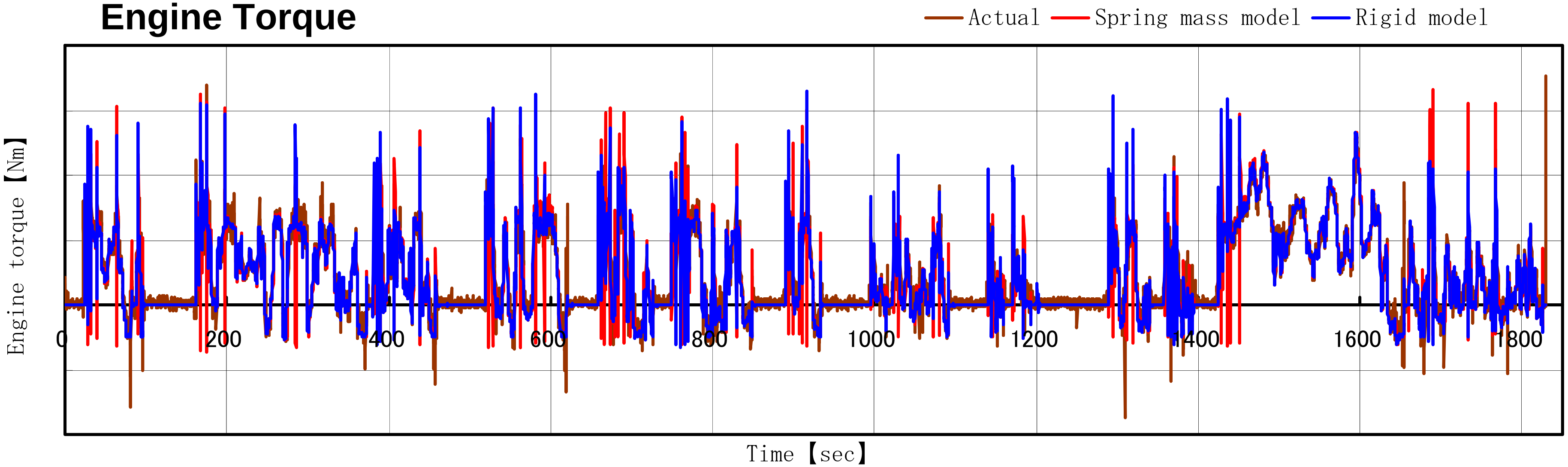
Verification of Parallel HEV Model with Rigid-Body (4)

[Verification results: Example of vehicle D]

- Whole JE05 verification: Comparison of HILS data with actual data

Verification item	Vehicle speed or Engine rev.	Engine		Fuel Economy
		Torque	Positive work	
	Determination coefficient	Determination coefficient	W_{eng_HILS} / $W_{eng\_vehicle}$	FE_{HILS} / $FE_{vehicle}$
Tolerance	0.97≦	0.88≦	0.97≦	≦1.03
Spring mass model	0.982	0.921	0.993	1.018
Rigid model	0.994	0.895	1.003	0.999

Engine Torque



Verification of Parallel HEV Model with Rigid-Body (5)

[Verification results: Four parallel HEVs]

<u>**Determination coefficient of HILS with actually measured data in JE05 one trip**</u>

	Vehicle speed or Engine rev.	MG		Engine		RESS power
		Torque	Power	Torque	Power	
Tolerance	0.97 ≤	0.88 ≤	0.88 ≤	0.88 ≤	0.88 ≤	0.88 ≤
Vehicle A	0.998	0.979	0.976	0.961	0.973	0.941
Vehicle B	0.999	0.887	0.910	0.895	0.954	0.914
Vehicle C	0.979	0.961	0.945	0.951	0.976	0.936
Vehicle D	0.996	0.981	0.978	0.892	0.931	0.972

Developed parallel HEV model with rigid-body system has sufficient accuracy in transient behavior.

Verification of Parallel HEV Model with Rigid-Body (6)

[Verification results: Four parallel HEVs]

Determination coefficient, comparison of positive work and fuel economy between HILS and actually measured data in whole JE05

Verification item		Vehicle speed or Engine rev.	Engine		Fuel Economy
			Torque	Positive work	
		Determination coefficient	Determination coefficient	W_{eng_HILS} / $W_{eng\_vehicle}$	FE_{HILS} / $FE_{vehicle}$
Tolerance		0.97≦	0.88≦	0.97≦	≦1.03
P-HEV	Vehicle A	0.998	0.961	1.017	0.986
	Vehicle B	0.996	0.880	1.023	1.005
	Vehicle C	0.976	0.915	0.988	0.995
	Vehicle D	0.994	0.895	1.003	0.999

W_{eng_HILS} : Engine positive work of HILS (kWh)
$W_{eng\_vehicle}$: Engine positive work of real vehicle (kWh)
FE_{HILS} : Fuel economy of HILS (km/l)
$FE_{vehicle}$: Fuel economy of real vehicle (km/l)

Developed parallel HEV model with rigid-body system has sufficient accuracy in engine positive work and fuel economy.

Summary and Future Plan

(1) Rigid-body powertrain model was developed and the parallel HEV model with the rigid-body powertrain model was confirmed to have sufficient accuracy.

(2) The developed HEV model will be disclosed in the future.

(3) In addition, we are planning to develop torque convertor AT model and fluid coupling model which is unsupported at the moment until the end of FY 2011.