Response of HILS to Cold-Start Test (Introduction of Predicted Temperature Method)

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【Background and Purpose】

- The HILS method currently used in Japan does not take the cold-start test in account. Accordingly, temperature changes are not taken into account by the HEV model for HILS.
- As gtr No. 4 is scheduled to introduce the cold-start test, a certain response is required.
- At the 13th heavy duty hybrids informal group meeting (HDH-IG), Japan proposed a predicted temperature method that inputs the temperature profile of each component in advance.

It is necessary to actually conduct HILS tests using the predicted temperature method and verify the validity of the method for evaluation proposed by Japan of the cold-start test on large-scale hybrid vehicles.

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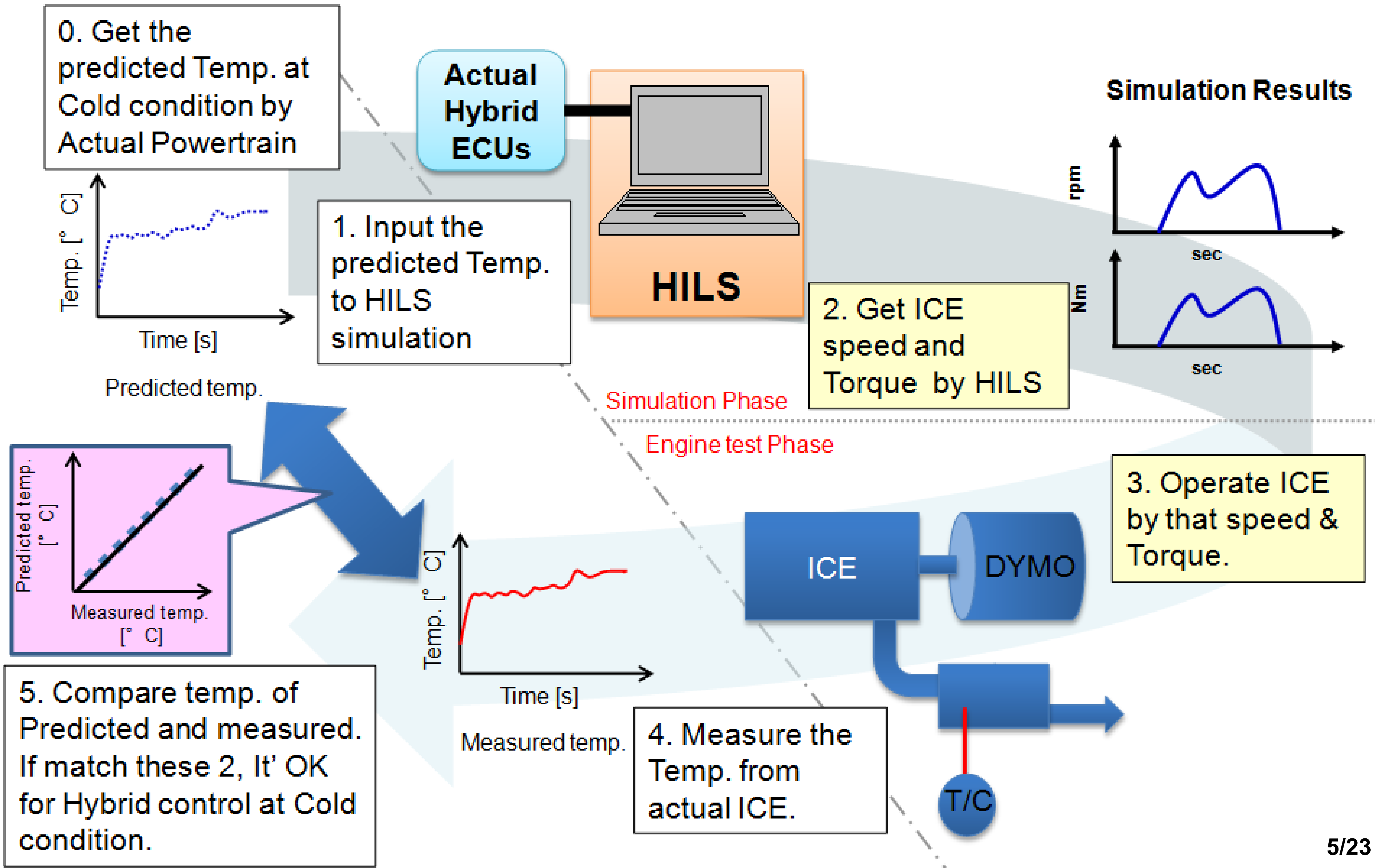
【Evaluation Concept】Verification Test for Cold State

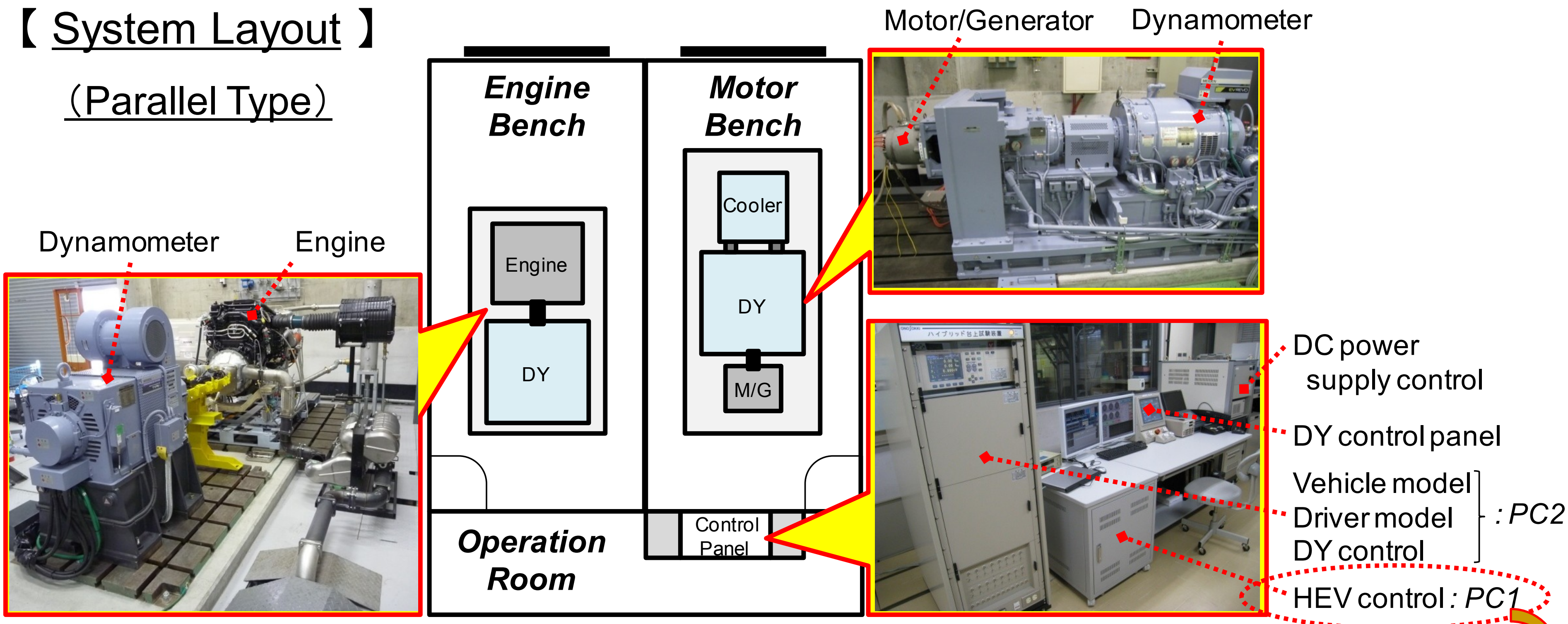
Hybrid control changing due to Temperature(s) change until Cold condition test.
That is depend on each system what Temp.(s) need to control Hybrid system



【Experiment Setup】HEV Power-train Test Bed System

【 System Layout 】

（Parallel Type）



Engine & Motor = Real or Model / Power-split system & Break system = Model

HCU（Hybrid Control Unit）

The manufacturers have never been disclosed HCU details. (Black Box)

・・・This test system replaces this portion with a model, which enables free combination of various control conditions.

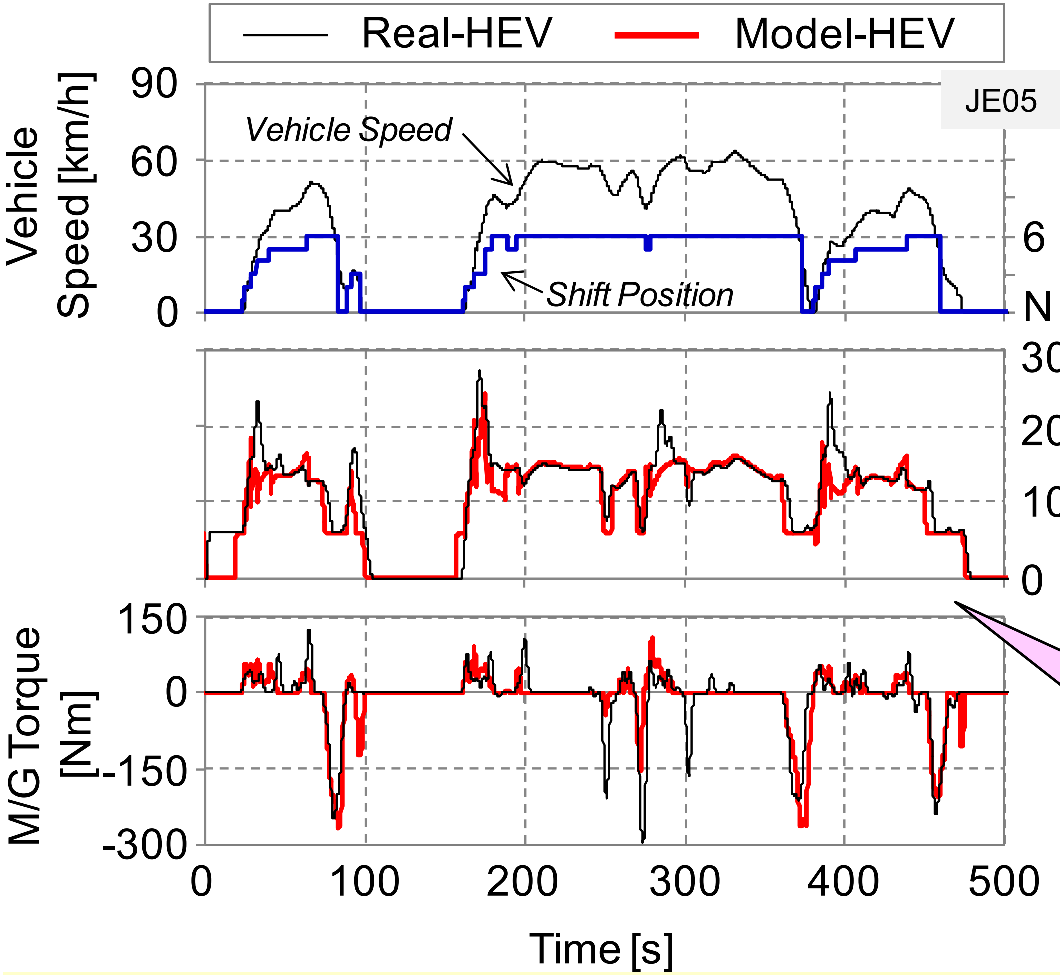
【 Major Equipment 】

- Engine Dynamometer：Type-I（MEIDENSHA）
- Motor Dynamometer：EVDY 250（MEIDENSHA）
- Measurement Control System：FAMS8000（ONO SOKKI）
- High-speed Operational Equipment （dSPACE）
- DC power Supply Control System （MEIDENSHA）

【Experiment Setup】HEV Power-train Test Bed System

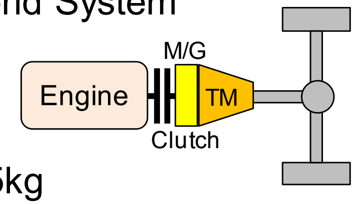
【Developing a Hybrid-Control Simulation Model】

Real HEV vs. Model HEV



➢Test Hybrid Truck（2010 year product）

- Parallel Hybrid System



- GVW 4,135kg

Reproduce the properties of Engine and Motor

We developed a simulation model for our experiment setup based on hybrid-control systems on hybrid trucks on the market.

【Experiment Conditions】Specifications of Virtual Hybrid Vehicles

We developed a virtual hybrid vehicle on a hybrid test bench.

<Assumed Vehicle>

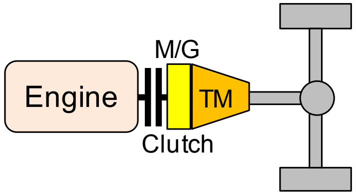
- Used specifications for conventional, middle-sized diesel vehicles (Test vehicle weight: 5,870 kg)
- Switches the mode of control of the power train in response to the gas temperatures after the exhaust-gas aftertreatment device
- The battery SOC concurrent to electricity generation is not taken into account. (Gives priority to electricity generation until the temperature reaches the control switching range)

Vehicle Specification

Vehicle weight		3,790kg
Full load capacity		4,050kg
Height ×Width		2.465×2.230m
Tire radius		0.4030m
Gear ratio	1st	6.574
	2nd	3.831
	3rd	2.274
	4th	1.385
	5th	1.000
	6th	0.729
Final gear ratio		4.333

System layout

E-C-M-T-･･･



Engine

4-cylinder Intercooler-turbo Diesel Engine (Displacement : 4.675L)

Max. Power 158kW / 2,500rpm
Max. Torque 628Nm / 1,400rpm

Motor

Permanent magnet Synchronous Motor

Max. Power 118kW / 3,300rpm
Max. Torque 340Nm / 0-3,300rpm

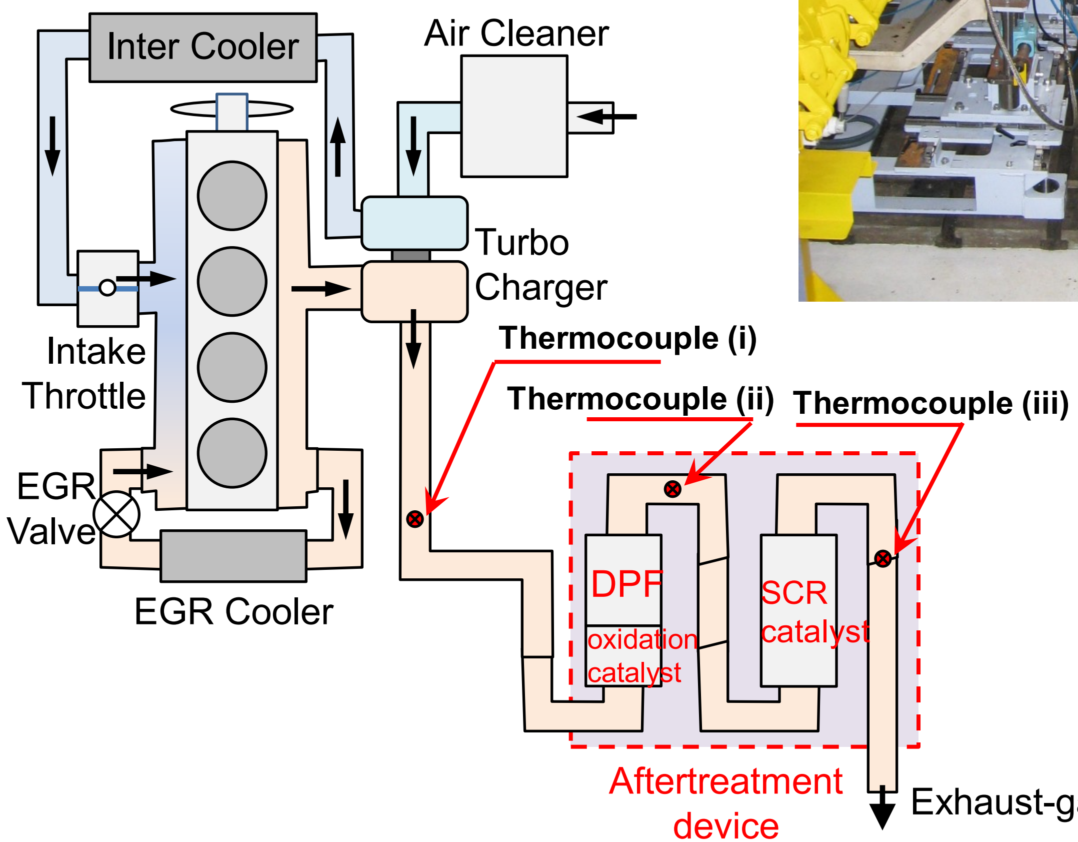
Battery

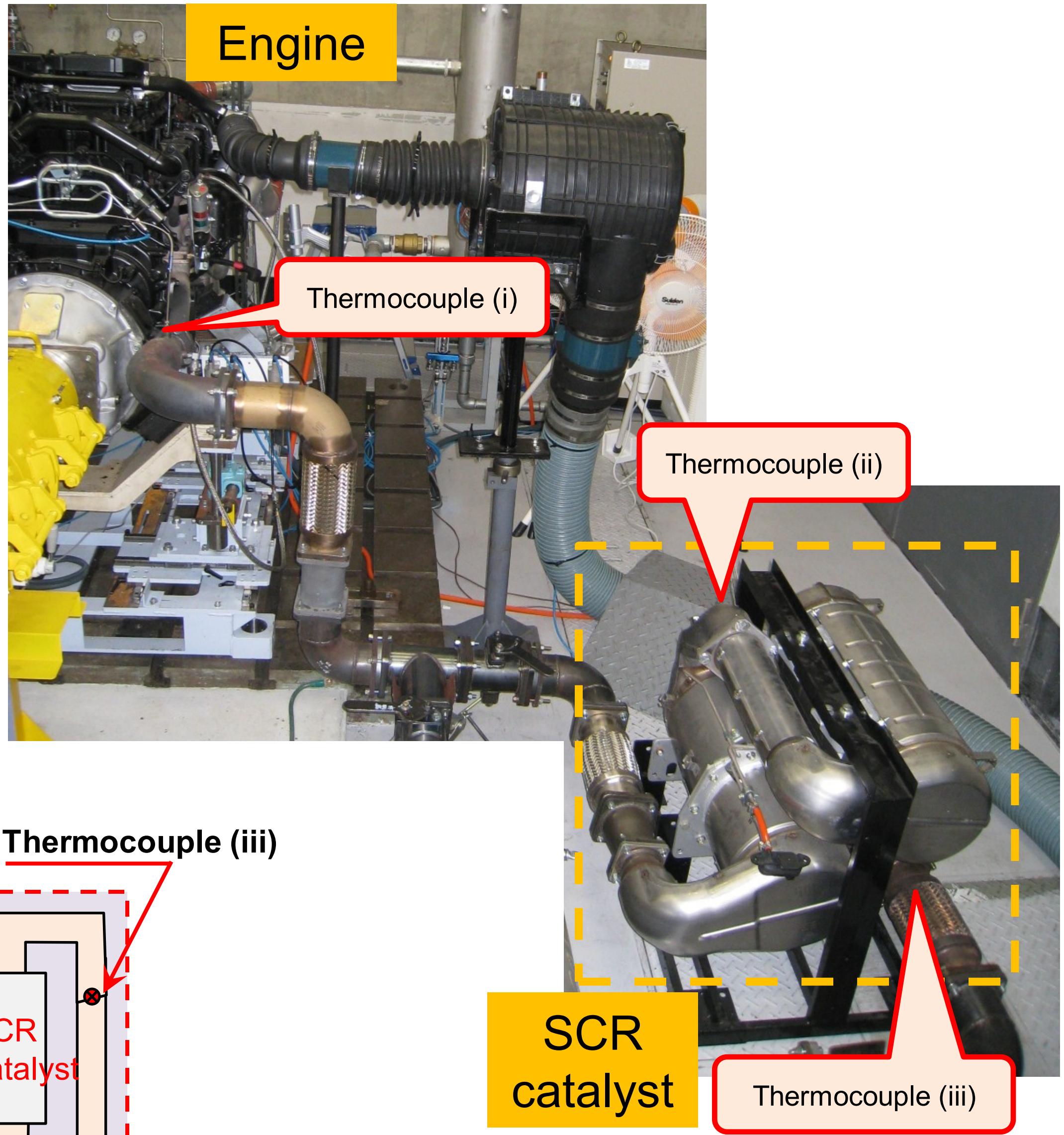
Lithium-ion Battery

Capacity : 2.0kWh (7.5Ah)

【Experiment Conditions】Exhaust gas temperature measurement points

The “control-switching temperature” above is defined as the temperature at which the catalyst in the exhaust-gas aftertreatment device becomes activated (<u>180° C or more at the thermocouple (iii)</u>).



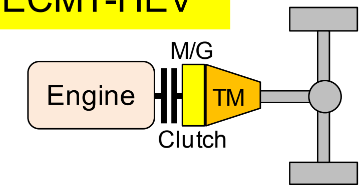


【Experiment Conditions and Method】

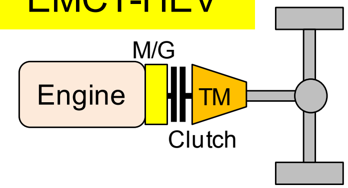
Running mode: WHVC (without slopes), cold start

(i) Introduction of pre-warm electricity generation control
--- ECMT-HEV+50Nm
(ii) Different HEV layout
--- EMCT-HEV+50Nm
(iii) When the predicted temperature profile significantly differs from the actual temperatures (Detail in the following slides)
--- Control with or without pre-warm electricity generation

ECMT-HEV



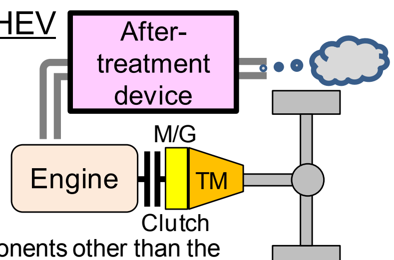
EMCT-HEV



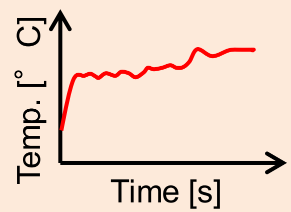
Hybrid power-train test bench

Getting a predicted temperature profile

Virtual HEV



(The components other than the engine are represented by simulation models)



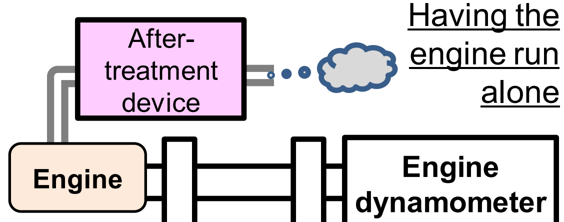
Predicted Temp.

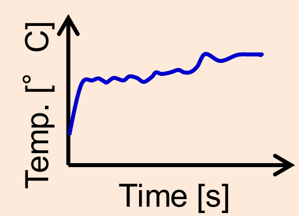
Getting actual temperatures

HILS

Using the predicted temperature profile, calculate time- engine rpm and time-torque.

Having the engine run alone





Measured Temp.

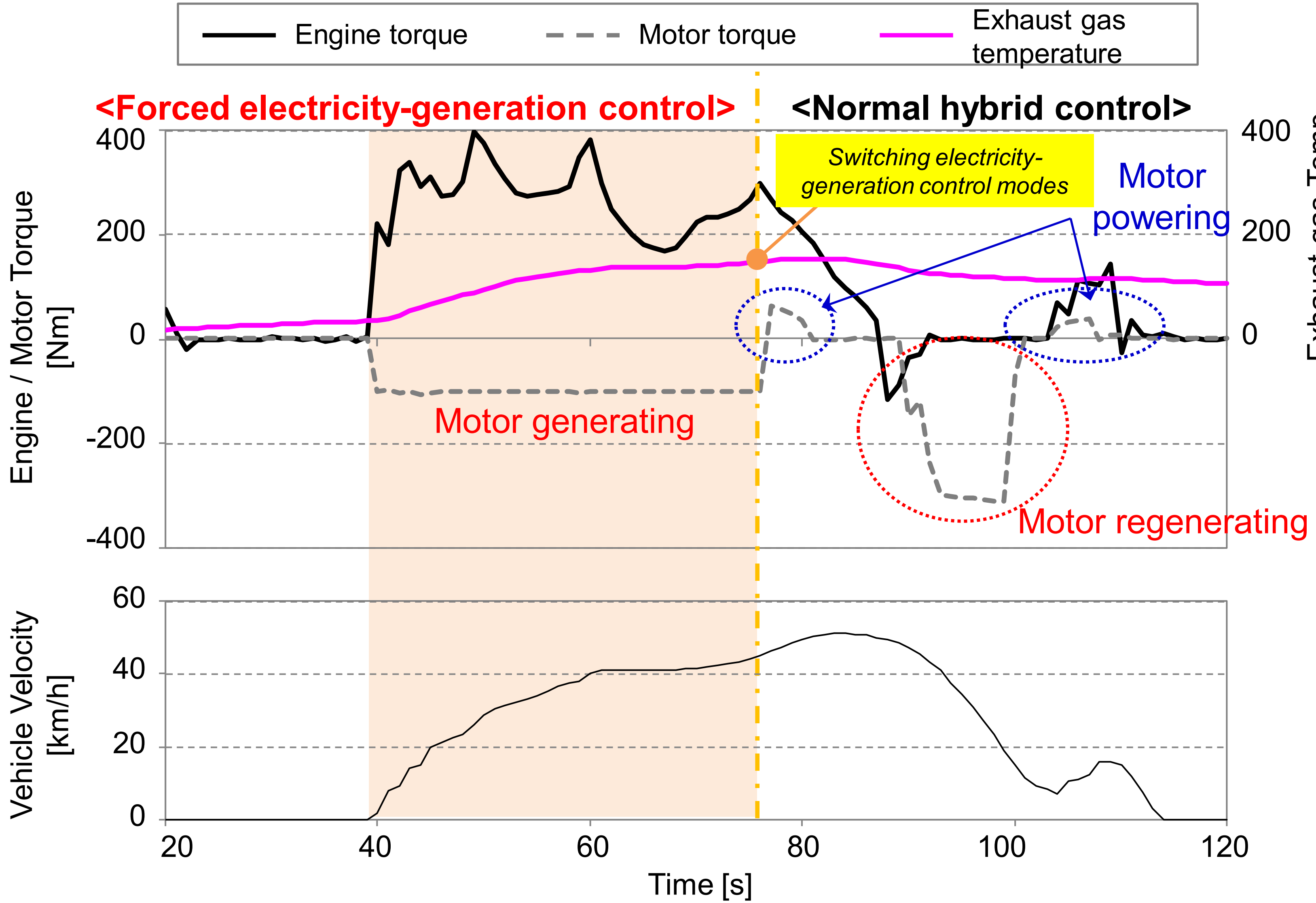
Predicted temperature profile and actual temperatures

=> - Temperature variation history (in time series)
- Correlation between temperatures

【Experiment Method】Control Model with Pre-warm Electricity Generation

Example: Pre-warm electricity generation control

--- Switches Control modes as exhaust gas reaches the temperature at which the catalyst in the exhaust gas aftertreatment device becomes activated.

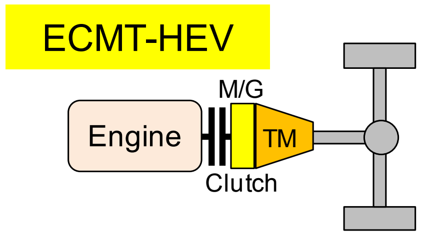


1. Background and Purpose
2. Evaluation Concept
3. Experiment Setup
4. Experiment Conditions and Method
5. Results of Evaluation Method Examination
6. Summary

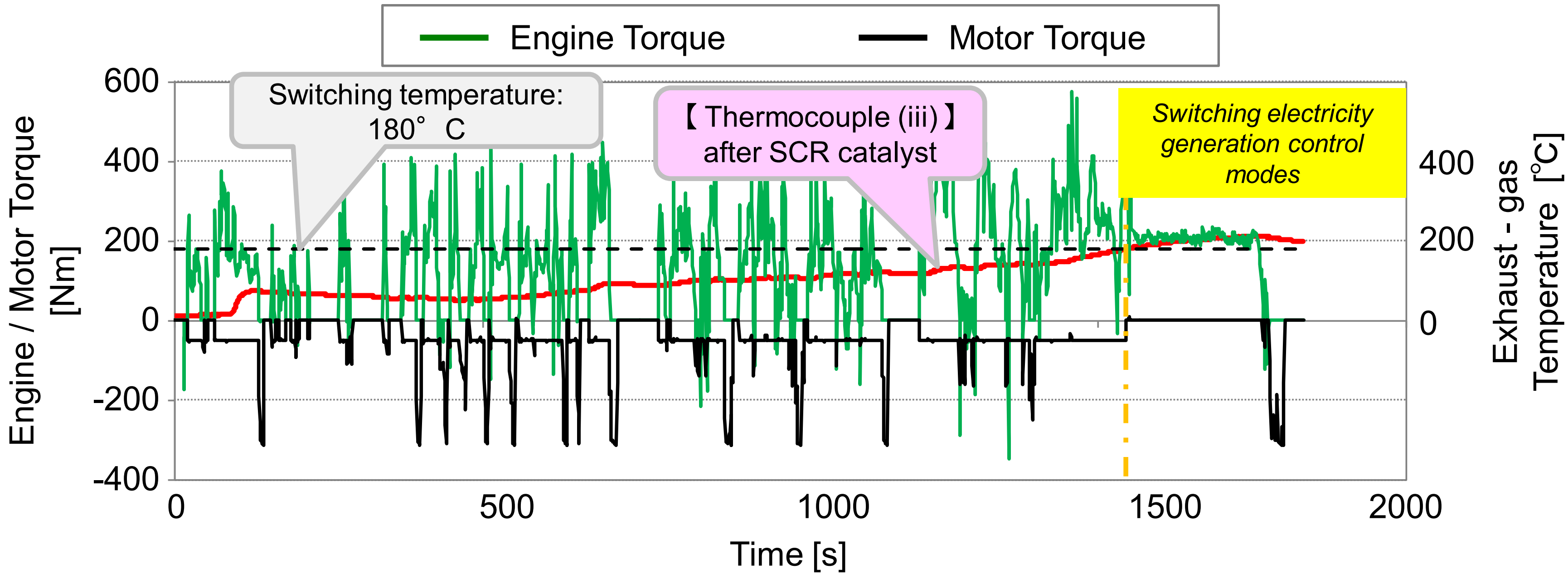
【Experiment Condition (i)】Introduction of pre-warm electricity generation control

<Controlling Condition>
* Keep generating electricity of +50 Nm till the exhaust gas temperature after the SCR catalyst reaches 180° C.

<System Layout>
* A type that separates the engine and the electric motor with a crutch.
 (Engine <>Crutch<>Motor<>TM<>Rear Shaft)

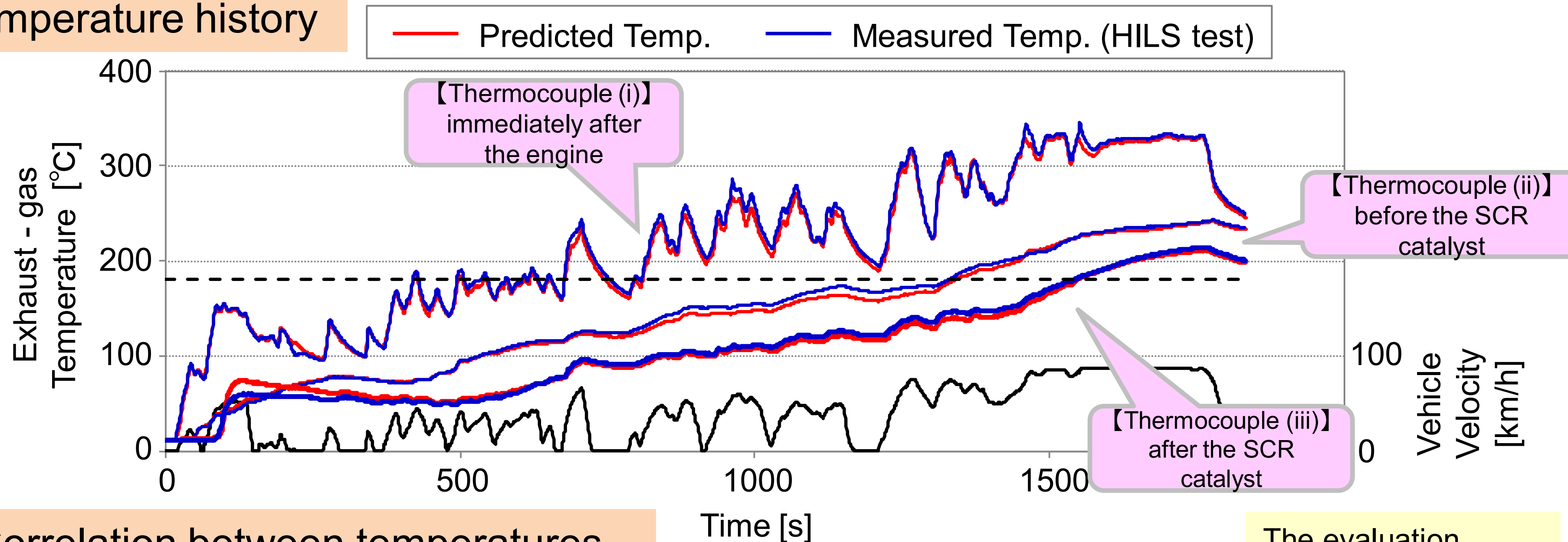


Predicted temperature profile

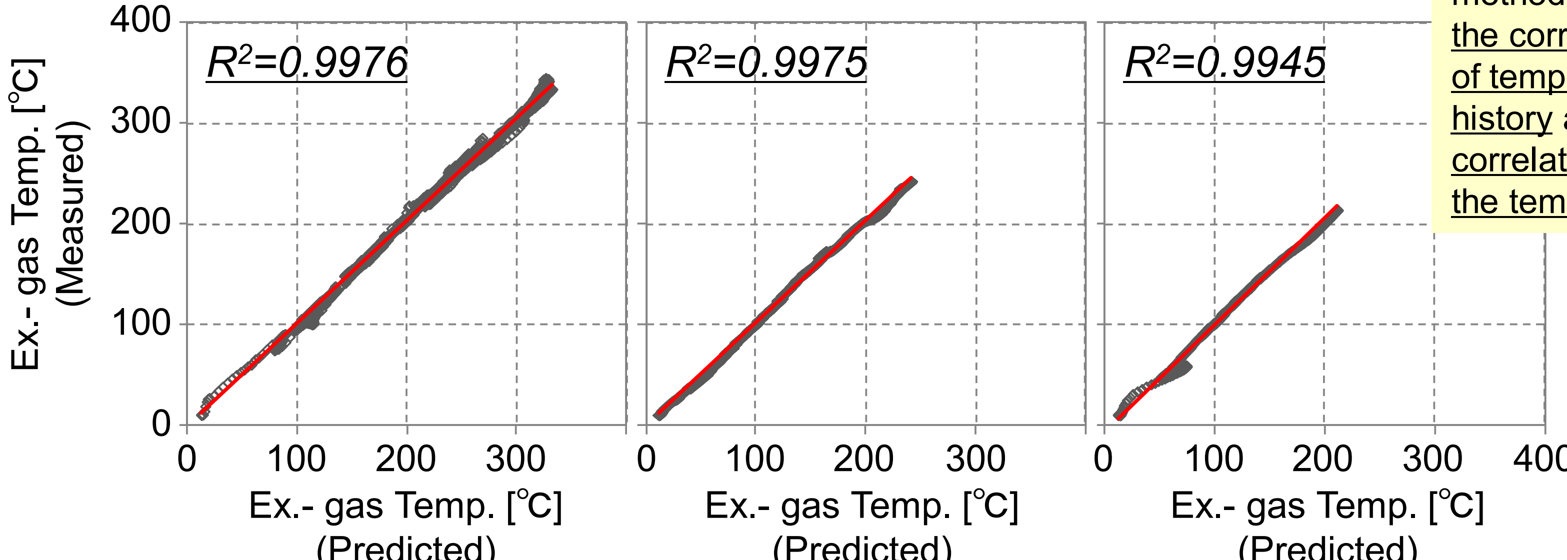


【Experiment Condition (i)】Introduction of pre-warm electricity generation control

Temperature history



Correlation between temperatures



【Thermocouple (i)】 immediately after the engine

【Thermocouple (ii)】 before the SCR catalyst

【Thermocouple (iii)】 after the SCR catalyst

The evaluation method confirmed the correspondence of temperature history and a strong correlation between the temperatures

【Experiment Condition (ii)】Different HEV layout

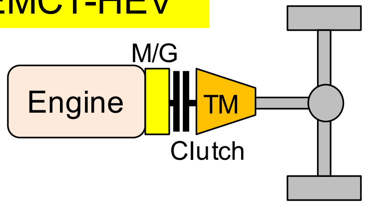
<System Layout>

* A type that directly connects the engine and the electric motor.
(Engine <>Motor<>Crutch<>TM<>Rear Shaft)

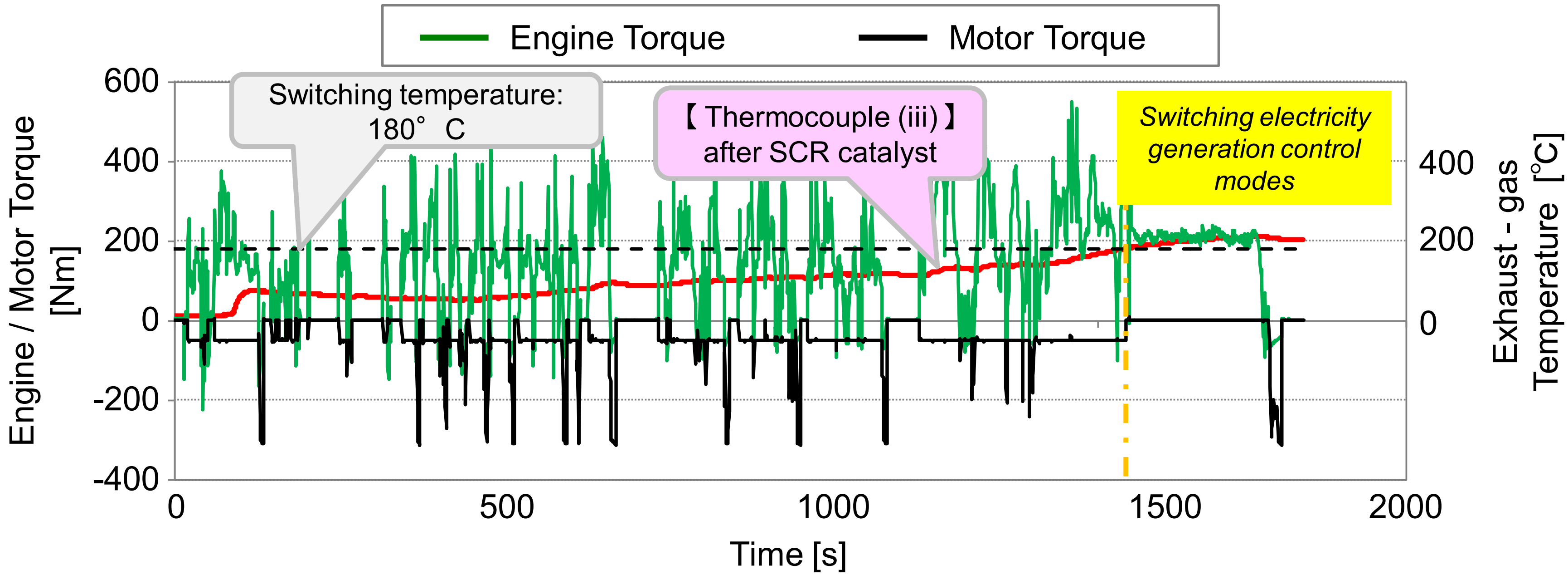
<Control Condition>

* Keeps generating electricity of +50 Nm till the temperature of exhaust gas after the SCR catalyst reaches 180° C

EMCT-HEV

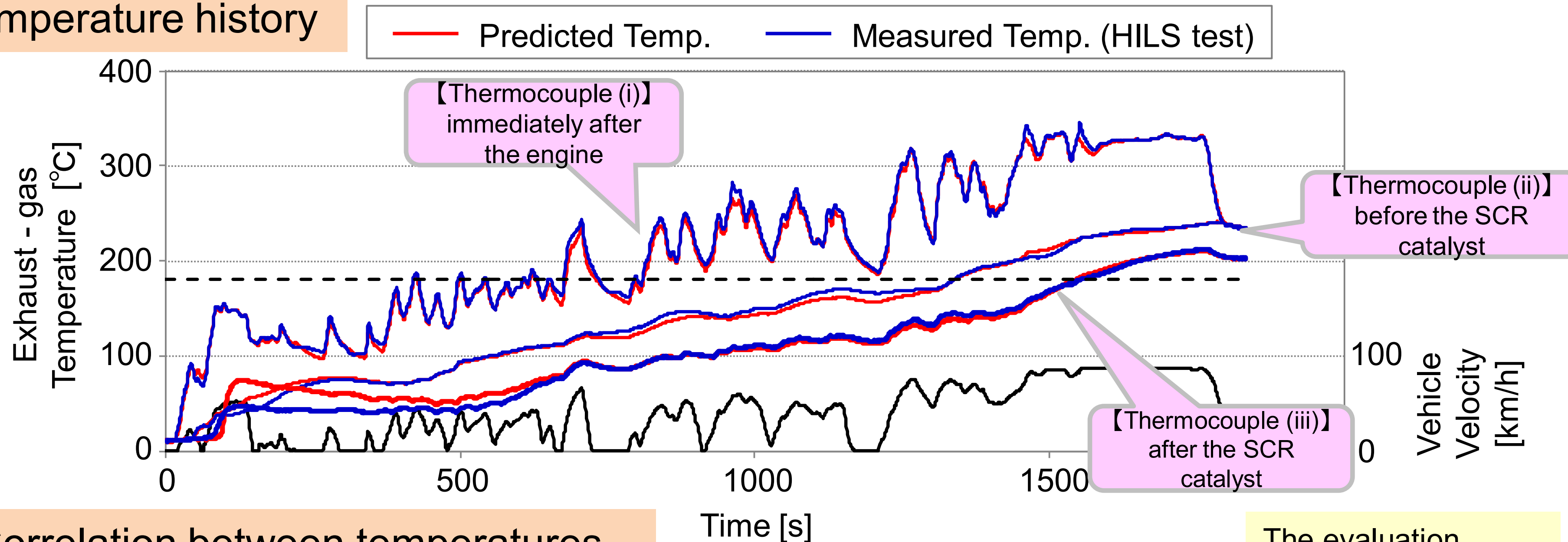


Predicted temperature profile

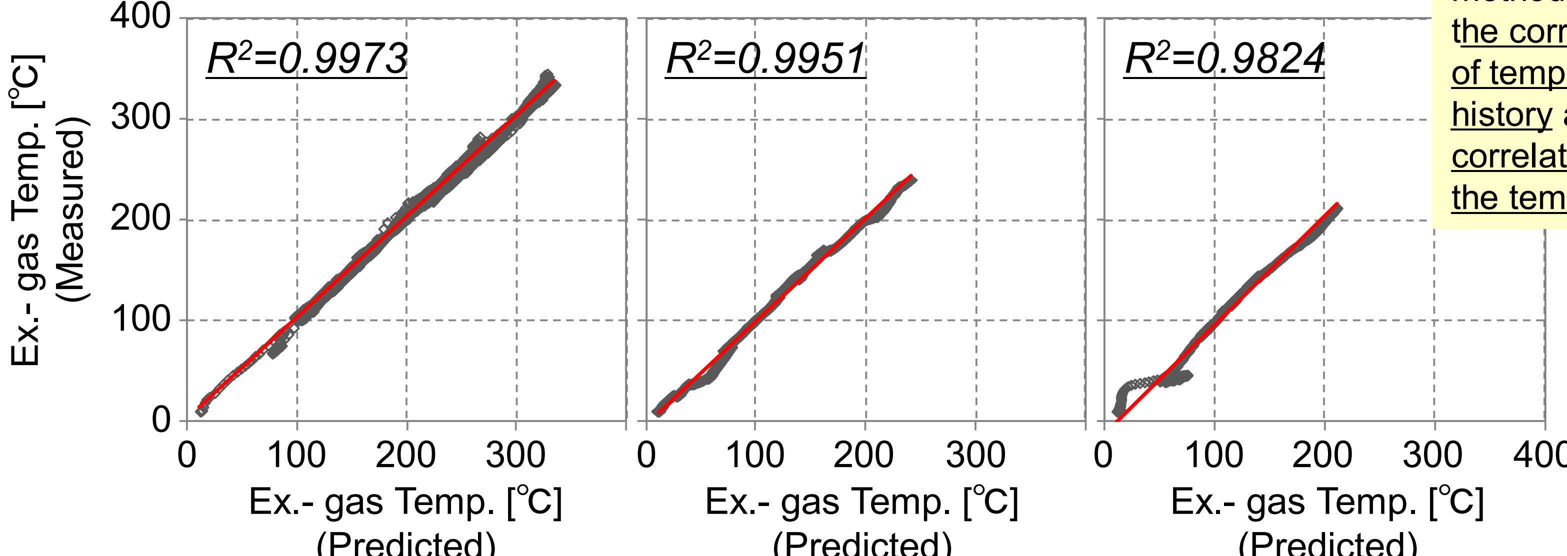


【Experiment Condition (ii)】Different HEV layout

Temperature history



Correlation between temperatures



【Thermocouple (i)】 immediately after the engine

【Thermocouple (ii)】 before the SCR catalyst

【Thermocouple (iii)】 after the SCR catalyst

The evaluation method confirmed the correspondence of temperature history and a strong correlation between the temperatures

【Experiment Condition (iii)】When the Predicted Temperature Profile Significantly Differs from the Actual Temperatures

A case was assumed where, in *Data collection and evaluation* in slide 23, the predicted temperature profile is significantly different from the actual temperatures and fails the evaluation test.

<Assumed condition>

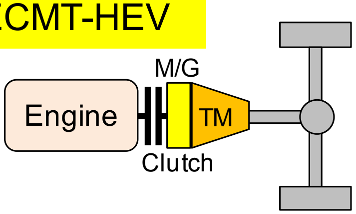
(i) The predicted temperature profile is obtained from an actual vehicle test.

-> *Control without pre-warm electricity generation: ECMT-HEV*

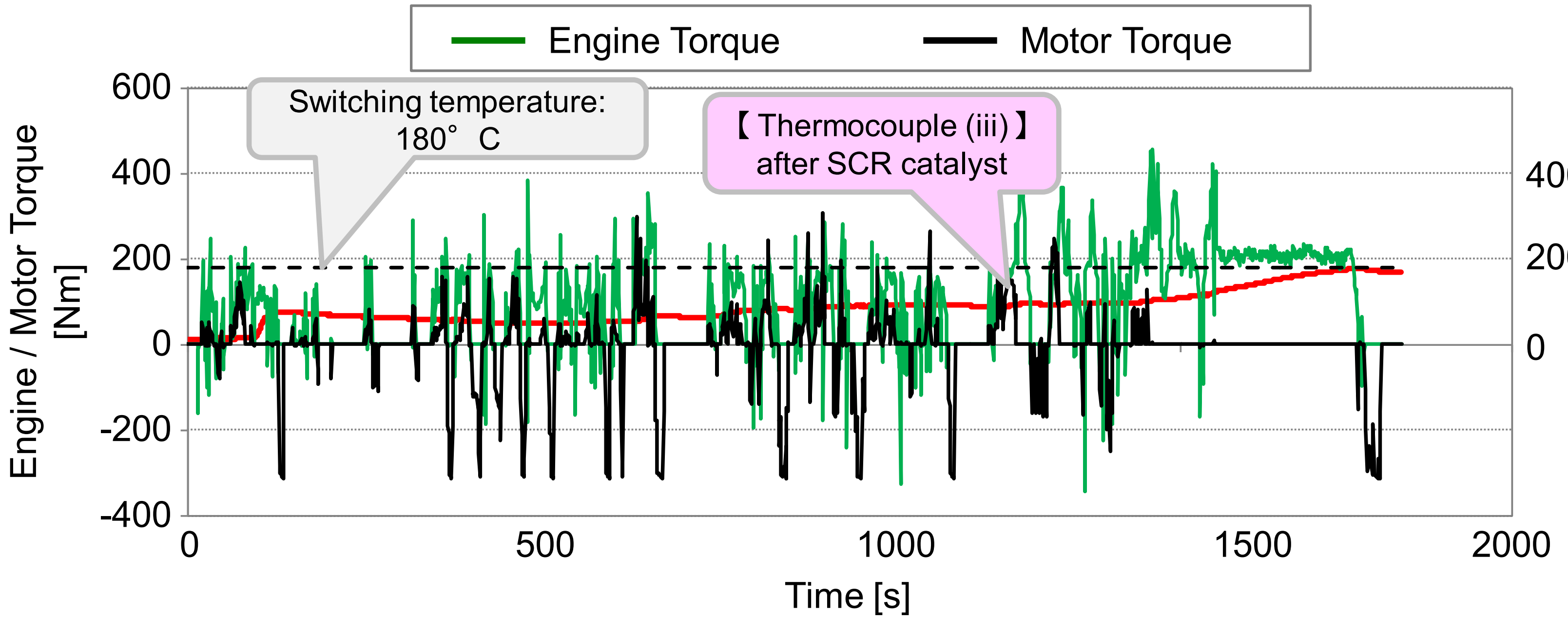
(ii) The actual temperatures are obtained from HILS + engine alone test.

-> *Control with pre-warm electricity generation: ECMT-HEV+50 Nm*

ECMT-HEV

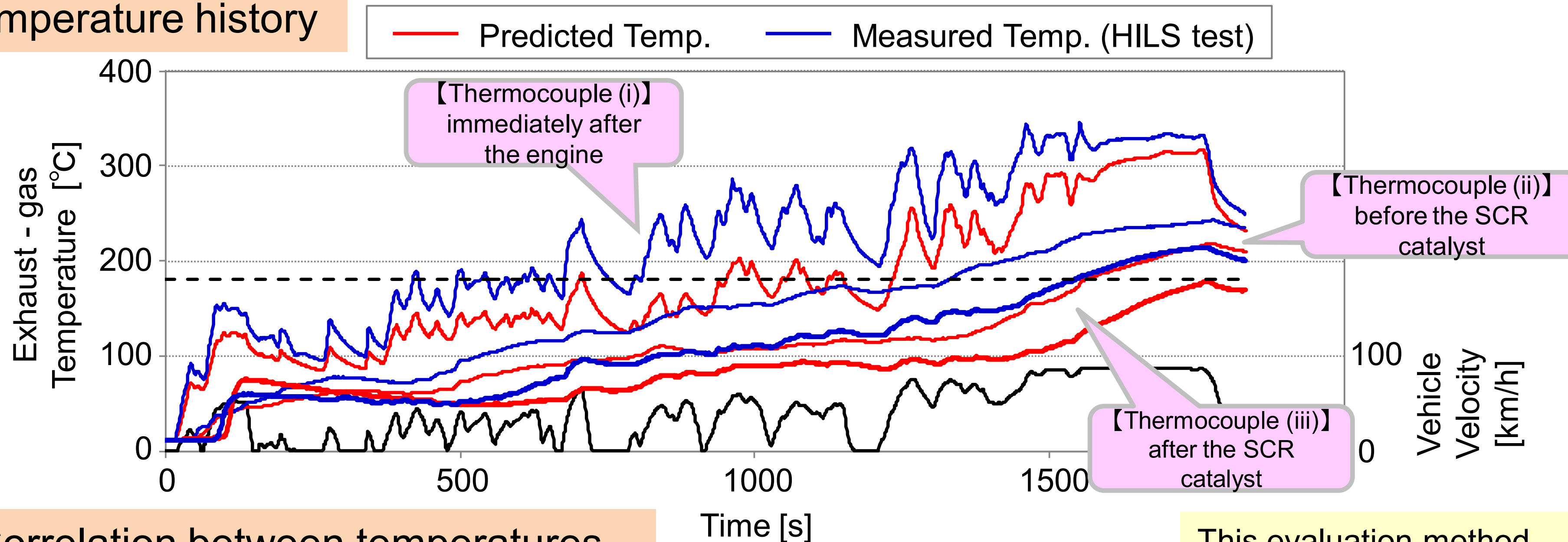


Predicted temperature profile – *No electricity generation*

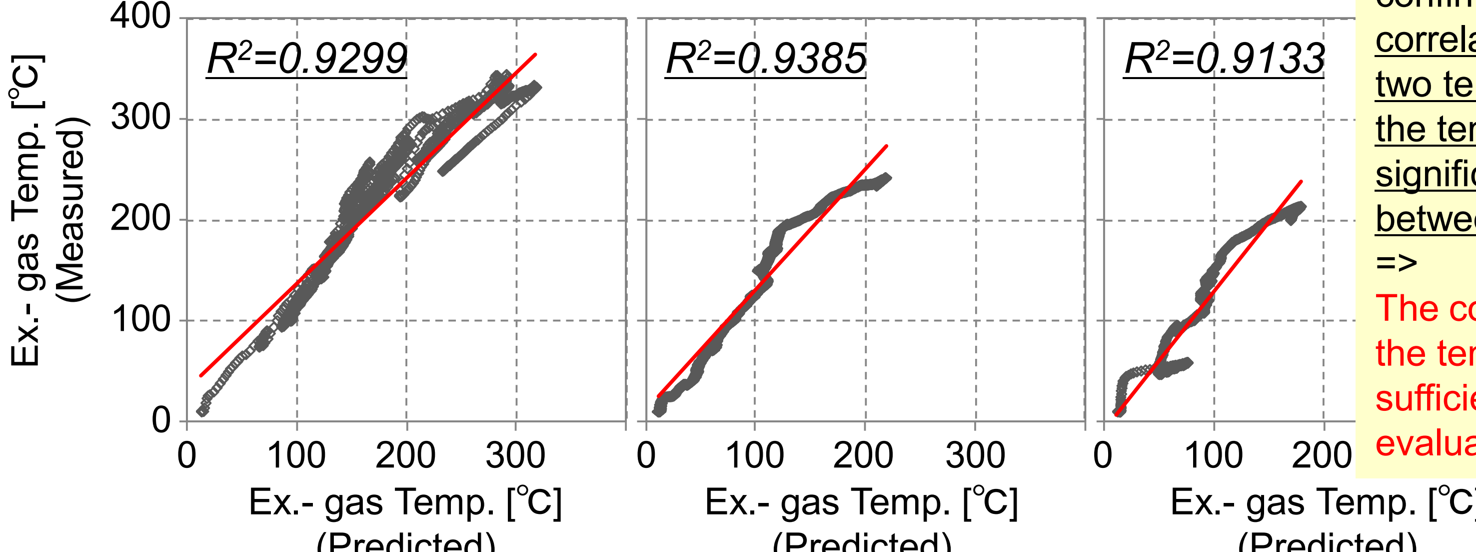


【Experiment Condition (iii)】When the Predicted Temperature Profile Significantly Differs from the Actual Temperatures

Temperature history



Correlation between temperatures



【Thermocouple (i)】 immediately after the engine

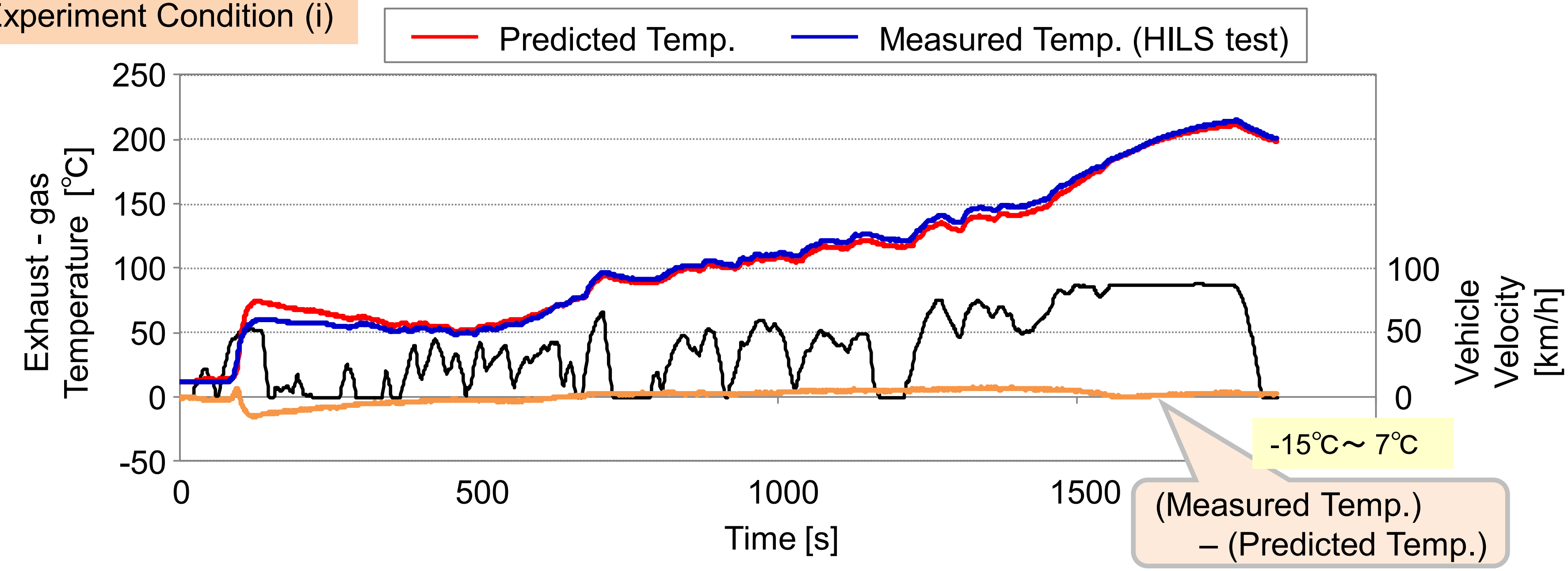
【Thermocouple (ii)】 before the SCR catalyst

【Thermocouple (iii)】 after the SCR catalyst

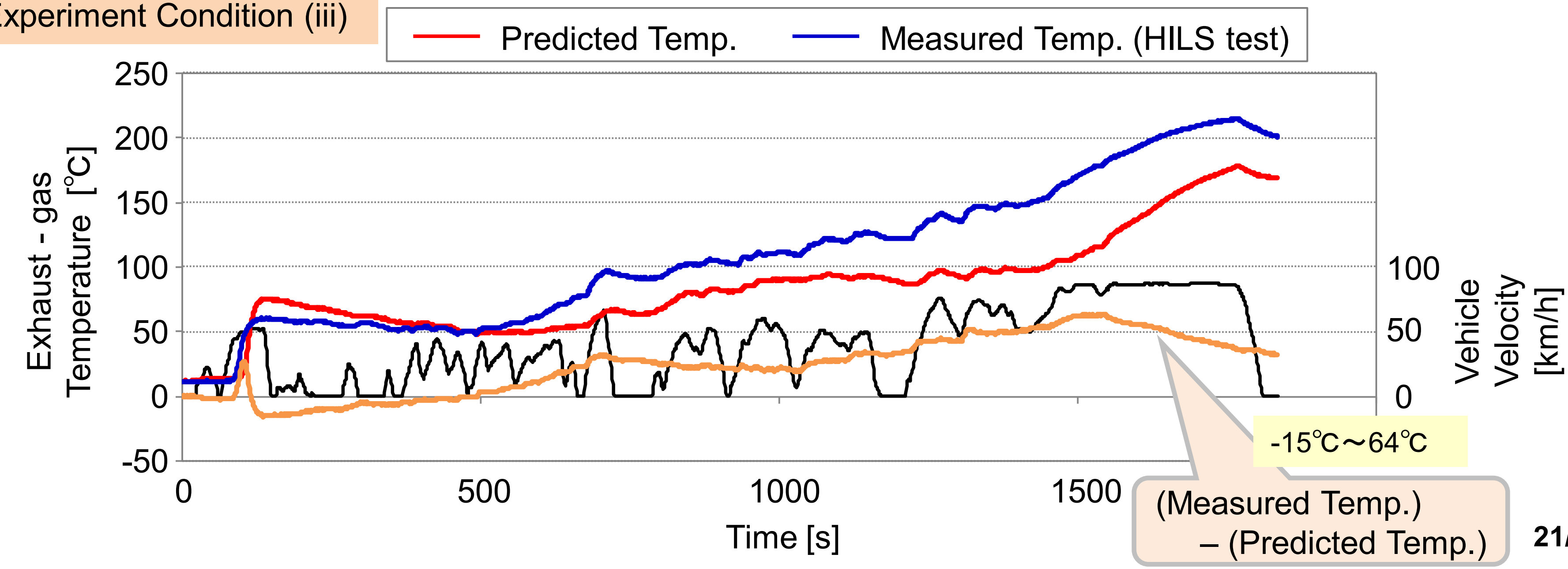
This evaluation method confirmed a strong correlation between the two temperatures, but the temperature history significantly differs between them.
=>
The correlation between the temperatures is not sufficient to validate the evaluation method.

#【Experiment Condition (i) and (iii)】Comparison of Temperatures After SCR Catalyst (Thermocouple (iii))

Experiment Condition (i)



Experiment Condition (iii)



【Summary】

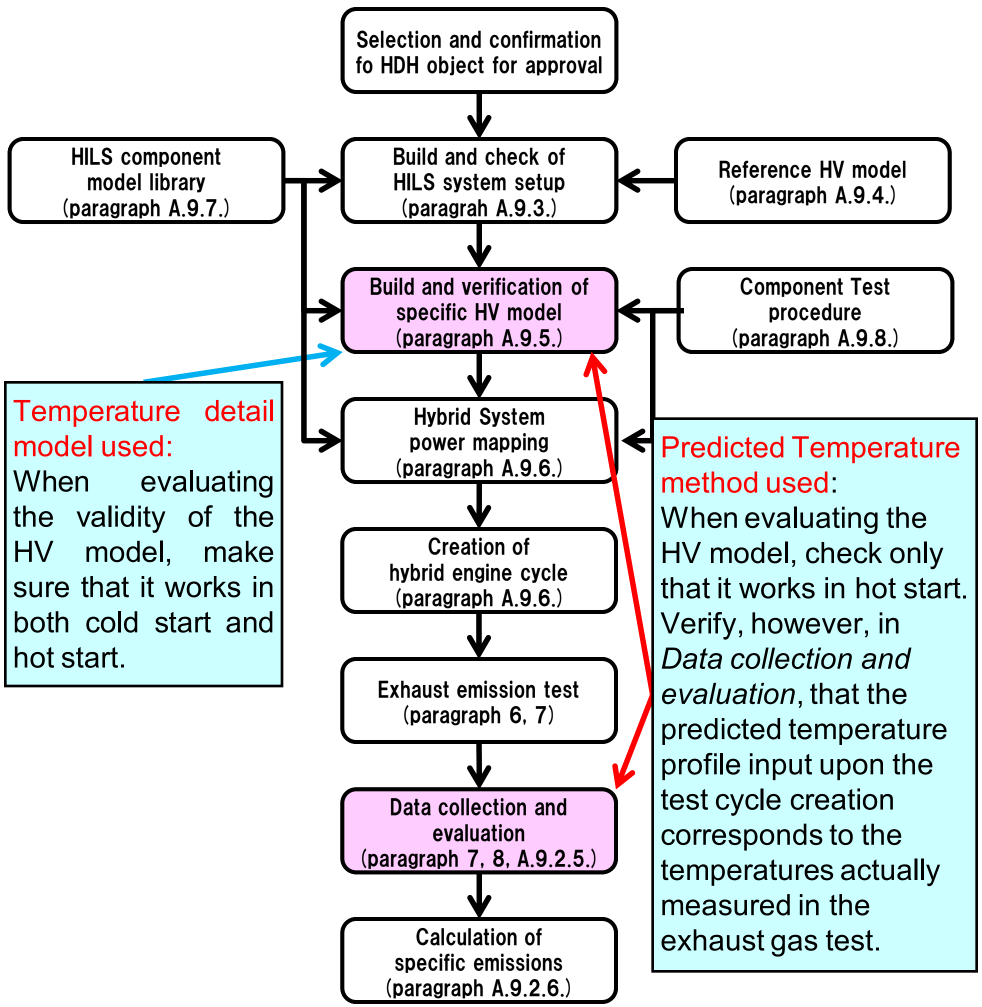
We examined the validity of the method for evaluation proposed by Japan of cold-start test on large-size hybrid vehicles. Specifically, we verified the correlation between the predicted temperature profile after the virtual hybrid vehicle running test and the actual temperatures after the HILS+engine alone test on the hybrid power-train test bench owned by NTSEL.

- > The examination showed that the evaluation method proposed by Japan proves a strong correlation between the predicted temperature profile and actual temperatures, without being affected by the introduction of pre-warm electricity generation control or difference in HEV layout.
- > Even when the predicted temperature profile significantly differs from the actual temperatures in cold start, the correlation between the temperatures (R^2) exceeds 0.9. However, considering that, when compared, absolute values at each point of time are different from each other by tens of degrees, the actual values of exhaust gas may be different.

As to the validity of the method for evaluation proposed by Japan of cold-start hybrid control in terms of correlation between the two temperatures after catalysts, we would like to propose the following:

Measure the temperature at points nearer to an exhaust pipe from the engine body,
compare the predicted temperature profile and actual temperatures in time series
and make sure that they show equivalent temperature history.

Procedure of HILS Tests on Vehicles That Switch the Mode of Control of Hybrid System in Response to Temperature



Test Procedure

The running conditions during the HILS validation are changed as follows:

* Vehicles that doesn't switch the mode of control in response to the temperature of a component: Hot start

* Vehicles that switch the mode of control in response to the temperature of a component
> Temperature detail model used: Hot start and cold start
> Predicted temperature method used: Hot start (subject, however, to verifying that the predicted temperature profile in test cycle creation corresponds to the temperatures actually measured in the exhaust gas test)

<Positioning in test procedure>

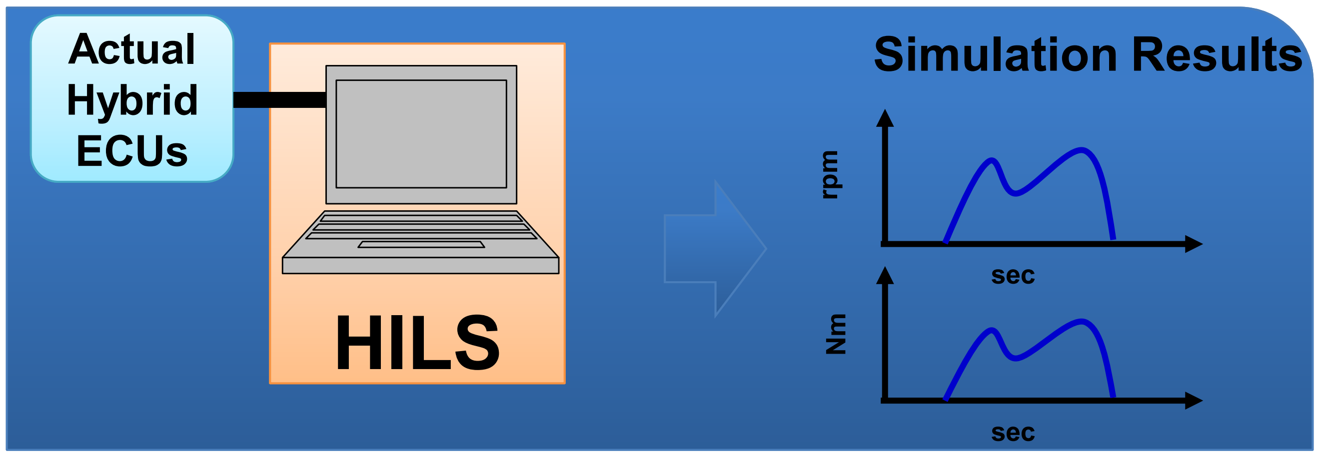
As shown at left, in *Data collection and evaluation*, check that the predicted temperature profile corresponds to the temperatures actually measured in the exhaust gas test.

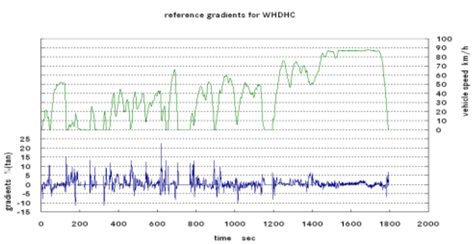
Annex

Verification Test for Hot State

No Hybrid control changing due to Temperature change until Hot condition test.

HILS side



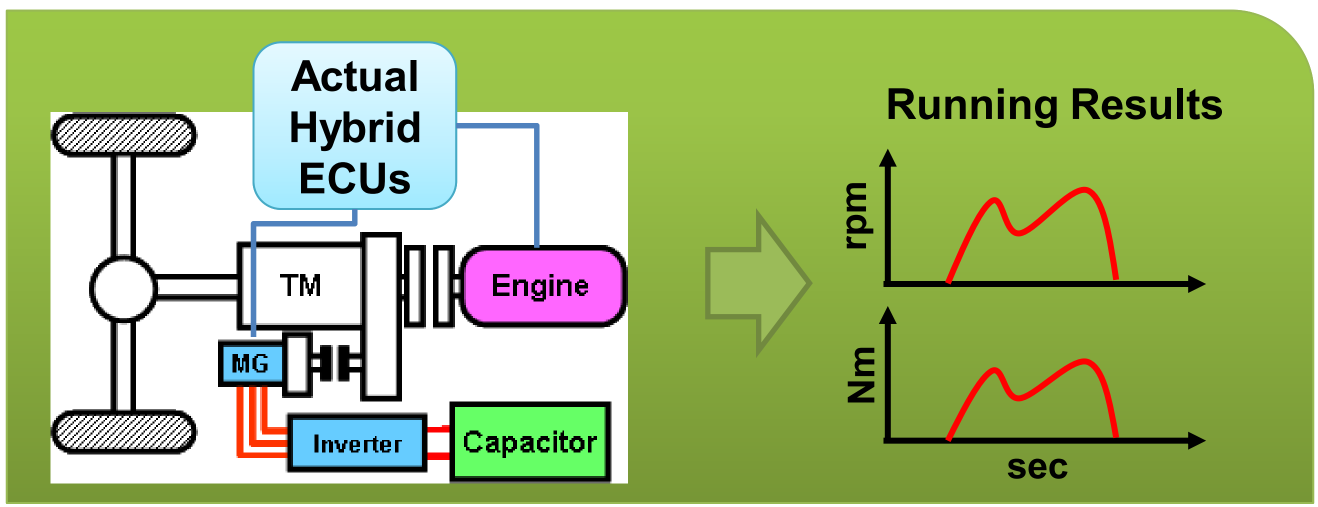


Reference vehicle speed (WHVC with slope)

If equal both ICE speed and torque

|| HILS models OK

Actual Powertrain side



gtr A 9.2.5.

ECE-TRANS-WP.29-GRPE-2014-11e prescribes, in A 9.2.5., as follows:

A.9.2.5. Data collection and evaluation

A.9.2.5.1. Calculation of hybrid system work

The hybrid system work shall be determined over the test cycle by synchronously using the hybrid system rotational speed and torque values from the valid HILS simulated run of paragraph A.9.6.4. to calculate instantaneous values of hybrid system power. Instantaneous power values shall be integrated over the test cycle to calculate the hybrid system work from the HILS simulated running W_{sys_HILS} (kWh). Integration shall be carried out using a frequency of 5 Hz or higher (10 Hz recommended) and include all positive power values.

The hybrid system work W_{sys} shall be calculated as follows:

(a) Cases where $W_{act} < W_{eng\_HILS}$:

$$W_{sys} = W_{sys\_HILS} \times W_{act} / W_{eng\_HILS} \quad \text{(Eq. 107)}$$

(b) Cases where $W_{act} \geq W_{eng\_HILS}$

$$W_{sys} = W_{sys\_HILS} \quad \text{(Eq. 108)}$$

Where:

W_{sys} : Hybrid system work (kWh)

W_{sys_HILS} : Hybrid system work from final HILS simulated run (kWh)

W_{act} : Actual engine work in HEC test (kWh)

W_{eng_HILS} : Engine work from final HILS simulated run (kWh)

All parameters shall be reported.