Working Paper No. **HDH-11-05e**
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Results of Examination and Issues to Address Regarding WHDHC

JAPAN AUTOMOBILE STANDARDS INTERNATIONALIZATION CENTER

On 31 July 2012, Mr. Stein, Secretary of the UNECE/HDH-IG presented the Excel tool developed by Prof. Hausberger (TU Graz).

This tool calculates the target power patterns of WHDHC (World Heavy Duty Hybrid Cycle) as proposed by Prof. Hausberger.

We used this tool to identify and discuss problems and issues to address.

We also used the Japanese HILS to simulate power patterns of WHDHC.

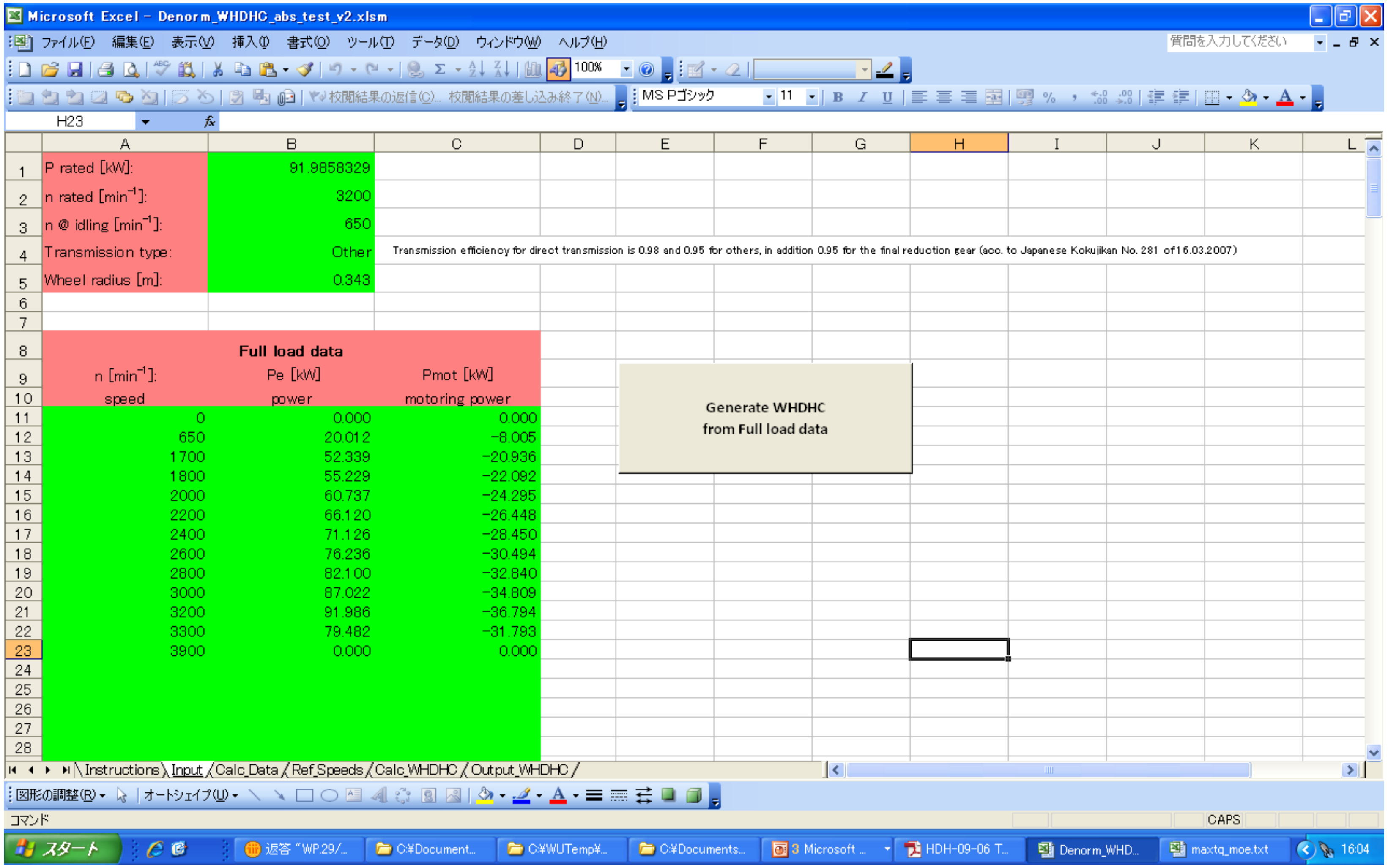
Results of Examination of WHDHC (Excel tool)

No	Item	Identified problems	Proposed solutions and issues
1	Negative work	* Difference from vehicle-based negative work * Negative work being small according to original conversion results	* Regeneration is important for HEVs, and the engine cycle can not produce regeneration. Thus, the negative work must be considered as vehicle-based.
2	Transmission shift-changing power gaps	* No problem for OPT-A (Pre-TM) * Problematic for OPT-B (Post-TM), as the transmission timing is fixed	* The revolution speed differs between OPT-A and OPT-B, which means the emissions will be also different. * If power patterns are specified using OPT-A, HILS cannot be applied.
3	Vehicle mass for OPT-B HILS	* Gaps between original conversion results and vehicle-based work	* Needs to discuss how to determine the vehicle mass that is correlated with system axial power.
4	Power pattern alignment for OPT-B HILS	* Gradient correction necessary for adjustment of power patterns in OPT-B	* Even if the vehicle mass is adjusted to power, a steep gradient will be partially necessary, which makes the driving with C/D impossible. Even if HILS simulation is performable, HILS accuracy verification using the same conditions will be impracticable.
5	OPT-B HILS simulation	* We performed power adjustment for WHDHC using real specifications and gradients and tried to perform HILS simulation but failed.	* An ECU error occurs due to an unrealistic road setting by the gradient set for power adjustment.

Examination of WHDHC Excel Tool

Examples of Excel Tool Input Data

* Data on the rated power, full load curve, etc. of power packs are input.



P rated [kW]:	91.9858329	
n rated [min^{-1}]:	3200	
n @ idling [min^{-1}]:	650	
Transmission type:	Other	Transmission efficiency for direct transmission is 0.98 and 0.95 for others, in addition 0.95 for the final reduction gear (acc. to Japanese Kokujikan No. 281 of 16.03.2007)
Wheel radius [m]:	0.343	

Full load data		
n [min^{-1}]: speed	Pe [kW] power	Pmot [kW] motoring power
0	0.000	0.000
650	20.012	-8.005
1700	52.339	-20.936
1800	55.229	-22.092
2000	60.737	-24.295
2200	66.120	-26.448
2400	71.126	-28.450
2600	76.236	-30.494
2800	82.100	-32.840
3000	87.022	-34.809
3200	91.986	-36.794
3300	79.482	-31.793
3900	0.000	0.000

Examples of Excel Tool Output Data

* Data on WHDHC' s target revolution speed/power pattern are output.
  - Two types of data are calculated: Pre-TM(OPT-A) and Post-TM (OPT-B, hub input).

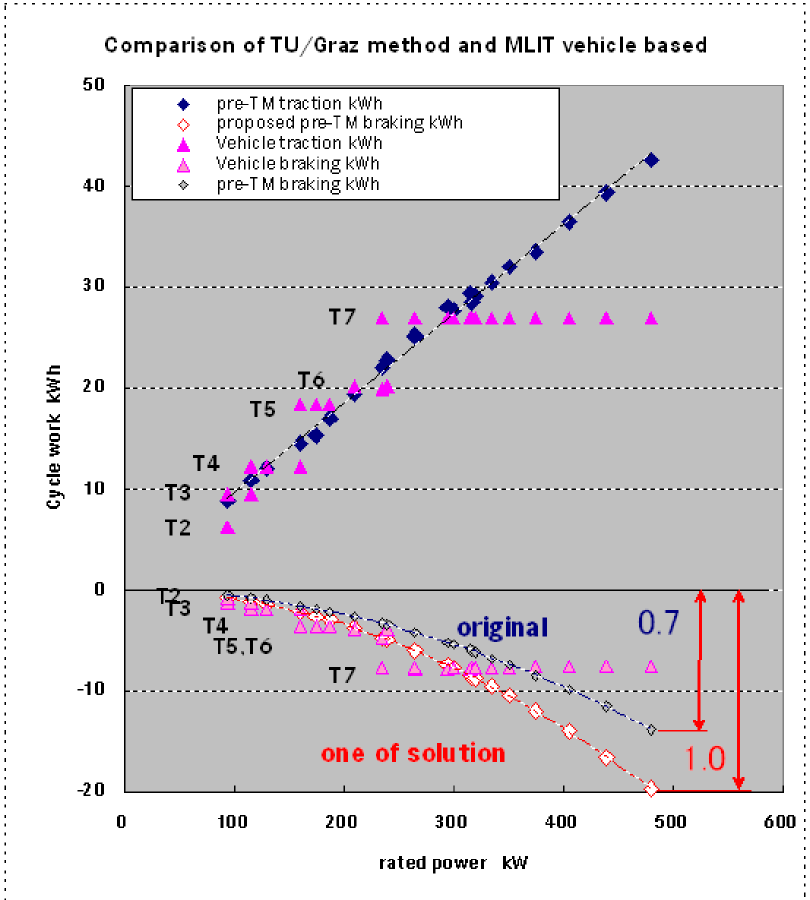
Microsoft Excel - Denorm_WHDHC_abs_test_v2.xlsm

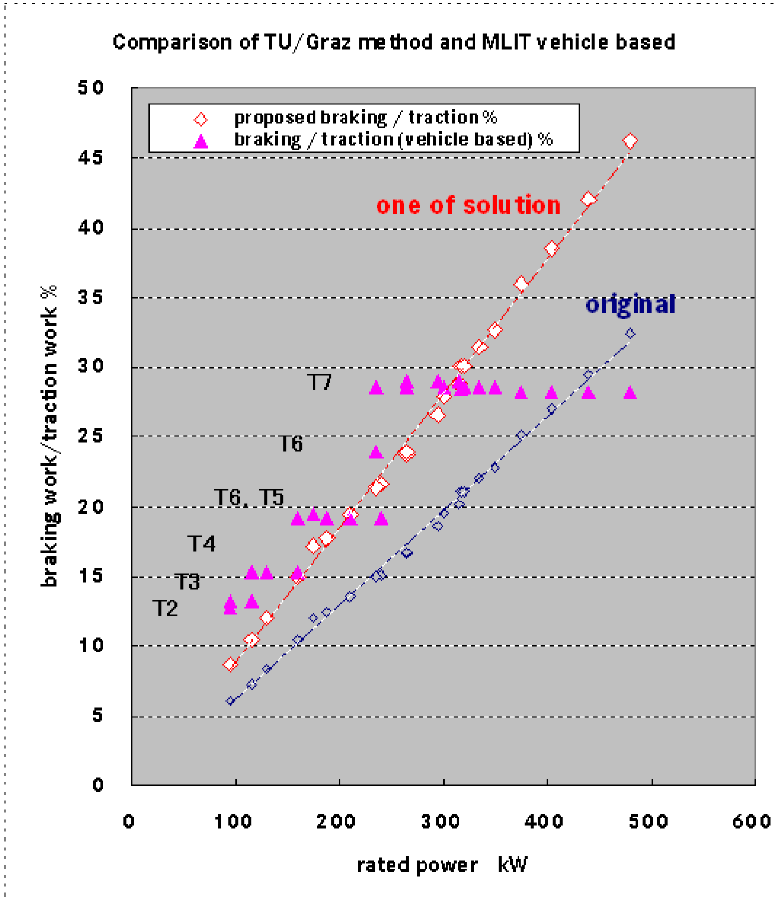
Denormalized WHDHC Option A (Powerpack output shaft)				Denormalized WHDHC Option B (Wheel hubs)		
cycle time	speed at powerpack output shaft	power at powerpack output shaft	cycle time	speed at wheelhubs	speed at wheelhubs acc. to WHVC	power at powerpack output shaft
	acc. to WHTC (ECE/TRANS/180/Add.4)			acc. to WHTC (ECE/TRANS/180/Add.4) (will be calculated acc. to respective transmission ratios in HILS model)	(calculated with wheel radius)	
time [s]	n [min⁻¹]	P [kW]	time [s]	n [min⁻¹]	n [min⁻¹]	P [kW]
0	650	0.00	0	-	0.00	0.00
1	650	0.00	1	-	0.00	0.00
2	650	0.00	2	-	0.00	0.00
3	650	0.00	3	-	0.00	0.00
4	650	0.00	4	-	0.00	0.00
5	650	0.00	5	-	0.00	0.00
6	650	0.00	6	-	0.00	0.00
7	688	1.87	7	-	18.17	1.69
8	1046	9.97	8	-	43.08	9.00
9	1337	0.56	9	-	63.26	0.51
10	1467	0.31	10	-	72.46	0.28
11	1523	0.64	11	-	76.25	0.58
12	1558	3.59	12	-	78.73	3.24
13	1580	2.98	13	-	80.27	2.69
14	1600	5.03	14	-	81.74	4.54
15	1643	6.19	15	-	84.68	5.59
16	1711	6.63	16	-	89.40	5.98
17	1786	6.92	17	-	94.50	6.25
18	1869	3.52	18	-	100.30	3.18
19	1673	0.00	19	-	110.82	0.00
20	1477	7.42	20	-	126.67	6.70
21	1716	14.56	21	-	142.30	13.14
22	1886	15.41	22	-	153.59	13.90
23	2004	10.91	23	-	161.24	9.85
24	2082	8.07	24	-	166.42	7.28
25	2127	5.57	25	-	169.29	5.03
26	2137	3.80	26	-	169.98	3.43
27	2129	3.12	27	-	169.44	2.82
28	2102	-0.10	28	-	167.66	-0.11

Instructions / Input / Calc Data / Ref Speeds / Calc WHDHC / Output WHDHC

Issues and Solutions 1: Negative Work

* We performed calculations with various power curves using the Excel tool, determined the cycle work and plotted the results.
  - WHDHC's positive work is approximately proportional to the power pack rated power, and the negative work is proportional to its squares.
    We consider these relations basically reasonable.
    However, the results of negative work are lower than the "calculation results based on the emissions standard vehicle specifications (half loaded on flat condition in WHVC) in the JARI Program" and therefore need to be improved.



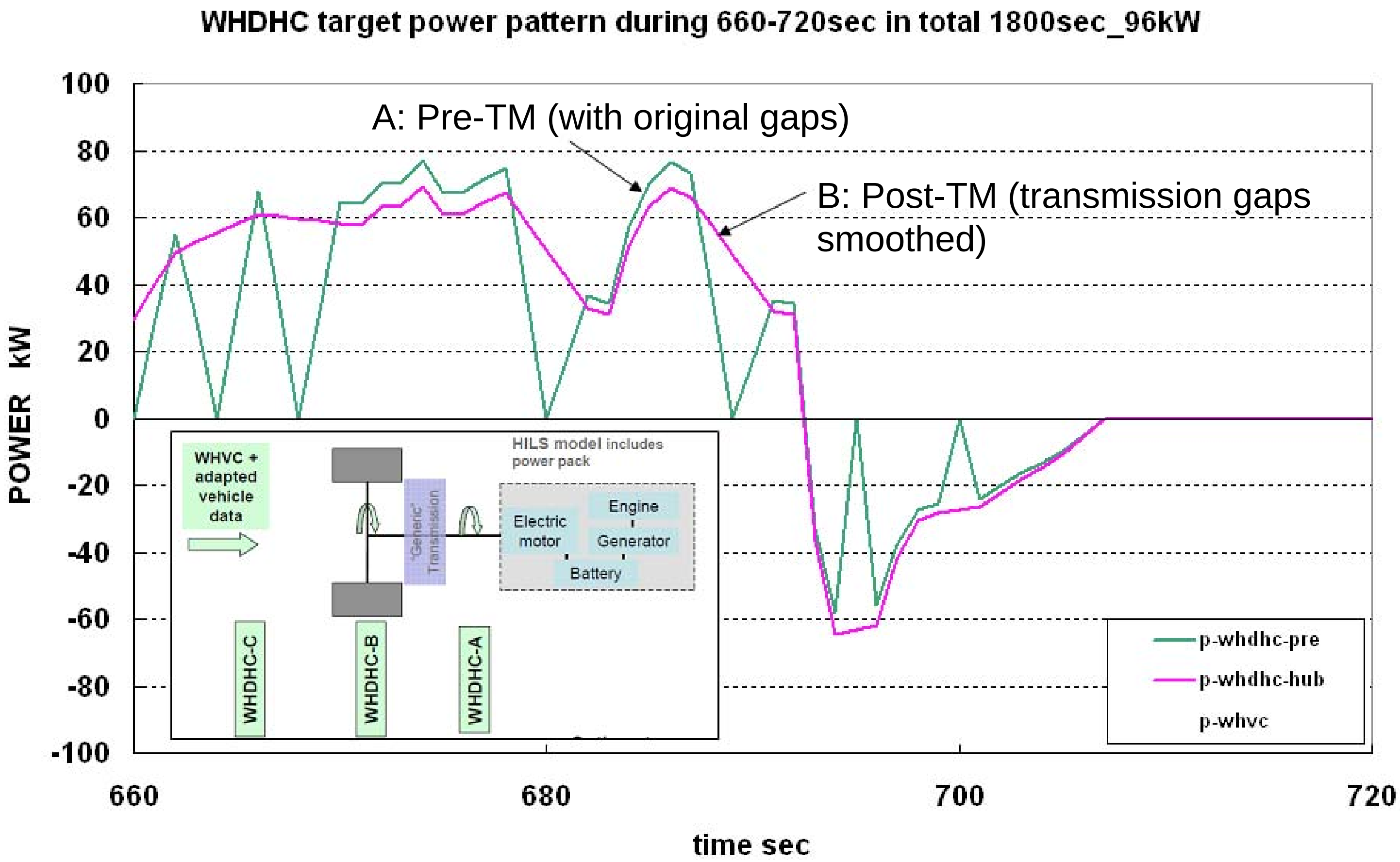


Issues and Solutions 2: Power Pattern's Transmission shift-changing Gaps

＊ In WHDHC's power patterns, there are zero-gaps derived from transmission shift-changing events.

It is unnecessary to include these gaps for Post-TM, because the shift-changing timing should be determined by the real control; If they were included in the target patterns, the shift-changing timing would become out of reality and design by manufacture. On the other hand, for Pre-TM, basically there is no unreasonableness with gaps like in WHTC.

<u>Proposed pattern is to smooth these gaps on original one.</u> (Post-TM)

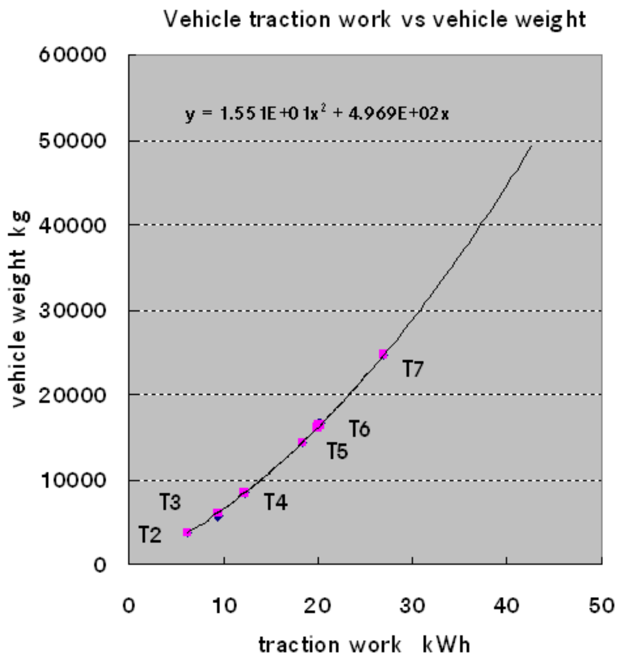


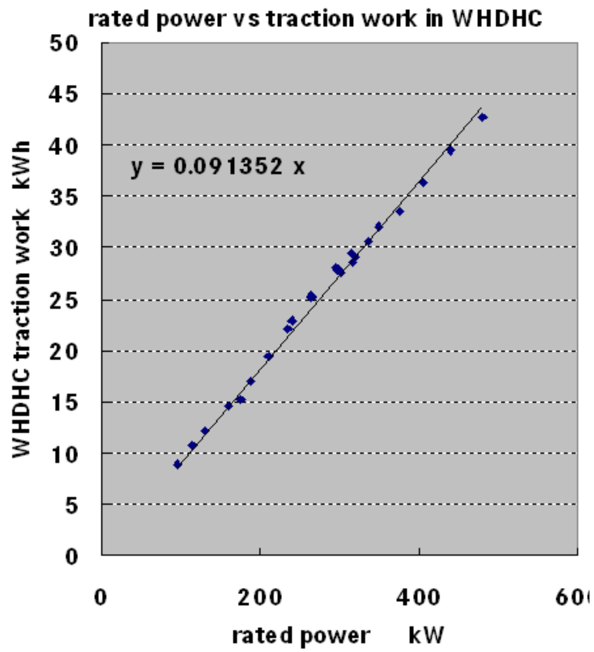
3. Input Vehicle Weight for OPT-B HILS

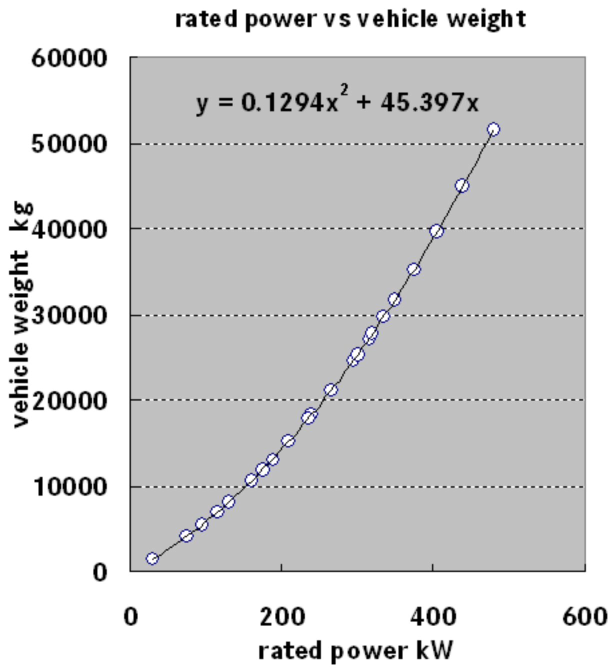
* In vehicle-based simulation, for adjustment to WHDHC' s target power patterns, the weight based on the standard vehicle specifications, as specified in T1-T7, creates large divergences in some cases (see p. 7).

As a solution, it would be good to newly define the vehicle weight that is correlated with the rated power.

To do this, for the positive side and the negative side, respectively, we approximated the relations among rated power, cycle work and vehicle weight and obtained relational expressions between rated power and weight.



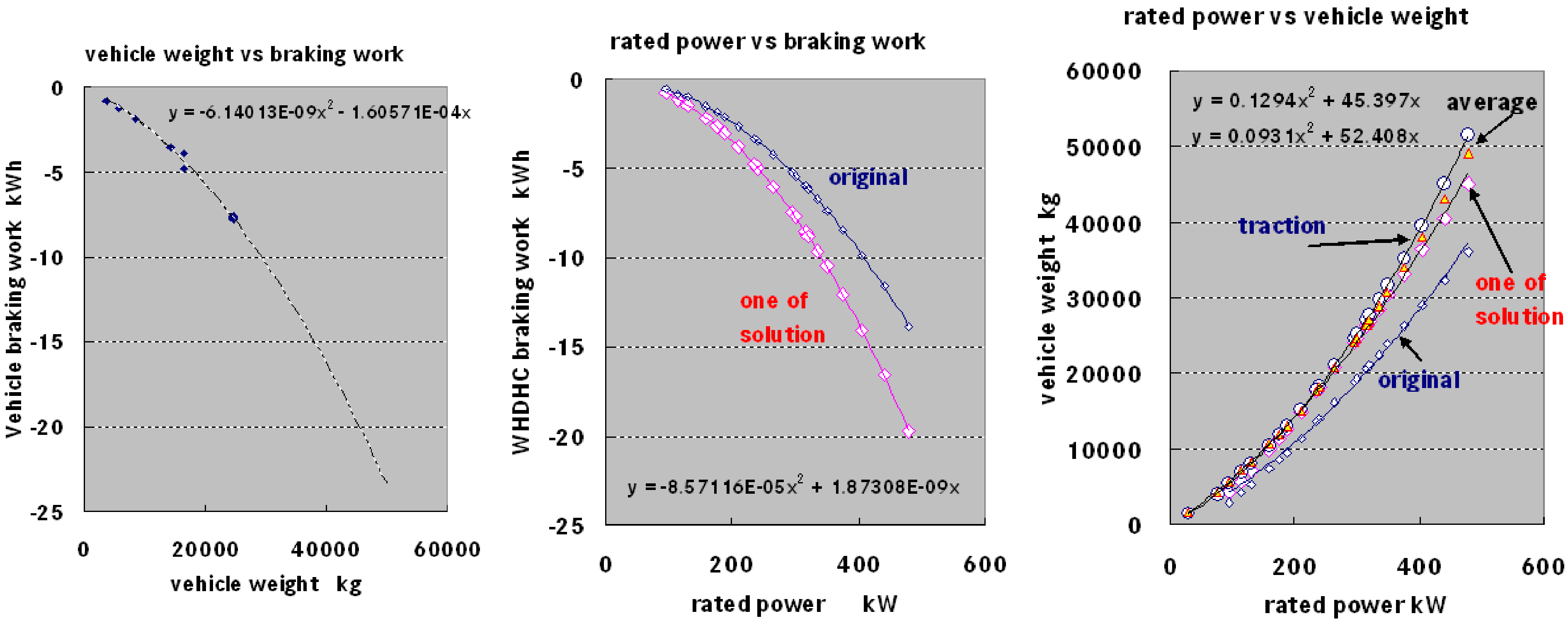




Positive-side approximate expressions

* We averaged the relational expressions between rated power and weight obtained for the positive side and the negative side, respectively, and had the following expression:

Idea; Vehicle weight (kg) =0.111265 x (rated power kW)^2+ 48.9025 x (rated power kW)

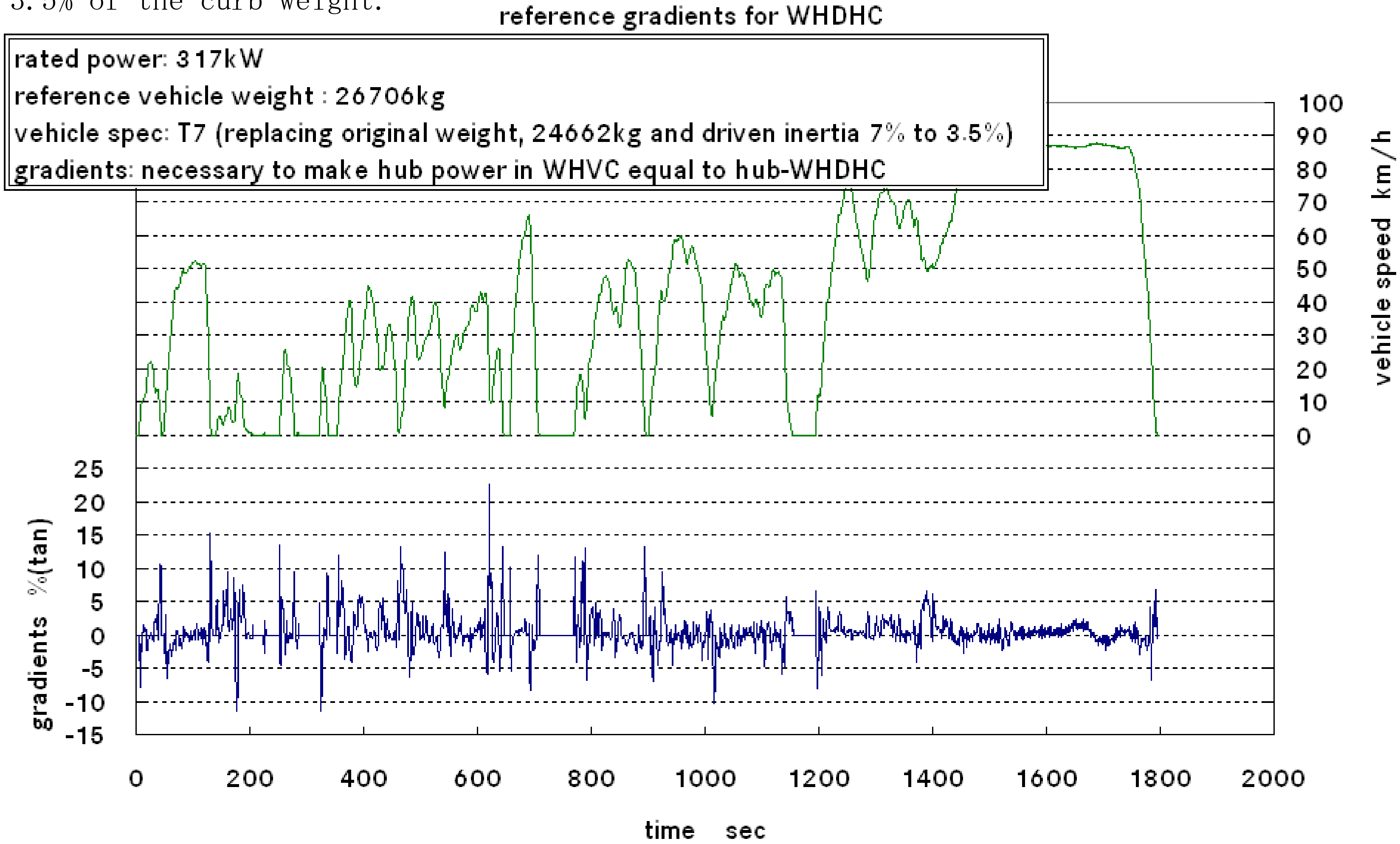


Negative-side approximate expressions and averaging

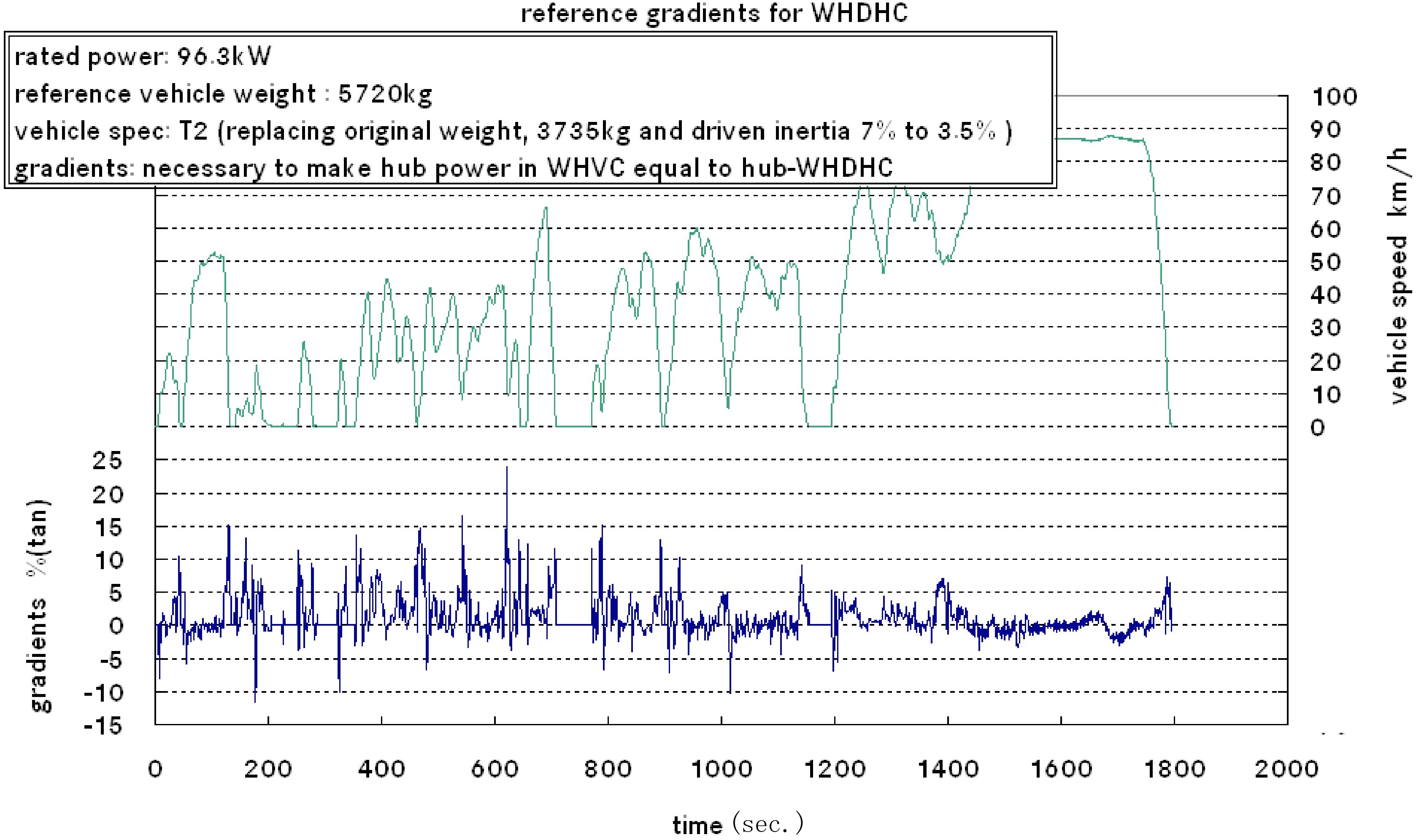
4. Load Adjustment Gradient Patterns for OPT-B HILS

* Even if the vehicle weight is correlated with the rated power, the vehicle-based power patterns and WHDHC' s power patterns do not match precisely, which necessitates the gradient setting. Calculation can be made once per second.

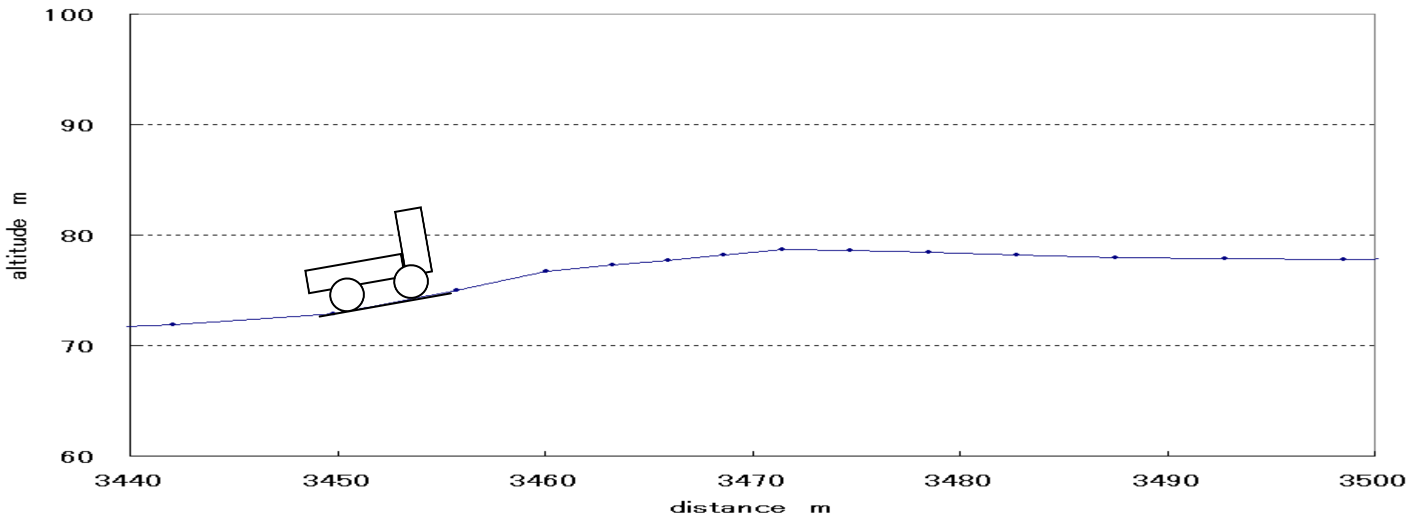
In the case of Post-TM (hub input), since data on power pack were output via the driving side and inertia of a part of the driven side, we assumed the remaining inertia of the driven side to be 3.5% of the curb weight.

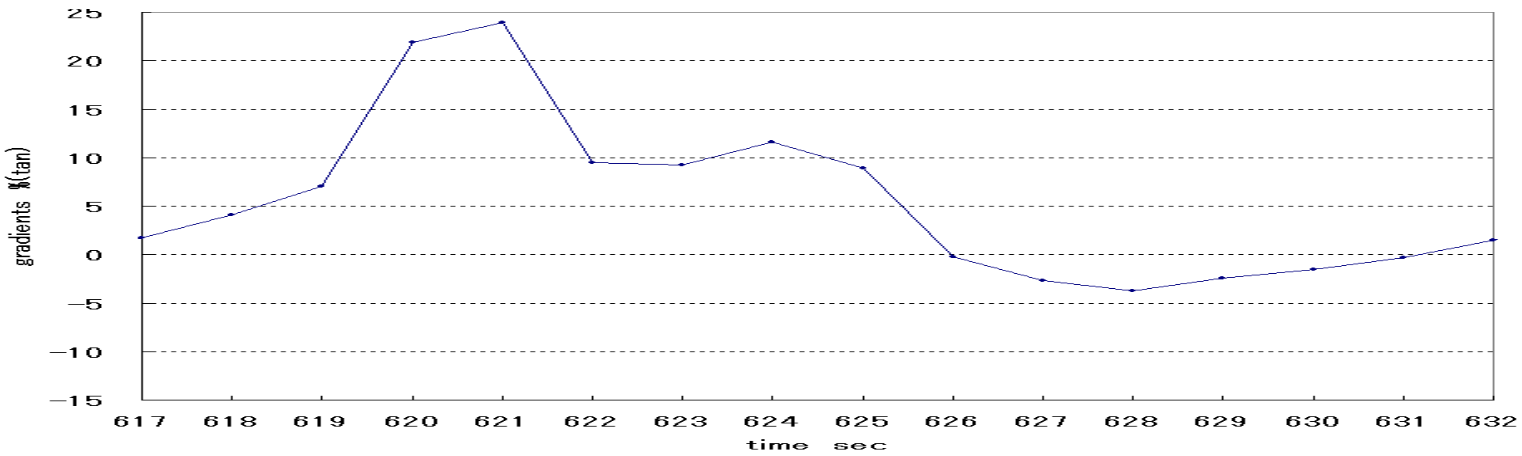


* As we correlated the vehicle weight with the rated power, the gradient patterns turned out to be similar in large and small vehicles.



* However, we determined that it was impossible to track WHVC with gradients on a chassis dynamometer. The graphs below show a part of the altitudes and gradients. You can see how difficult it would be to track the vehicle speed with gradients which change every second for 30 minutes.

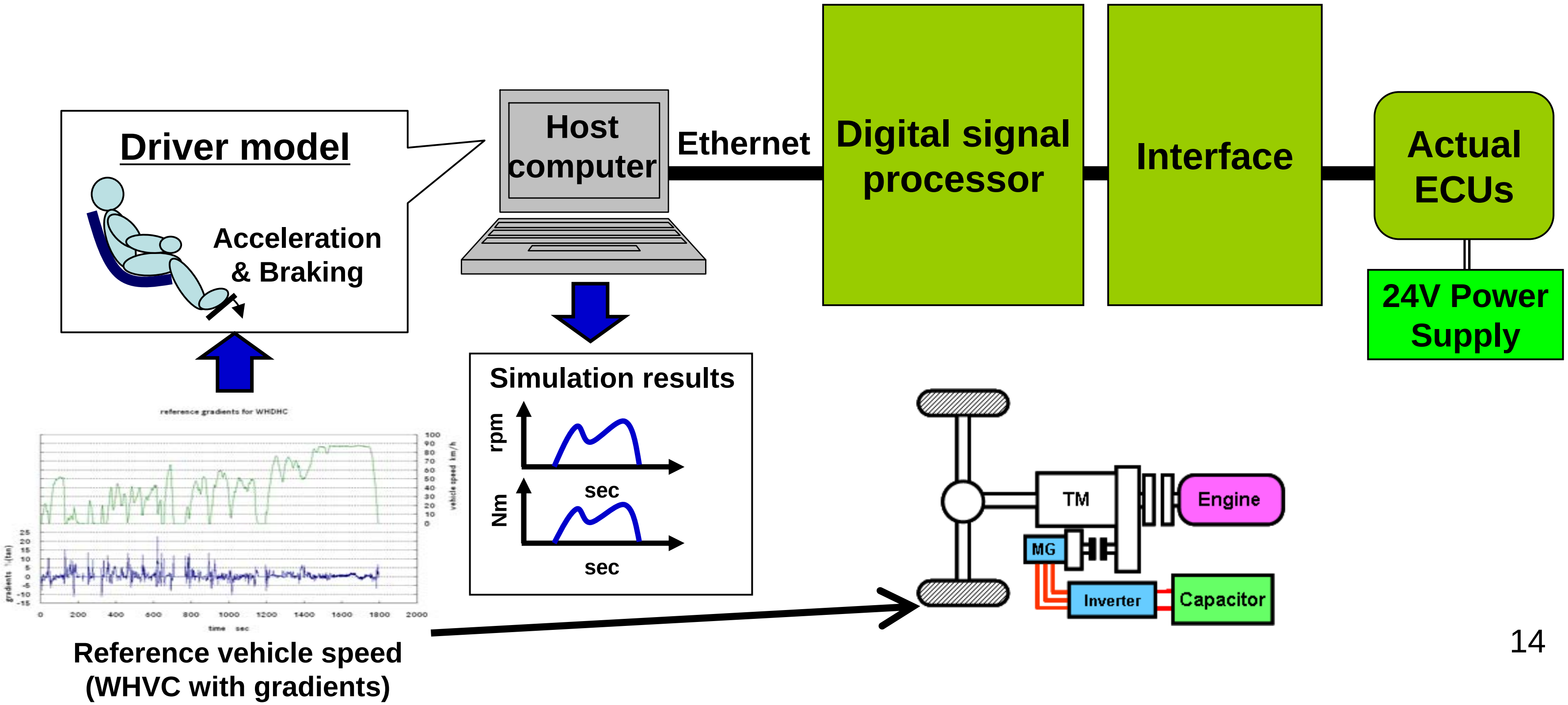




＊ In HILS, we consider such tracking possible if we have the refined driver model or accelerator or brake opening patterns tuned many times in advance.

Here, we can propose to perform the HILS accuracy verification on practical condition and the emissions simulation using gradients. If this works out, simulation that reproduces WHDHC Post-TM power patterns using an open-source model should be possible.

If tracking cannot be done even with this HILS simulation, then the "WHVC + WHTC's torque correction" method proposed by JASIC will be desirable.



5. Summary

- We consider the negative work of WHDHC developed by TU Graz insufficient.
- We consider the transmission shift-changing gaps included in Post-TM' s target power patterns unnecessary.
- The vehicle weight matches WHDHC' s power patterns better if correlated with the rated power.
- With the setting of gradients, the vehicle-based WHVC driving and the WHDHC Post-TM power patterns match better.

  => However, as gradients change every second, tracking on a chassis dynamometer is impossible.

  => In HILS, the possibility of tracking by simulation using a refined driver model cannot be denied.

  => If tracking cannot be done even with the simulation, then JASIC' s proposal will be desirable.

Other:

- For Pre-TM, if the same revolution speed as that of WHTC is combined with WHDHC' s power patterns and the mechanical brake is defined, it will be no problem as the power pack bench target. However, HILS simulation using the vehicle is not performable with the current Japanese HILS.

Examination of the Issues for Applying WHDHC to HILS

1. Overview of the Examination
2. Vehicle Specifications Used in the Examination
3. Examination of the Method for Applying WHDHC to HILS
4. Result of the Application of WHDHC to HILS
5. Summary

1. Overview of the Examination

As a test cycle for measurement of emissions from heavy-duty vehicles, WHDC has been adopted as part of the global harmonization of regulations.

WHDC is a cycle in which the engine axial revolution speed and torque are defined.

However, WHDC cannot be applied to the HILS method, whose use in emission testing for heavy-duty hybrid vehicles is being discussed, since the HILS requires the vehicle speed patterns.

With this background, WHDHC, which is based on WHDC with the deceleration energy re-defined, has been proposed by TU Graz.

In WHDHC, the revolution speed and power of Pre-TM(OPT-A) and Post-TM(OPT-B) are defined, which means that the torque is also defined. Moreover, TU Graz has reported that WHDHC and WHVC use different torque ranges.

To simulate running on WHVC in HILS while tracking the torque defined in WHDHC, it is necessary to use gradients to compensate for the torque differences.

We conducted this examination to see if WHVC with gradients corresponding to the torque differences can be used in HILS.

2. Vehicle Specifications Used in the Examination

We used the specifications of the real vehicle shown in the following tables in our examination of the issues for applying WHDHC to HILS:

Vehicle specs	
Equivalent mass (engine)	0.03
Equivalent mass (tyre)	0.07
Curb vehicle mass (kg)	4,730
Maximum laden mass (kg)	3,150
Capacity	2
Overall height (m)	3.320
Overall width (m)	2.310
Tyre radius (m)	0.389
Number of gears in the main transmission	6
1st gear ratio	6.718
2nd gear ratio	4.031
3rd gear ratio	2.303
4th gear ratio	1.443
5th gear ratio	1.000
6th gear ratio	0.740
Final gear ratio	4.875
Idling revolution speed (rpm)	570
Rated revolution speed (rpm)	3,000
Revolution speed limit with load (rpm)	3,400
Maximum engine power (kW)	152
Motor power (kW)	55

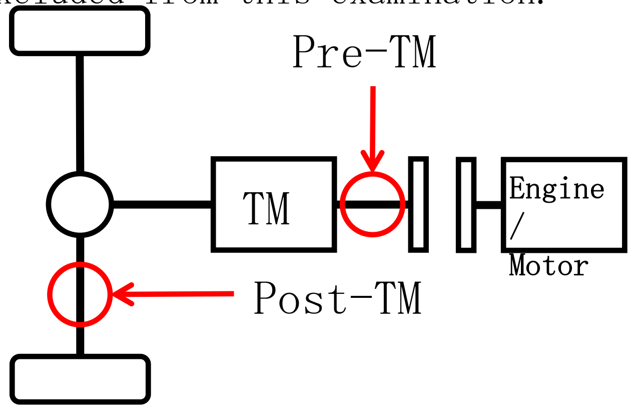
Engine full load data	
n [rpm]	Pe [kW]
speed	power
570	18
800	39
1400	73
3000	152
3200	129

3. Examination of the Method for Applying WHDHC to HILS (1)

In WHDHC, the revolution speed and power of Pre-TM and Post-TM are defined. While the revolution speed defined in WHDHC is calculated based on WHTC for Pre-TM, it is based on WHVC for Post-TM.

For applying WHDHC to HILS, WHVC must be used as the target vehicle speed, which requires a CVT-like action to track the revolution speed of Pre-TM.

For this reason, Pre-TM was excluded from this examination.



Locations where the revolution speed and power are defined in WHDHC

In WHDHC, the revolution speed and power are defined, which means that the torque is also defined. Moreover, TU Graz has reported that WHDHC and WHVC on flat condition use different torque ranges. To track the torque in HILS, it is necessary to calculate gradients from the torque differences.

Since it is preferable to determine the gradients consistently, we used a Japanese HEV conversion program, convDHEV, to calculate the torque required for WHVC.

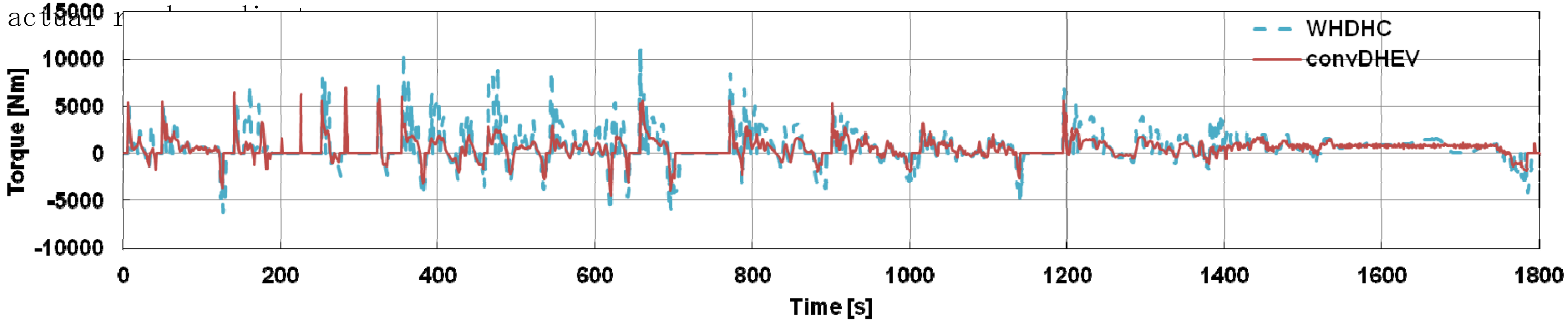
3. Examination of the Method for Applying WHDHC to HILS (2)

The graphs below show the torques determined with WHDHC and convDHEV and the required gradients calculated from the torque differences.

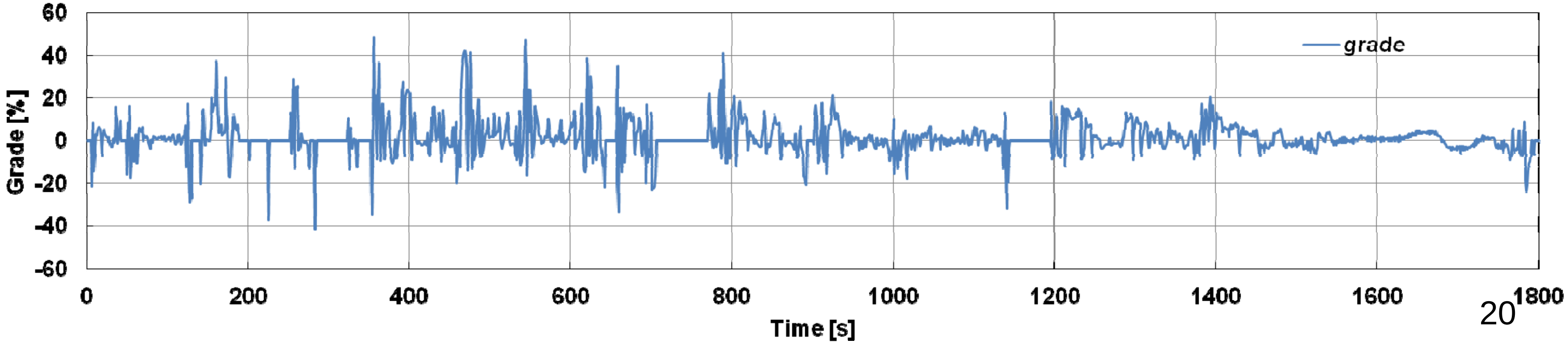
We used the following formula to calculate the gradient, without accounting for the cos component.

$$\theta = \tan\left(\operatorname{asin}\left(\left(\tau_{WHDHC} - \tau_{convDHEV}\right)/\left(rd \times g \times m\right)\right)\right) \times 100$$

A large difference between torques calculated with WHDHC and those with convDHEV was observed in many parts. The maximum required gradient that was calculated was 49.9%, which deviates greatly from the actual road gradient.



Torques determined with WHDHC and convDHEV and gradients calculated from the torque differences



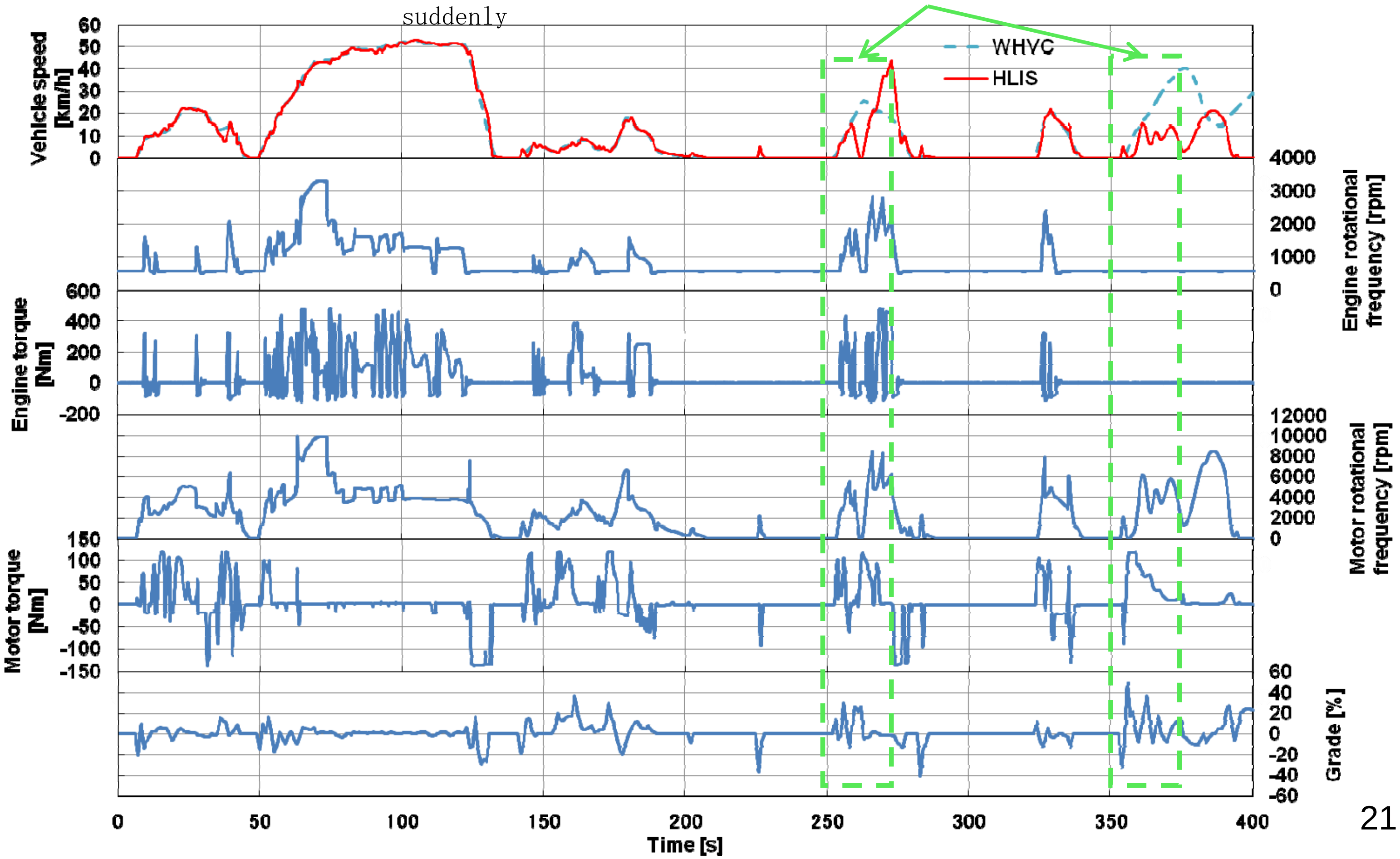
Gradients calculated from the torque differences

4. Result of the Application of WHDHC to HILS

These graphs show the results of our HILS simulation of WHVC (with gradients).

In the simulation, an HECU error (clutch-related) occurred at around 350 seconds, where a large ascending gradient entered, or stopped responding to the torque command at the same point, making it impossible to continue simulation.

The cause of the error is presumed



Results of Run on WHVC (with gradients) in HILS

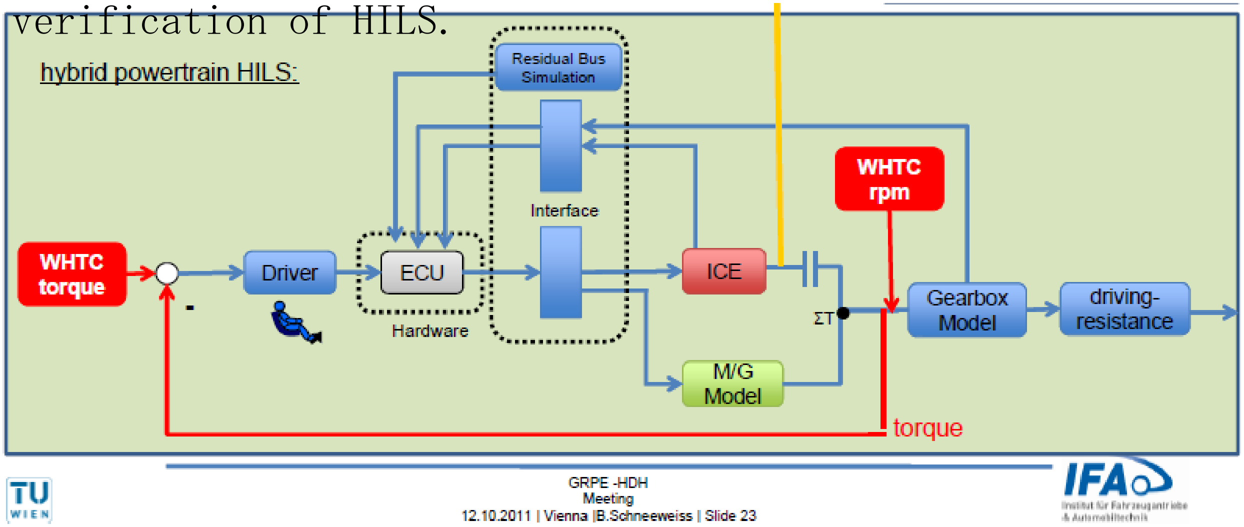
5. Summary

1. The revolution speed specified in WHDHC is based on WHTC for Pre-TM and WHVC for Post-TM. Only Post-TM can be applied to HILS.
2. To simulate running on WHVC in HILS and adjust it to the revolution speed and power of Post-TM specified in WHDHC, it is necessary to set gradients.
3. With the vehicle specifications used in this examination, the maximum gradient was 49.9% for ascending and -35.5% for descending.
4. In the HILS simulation of WHVC (with gradients), an HECU error occurred.
5. The cause of the error is presumed to be the large gradient that does not exist in the real world.

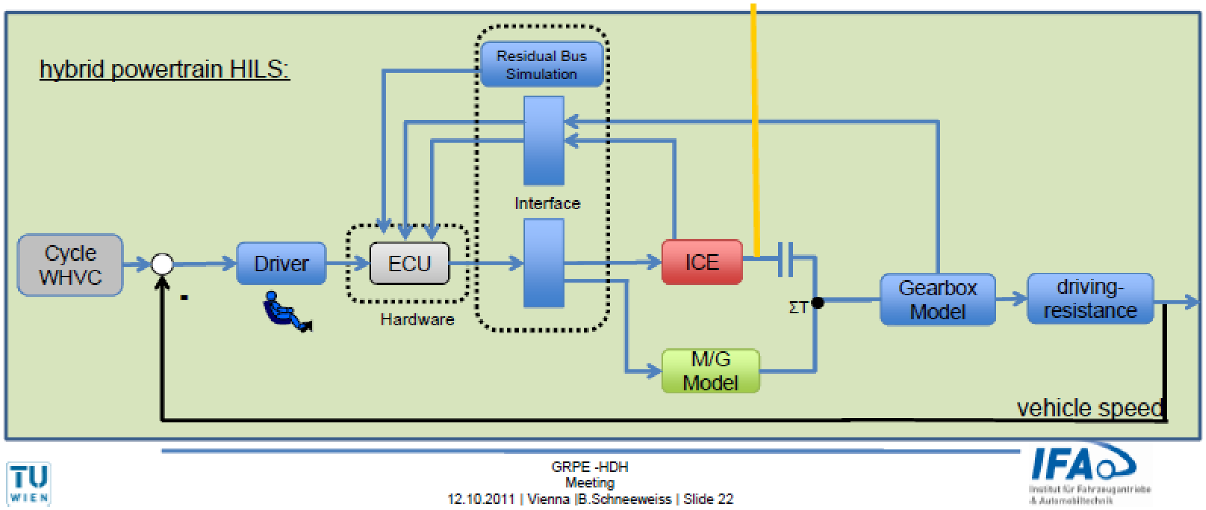
Supplement: Possibility of the torque (power)-tracking HILS

1. The HILS that tracks the torque without the vehicle, proposed by TU Wien, would be fundamentally different from the vehicle-based HILS, and therefore there are many problems including re-development of the model, renovation of the actual ECU, and difficulty of verification of HILS.

Vehicle-less HILS that tracks the torque

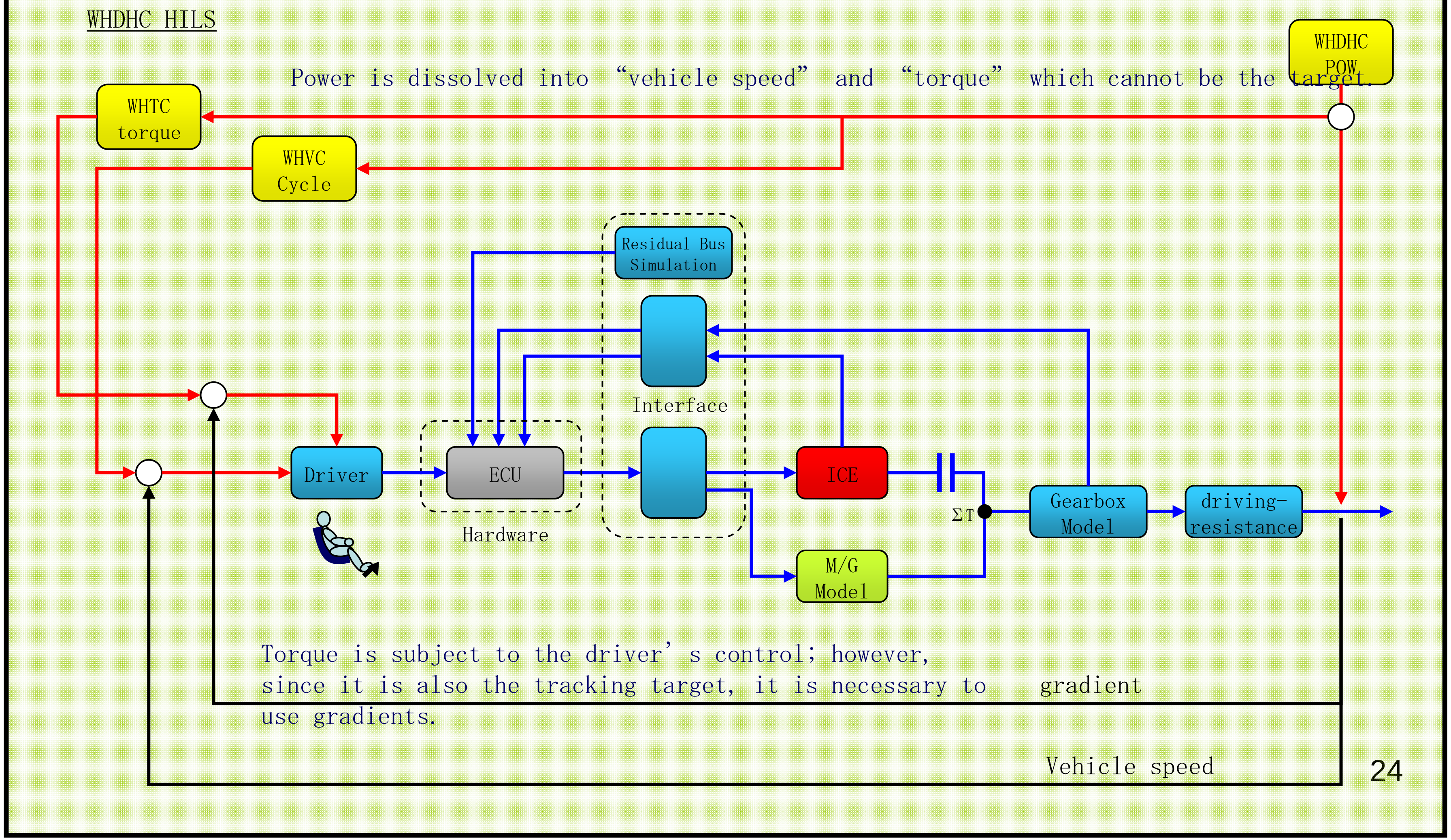


Vehicle-based HILS that tracks the vehicle speed



Source: HDH-07-04

2. In WHDHC HILS, the power is the target, whereas, in reality, the vehicle speed and torque are the target. In this case, the torque, which is supposed to be controlled, would need to be forcefully adjusted to the target using gradients, causing the simulation to be performed under unrealistic conditions. Furthermore, since it is impossible to use the actual vehicle, we would not be able to verify the simulation accuracy.



▼ Confirmation of WHDHC in SILS

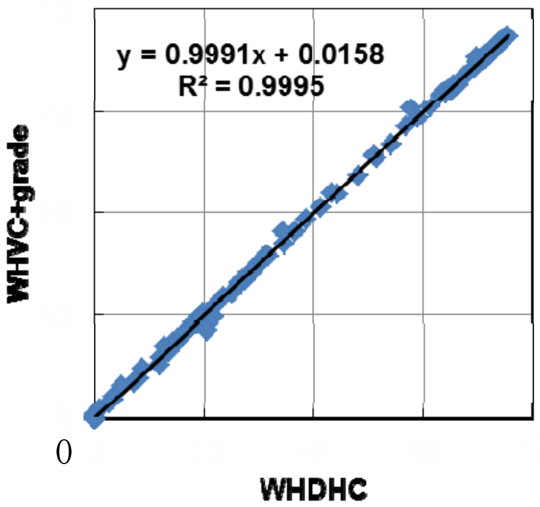
The graphs below show the results of simulation of running on WHVC for 140 seconds in SILS, using the Japanese standard vehicle specifications and the gradients for adjustment to WHDHC's power.

If fixed gradients were used, predictive control would be easy since the accelerator/brake commands required for the vehicle speed/acceleration would be determined consistently. However, in the case where gradients change every second, even if the vehicle speed/acceleration remains unchanged, the accelerator/brake opening changes every time, and prediction will be impossible, leading to lowering of the tracking performance.

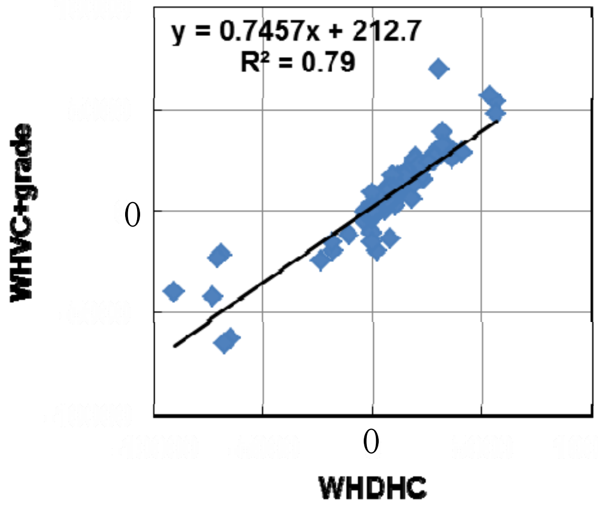
In SILS, although simulation was possible to some extent, since the acceleration did not match its target value, the correlation with WHDHC in torque and power was lowered. In HILS, simulation was not performable.

$$F_w = rd \times (F_r + F_g) + F_i$$
$$F_r = g \times (la + lb \times V + lc \times V^2)$$
$$F_g = g \times ms \times \sin(\mathrm{atan}(\theta))$$
$$F_i = j_1 \times \alpha$$

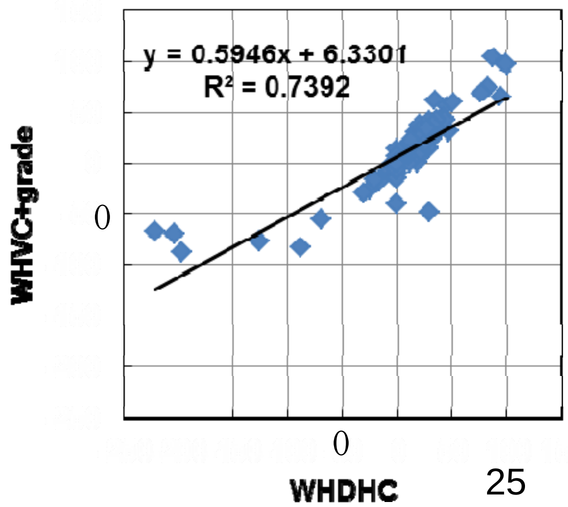
F_w: Wheel hub's required torque
F_r: Load torque
F_g: Gradient resistance
F_i: Chassis rotary inertia
rd: Tyre radius
g: Gravity acceleratic
la, lb, lc: Load fac
V: Vehicle speed
θ: Gradient
ms: Vehicle weight
$j1$: Rotary inertia moment
α: Rotary acceleration



Revolution speed



Torque



Power