Working Paper No. **HDH-15-05e**
(15th HDH meeting, 24 to 25 October 2013)

Examination of WHVC slope

Purpose

- At the 14th meeting of the Informal Group on HDH held in Geneva, the JRC made the following report: "The chassis dyno test for the Validation Test Program 2 showed that the actual positive cycle work on 30 sec moving averaged slope widely deviated from the target (by 38%)".

- In response, we analyzed the test results based on information currently available
- And also explored the best slope patterns for WHVC.

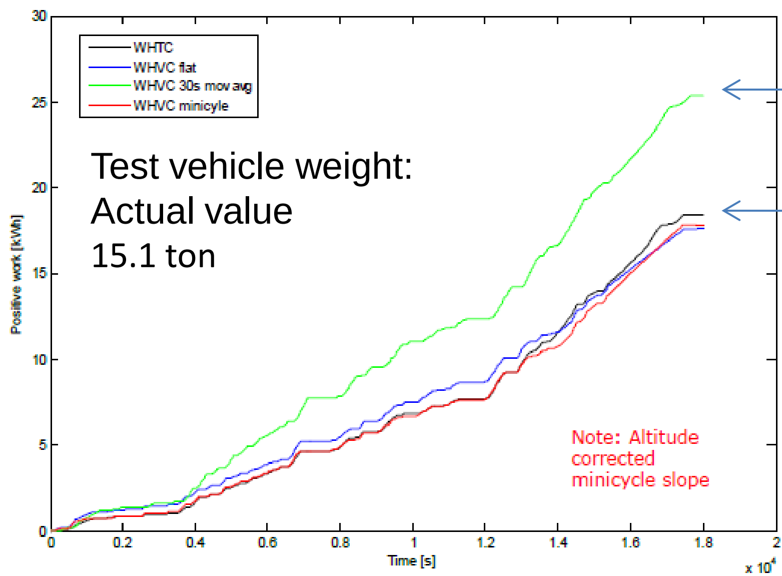
Analysis of JRC Test Results

Outline of JRC Report

The figure below shows the positive total work in time history in HDH-14-04e, page 10.
The measured work in WHVC with 30 sec moving averaged slope was about 25.5 kWh, exceeding by 38% the calculated work in averaged WHTC of 18.43 kWh*, the targeted reference.

* The results of calculation by the averaged WHTC method proposed by the Institutes. This method does not require the full-load curve normally required for WHTC and allows calculating the time-history power pattern using only a system rated output power of 198 kW.

Positive work



30sec moving averaged slope: c.a. 25.5kWh

+38%

Averaged WHTC: 18.43kWh

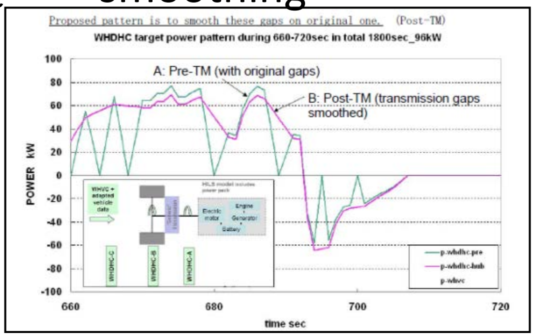
Mini-cycle works perfectly on the first 11 cycle. Can't follow during the last cycle.
30s moving average slope fails.
It was hard to follow by the driver and chassis dyno and gives wrong work.

What caused the deviation of the positive cycle work? (1)

We analyzed factors that might have caused the deviation using JASIC slope calculation tool. Since JASIC tool is based on WHDHC power patterns (calculated in the same manner as WHTC on the positive side), we estimated the full-load curve necessary as input data, which defined the rated output power and positive cycle work at the known values of 198 kW and 18.4 kWh, respectively (Fig. 1).

In comparison of all calculated results, the positive total work in time history showed that the value in 30 sec moving averaged slope deviated from WHDHC by 18.5% (Fig. 2).
What caused the deviation was the smoothing upon zero gaps by gear shifting to the target power pattern* (+13.2%) and mathematical error in the process of the conversion from instantaneous (second by second) slope into moving averaged one (+4.8%).

* smoothing



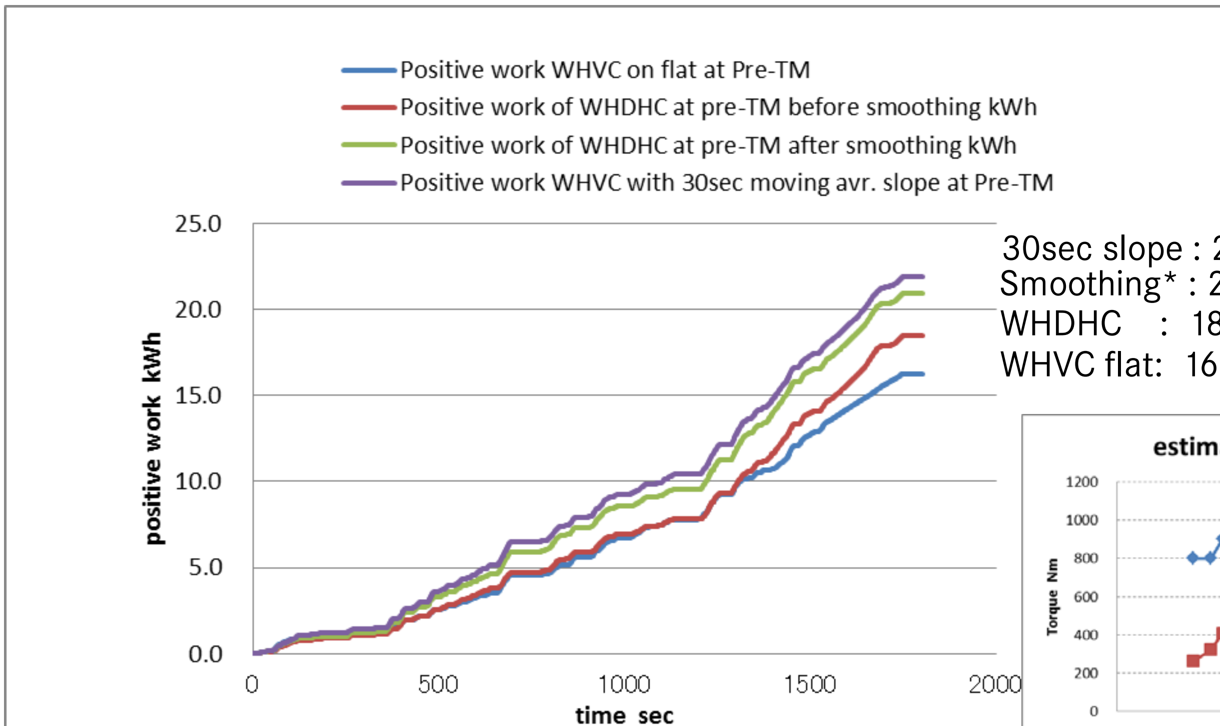


Fig.2 comparison of positive work Pre-TM

30sec slope : 21.9kWh
Smoothing* : 20.9kWh
WHDHC : 18.4kWh
WHVC flat: 16.2kWh

+18.5%
+13.2%

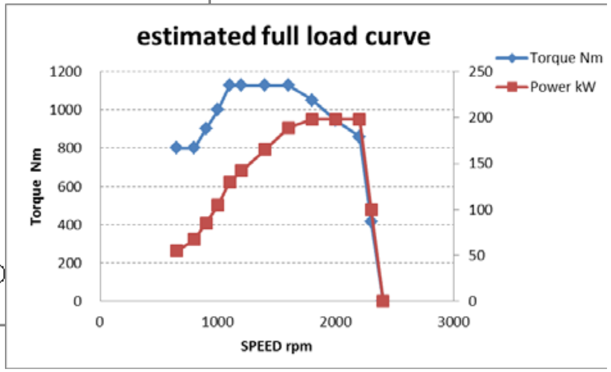


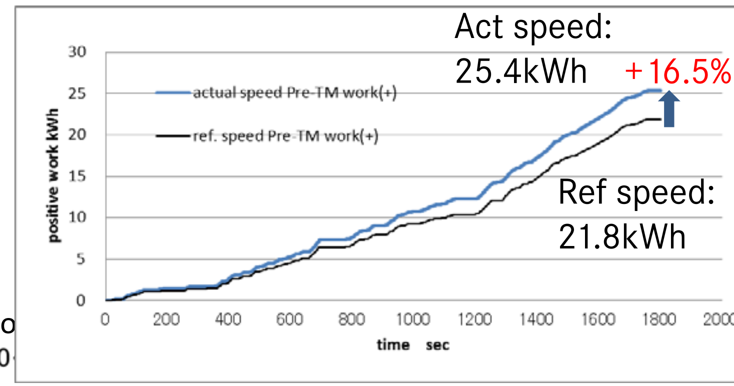
Fig.1 estimated full torque curve

What caused the deviation of the positive cycle work? (2)

Based on the data on vehicle speed actually measured by JRC in its chassis dyno test provided by the institutes, we compared calculating positive cycle works on a 30 sec moving averaged slope by actual vehicle speed pattern or targeted vehicle speed pattern. We found that work in actual vehicle speed pattern increased by 16.5%.

A possible cause is that, since gear shifting time is long, the vehicle speed rapidly accelerates after gear shifting to make the vehicle run within the limits of tolerance. Another factor might be many times of out of tolerance. (Fig. 6).

time range for the total cumulative value of time deviations
181.7
max. time range for one deviation
12.5



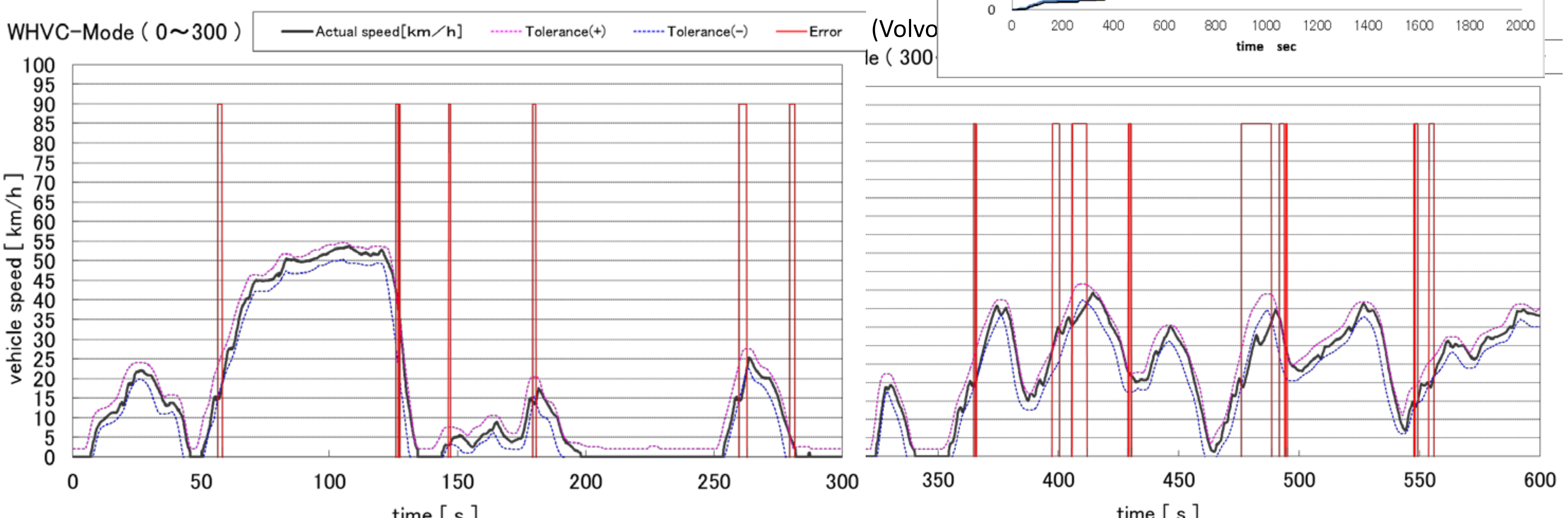


Fig.6-1 Actual speed pattern and comparison of positive work

What caused the deviation of the positive cycle work? (2)

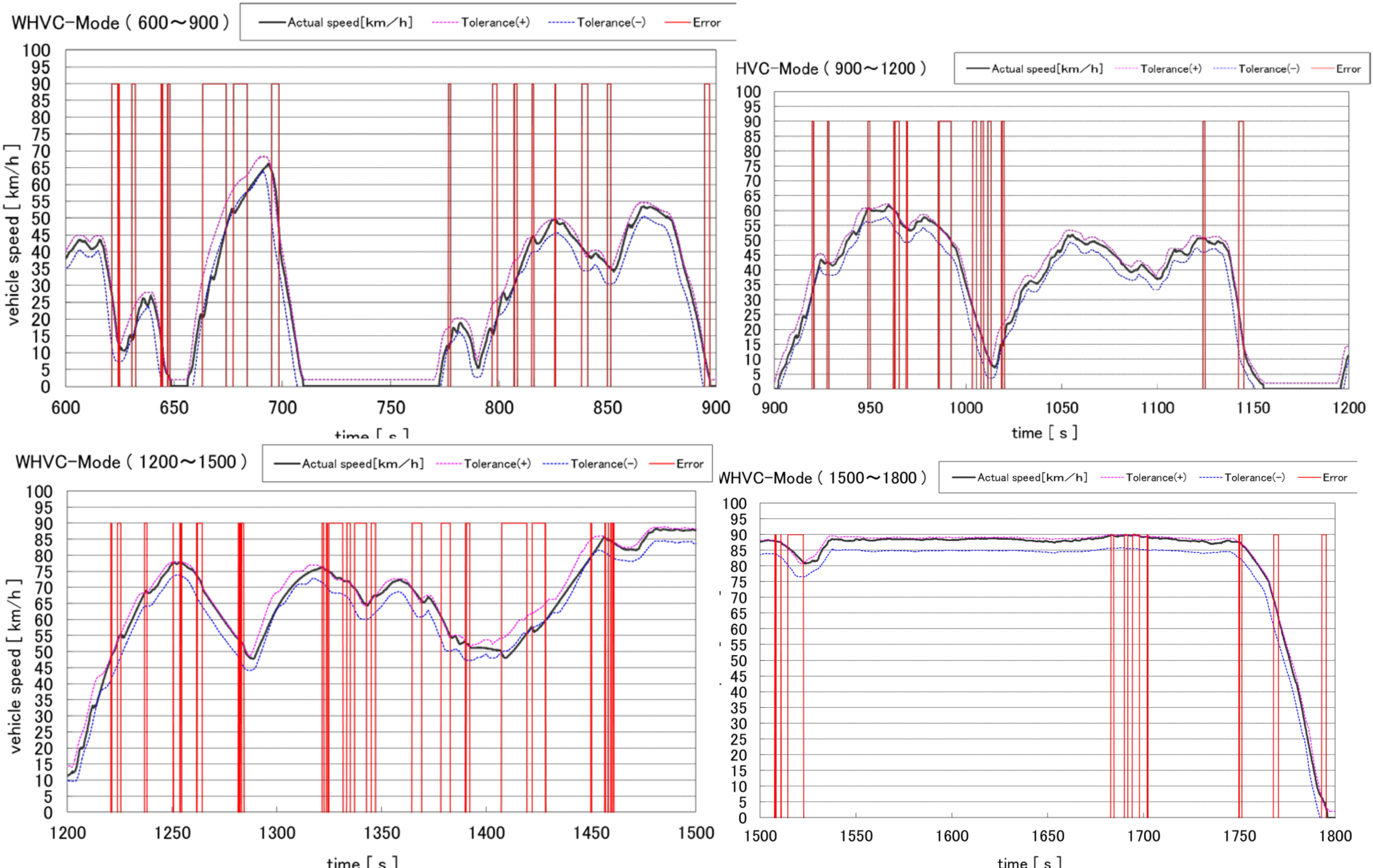


Fig.6-2　Actual speed (continued)

Proper Comparison

Whether smoothing is technically necessary or not is yet to be reconsidered, but, if smoothing is done, it would be more reasonable to use reference values after smoothing. This means that, when properly compared, positive cycle work should be compared between an actual work of 25.5 kWh and targeted value of 20.9 kWh for WHDHC with smoothing. The result is that actual work is higher than target work by 22% (Fig. 7).

This may be explained by the limited ability of the actual vehicle speed closely following the target vehicle speed (+16.5%) and mathematical error in the 30 sec moving averaging process. (+4.8%).

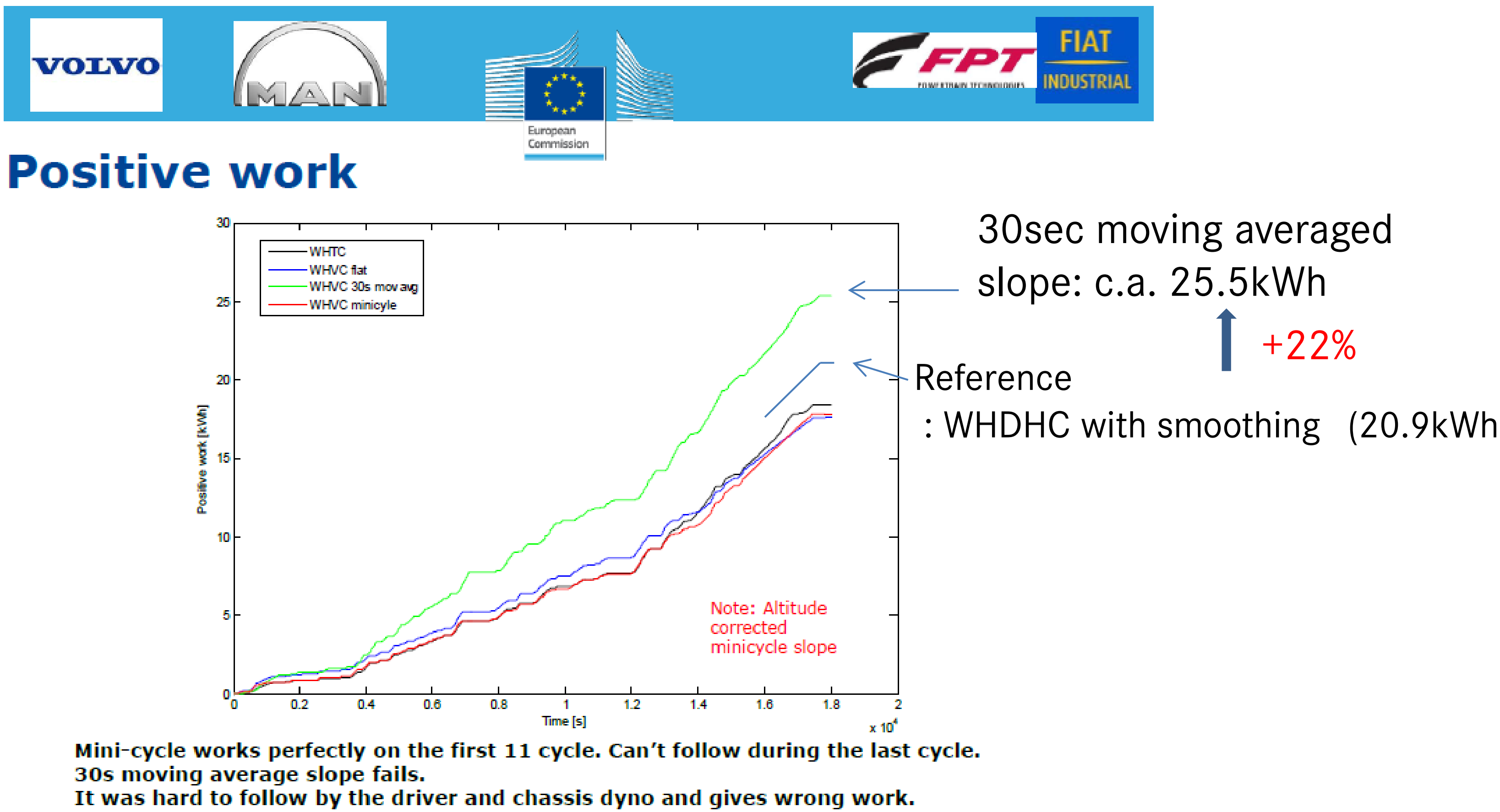


Fig. 7 Comparison deemed appropriate of cycle work on a 30 sec moving average slope

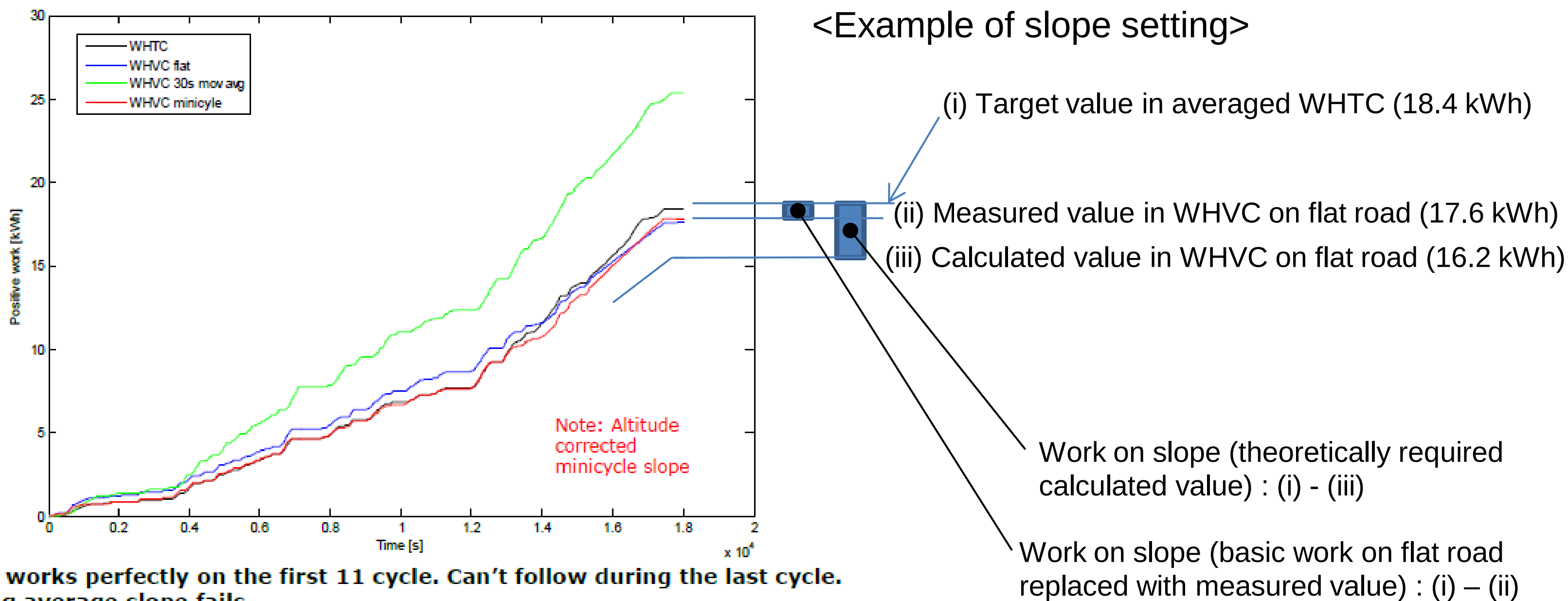
(FIY) Case of mini-cycle slope

Slope setting is based on WHVC flat road power pattern. For mini-cycle slope, the power pattern uses actually measured values rather than calculated value. Deviation of cycle work due to difference between the actual vehicle speed and the targeted vehicle speed is compensated with slope to match the targeted averaged WHTC work (Fig. 8).

As discussed later in detail, we believe that calculating slope using measured values on flat road is not suitable for the certification purpose, considering its reproducibility.

European Commission

Positive work



Mini-cycle works perfectly on the first 11 cycle. Can't follow during the last cycle.
30s moving average slope fails.
It was hard to follow by the driver and chassis dyno and gives wrong work.

Fig. 8 Reason why deviation of work on mini-cycle slope is small

Exploring a best slope

Slope Patterns Examined

The table below examines WHVC on 30 sec moving averaged slope and mini-cycle slope, and those on fixed slope.

Proposed slope	Outline of slope setting method	Outstanding issues
30 sec moving averaged slope	Calculate an instantaneous slope that matches WHTC-based targeted power pattern on a second-by-second basis, and, to make it a practical slope by its 30 sec moving averaging for making vehicle run possible. When vehicles' deceleration matched to WHTC (equivalent to engine motoring), it will basically give uphill slopes during deceleration. therefore it cannot get appropriate recuperated potential. It is necessary to define power pattern on the negative side.	1. Targeted power pattern - How could we apply WHTC determined by the engine full-load curve to HEVs comprised of engine and the motor? - How could we define the power pattern on the negative side? - How could we treat the zero torque gap from gear shifting in WHTC? 2. Slope calculation method Which value could we use as WHVC flat road power pattern that serves as the basis for slope calculation: calculated value or measured value? 3. Which is better: 30 sec moving averaged slope or mini-cycle slope? 4. How could we determine the weight, curb weight, and front area of the tested vehicle in harmonized concept for the certification?
Mini-cycle slope	WHTC is divided into 12 peaks and constant slope is calculated to match positive work for each peak. The slope is completed by connecting 12 types of slopes thus obtained. The recuperated potential from vehicle's deceleration depends on each constant slope.	
Fixed 30 sec moving averaged slope	After calculating the 30 sec moving averaged slopes for different sized vehicles, determine typical slope as the fixed slope pattern. No calculation is made for individual slopes.	
Fixed mini-cycle slope	After calculating the 30 sec moving averaged slopes for different sized vehicles, determine typical slope as the fixed slope pattern. No calculation is made for individual slopes.	

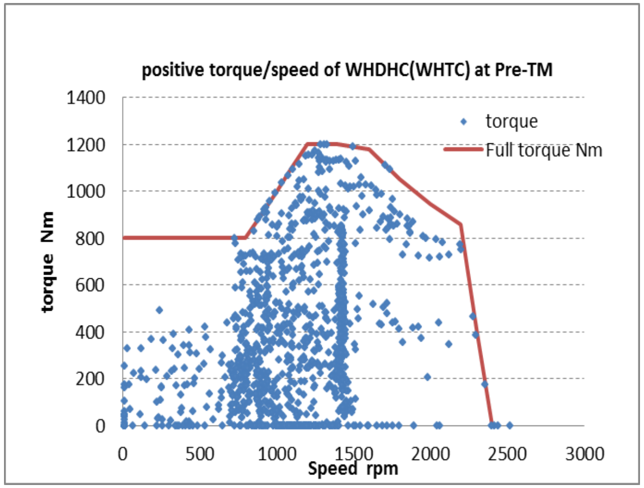
Targeted Power Patterns: How Could We Apply WHTC to HEVs?

The averaged WHTC proposed by the institutes consists in applying the conventional WHTC time-history power pattern of representative engine to the HEV having same rated output power.

We find the proposal reasonable for the following reason. In WHTC that defines power patterns from full-load curve, one of the sample of parallel HEV that can electrically start on the motor sees its driving points shift to low speeds and its positive cycle work reduces significantly compared to those of the conventional (Fig. 9). Thus, this method looks not applicable to HEVs in a fair manner.

* Rated system output power: continued maximum output power for engines and maximum output power for motors.

<u>With</u> electric run: positive work <u>16.5 kWh</u>
(one of the sample of HEV, 198kW)



<u>Without</u> electric run: positive work <u>19.3 kWh</u>
(one of the sample of the conventional, 198kW)

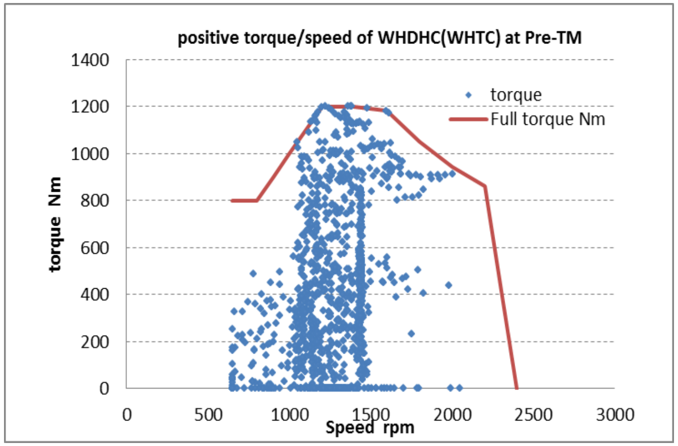


Fig.9 2 kind of de-normalization of WHDHC (WHTC) positive side

Targeted Power Pattern: How Could We Apply WHTC to HEVs?

Just as WHTC, the averaged WHTC defines power patterns on a pre-TM basis. For accurate comparison, however, HEVs and conventional vehicles should be compared on a hub-output (post-TM) basis. We find it reasonable to compare HEVs and conventional vehicles by defining hub-output power patterns derived from representative conventional engine, representative conventional TM and Diff. Then evaluate HEV power pack with specific inertia and transmitted efficiency using the hub-output power pattern defined above.

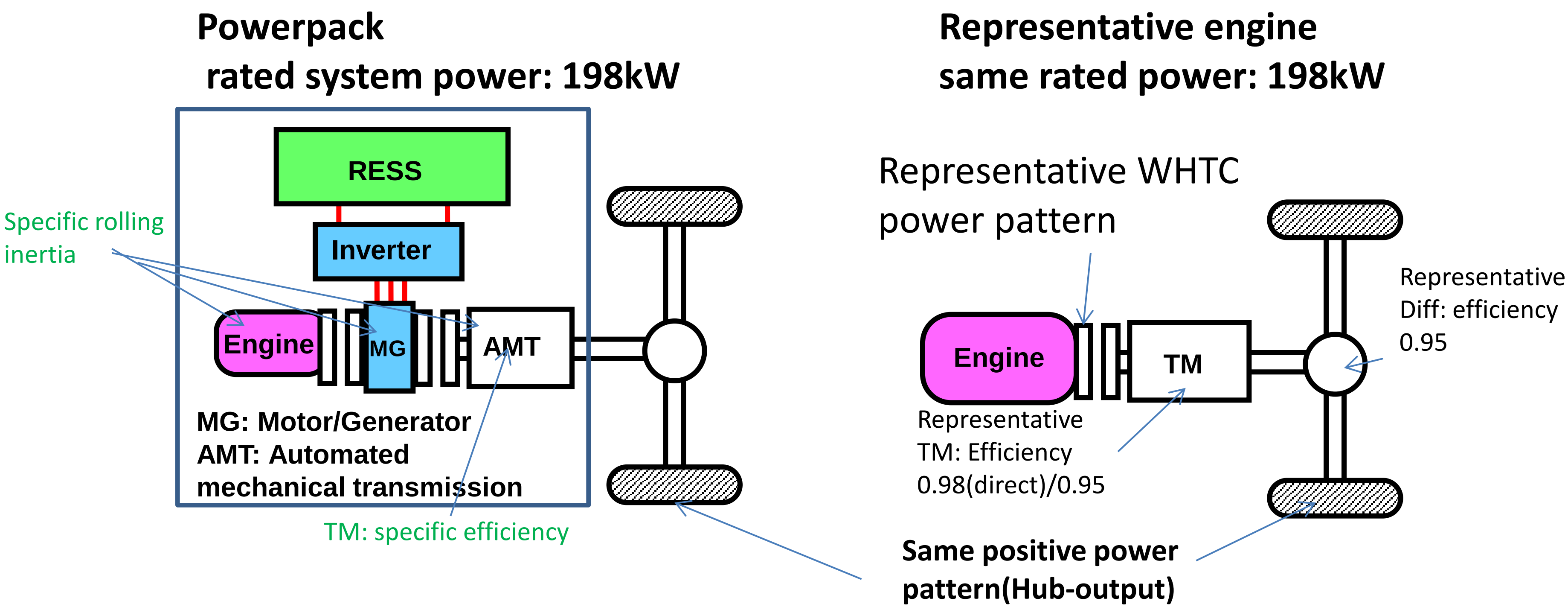


Fig.10 Hub-output(Post-TM) is reasonable approach

Targeted Power Pattern: How Could We Set the Negative Power Pattern?

Just as WHTC, the averaged WHTC defines only values equivalent to engine motoring for the negative side. So, to apply the averaged WHTC to HEVs, it is necessary to define a negative power pattern that allows an appropriate recuperated potential. We find it reasonable to replace the *engine motoring part* with *negative power gained by the vehicle while running in WHVC flat road deceleration*.

Figure 11 compares the instantaneous slope and power pattern with or without replacement (Rated system output of 320 kW and tested vehicle weight of 29.1 ton; The figure shows the time history of 800 sec to 1000 sec).

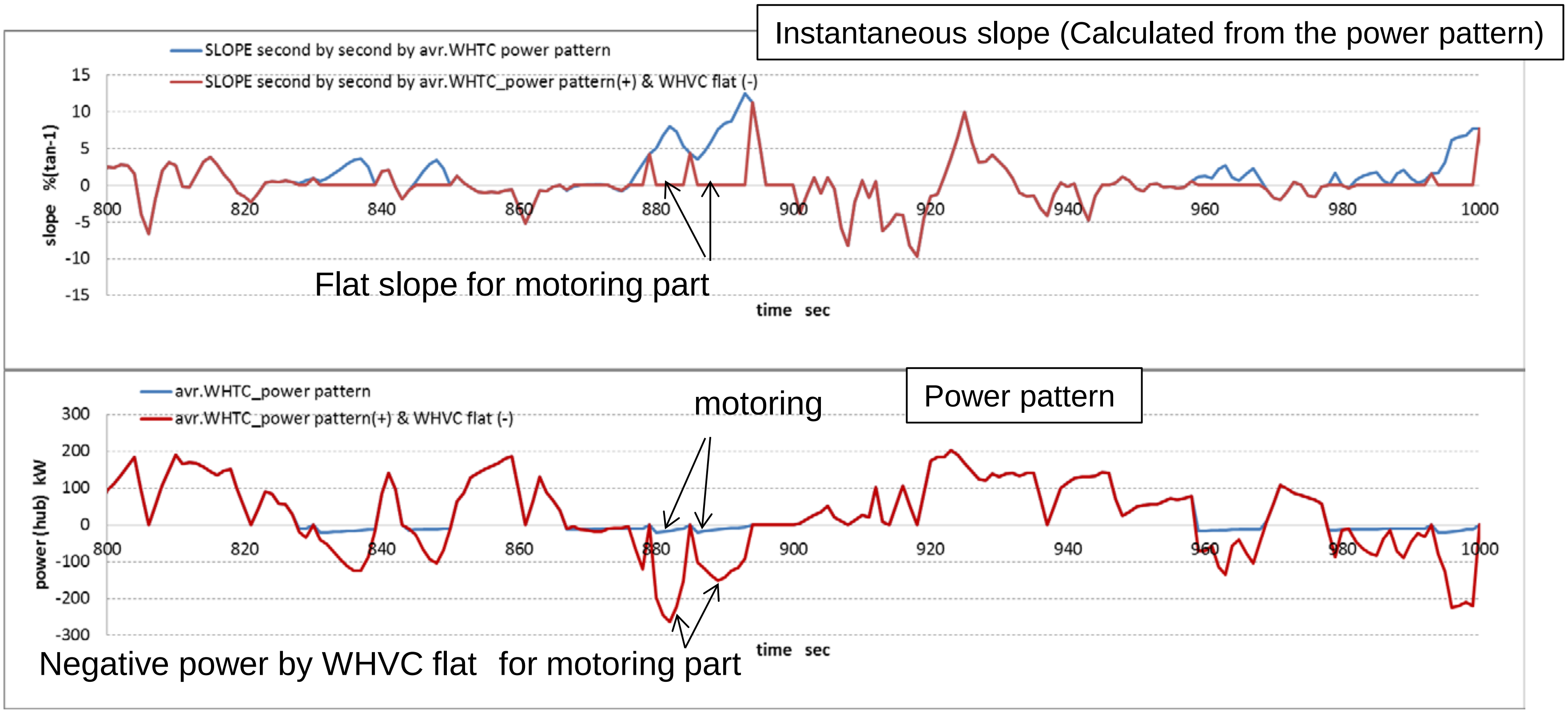


Fig. 11 Setting the negative power pattern

Targeted Power Pattern: How Could We Treat the Torque Gap from Gear Shifting?

Just as WHTC, the averaged WHTC keeps the zero torque gaps from gear shifting. This gap is produced when the engine clutch is disengaged. So, in principle, while running with the clutch engaged, we should not reproduce this in such a way that the engine load goes down to zero by giving instantaneous up-hill slope. On the other hand, it is nevertheless not reasonable, either, to always disengage the clutch and shift the gear at this timing. That was why we proposed smoothing (filling) the gap.

After reexamining the issue, however, we decided to withdraw our proposal considering that: For the 30 sec moving averaged slope, we can eliminate the gap by using moving average (Fig. 12); In the mini-cycle, the slope is constant for each peak and the gap is not reproduced; It is desirable to minimize the correction of WHTC.

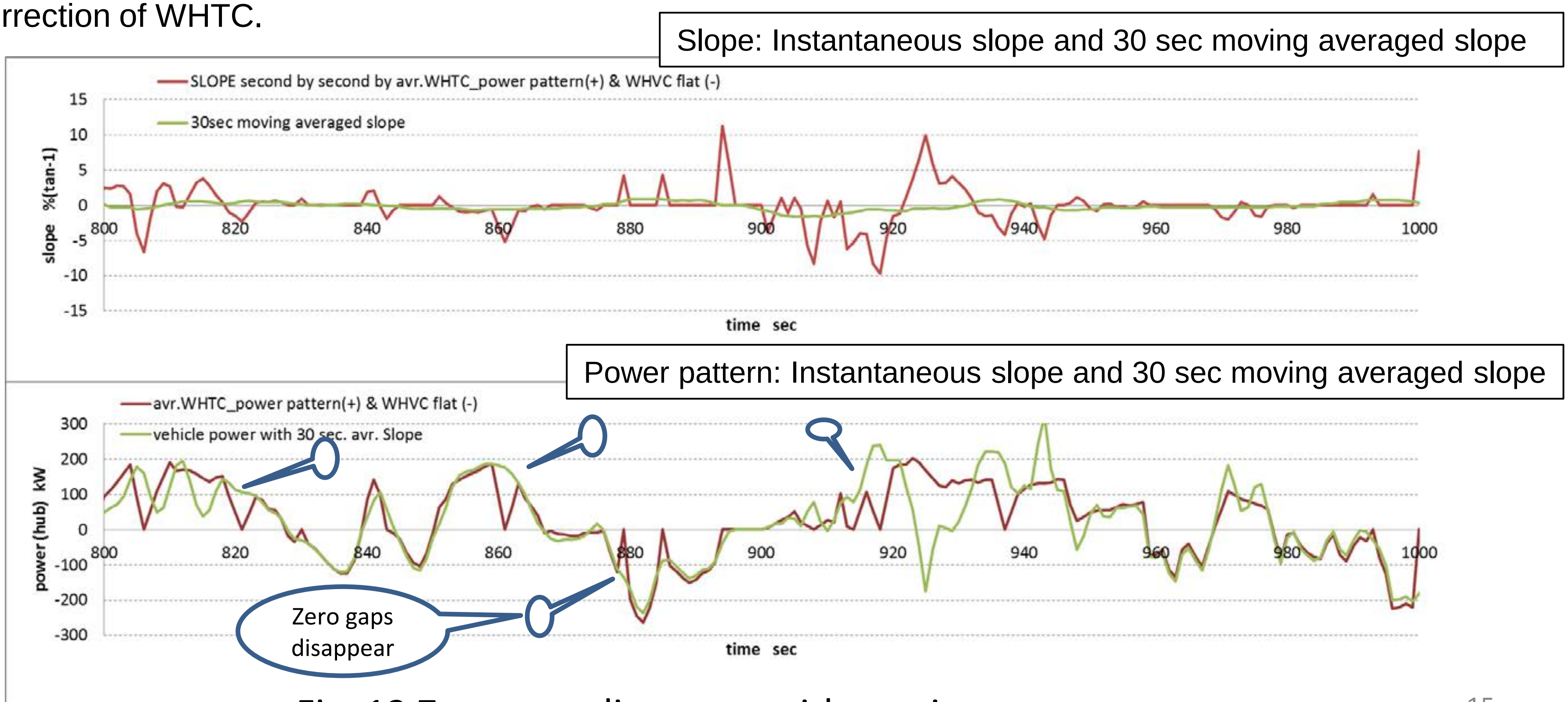


Fig. 12 Zero gaps disappear with moving average

Slope Calculation Method: Theoretically Calculated Values or Flat-Road Measured Values?

The institutes propose calculating slopes using actual power pattern in WHVC on a flat road obtained in HILS validation as reported by JRC. (at the second certified test that doesn't require HILS validation, power pattern is obtained by HILS run instead of actual measurement.)
On the other hand, JASIC proposes theoretically calculating the slope before HILS validation.

Process proposed by the Institutes

HILS Validation:
Chassis dyno or power pack test
WHVC flat road

⇩

Slope calculation:
Calculate the slope using measured power patterns in WHVC flat road on chassis dyno or simulated power patterns in HILS

Process proposed by JASIC

Slope calculation:
Calculate the slope from theoretical values of WHVC flat road power pattern

⇩

HILS Validation:
Chassis dyno or power pack test
WHVC with slope

↘ ↙

Emission HILS running WHVC with slope

⇩

Engine test for emission

Fig. 13 Comparison of slope calculation process: Measured values or theoretical values

Slope Calculation: Theoretically Calculated Values or Flat-Road Measured Values?

Having compared the advantages and disadvantages of the two proposals, we find that JASIC proposal looks better for the certification purpose.

Factors needed for the certification test	Process proposed by Institutes	Process proposed by JASIC	comments
<u>Reproducibility</u> Which method is better in reproducibility of the results of slope calculation?	+	++	The Institutes' proposal looks technically possible , but, for the certification purpose, it is desirable for slope calculation to be reproducible. Theoretical calculation guarantees the reproducibility for any system independent of tracking ability on the reference speed.
<u>Impartiality</u> Which method is more impartial to various HEV systems?	?	++	If actual power pattern on flat is larger than the reference the calculated slope derived from actual power pattern becomes gentler than the theoretical slope. It means the larger deviation compared to the reference can get the gentler slope. It doesn't look fair slope making.
<u>Practicality</u> Is it practical as a method for certification test?	+	++	The Institutes' proposal looks technically possible to always use the actual power pattern on flat or HILS run on flat in the slope calculation process for the certification. However from the practical view if getting the same technical outcome it looks better to choose the lower manpowered way. JASIC process doesn't require additional work on flat.

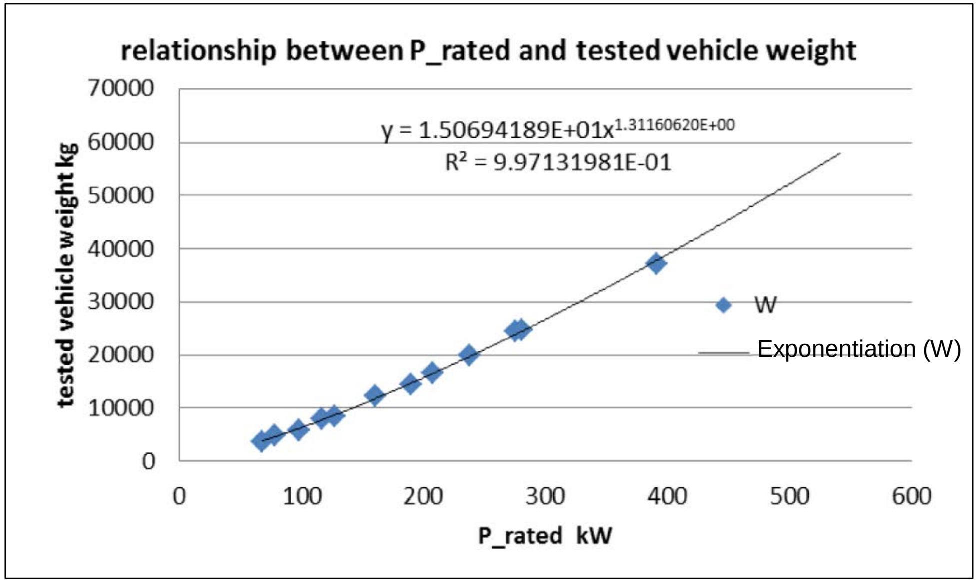
Comparison between 30 sec Moving Averaged Slope and Mini-Cycle Slope

To compare WHVC on 30 sec moving averaged slope and WHVC on mini-cycle slope, we took data on Japanese standardized vehicle categories, calculated their slopes at every 20 kW between rated system output of 80 kW and 400 kW, and looked up 3 items of their positive cycle work, correlation of positive power pattern, and negative/positive cycle work.

We defined the tested vehicle weight (W) as a function of rated system output power (P_rated):

W=15.069 x P_rated^1.312

The formula is designed, using standardized vehicles with half/full load to calculate the positive cycle work in WHVC on flat and also calculate the rated power using averaged WHTC method to get the same positive cycle work. Note that for the curb weight and front area, we used standard data.



Japan standardized vehicle category for exhaust gas			T2	T2	T3	T3	T4	T4	T5	T5	T6	T6	T7	T7
load			half	full	half	full	half	full	half	full	half	full	half	full
W	tested vehicle mass	kg	3735.0	4933.0	5735.5	7873.0	8450.5	12319.0	14287.5	19832.0	16585.0	24350.0	24662.0	37149.0
W0	vehicle curb mass	kg	2482	2482	3543	3543	4527	4527	8688	8688	8765	8765	12120	12120
A	front area	m^2	3.74868	3.74868	5.48475135	5.48475135	6.212758	6.212758	7.59201	7.59201	7.30566	7.30566	7.37289	7.37289
μr	rolling resistance coefficient	kg/kg	0.009842	0.008698	0.008199	0.007365	0.007213	0.006559	0.006362	0.006017	0.006191	0.005853	0.005844	0.005604
μr x W		kg	36.76	42.91	47.02	57.99	60.95	80.80	90.89	119.34	102.68	142.52	144.12	208.17
μa x A	air resistance coefficient x front area	kg/(km/h)^2	0.010377	0.010377	0.015567	0.015567	0.017744	0.017744	0.021868	0.021868	0.021012	0.021012	0.021213	0.021213
G	Acceleration of gravity	m/s^2	9.80665	9.80665	9.80665	9.80665	9.80665	9.80665	9.80665	9.80665	9.80665	9.80665	9.80665	9.80665
	efficiency of the transmission		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
	efficiency of the final reduction gear		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
positive cycle work(hub) by WHVC on flat		kWh	5.712	6.561	8.264	9.790	10.693	13.500	15.924	19.992	17.437	23.163	23.558	32.819
negative cycle work(hub) by WHVC on flat		kWh	-1.241	-1.754	-2.000	-2.927	-3.152	-4.874	-5.767	-8.280	-6.838	-10.387	-10.646	-16.406
calculated P_rated by avr. WHTC (Pre-TM)		kW	68.02	78.12	98.40	116.57	127.32	160.75	189.61	238.05	207.62	275.81	280.51	390.79

Fig. 14 Vehicle data used for calculation and the graph for the formula

Comparison between 30 sec Moving Averaged Slope and Mini-Cycle Slope

Figure 15 shows the results of calculated deviation of the positive cycle work on each slope from the targeted positive cycle work in averaged WHTC.

The cycle work with 30 sec moving average slightly deviates from the target because of the mathematical error in the process of averaging slope. On the other hand, mini-cycle calculates the slope by matching itself with the positive work cycle, so deviation may be reduced to zero. For your information, the deviation in positive cycle work on a flat road is also shown.

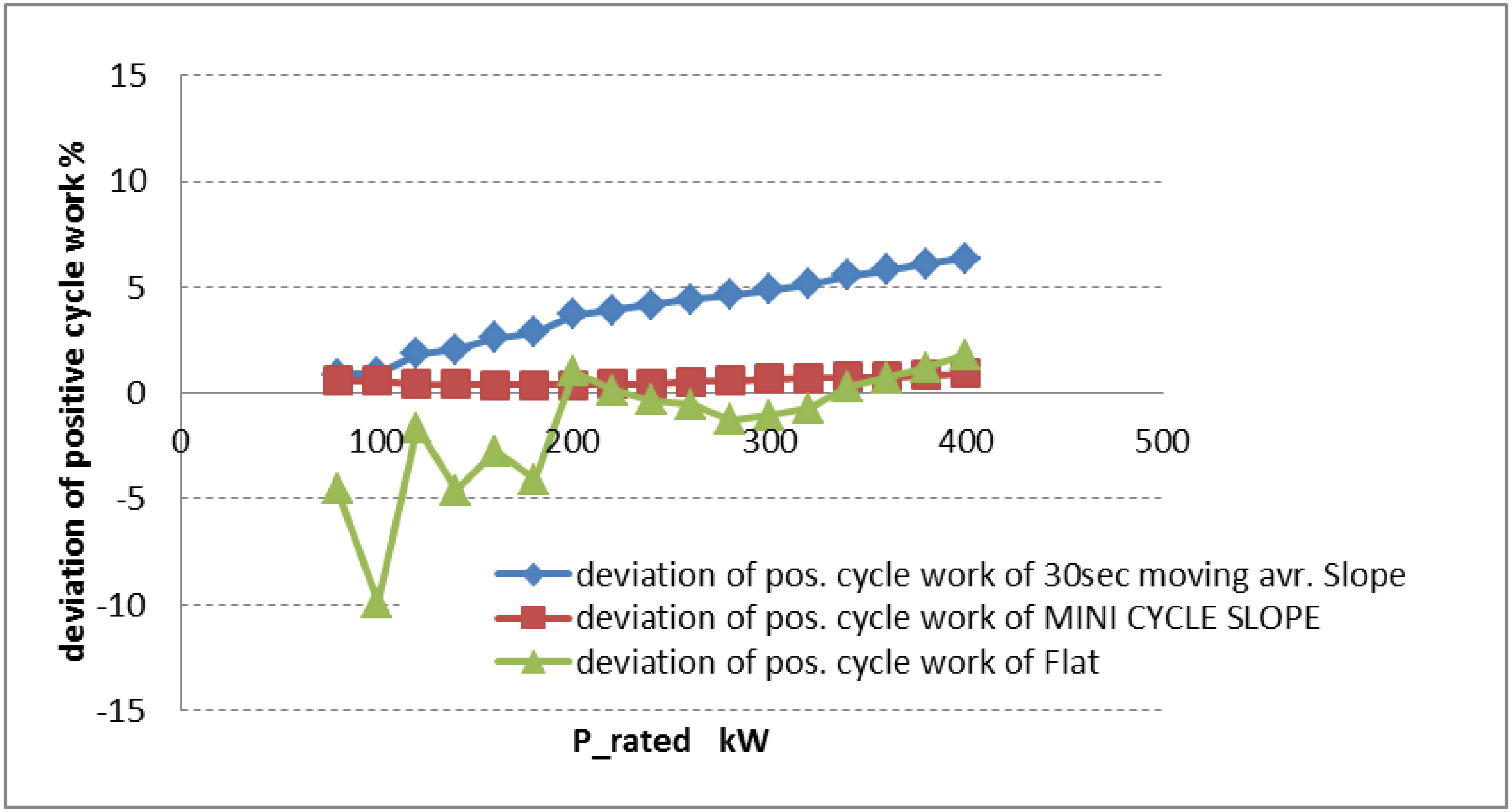


Fig. 15 Comparison of the deviation of the positive cycle work

Comparison between 30 sec Moving Average Slope and Mini-Cycle Slope

Figure 16 shows the results of calculation of determination coefficient R^2 we did to compare the correlation between positive power patterns on each slope and positive power patterns in averaged WHTC.

The correlation with positive power pattern on the 30 sec moving averaged slope is better when the determination coefficient is 0.6 to 0.7. The mini-cycles and flat road were equivalent 0.5 to 0.6.

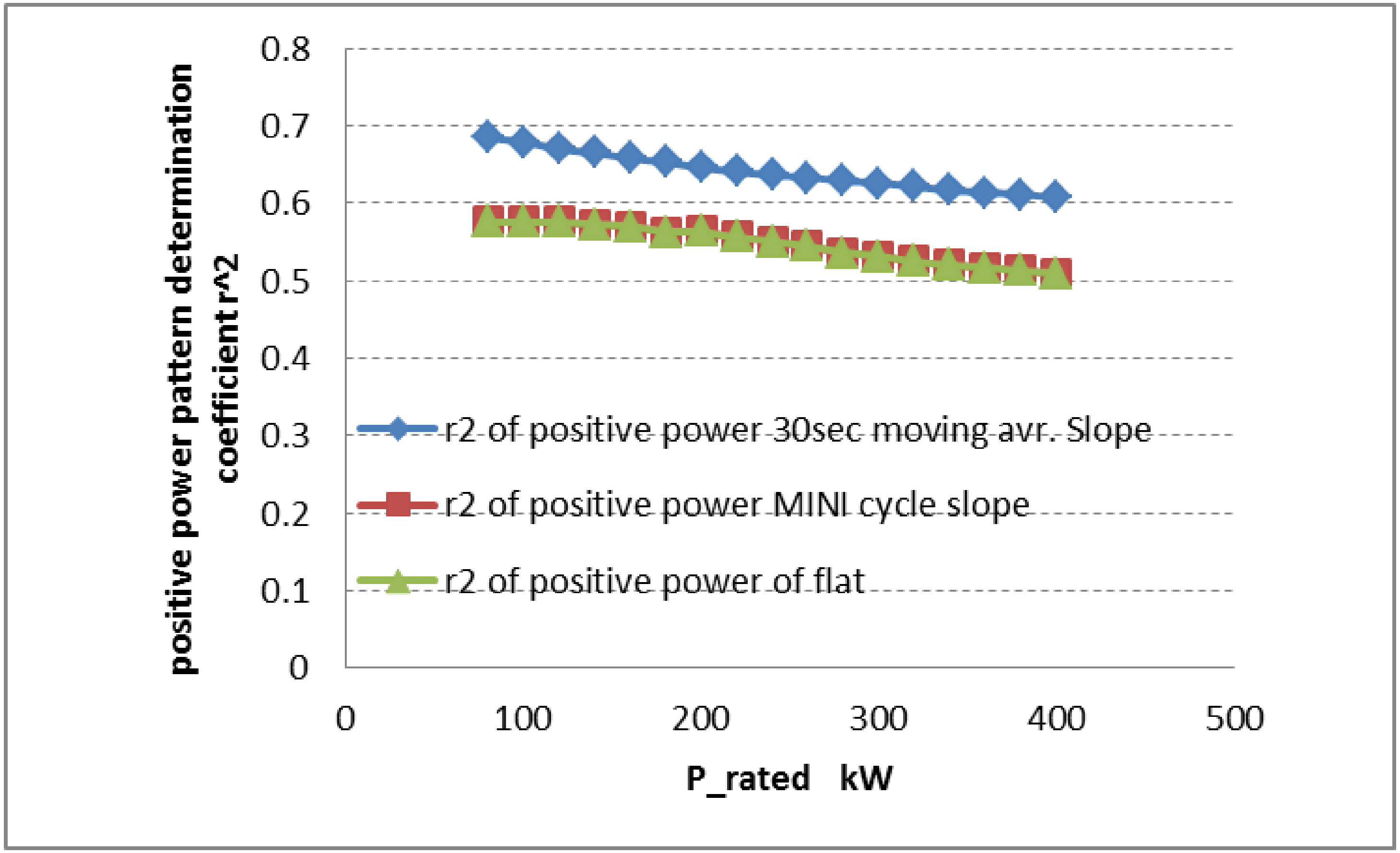


Fig. 16 Comparison of correlation of positive power patterns r^2

Comparison between 30 sec Moving Average Slope and Mini-Cycle Slope

Figure 17 shows the results of calculation of negative/positive cycle work on each slope.

Negative/positive cycle work used as reference for recuperated potential shows WHVC on 30 sec moving averaged slope closer to the target, “negative cycle work in WHVC on flat road divided by the positive cycle work in averaged WHTC”, while mini-cycle slope and driving on a flat road showed slight deviation.

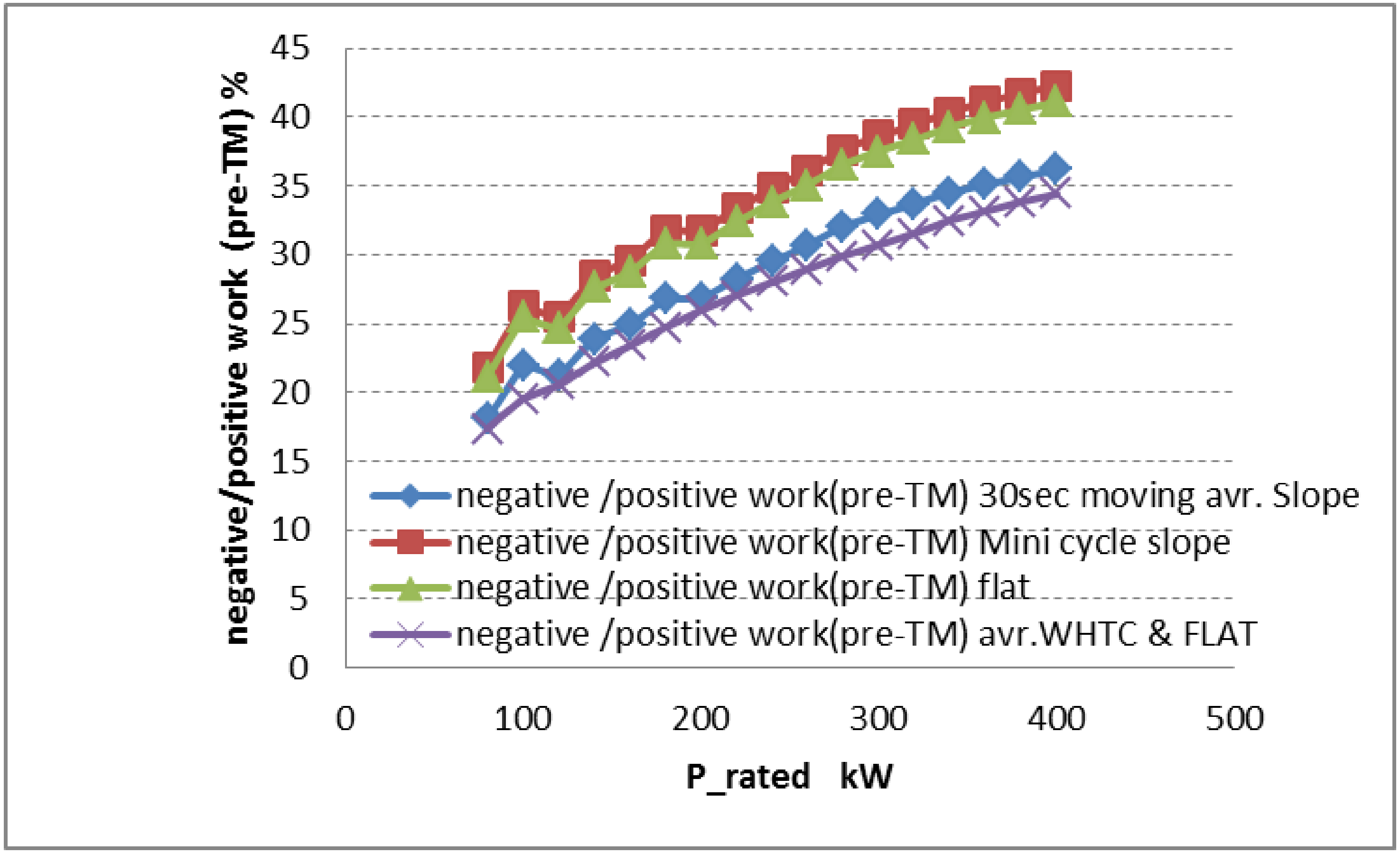


Fig. 17 Results of comparison: Negative/positive cycle work

Comparison between 30 sec Moving Average Slope and Mini-Cycle Slope

The results of comparison are shown in the table below.

Comparison between the 30 sec moving averaged slope and the mini-cycle slope suggests that there is no crucial difference between them.
It would be therefore necessary to see in test which is closer to WHTC emission.

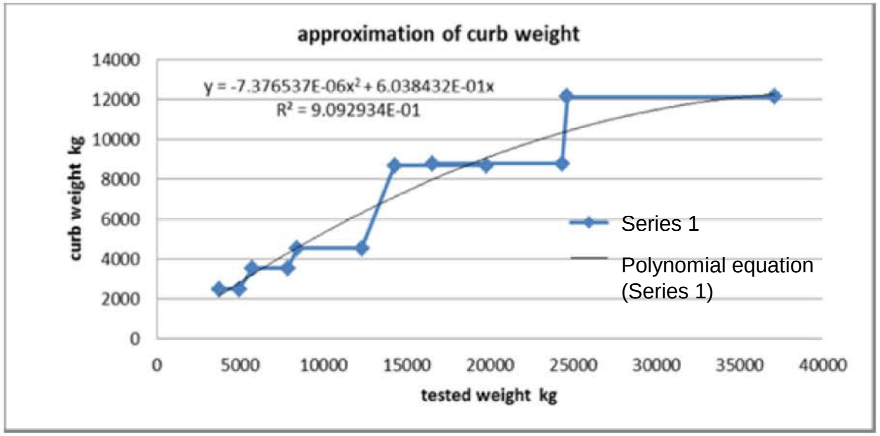
Proposed slope	Positive cycle work	Positive power pattern correlation	Negative/positive cycle work
30 sec moving averaged slope	0 A slight deviation caused by the mathematical error is occurred in 30 sec moving averaging process (c.a. 1 to 6%)	+ Better than mini-cycle slope (R^2= c.a. 0.6 to0.7)	+ The value is closer to the reference (c.a. 18 to 36% at Pre-TM)
Mini-cycle slope	+ Matching with slope is possible. (c.a. 0%)	**0** Equivalent to flat road driving. (R^2= c.a. 0.5 to 0.6)	**0** A slightly larger than the reference (c.a. 21 to 42% at Pre-TM)

Examination of Fixed Slope

Next the possibility of the fixed slope approach was examined in order to make the certification be more simple.

- First of all the formula concept of the tested vehicle weight is expanded to “the curb weight” and “the front area” based on Japan standardized vehicle specification to reduce the cause of the deviation by discontinuity of figures between vehicle categories. (Fig.18)
- And if the curb weight and front area are fixed by vehicle category, they vary from region to region.
- This allows you to define the weight, curb weight, and front area of the tested vehicle based solely on the rated system output power, making this method a harmonized approach.

tested vehicle weight W	curb vehicle mass W0	front area
(kg)	(kg)	(m^2)
W=15.0694189 * P_rated^1.3116062	W< 35250: W0= -0.000007376537 *W^2 +0.6038432*W W>=35250: W0=12120	W<18400: A= -0.0000001692191*W^2 +0.0006332672*W +1.668713,7.592 W>=18400: A=7.592



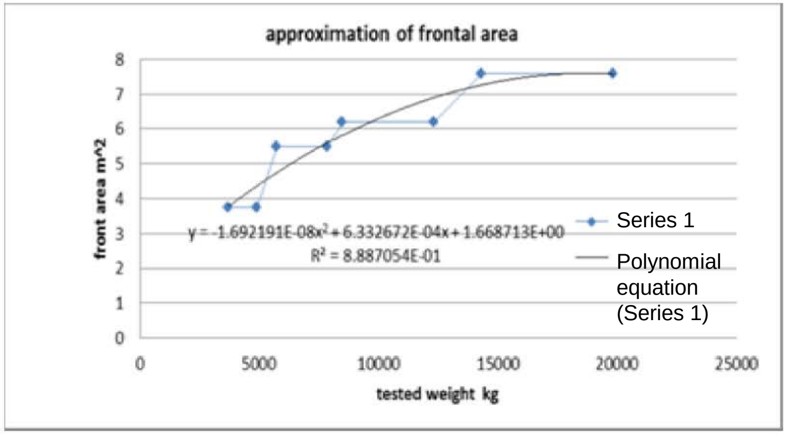


Fig. 18 Approximation formula for fixed slopes

Examination of Fixed Slope

Using the approximation formula in page 23, we averaged 17 individual slopes calculated at every 20 kW between the rated system output of 80 kW and 400 kW as the fixed slope (Fig. 19 Fixed slope is shown in red).

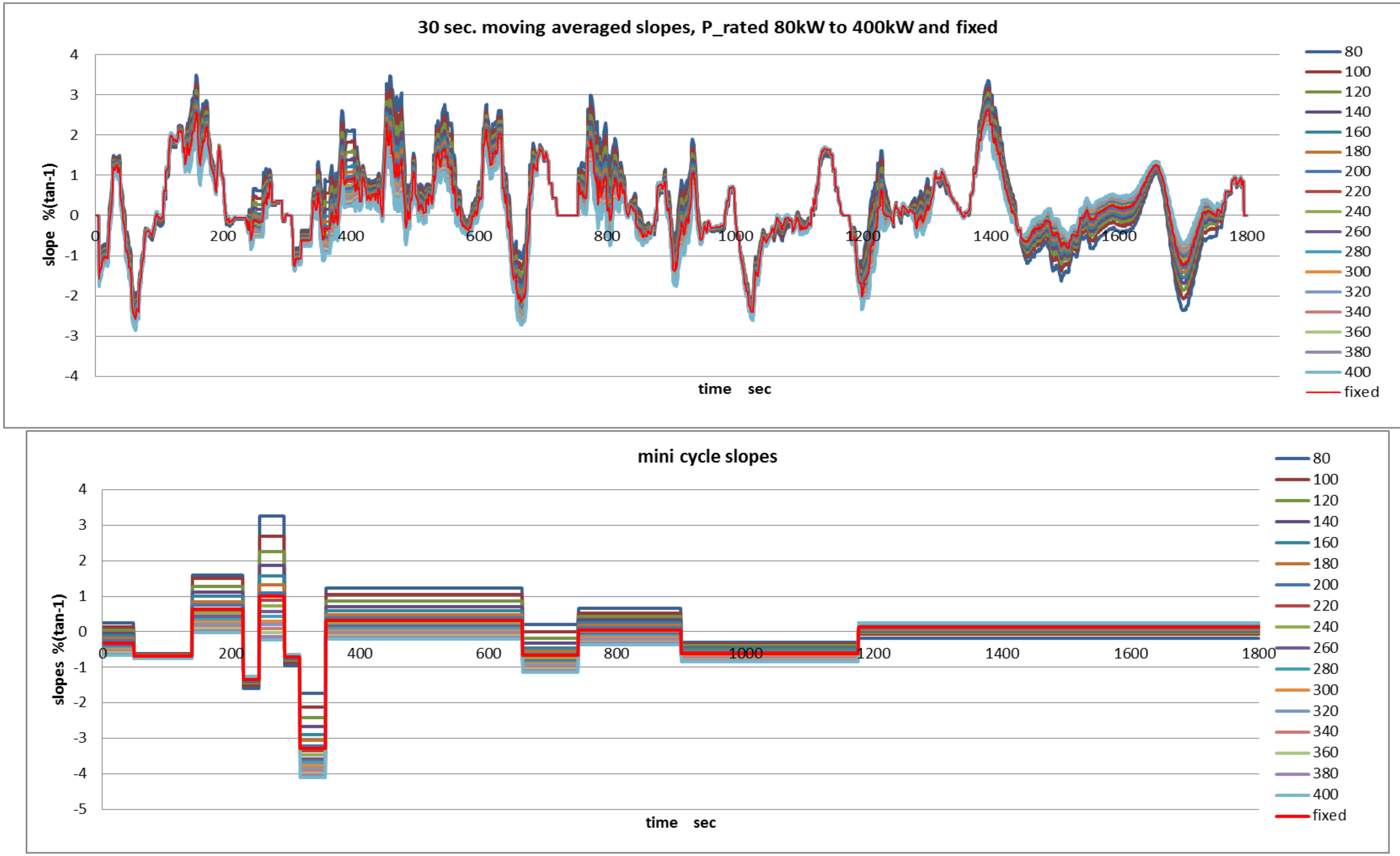


Fig. 19 Comparison of fixed slopes and individual slopes

Results of Calculation of Fixed Slope

The 3 items, positive cycle work, correlation of positive power pattern, and negative/positive cycle work. are also calculated in WHVC with both slopes, “30 sec. moving averaged fixed slope” and “mini cycle fixed slope” for 17 rated powers, 80kW to 400kW every 20kW.

Figure 20 shows comparison of deviation in positive cycle work .
For both of 30 sec moving average and mini-cycle, deviation is slightly larger on fixed slope than on individually calculated slopes (see Fig. 15). As on individually calculated slopes, deviation is smaller on mini-cycle slope.

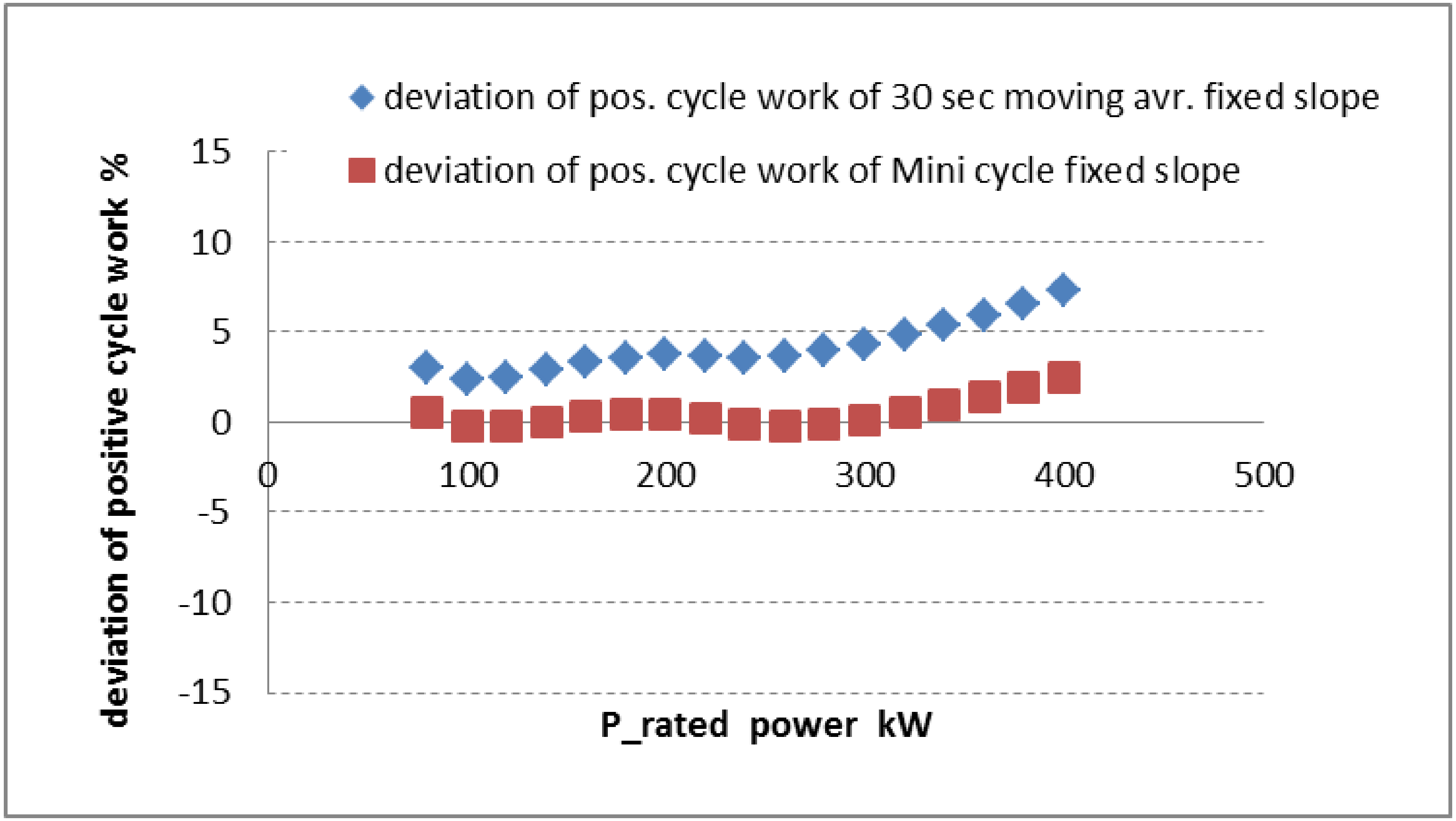


Fig. 20 Comparison of deviation in positive cycle work on fixed slope between 30 sec moving average and mini-cycle

Results of Calculation of Fixed Slope

The determination coefficient R^2, correlation of the positive power pattern , between WHVC with slope and the reference (averaged WHTC), calculated for both fixed slopes are shown in fig.21.
R^2 of “30 sec moving averaged fixed slope” is 0.6 to 0.65 still better than that of “mini cycle fixed slope” which is 0.53 to 0.58.
And there figures are almost equivalent to those of individual slopes.(see Fig. 16)

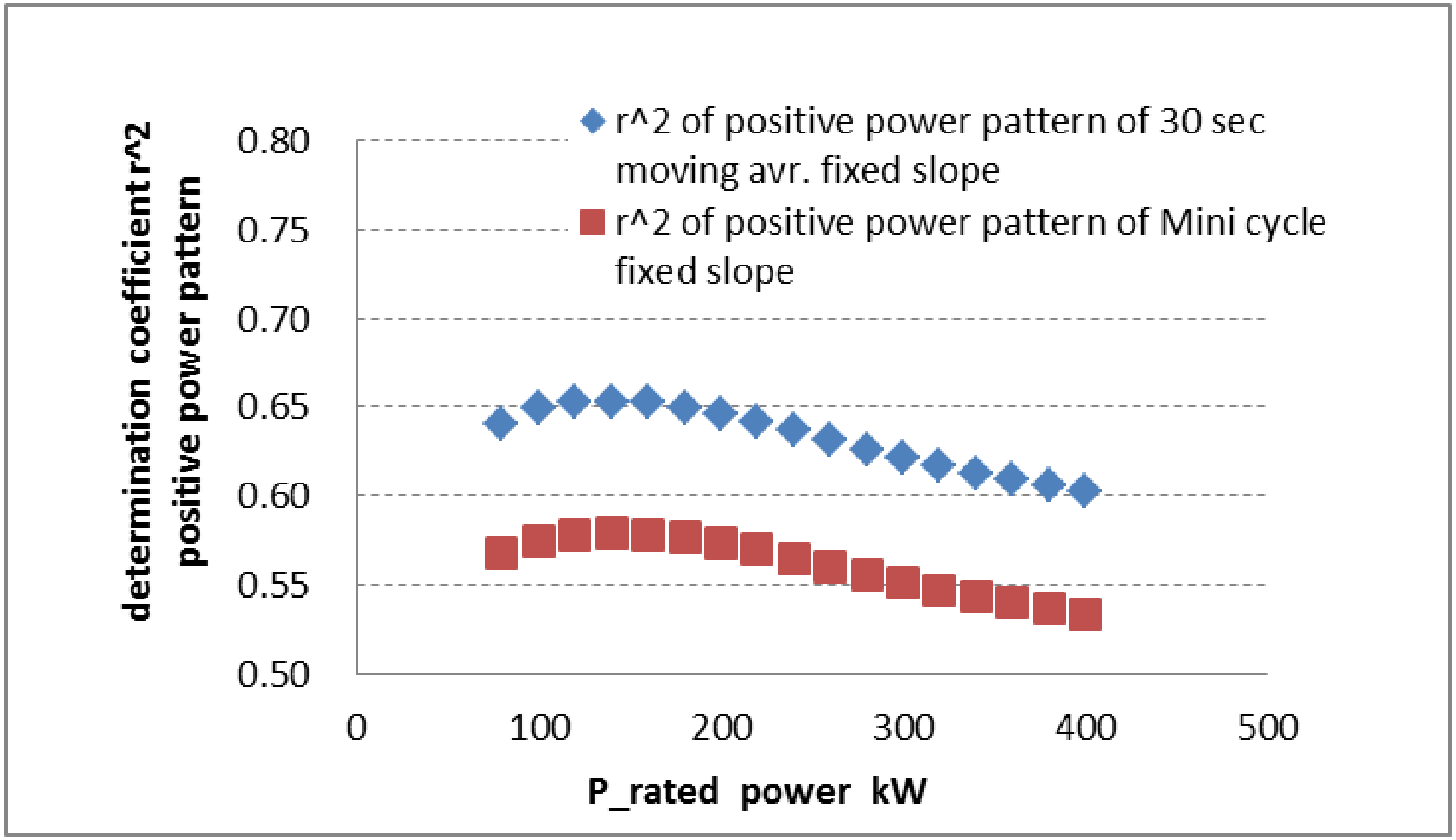


Fig. 21 Comparison of correlation of positive power pattern (R^2) between
30 sec moving averaged fixed slope and mini-cycle fixed slope

Results of Calculation of Fixed Slope

Figure 22 compares the negative/positive cycle work between “30 sec moving averaged fixed slope” and “mini-cycle fixed slope”. The results are almost equivalent to individually calculated slopes (see Fig. 17). Note that, as with on individually calculated slopes, the 30 sec moving averaged fixed slope showed values close to the reference.

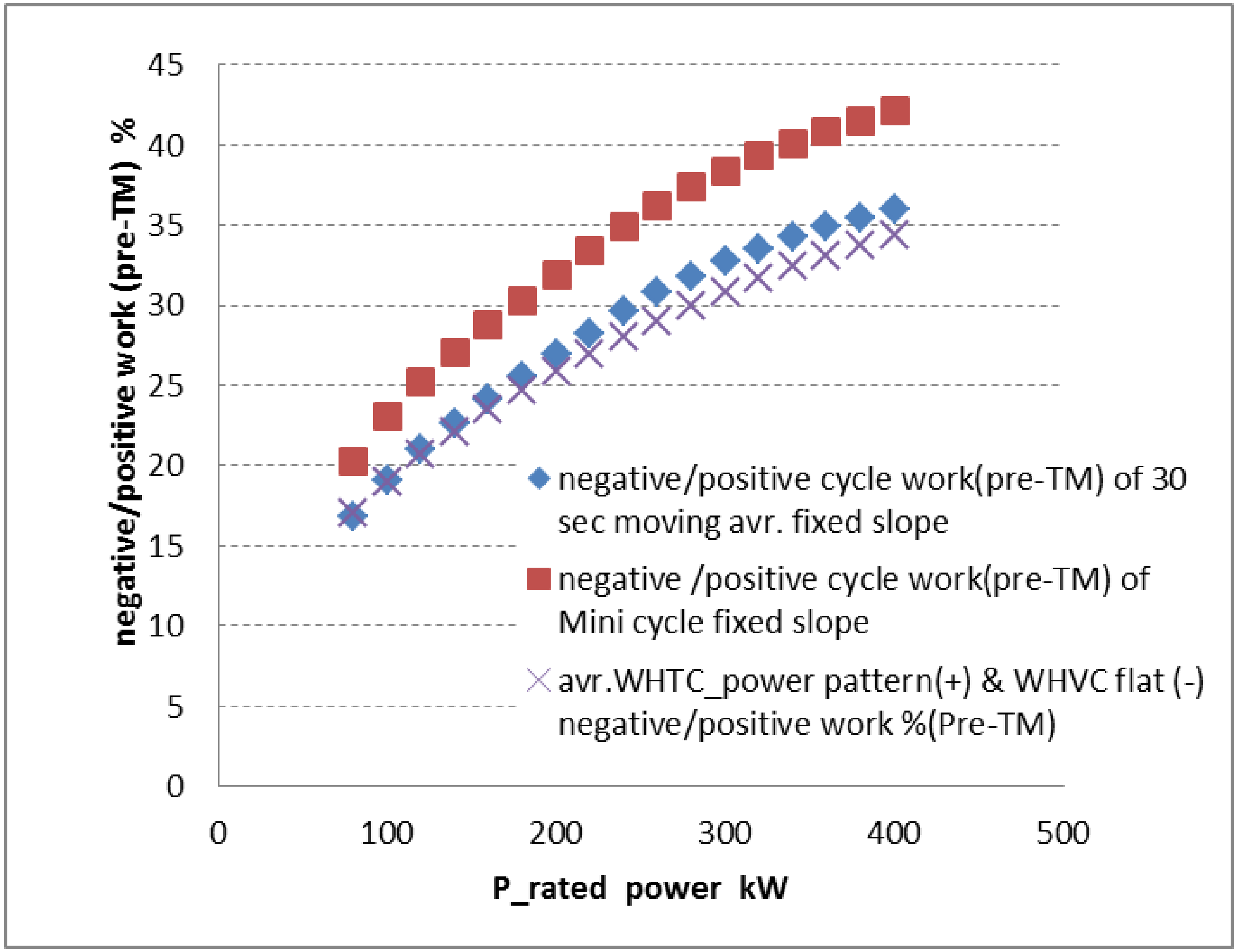


Fig. 22 Comparison of negative/positive cycle work between 30 sec moving averaged fixed slope and mini-cycle fixed slope

Summary of Comparison between 30 sec Moving Averaged Fixed Slope and Mini-Cycle Fixed Slope

The summary of comparison is as shown in table below.

The comparison between "the 30 sec moving averaged fixed slope" and "the mini-cycle fixed slope" suggests that there is no crucial difference between them, but, considering the positive power pattern that we think contributes most to the emission performance, we would like to recommend the 30 sec moving averaged fixed slope.

Another reason we recommend fixed slope is that it has no specifically serious flaws even compared with individually calculated slopes in the table of page 22.

Proposed slope	Positive cycle work	Correlation with positive power pattern	Negative/positive cycle work
30 sec moving average fixed slope	**0** Compared with individual slopes, fixed slope shows slightly larger deviation, but looks acceptable. (c.a. 2.5 to 7.5%)	+ Slightly better than mini cycle fixed slope Almost equivalent to the result of individual slopes (R^2= c.a. 0.6 to 0.65)	+ Close to the reference Almost equivalent to the result of individual slopes (c.a. 17 to 36% at Pre-TM)
Mini-cycle fixed slope	+ Compared with individual slopes, fixed slope shows slightly larger deviation Still better than 30sec moving averaged fixed slope (c.a. 0 to 2.5%)	**0** Almost equivalent to the result of the individual slopes (R^2= c.a. 0.53 to 0.58)	**0** Slightly larger than the reference Almost equivalent to the result of individual slopes (c.a. 20 to 42% at Pre-TM)

Summary

Table below summarizes the results of examination of 30 sec moving averaged slope and mini-cycle slope, and fixed slope of each of them in WHVC.

Proposed slope	Results of examination
30 sec moving averaged slope Mini-cycle slope Fixed 30 sec moving averaged slope Fixed mini-cycle slope	1. Targeted power pattern How could we apply WHTC determined by the full-load curve of the engine to HEV comprised of an engine and a motor? => We find the values on the hub in the averaged WHTC power pattern proposed by the Institutes reasonable. How could we define the negative power pattern? => We find the negative power pattern in WHVC on flat road looks reasonable. How could we treat the zero torque gaps in shift change included in WHTC? => We find it better not to do smoothing. 2. Method for calculating slopes As the basis for slope calculation, which could we use as the power pattern in WHVC on flat road: calculated value or measured value? => The calculated values are more suitable for the certification purpose. 3. Which is better? Comparison between 30 sec moving average slope and mini-cycle slope => We find that they looks technically equivalent. 4. How could we determine the weight, curb weight, and front area of the tested vehicle? => By defining the weight, curb weight, and front area of the tested vehicle using an approximation formula based on the data on Japanese standardized vehicle categories, we can get appropriate values for positive cycle work, positive power pattern determination coefficient and negative/positive work on fixed slope. So we would like to recommend this method.