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A Development of Fuel Saving Driving Technique for Parallel HEV

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Abstract

This paper examines the effect of pulse-and-glide (PnG) driving strategies on the fuel efficiency when applied on parallel HEVs. Several PnG strategies are proposed, and these include the electrical, mechanical, and combined PnG strategies. The electrical PnG strategy denotes the hybrid powertrain control tactics in which the battery is charged or discharged according to the power demanded while maintaining the constant vehicle speed. On the other hand, the mechanical PnG strategy denotes the powertrain control tactics in which the vehicle accelerates or decelerates according to the power load while minimizing the battery usage. The combined PnG strategy involves both electrical and mechanical strategies to find a balanced point in between them. Here, a tradeoff relationship between the fuel efficiency and the vehicle drivability related to the tracking performance of the desired target speed is revealed. In the assessment of the feasibility of applying each of the formerly mentioned hybrid driving strategies, the causes of driveline heat loss are recorded and analyzed by their types. These include the engine heat loss, engine friction loss, motor loss, and the resistance loss. The motor loss includes all of the electrical energy loss induced in the powertrain electronics, and the resistance loss includes the loads acting on the vehicle such as the aerodynamic drag and rolling resistance. These factors are quantitatively analyzed for different driving strategies along with the related fuel efficiency in an integrated manner. The experimental validation is conducted using a real HEV equipped with a gasoline spark-ignition engine, transmission-mounted electric drive, and a 6-speed dual clutch transmission.

Keywords

Energy Efficient Driving, Hypermiling, Pulse and Glide, Hybrid Electric Vehicle, Dual Clutch Transmission, Transmission Mounted Electric Drive

1. Introduction

Along with the reinforcement of the vehicle regulation related with emission gas and fuel mileage, eco-friendly vehicle technology has been drawing increased attention. Such trend has also caused daily drivers to explore and share various driving techniques [1, 2, 3, 4, 5] for fuel mileage improvement. Pulse and glide (PnG) driving skill is an example, and this has been practiced by the hypermilers throughout the world.

Cruise control function in conventional vehicles uses a fixed engine operating point for a given load, and it may not be placed so close to the engine OOL (optimum operating line). So to improve such shortcoming, hypermilers repeat the cycle of acceleration and deceleration while keeping the average vehicle speed as the same as that when using the cruise control function. Such maneuver may truly improve the fuel mileage by shifting the engine operating point closer to the OOL. However, this currently must be implemented passively by the drivers, which may increase driver's fatigue and lead to inconsistent result in fuel mileage improvement due to the driver's inappropriate application of the PnG skill.

Hence car manufacturers have launched automated PnG control function [6, 7, 8] with ACC [9, 10, 11] and platoon control [12], but most of them were aimed for the application in conventional vehicles driven by internal combustion engines. So this study focuses on validating the effect of PnG driving strategy applied in parallel hybrid electric vehicles (HEV), and analyzing its future applicability.

The engines in HEVs are generally designed to operate along the OOL [13, 14, 15] by using the motor to level the load. However, such strategy inevitably involves energy loss in the power electronics (PE) during the charging and discharging processes. Hence, additional fuel efficiency improvement can be achieved by minimizing the PE usage and at the same time operating the engine on OOL. Such strategy has been studied in the past only with the fixed engine speed [16], and lacked the experimental verification process on the real vehicle [17].

This paper proposes a PnG strategy for parallel HEVs, in which the vehicle repeats the acceleration and deceleration cycle while maintaining the average speed at the set value. The fuel mileage improvement obtained by applying such strategy is recorded and analyzed. The experiments are conducted by using chassis dynamometer and on proving ground.

2. Fuel-Efficient Driving Strategy for TMED HEV

2.1. Problem Definition

When it comes to the driving efficiency (fuel efficiency) of the vehicle equipped with a dual clutch transmission - transmission mounted electric drive (DCT-TMED) system, the most critical issue for achieving high efficiency is to minimize the energy consumption that is not transmitted to the wheels to drive the vehicle. The major cause of such energy waste is twofold: the engine heat loss and the electrical loss.

The engine heat loss indicates all of the heat generated by the engine, cooling system, and exhaust. In other words, the engine heat loss is identical to the difference between the enthalpy of the consumed fuel and the effective brake power. Such heat loss includes heat generation, transient energy loss due to engine on-off, friction loss, pumping loss, and engine clutch slip loss. The electrical loss is related to all of the heat loss induced by the powertrain electronics. Such loss may depend on the motor assist/regeneration efficiency, inverter efficiency, and battery charging/discharging efficiency.

The driving strategy focuses on the optimized means to meet the demanded power by using the two different power sources. Hence, mentioning the cause of energy loss which applies to both power sources in an identical manner – such as auxiliary power loss and transmission loss – is considered less relevant to the topic of this research.

Factors that contribute to the fuel efficiency of the DCT-TMED type HEVs include: engine operating point, motor assist/regeneration load, engine on-off frequency, and deviation of actual vehicle speed from the desired speed. Transmission gear selection is assumed identical for all driving strategies and thus is considered trivial.

After all, assessment of the driving efficiency achieved by different hybrid driving strategies for DCT-TMED HEVs narrows down to minimizing the total amount of energy loss induced by the aforementioned factors.

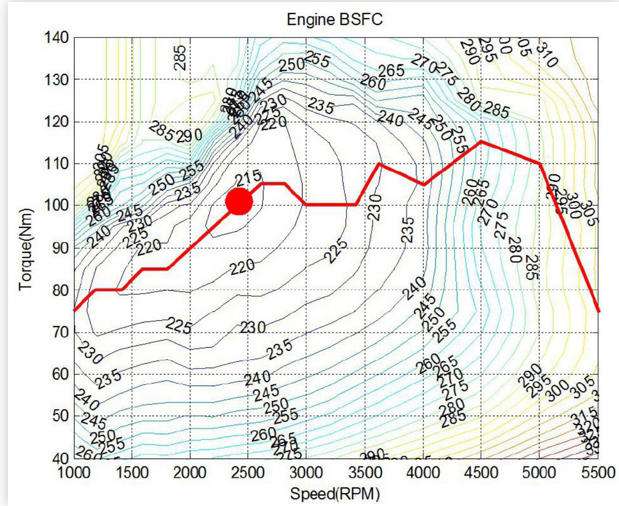
2.2. Fuel Efficiency Improvement Driving Strategy for TMED HEV

2.2.1. Electrical PnG Strategy

A quantitative measure of the engine efficiency is the brake specific fuel consumption (BSFC) expressed in g/kWh, and it indicates the amount of fuel used to produce a unit amount of energy. Hence, operating the engine at the point with low BSFC value can lead to improved fuel efficiency. Shown in Figure 1 is an example of the engine BSFC map.

The most efficiency engine operating point is referred as the sweet spot (SS), and is shown with a red point in Figure 1.

FIGURE 1 BSFC depending on engine operating point



The red curve marked in the figure is the optimal operating line (OOL) which comprises of the points with lowest BSFC value for each engine speed. Hence, operating the engine near OOL as much as possible can lead to highest fuel efficiency, when the engine alone is considered. However, since the driving load varies due to the changing road inclination, aerodynamics drag force depending on vehicle speed, wind, and rolling resistance, the engine load must be set according to the driver's demand rather than the OOL in conventional vehicles with internal combustion engine. Hence operating the engine inefficiently at the point with high BSFC value was inevitable. With the hybridization of the powertrain, however, leveling the load through using the motor assist or regeneration torque became possible, which enabled operating the engine at OOL while meeting the driver's demand power at the same time. Such driving strategy is generally adopted in parallel hybrid vehicles, especially when the cruise control mode is turned on. As long as the battery SOC is within the normal range, engine operates near the OOL while the excessive power charges the battery and lack of power discharges the battery. With such tactics, the vehicle is able to run at a constant speed. Here, notice how the battery SOC fluctuates up and down depending on the level of power demand, while the vehicle speed remains the same. So this driving strategy is hereinafter referred to as the electrical PnG.

When referring to OOL in hybrid powertrain, the system OOL that takes account of both engine and PE efficiency carries more importance than the engine OOL that is only based on the engine thermal efficiency. The difference between the system OOL and engine OOL stems from the fact that the efficiency in the PE is not 100%. If the engine alone is used to drive the vehicle, simply the engine OOL effectively describes the efficiency of power generation. However, since the electrical PnG involves the use of engine as well as electrical power generation and depletion, the resulting combined efficiency may not be identical to that obtained from engine OOL.

For the reduction in the amount of PE energy loss, the placement of the system OOL with respect to the conventional engine OOL varies depending on the demand power. When the demand torque at a given speed is lower than the engine

FIGURE 2 Difference between engine OOL and system OOL

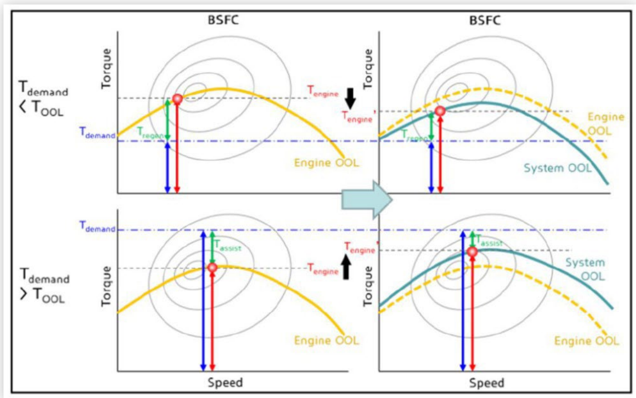
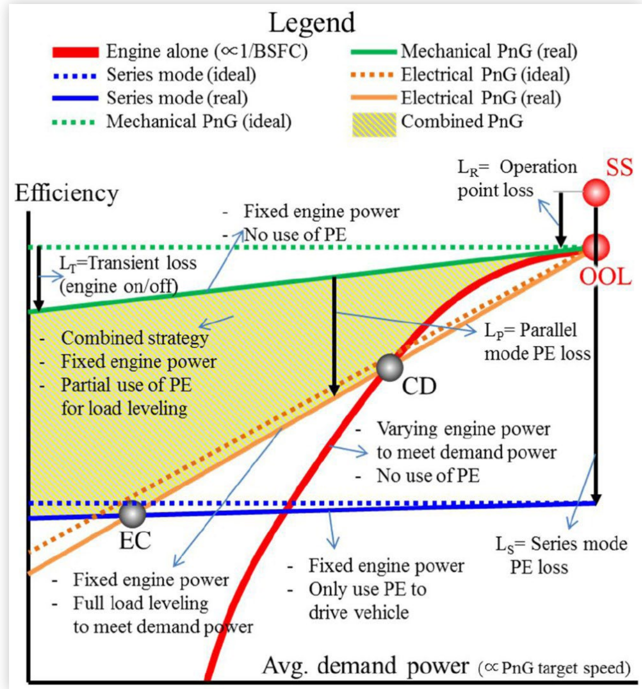


FIGURE 3 Efficiency vs. power by different PnG modes



OOL torque so that the motor must regenerate to charge the battery, the system OOL is placed under the engine OOL, which indicates that the engine must run at the operating point with the decreased load. On the other hand, when the demand torque at a given speed is higher than the engine OOL torque so that the motor must assist by discharging the battery, the system OOL is placed above the engine OOL, which indicates that the engine must run at the operating point with the increased load. The shifted system OOL relative to the engine OOL is shown in Figure 2. It is reasonable to accept the conventional engine OOL as the system OOL when the demand torque is identical to the engine OOL torque, since in this case PE is unused and the powertrain acts as a conventional vehicle without a hybrid powertrain.

Powertrain efficiency curve along average load at a fixed speed for the electrical PnG strategy is shown in Figure 3. It can be seen here that the electrical PnG efficiency is maximized when the demand load is identical to the engine OOL load so that the PE usage is minimized. As the average load decreases, the difference between the engine OOL load and demand load is increased, which leads to the increased use of PE. Hence the overall loss L_P proportionally increases. Such loss is inevitable in the electrical PnG that depends on the use of PE.

2.2.2. Conventional Non-Hybrid Driving Strategy When an engine's thermal efficiency is measured at a fixed speed, it is the highest on the engine OOL. It decreases as the operating point deviates away from the OOL, and generally, this decrement occurs in a convex form rather than in a linear shape. However, the energy conversion efficiency of the PE is relatively consistent, which leads to a linear decrease in the system efficiency as the average operating point deviates away from the engine OOL. So when the load deviation from the engine OOL is sufficiently small, the conventional engine efficiency alone turns out to be higher than the parallel hybrid system efficiency which takes the form of electrical PnG. For such condition, it is more advantageous to use the conventional non-hybrid driving strategy than the electrical PnG strategy, and the corresponding efficiencies are plotted in Figure 3 between the conventional driving point (CD) and OOL. Here, CD indicates the point where the conventional non-hybrid driving efficiency and the electrical PnG efficiency intersect.

2.2.3. Mechanical PnG Strategy Avoiding the PE energy loss while operating the engine at the OOL simultaneously leads to unbalanced demand and produced wheel torque. Such difference between the demand and produced torque leads to the acceleration or deceleration of the vehicle. Here, notice how the mechanical or kinetic energy of the vehicle fluctuates depending on the level of power demand, while the PE use is minimized. Hence, the driving strategy in which the vehicle speed is mechanically swung up and down to keep the engine operation point on OOL and minimize the PE energy loss is hereinafter referred to as the mechanical PnG.

In mechanical PnG strategy, when the engine OOL power exceeds the power required for the vehicle to maintain the constant speed, the vehicle accelerates (pulse phase). When the engine OOL power is less than the power required for the vehicle to maintain the constant speed, the vehicle decelerates. The selected driving strategy may also decide to turn the engine off (glide phase), especially when the vehicle speed increases beyond the predefined speed limit. On the other hand, the engine is turned back on when the speed decreases below the lower predefined speed limit as well. Due to high load such as when climbing a steep hill, if the vehicle speed drops below the acceptable range even when the engine is operating at OOL, increasing power is inevitable. This can be achieved either through downshifting, power assist from PE, or operating beyond engine OOL, depending on which option serves the most favorable system efficiency.

Mechanical PnG is similar to the PnG conducted in the conventional non-hybrid vehicles in the sense that the use of PE is minimized. However, the difference from the conventional vehicle is that the engine comes to a complete stop during the glide phase in case of hybrid vehicles. Such driving strategy is superior to the others when the fuel efficiency alone is considered. However, its critical shortcoming is in drivability related to the undesired fluctuation of vehicle speed caused by the difference between the actual and demand power.

Another form of loss that must be considered in case of mechanical PnG is the transient state loss caused by repetition of engine start/stop. This energy loss is explained by the additional use of fuel and PE at the moment of engine cranking. Cranking and stopping the engine takes places more frequently for less demand power, which leads to a greater amount of deviation for the real mechanical PnG efficiency from the ideal mechanical PnG efficiency. Such loss, L_T, is shown in Figure 3, and it increases linearly with decreasing demand power.

2.2.4. Series Mode Strategy In series mode, engine and the driveline are not mechanically linked. The engine can always operate at the sweet spot (SS), and the produced power is not directly transmitted to the vehicle but rather is used to charge the battery, and only the PE is used to provide power for the vehicle.

Since the route of power flow remains consistent, the amount of power loss in the system is only majorly dependent on the amount of power use. Hence, the system efficiency and loss (denoted by L_S in Figure 3) are relatively consistent throughout the entire demand power .

The engine clutch engagement point (EC) shown in Figure 3 indicates the intersection between the efficiency curves of series more strategy and electrical PnG strategy. Due to the difference in the SS and OOL at a given operating speed, the series mode efficiency is higher than the electrical PnG efficiency before EC is reached. For such condition, it is more advantageous for the overall fuel efficiency to keep the engine clutch disengaged and remain in the series mode. Such condition is not experimentally dealt in this study, but it can be considered especially in the system with expanded PE capacity.

2.2.5. Combined PnG Strategy Now this study suggests a driving strategy for constant average load, which combines the aforementioned strategies: electrical PnG, mechanical PnG, conventional strategy, and series mode strategy. As listed in Table 1, each strategy has its distinctive advantage and disadvantage. Here, it is natural to group the electrical PnG, conventional strategy, and series mode strategy together since they are optimized for maintaining a constant speed, whereas the mechanical PnG is optimized for overall fuel efficiency. Among the three speed-tracking optimized strategies, different efficiencies are exhibited for different region of demand load as shown in Figure 3, so it is meaningful to switch to the one that provides a higher efficiency. In other words, the bold black curve in Figure 4 represents the highest possible efficiency that is reachable while maintaining the constant speed. The combined efficiency for the speed-tracking optimized strategy is shown in bold black curve in Figure 4, whereas the efficiency for the fuel efficiency-optimized strategy (mechanical PnG with transient loss considered) is shown in green.

From Figure 4, a tradeoff relationship between drivability (ability to track the desired speed) and efficiency can be deduced. By combining the speed-tracking-optimized driving strategy and the efficiency-optimized driving strategy, compromising drivability or efficiency for one another is possible. Such combined tactics corresponds to the region enclosed by the green and black curve in Figure 4.

As the chosen driving strategy approaches the green curve, the efficiency tends to increase with the amount of speed fluctuation. The opposite happens when the chosen strategy approaches the bold black curve.

The basic principle of the combined PnG strategy is to set the amount of PE use in between that of the electrical and mechanical PnG. During the pulse phase, the engine operates near OOL. In case of electrical PnG, PE absorbs all of the remaining power into the battery, and none in case of mechanical PnG. Now, the combined PnG only absorbs some of the remaining power into the battery, so that it allows some

TABLE 1 Comparison of Driving Strategies

	Engine operation point.	PE load	Speed deviation	L_P or L_S	L_T	L_R	Advantage	Disadvantage
Elec. PnG	OOL	part	None	minor	minor	minor	Meets power demand for wide range of load	PE loss, deviation from OOL, transient state loss
Non-hybrid	non-OOL	none	None	none	none	major	No PE loss	Narrow optimum operating point
Mech. PnG	OOL	none	Present	none	major	minor	Highest efficiency for wide range of load	Speed fluctuation/ Transient state loss
Series mode	SS	full	None	major	minor	none	SS always reachable	PE loss for wide range of load

FIGURE 4 Comparison of speed-tracking optimized driving strategy and efficiency-optimized driving strategy

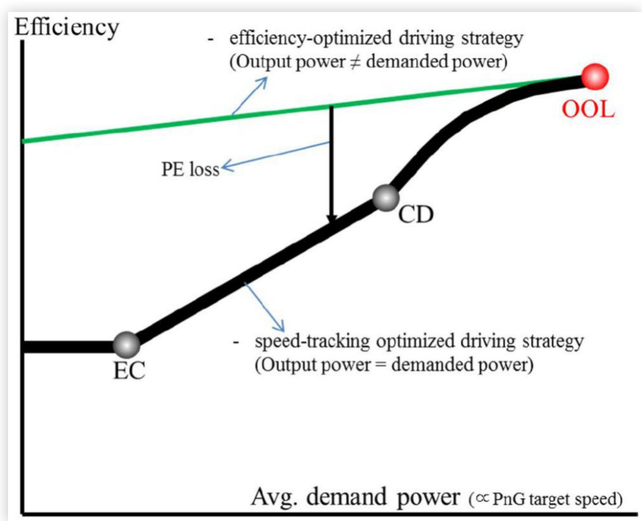
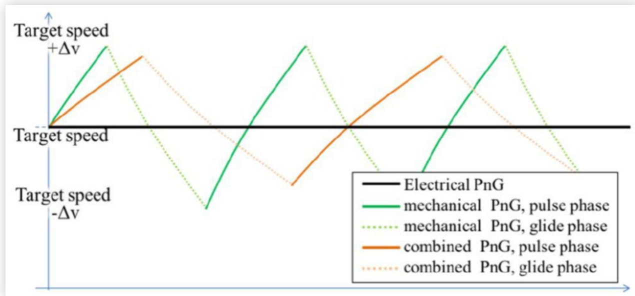


FIGURE 5 Example of speed fluctuation for speed-tracking-optimized driving strategy, efficiency-optimized driving strategy, and combined driving strategy



acceleration of the vehicle but less in magnitude than in case of the mechanical PnG. Likewise, during the glide phase, the engine comes to a complete stop. In case of electrical PnG, PE is fully used to provide power to maintain the constant speed, but is not used at all in case of mechanical PnG. Now, the combined PnG only partially use the PE, so that it allows some deceleration of the vehicle but less in magnitude than in case of the mechanical PnG. An example of the speed change for each strategy is demonstrated in Figure 5.

3. Experimental Validation

3.1. Experimental Validation Setup

The experimental validation mainly focused on recording the overall fuel efficiency for the aforementioned electrical PnG and mechanical PnG. To observe the efficiency difference, a real vehicle was used to run on the dynamometer. For fair comparison, identical vehicle, dynamometer, recording devices, and test scenario were used. Vehicle variables including fuel consumption were recorded using vehicle CAN data.

The powertrain of the test vehicle consists of a spark-ignited internal combustion engine, a motor coaxially connected to it through the engine-clutch, and a dry-type dual clutch transmission. This powertrain is illustrated in Figure 6, and specification of the test vehicle is listed in Table 2.

To minimize the effect of external disturbance, experiments were conducted on the dynamometer rather than on

FIGURE 6 General Structure of DCT-based Parallel HEV

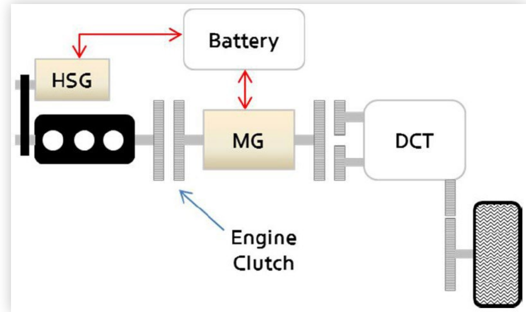


TABLE 2 Vehicle Specifications and Road Load Coefficients

Vehicle Type	Small sized SUV
Vehicle Weight(kg)	1530
Engine	1.6 L
Transmission	6 speed DCT

streets. Target average speed was set on 50 km/h, 80 km/h, and 110 km/h. For each scenario, both speed-tracking optimized driving strategy and efficiency-optimized driving strategy were tested. In case of the efficiency-optimized driving, speed fluctuation is inevitable (as discussed in earlier chapters) and experiments for the speed fluctuation range of ±5, ±10 were conducted to examine the effect of the frequency of phase transition on the driving efficiency. The vehicle load was simulated by the dynamometer based on the total load torque data measured as a function of vehicle speed.

3.2. Experimental Validation Result

Listed in Table 3 are the test results obtained from the experimental validation. Fuel mileage values for each scenario were computed by dividing the distance travelled by the calibrated sum of the amount of fuel injected. Here, for a fair comparison, the amount of fuel consumed is calibrated by the difference between the battery SOC at the initial and final conditions of the experiment.

The results show that the overall fuel efficiency improves with slower target speed. For the target speed of 50 km/h and 80 km/h, the efficiency-optimized driving strategy based on

TABLE 3 Comparison of Fuel Efficiency by Case

Target speed [km/h]	Δ speed [km/h]	Distance travelled [km]	ΔSOC [wh] (initial-final)	Fuel used [ml] (SOC-corrected)	Fuel efficiency [km/l]	Effic. improve. [%] (rel. to const. Spd.)
50	0	2.56	0.00	91.59	27.95	-
	±5	2.48	5.12	87.52	28.34	1.38
	±10	2.89	8.00	97.08	29.77	6.51
80	0	9.96	217.72	476.65	20.90	-
	±5	10.18	50.95	472.51	21.54	3.10
	±10	9.95	54.42	467.42	21.29	1.87
110	0	5.00	2.98	307.37	16.27	-
	±5	5.00	28.51	308.87	16.19	–0.49

the mechanical PnG driving showed higher fuel efficiency than the speed-tracking optimized driving strategy, as expected. For the case of 50 km/h and 80 km/h, 1.21~6.25% and 1.91~3.05% of fuel mileage improvement could be observed, respectively. Such improvement corresponds to the vertical difference between the green and black curve shown in Figure 4.

However, no fuel mileage improvement could be observed for the case of 110 km/h. This is because the OOL power and the load power are equal, and the efficiency difference from the PE usage does not occur. Such condition can be demonstrated by the efficiency curves for both strategies converging at OOL as shown in Figure 4.

3.3. Result Analysis

3.3.1. Comparison of Simulation and Test Result Figure 7 shows the fuel efficiency trend obtained by simulation and real vehicle experiment. Although the numerical value of the fuel efficiency may vary between the simulation and experiment results, the relative difference of the efficiencies among different scenarios is identical. For both results, the maximum efficiency improvement potential is higher for the case of 50 km/h than for the case of 80 km/h. This result reflects the vertical gap between the efficiencies of the speed-tracking-optimized driving strategy and efficiency-optimized driving strategy, which is greater for the case of 50 km/h than for the case of 80 km/h. Also, the results indicate that the fuel mileage improvement is greater with ±10 scenario than with ±5 scenario for the case of 50 km/h. However, for the case of 80 km/h, the fuel mileage improvement is greater with ±5 scenario than with ±10 scenario. Such conflicting figures are caused by the combined effect of the transient loss for the engine on/off and the increasing aerodynamic drag. This is further dealt in detail in the following section.

3.3.2. Energy Loss Analysis Energy loss in each components of the driveline is calculated based on the recorded data of fuel consumption, engine speed, engine torque, motor speed, motor torque, LDC voltage and power, transmission input shaft speed, wheel speed and battery SOC. Previously obtained engine BSFC, transmission efficiency and PE charging/discharging efficiency tables are considered in the computation of the energy loss. The energy loss is grouped in four categories: engine heat loss, engine friction loss, PE (motor/generator) loss, and resistance loss. The computed results are shown with the unit of joules-per-kilometer-travelled in bar-graph format for convenient comparison in Figure 8.

Obviously, less amount of loss signifies higher overall efficiency. The major cause for the reduced total energy loss in case of the efficiency-optimized PnG is the absence of the PE loss. Trivial amount of PE loss still exists due to the auxiliary power use, but most of the PE loss is eliminated by refraining from using PE for driving the vehicle.

Also, the PE loss increases with the increasing PE use, and the PE use increases with greater difference between the

FIGURE 7 Fuel efficiency result: (a) Simulation result (b) Actual vehicle

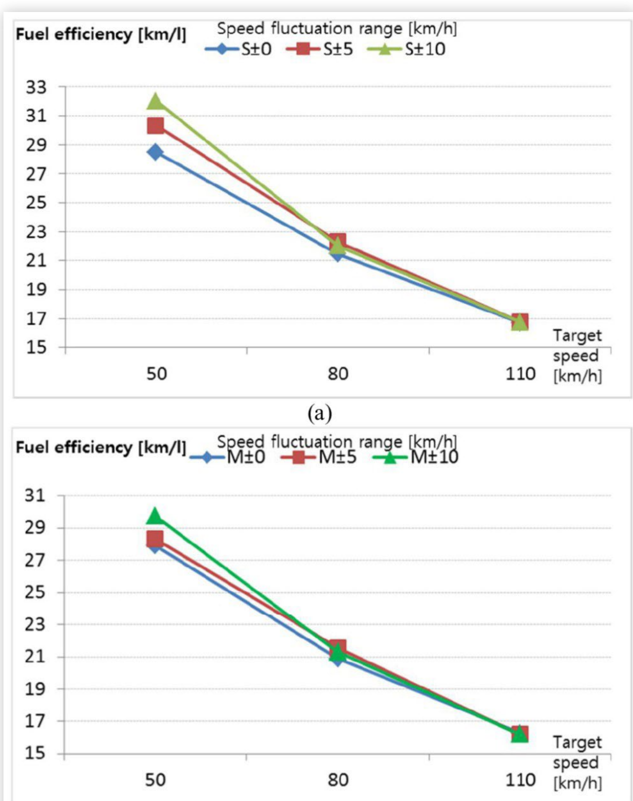
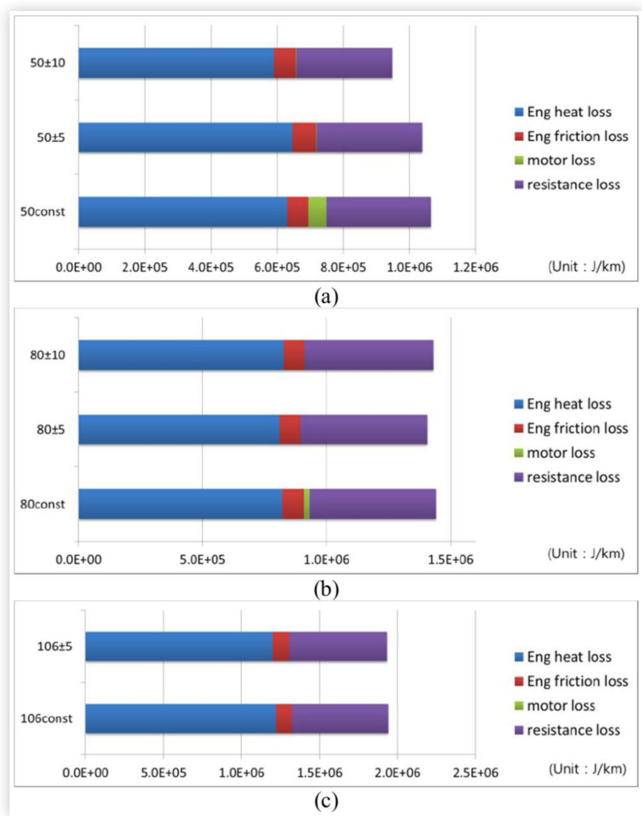


FIGURE 8 Amount of energy loss: (a) 50kph (b) 80kph (c) 106kph



OOL power and demand power. Hence, more PE loss can be observed for the case of less load. This indicates that the efficiency improvement potential by taking the efficiency-optimized driving strategy over speed-tracking-optimized driving strategy is greater for the case of 50 km/h than in case of 80 km/h. This explains why greater amount of loss could be reduced for the case of 50 km/h.

For the same reason, nearly no fuel efficiency difference could be observed in case of 110 km/h, regardless of which driving strategy is chosen. The OOL power almost exactly matched with the demand power due to the high amount of aerodynamic drag caused by driving at 110 km/h, which made the effort to further reduce the PE use trivial.

Furthermore, the effect of the aerodynamic drag must be analyzed. Due to the aerodynamics resistance which increases with the square of the vehicle speed, the average resistance experienced by the vehicle is greater when the speed fluctuation range increases, although the average speed may be the same. This explains why the fuel mileage result for the case of 80 km/h ± 5 is better than the case of 80 km/h ± 10.

However, we must not ignore the fact that the fuel mileage result for the case of 50 km/h ± 5 is worse than the case of 50 km/h ± 10. This is explained by the frequency of the engine turn on/off caused by the transition between pulse and glide phase. Since the engine operating point cannot maintain the OOL during engine turn on/off, higher frequency of transition between pulse and glide phase leads to efficiency degradation. So here, since the effect of average aerodynamic drag difference caused by speed fluctuation is less in case of 50 km/h than 80 km/h, the effect of engine transient state loss turned out to be more significant than that of the aerodynamic drag.

3.3.3. Drivability Analysis Choosing the efficiency-optimized driving strategy over speed-tracking-optimized driving strategy inevitably brings changes in the drivability, since the speed-tracking ability depends on the difference between the OOL torque and load torque. The magnitude of acceleration is greater during the pulse phase than the glide phase in case of driving at the average speed of 50 km/h. This is explained by the relatively small load torque and large difference between the OOL and load torque. In case of driving at the average speed of 80 km/h, the magnitude of acceleration is smaller during the pulse phase than the glide phase. This is now due to the relatively large load torque and small difference between the OOL and load torque.

Hence, this study confirmed that adopting the PnG strategy increases efficiency at the expense of drivability - the ability to maintain the desired speed. The increased gap between the OOL and load torque leads to greater magnitude of acceleration during pulse phase, and increased load torque leads to greater magnitude of deceleration during the glide phase.

4. Conclusion

This study has revealed the effect of adopting electrical PnG as a part of speed-tracking-optimized driving strategy, and mechanical PnG as a part of efficiency-optimized driving strategy on the fuel efficiency and drivability, based on the vehicle with a DCT-type parallel hybrid powertrain. Using an actual vehicle experiment data obtained on the dynamometer, the following conclusion could be drawn.

(1) The overall cruising fuel efficiency improves with the mechanical PnG driving strategy when compared to the case with the electrical PnG driving strategy. Such improvement in efficiency could be obtained at the expense of the speed-tracking performance. The overall efficiency is a trade off against the drivability.

(2) The amount of fuel efficiency improvement increases for slower target speed. The overall fuel efficiency improvement ranged up to 6.25% and 3.05% in case of setting the target speed at 50 km/h and 80 km/h, respectively. No significant efficiency improvement could be observed in case of driving at 106 km/h.

(3) The advantage of increasing the speed fluctuation range during mechanical PnG is the reduction of transient energy loss. The disadvantage of it is the degraded drivability and increased mean aerodynamic drag loss. Hence the optimum speed fluctuation range should be found in balanced transient loss and drag loss.

5. Future Works

For the effective application of the PnG driving strategy in pass-production vehicles, several factors must be further considered. Besides the speed-tracking-optimized driving strategy and the efficiency-optimized driving strategy, a compromised driving strategy shall be developed to find an optimum point in the tradeoff between the overall efficiency and the drivability. Also, the relationship between the system efficiency and the transmission control strategy must be clarified along with the modeling of the optimum speed fluctuation range. Furthermore, since PnG driving strategy inevitably involves speed fluctuation, its application potential with SCC shall be studied.

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