特集 A Stand-alone Charging Management System to Improve Fuel Economy, Based on An Algorithm of Estimating Vehicle Motion*

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Increased interest in global warming issues requires rapid improvements in reduction of CO2 emission. The automotive industry is placing high importance on improving fuel economy performance across their entire product lines. The Charging Management System is a necessary element of the fight for improved fuel economy. Many of today's Charging Management System perform at least two important functions: improving efficiency based on vehicle motion, and detecting the battery state of charge. These systems become more complicated as more components (i.e. generators, current sensors and ECU) and software are added. Therefore, it is difficult to develop Charging Management System for an entire product line and difficult to retrofit the systems for vehicles already in production. A Stand-alone Charging Management System solves these issues. This system is independent of the other vehicle systems.

The software for improving fuel economy is installed in the generator or current sensor. These components can be connected through digital communication to gather information from each other, and be retrofitted to older vehicles. A Stand-alone Charging Management System controls regeneration during deceleration. This system estimates vehicle motion by alternator speed.

Key words: Fuel economy, Retrofit, Stand-alone, Charging control, Regeneration, Vehicle motion estimation

1．INTRODUCTION

1.1　Technology for improving fuel economy

Automobile exhaust emissions affect global warming, and CO2 emission control is tightening up all over the world. To achieve reductions, the industry needs a technique that results in a large reduction in CO2 emission. Therefore, Electric Vehicles (EV), Hybrid Vehicle (HV) systems, and high efficiency engines are advanced to improve fuel economy.

Charge management is one technique for improving fuel economy, and Table 1 compares its estimated effect on fuel economy versus other techniques. Regeneration is converting a vehicle's kinetic energy to electric energy for battery recharging during deceleration. In this way, regeneration recovers the kinetic energy that conventional vehicles waste as thermal energy when braking. Regeneration provides an approximate 1% increase in fuel economy, though this result is influenced by the engine capacity and electric load.

The second system is "Idle Start & Stop" which stops the engine while waiting at stoplights. This is an effective way for drivers living in urban areas to reduce fuel consumption by an estimated 5%.

Table 1 Comparison of Charging Management System

		Regenerating	Idle Start & Stop	Strong HV
Improvement fuel economy		+1%	+5%	+40%
Modification		Minor change	Big change	Bigger change
Technique	Battery type	Pb-battery	Strong Pb-battery	Ni or Li battery
	Battery state detection	Precise	More precise	Most precise
	Other function	•Deceleration detection •Generator voltage control		

Strong HV represented by Toyota's "Prius" is known as a very low emission vehicle. This system accomplishes 40% better fuel economy than conventional systems by combining engine and electric motor enhancements.

As shown in Table 1 under Technique, changes are needed for each method of improving fuel economy. The regeneration system needs to detect a vehicle's deceleration to recognize when the system should increase the generator's output, and the generator's output must be controlled to convert kinetic energy to electric energy. Regeneration also needs to detect battery condition to maintain its state of charge. Maintaining

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the state of charge not only prevents the battery from running out of power, but also ensures some under charged capacity to take in regenerative energy during deceleration.

However, vehicle modifications needed to implement the charge management system for conventional vehicles are difficult.

2．DENSO'S ROADMAP OF CHARGING MANAGEMENT SYSTEM

The number of cars sold in Japan was steady at approximately 5.8 million annually until 2005, but it has been gradually decreasing since 2006.[1] The useful life of a car in Japan has also increased steadily since 1992.[2] This data indicates that the proportion of new vehicles to the total car population in Japan is decreasing. The automotive industry hopes sales of newly developed cars will decrease overall CO_2 emission. But the effect of new cars is limited, as the share of new cars to the total car population in Japan is shrinking.

Considering this market trend, DENSO proposes two ways of reduce global warming (**Fig. 1**). One is referred to as "Integrating System", where improved systems are installed in new EMS (Energy Management System), first for luxury vehicles, with later implementation for other vehicle classes. This kind of system is "Vehicle Electric Power Flow Management System"[3] which DENSO announced to SAE in 2006.

The other is the "Retrofit System". This system is not dependent on vehicle information, so the system can be attached to vehicles already in use. This system can improve fuel economy for any vehicle class; particularly smaller class vehicles can expect the largest improvement. In this way, the new system for improving fuel economy can be implemented to the current auto population, significantly reducing CO_2 emission.
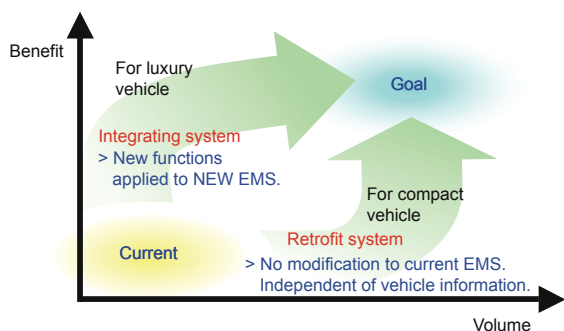
We understand the cost of the parts is important in the aftermarket. In our assumption, the average Japanese driver can pay for the system in 5 years. If fuel price will have increased, driver can pay for it shorter period.

This paper reports on the "Retrofit System" for the Charging Management System. We investigated an algorithm estimating vehicle motion so that this system can execute "charging control" without using vehicle information. Then we evaluated fuel economy, and confirmed that our Stand-alone Charging Management System can improve fuel economy by 1%.

2.1 Improvement of fuel economy by charging control

Figure 2 shows energy flow on charging control. Normally an alternator generates power to run accessories and to charge a battery which consumes fuel. Charging Management System has achieved a more effective generating power system based on vehicle condition. For example, regenerating control will increase alternator output during vehicle deceleration. In this case the engine runs without consuming fuel, by transmitting kinetic energy of wheel to the engine.

The Charging Management System controls the battery state of charge (SOC) in order to receive the regenerating power during deceleration. The system controls charging voltage to maintain SOC by the feedback control method excluding deceleration. This is achieved by detecting battery charging current and calculating the integrated value relative to the battery state of charge (SOC).

The Charging Management System is necessary to detect vehicle deceleration and control the battery state of charge.
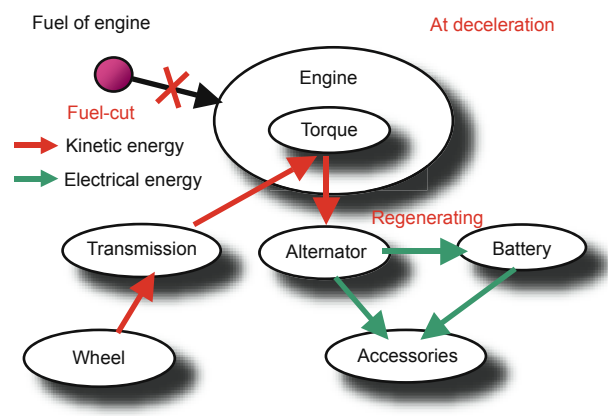

Fig. 1 DENSO's road of Charging Management System

Fig. 2 Energy flow on charging control

3．STAND-ALONE CHARGING MANAGEMENT SYSTEM

A Stand-alone Charging Management System refers to a charging control system installed in a component such as inside a battery sensor or alternator, excluding the ECU. This retrofit system makes it possible to install the system in a vehicle already on the road.

The Stand-alone Charging Management System is depicted in **Fig. 3**. This example shows a system installed inside a battery sensor. The battery sensor has three functions for charging control: battery-condition detector, vehicle motion estimation and charging voltage control.

The Battery-Condition Detector measures the battery charging current, voltage and battery temperature. The purpose of the Battery-Condition Detector is to control the SOC by calculating both voltage and current, and calculating the integrated value of battery current. Even if this system is retrofitted to an older vehicle, the Battery-Condition Detector can measure the SOC as long as the battery condition and type are considered.

The Stand-alone Charging Management System allows for the exchange of information between the sensor and the alternator by data communication such as LIN (Local Interconnect Network). Vehicle motion estimation receives the alternator speed, calculates and judges the vehicle motion by alternator speed, and detects vehicle deceleration. Charging voltage control sends the target-voltage to the alternator, controlling the SOC and regenerating power in the battery.
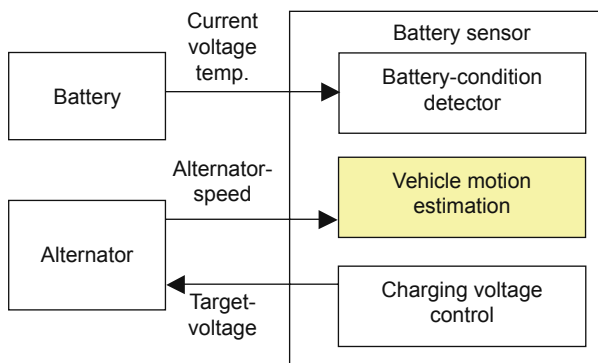

Fig. 3 Stand-alone Charging Management System

3.1 Analysis for vehicle motion estimation

A key component of the Stand-alone Charging Management System is the technique of vehicle motion estimation.

Figure 4 presents an example driving pattern based on the Japan 10/15 fuel economy schedule. This shows behavior of vehicle and alternator speed. Vehicle motion is designated by 4 states: idle, acceleration, cruise driving and deceleration.

While the vehicle runs at idle or drives at cruising speed, the alternator speed is in a stable condition. Idle refers to the alternator speed in lower and stable condition; cruise driving refers to the alternator in higher and stable condition. In other words wheel speed depends on both engine speed and transmission gear ratio. Then during cruise driving, transmission gear ratio is in a fixed condition so that alternator speed is proportionate to vehicle speed.

Conversely, while the vehicle accelerates, the alternator speed increases and while decelerating the alternator speed decreases. However in those conditions the vehicle changes transmission gear ratio and the vehicle velocity slows down. In this case alternator speed rate increases based on transmission gear ratio changing, regardless of the rate of vehicle deceleration. A Stand-alone Charging Management System is not free from this behavior, thus it is important to develop an algorithm to estimate vehicle motion.

3.2 Algorithm for vehicle motion estimation

Firstly, a vehicle motion estimation algorithm has to describe vehicle motion so that this system can achieve charging control according to vehicle behavior. It is desirable that the algorithm is simple and precise so that fuel economy performance will be more effective and improve overall system reliability. The Stand-alone Charging Management System is defined by the State Flow Model according to four states of vehicle motion.
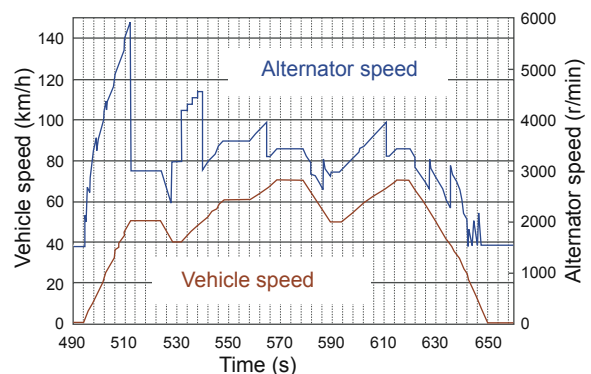

Fig. 4 Driving pattern on vehicle

The advantage of the State Flow Model is it provides the ability to precisely model the change in vehicles motion as a state of transition. For example, when the vehicle is at idle condition, the next presumed state is acceleration. **Figure 5** shows the algorithm of estimating vehicle motion in terms of the four states. This State Flow Model is adopted to simplify the possible state combinations, excluding the passes directly between acceleration state and deceleration state. In the example of state transition from idle state to cruise driving state, the transition state (acceleration) is allowed in this flow model. The elimination of state transitions directly between acceleration and deceleration simplifies the model and provides a more stable and reliable model estimate of vehicle motion.

Secondly, while the vehicle is decelerating, alternator speed is not a direct speed relation of the transmission gear ratio change. During deceleration, the Stand-alone Charging Management System uses a 1/n filtering operation to account for the variation of alternator speed (AS). This method calculates alternator speed at a predefined sampling rate (k). Even Alternator Speed (EAS) can then be expressed as

$$EAS_{(k)} = \{(n-1)\, EAS_{(k-1)} + AS_{(k-1)}\}\, /n$$

where k is the time index (time step is assumed to be 64 milli-seconds), properly choosing parameter n and clearing the Even Alternator Speed at the right time is necessary to achieve improved performance vehicle motion model.

3.3　Evaluation result of estimating algorithm

The estimation algorithm has to be accurate so it insures more efficient fuel economy. Two indicators used to evaluate its accuracy are correct detect and erroneous detect ratios. The correct detect ratio refers to correctly judging the deceleration rate during the vehicle deceleration period.
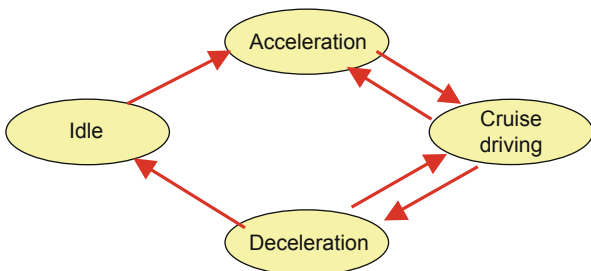
The erroneous detect ratio refers to erroneously judging the deceleration rate during other than vehicle deceleration period. This evaluating method is shown in **Fig. 6**.

As the result of improving the estimating algorithm with an automatic transmission equipped vehicle, the correct detect ratio is 88% and erroneous detect ratio is 7% by only using alternator speed. This estimating algorithm can also judge vehicle motion equally on vehicles with manual transmissions, by adapting the algorithm for a manual transmission. Behavior of alternator speed with a manual transmission is basically similar to the behavior of the alternator speed with an automatic transmission, including during periods of acceleration and deceleration.

The result of actual fuel economy performance is shown in **Fig. 7**. The conditions of this fuel economy test are indicated in **Table 2**. The horizontal axis of this figure indicates Alternator Output, and the vertical axis indicates fuel consumption during mode driving. Generally, fuel consumption increases in proportion to Alternator Output.
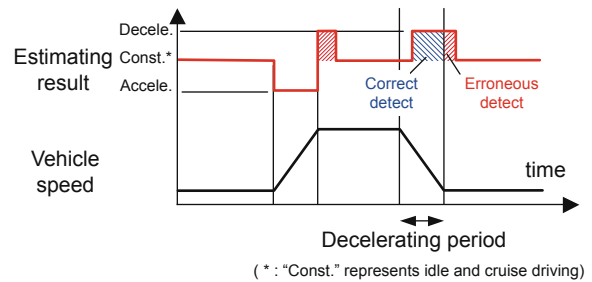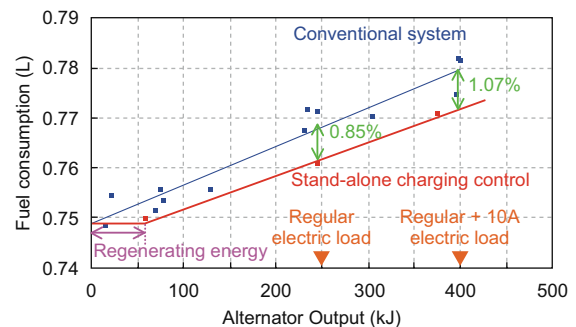
Fig. 6　Indicator of evaluation algorithm

Fig. 7　Actual fuel economy performance

Table 2　Condition of the fuel economy test

Driving mode	EU
Weight	1300 kg
Engine	Petrol, 1.6 liter, 4 cylinder
Transmission	6-speed automatic transmission

Fig. 5　Algorithm of estimating vehicle motion

The slopes relate to generating efficiency, the slope is graded by generating at high efficiency range of engine and alternator. In **Fig. 7**, the flat characteristic of stand-alone charging control represents regeneration energy, because fuel does not inject during regeneration. Compared with a conventional system, the Stand-alone Charging Management System results in better fuel consumption by 0.85% at regular electric load conditions. In addition, when electric load increases by 10A, the improvement in fuel consumption is up to 1.07%. Those differences of fuel consumption indicate Engine and Alternator difference of efficiency, because those efficiencies depend on their operating point. We assume it is possible to improve fuel saving benefit by increasing regenerating energy. Therefore, implementing bigger battery and higher output alternator are ways to improve fuel consumption.

4．CONCLUSION

We developed a Stand-alone Charging Management System that can be installed in vehicles already in use. This system detects vehicle motion based on an algorithm, and the algorithm correctly detects vehicle motion nearly 90% of the time. The algorithm shows that this system regenerates power during deceleration to improve fuel economy. From our evaluation, the Stand-alone Charging Management System can improve fuel economy by one percent, contributing to a reduction of worldwide CO2 emission.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

EV: Electric Vehicle
HV: Hybrid Vehicle
EMS: Energy Management System
SOC: State Of Charge
LIN: Local Interconnect Network
AS: Alternator Speed
EAS: Even Alternator Speed

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