Technology for Increased Fuel Efficiency in New INSIGHT

Toshihiko FUKUDA* Takahiro EGUCHI*

ABSTRACT

The 2009 model year INSIGHT was developed with the goal of achieving a higher level of actual fuel efficiency and driving performance.

An analysis has revealed that the ways of operating a vehicle that result in reduced fuel economy are rough accelerator operation during vehicle cruising, excessive accelerator operation during acceleration, and accessory loads, such as air conditioning.

The developed system employs fuel economy priority control, which uses an ECON mode selector switch to permit high fuel economy driving. In ECON ON mode, the engine and transmission are coordinated with each other. Restricting the engine throttle and optimizing the CVT shift response enable the minimum fuel consumption amount (Gram Fuel minimum; hereafter called GF minimum) to be traced, even during rough accelerator operation, thus facilitating low-fuel-consumption driving. In tests of actual fuel efficiency, these technologies reduced the level of variation between users and enabled the achievement of a 9.5% reduction in average fuel consumption in ECON ON mode.

1. Introduction

Considering the importance of protecting the global environment by reducing CO_2, plus the depletion of crude oil supply, increased fuel economy in automobiles is becoming even more critical. In 1999, Honda developed the Integrated Motor Assist (IMA) system, and released the INSIGHT[(1), (2)] as a dedicated hybrid vehicle. Subsequently, in 2001, it released a small sedan called the CIVIC Hybrid[(3), (4)], and in 2004 a medium sedan called the ACCORD Hybrid[(5)]. In 2005, the CIVIC Hybrid[(6)–(10)] underwent a full model change involving the adoption of 3-stage VTEC technology including deactivation of all cylinders, a hydraulic booster brake system, and a hybrid air conditioner, aiming at enhanced fuel economy.

Nearly 10 years have passed since the first hybrid vehicle was put on the market, and now a dedicated hybrid car was developed aiming at widespread popularization through reduced cost. This paper describes the technology that has been developed for the enhancement of actual fuel economy in order to meet the needs of various users.

* Automobile R&D Center

2. Development Goals

An analysis has revealed that the following ways of operating a vehicle are the main factors involved with reduced fuel economy.

(1) Rough operation of the accelerator during vehicle cruising
(2) Excessive operation of the accelerator during acceleration
(3) Accessory loads, such as the air conditioner

A CVT hybrid vehicle enables the engine output, motor output, and transmission ratio to be controlled freely. Accordingly, this development was aimed at obtaining an increase in actual fuel economy of 10% by enhancing engine control and CVT shift control. The same drive feeling was also sought to be achieved by fully utilizing the features of IMA to provide torque assistance from the motor, and to realize CVT shift control in which torque varies linearly with the depression of the accelerator.

3. Outline and Specifications of Power Plant

The engine of the new INSIGHT employs the system for deactivation of all cylinders employed in the 2006 model CIVIC Hybrid, plus plateau horning, low friction piston rings, and other friction reduction technologies. As a result, friction was reduced and the fuel economy of the engine on its own was increased by 2.0%.

The motor used was a thin DC brushless type. Along with the use of a lower rated voltage, the rotor and stator were both enhanced, aiming at higher efficiency. Also, the motor was reduced in thickness, the size of the magnet was minimized, and the materials were changed, thereby realizing a price reduction.

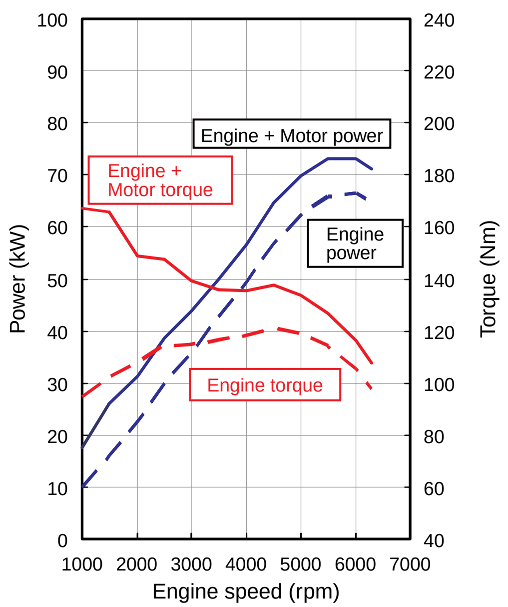

Fig. 1 Output performance of IMA system

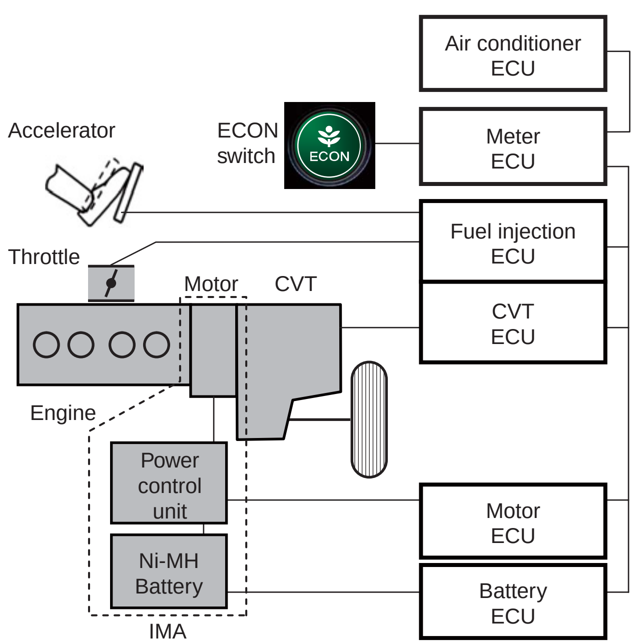

Fig. 2 New INSIGHT system

Regarding the battery, the number of cells was reduced by increasing the output density, and the voltage was reduced to 100 V, realizing reduced size, weight, and price. The abovementioned engine, motor, and battery resulted in a power plant that had a high-torque response in the low-speed range, which is unattainable with a conventional gasoline vehicle. Figure 1 shows the power plant torque and power characteristics verses engine speed.

The CVT used in this development had a low final ratio that was 6.7% less than that of the CVT in the 2006 model year CIVIC Hybrid, with overall development aimed at optimizing fuel economy and drive feeling through the power plant torque, vehicle weight, and tire diameter.

Figure 2 shows the control system of the new INSIGHT. In this system, fuel economy priority control using an ECON selector switch was employed. In ECON OFF mode, the engine is designed to respond well to the accelerator operation, and in ECON ON mode, high fuel economy operation can be easily realized.

The following four items are affecting when the mode is switched between ECON OFF and ECON ON.

(1) GF minimum control[11]
(2) Driving-force-on-demand control
(3) Deceleration regeneration control
(4) Air conditioner control

Details of the above are described below.

4. GF Minimum Control

Rough operation of the accelerator during vehicle cruising is one way of operating a vehicle that results in the reduction of fuel economy. If, during usual cruising, the accelerator is maintained at a fixed position, the CVT is shifted to the optimum ratio and the fuel economy increases. However, if the driver operates the accelerator roughly by repeatedly depressing and releasing the accelerator, the CVT will shift to increased engine speed as soon as the accelerator is depressed, and inertia load occurs. Also, the engine will be subjected to a high load, and it will deviate from the point of minimum fuel economy, resulting in a decrease of the fuel economy.

The new INSIGHT employs GF minimum control in consideration of the above issue. GF minimum control is used to control the engine speed and engine load, utilizing a Brake Specific Fuel Consumption (BSFC) map and the transmission efficiency of the CVT, so that the fuel consumption with respect to the power demand is minimized, thus enabling the GF minimum target to be achieved.

Figure 3 shows the BSFC map, and Fig. 4 indicates the CVT efficiency. In Area 1 of the BSFC minimum target line in Fig. 3, the CVT efficiency increases in inverse proportion to the engine speed. In Areas 2 and 3, the efficiency is roughly constant between 1 000 and 1 500 rpm. In Area 4, there is almost no difference in efficiency between 1 500 and 2 500 rpm. Consequently, in this system, the GF minimum target can be achieved by controlling the engine speed and engine load in such a way that the BSFC minimum target line shown in Fig. 3 is traced with respect to power demand.

Details of CVT shift control for determining the engine speed and throttle control for determining the engine load - which were employed in order to trace this GF minimum target line - are described below.

4.1. CVT Shift Control

CVT shift control, which achieves the GF minimum target, is described below.

(1) Area 1 shown in Fig. 3 is the zone in which the driving-force-on-demand accelerator (controlling accelerator for determining driving-force-on-demand) is extremely small. Here, a CVT shift schedule is used in which the lowest possible engine speed at which the vehicle can run is maintained, so the fuel consumption rate versus the power demand is minimized.

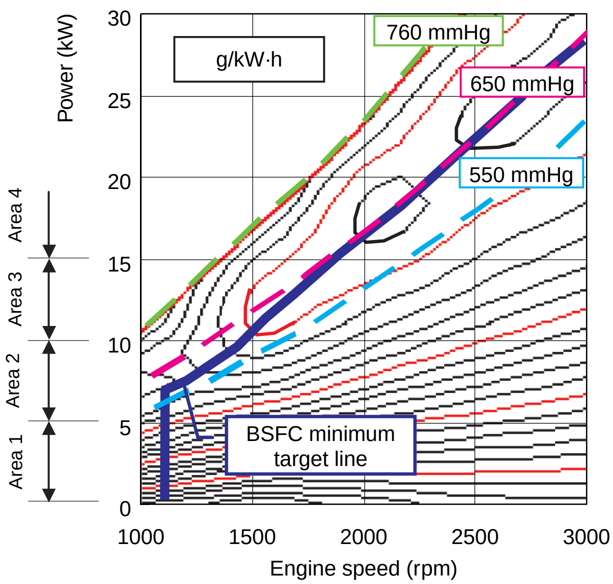

Fig. 3 Brake specific fuel consumption map

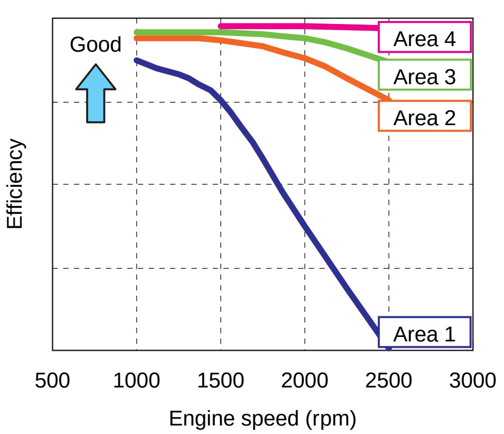

Fig. 4 CVT efficiency

In Areas 2 to 4, in which the accelerator is depressed more than an extremely small driving-force-on-demand accelerator, a shift schedule that takes into account drive feeling is utilized. It is a shift schedule in which the engine speed rises linearly with respect to the increase in vehicle speed, as shown in Fig. 5, while the BSFC minimum target line shown in Fig. 3 is traced.

In total, driving force was generated linearly with respect to the driving-force-on-demand accelerator, without any dip occurring in the generated power, as shown in Fig. 6.

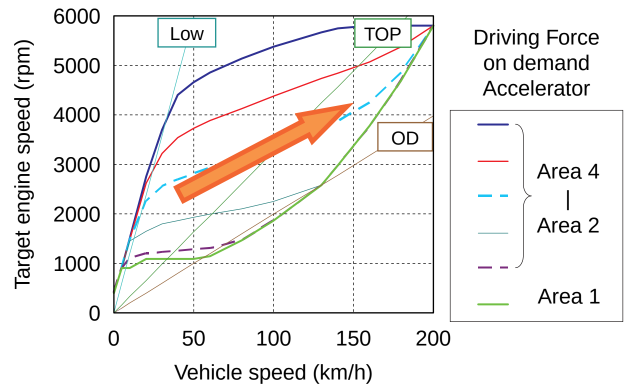

Fig. 5 CVT shift schedule

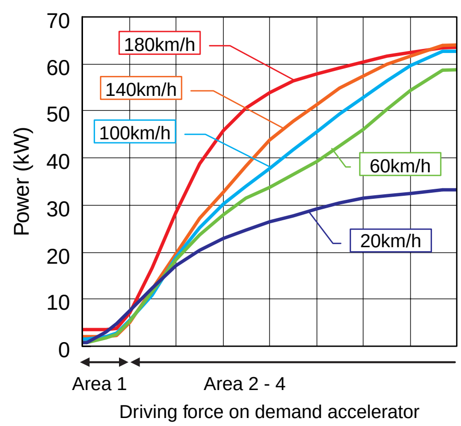

Fig. 6 Power versus Driving - force - on - demand accelerator

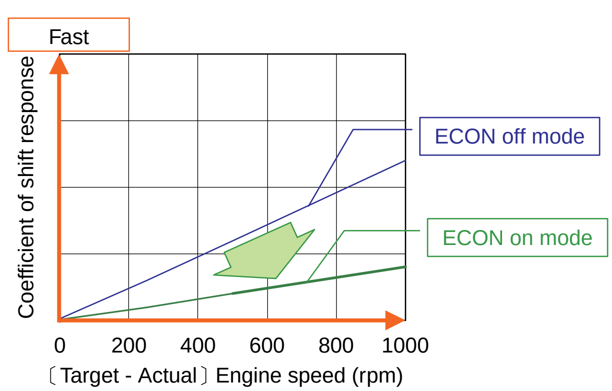

Fig. 7 Coefficient of shift response

(2) Figure 7 shows the CVT shift response characteristics in the ECON OFF mode and ON mode, respectively. As shown in Fig. 7, the shift response of the CVT is determined by the deviation between the target engine speed and the actual engine speed. In the ECON ON mode, this shift response coefficient is reduced, thus reducing the speed at which a down-shift occurs when the accelerator is depressed. This helps prevent the engine speed from inadvertently rising when the driver depresses the accelerator roughly, thus facilitating high fuel economy driving.

4.2. Throttle Control

Figure 8 shows the throttle limits in ECON OFF mode and ECON ON mode, respectively. By limiting the throttle position with respect to the actual engine speed and driving-force-on-demand accelerator, loading exceeding the best BSFC of the engine is avoided, and the BSFC minimum target line is traced. Also, the throttle limit region is switched depending on whether ECON OFF or ECON ON mode is active.

In ECON OFF mode, the throttle limit region is minimal. Consequently, the GF minimum target line can be traced at low accelerator demand, and when the depression of the accelerator is large the throttle is not

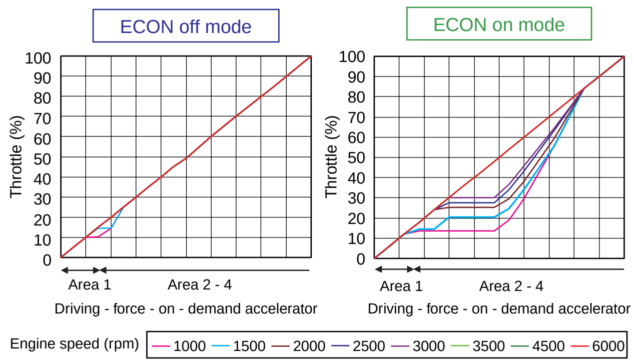

Fig. 8 Restriction of throttle

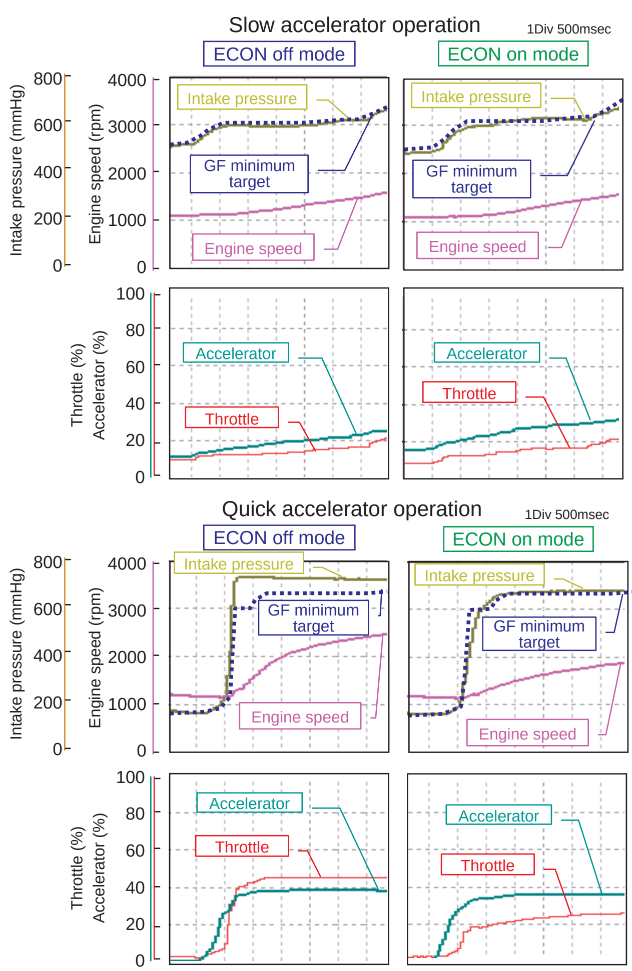

Fig. 9 Comparison using different speed of accelerator operation and control modes

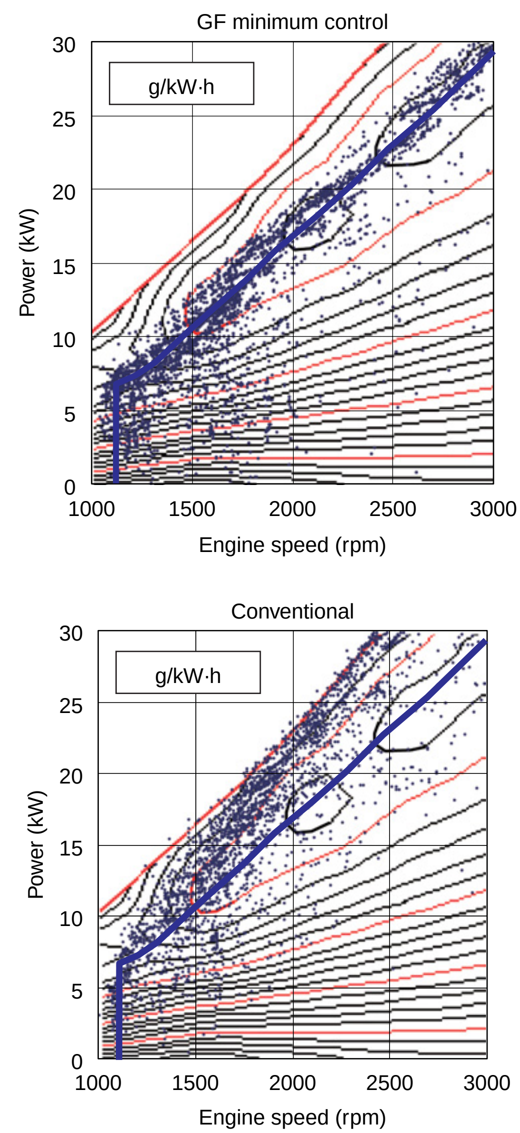

Fig. 10 Comparison with and without GF minimum control

limited, so a rapid torque response is obtained.

In ECON ON mode, the throttle limit zone is increased, enabling the GF minimum line to be traced even when the driver operates the accelerator roughly. Also, even if the throttle is greatly limited, a driving force that is linearly proportional to the depression of the accelerator is realized as a result of control of engine speed by the CVT and torque assistance from the IMA motor.

Figure 9 shows the response characteristics of the vehicle when the accelerator is operated slowly and when it is operated rapidly, with ECON OFF mode active and with ECON ON mode active. In the case of low fuel consumption driving in which the accelerator is operated slowly, there is no major difference in response between with ECON OFF mode active and with ECON ON mode active. In the other case, when the accelerator is operated rapidly, the intake pressure and engine speed rapidly respond to the operation of the accelerator with ECON OFF mode active. When the accelerator is operated rapidly in ECON ON mode, the limit imposed on the throttle results in the intake pressure in the engine increasing gradually. In addition, the shift response characteristics of the CVT for ECON ON mode suppress the rise of the engine speed, thus achieving higher fuel economy.

Figure 10 shows a comparison of the GF minimum target line traced, with and without GF minimum control which utilizes CVT shift control and throttle limit control.

Compared to the conventional control method, this GF minimum control enables the GF minimum line to be traced accurately, thus raising the fuel economy by 0.3 km/L in 10-15 mode.

5. Driving-force-on-demand Control

Conventionally, Honda's CVT has provided good drive feeling by selecting the optimum shift schedule from 16 kinds of maps according to the particular running conditions such as inclination, road surface condition, accelerator pedal operation, and lateral G when cornering.

However, with the new INSIGHT, the mode is switched between ECON OFF and ECON ON using the ECON switch in order to simultaneously realize good fuel economy and drive feeling. In the case of conventional CVT shift control, which is based on the accelerator, when the mode is switched, the torque output characteristics versus the accelerator position change, so it is necessary to have a shift schedule for each mode, resulting in the CVT shift control becoming more complicated. Also, the relationship between the throttle and the engine speed is altered, and the abovementioned GF minimum control can no longer be implemented.

In order to overcome these issues, the new INSIGHT employs driving-force-on-demand control.

As shown in Fig. 11, normal drive-force-on-demand control directly determines the demand driving force, that is, the demand power, from the accelerator position, and performs engine throttle control and CVT shift control with respect to the demand power. Consequently, the throttle and engine speed are controlled independently with respect to the acceleration operation. As a result, there were cases in which there was a non-linear torque feeling or response with respect to an accelerator operation, or a non-linear increase in the engine speed with respect to vehicle speed.

Details of the driving-force-on-demand control of the new INSIGHT, used to overcome these issues, are explained below.

5.1. New INSIGHT Driving-force-on-demand Control

Figure 12 shows an overview of the driving-force-on-demand control that has been employed in the new INSIGHT.

(1) The accelerator position is converted into driving-force-on-demand accelerator position for each vehicle speed which determines the driving force on demand.

(2) Engine throttle control and CVT shift control are performed based on the driving-force-on-demand accelerator position.

The engine output torque is determined by the engine throttle control, and the engine speed is determined by the CVT shift control, hence the power for each vehicle speed

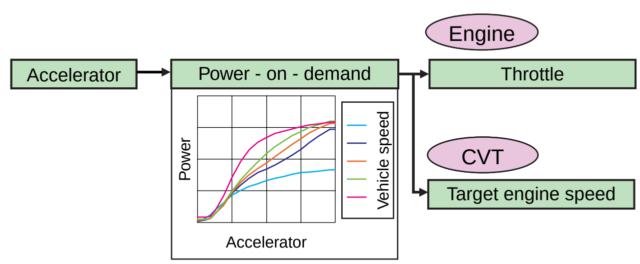

Fig. 11 Normal power - on - demand control

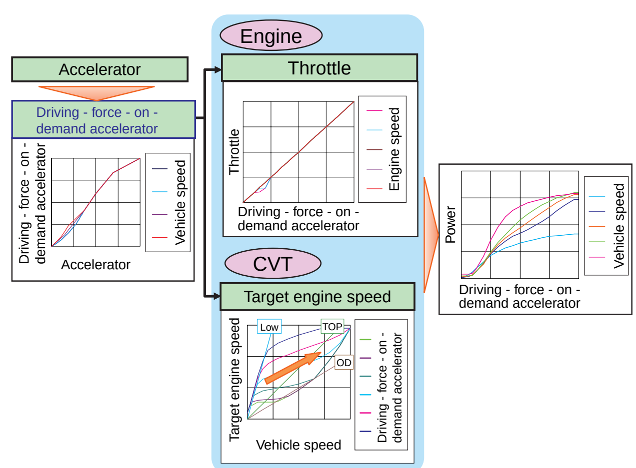

Fig. 12 New INSIGHT control

is determined. In other words, the driving force can be determined.

The driving-force-on-demand control that is employed in the new INSIGHT is directly linked to the accelerator operation, so it provides a linear feeling of torque and response, which was the merit of conventional Honda's vehicles with CVT, and a linear feeling of engine speed versus vehicle speed. In addition, the previous CVT shift control can be used without change, enabling good drive feeling to be sustained.

Also, by optimally setting the shift schedule and the throttle limit versus driving-force-on-demand, GF minimum control is maintained, regardless of whether ECON OFF or ECON ON mode is active. Changing the drive feeling can then be done separately by simply changing the relationship between accelerator and driving-force-on-demand.

5.2. Driving-force-on-demand Accelerator Characteristics

One kind of fuel economy enhancement technology is technology that stops the supply of fuel while the vehicle is moving. In the case of the CIVIC Hybrid, all cylinders are deactivated in the accelerator low position region, and when the accelerator is not depressed, thus stopping the supply of fuel while reducing friction, and realizing motor-only drive (MD). However, because the MD zone is narrow with respect to the accelerator position, it was challenging to keep MD operation when with a rough accelerator work. Accordingly, with the new INSIGHT, the gain of the driving-force-on-demand accelerator versus accelerator characteristics in ECON ON mode has been reduced, resulting in extended MD operation while gradually decelerating from a cruising condition. The features of this modification are as follows:

(a) Increased MD frequency

(b) Better sustainability of FC (Fuel Cut) operation in a situation such as on gentle downhill runs

Figure 13 shows the actual accelerator position versus driving-force-on-demand accelerator position characteristics.

In ECON ON mode, this change in characteristics resulted in a 20% increase in MD frequency. Also, the frequency of use of driving-force-on-demand accelerator moved to the low position side, thus realizing high fuel economy operation.

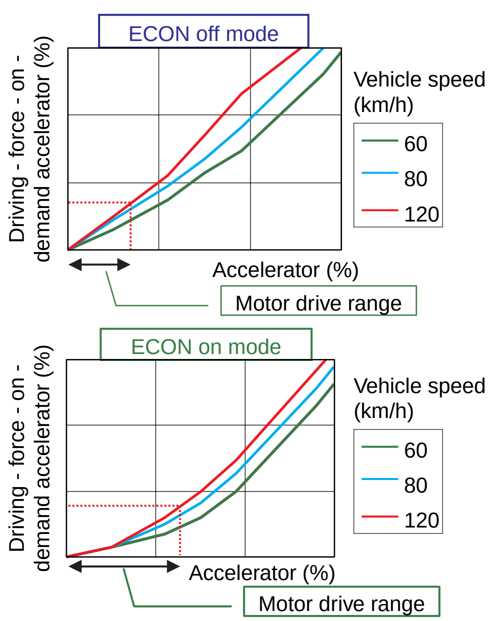

Fig. 13 Driving - force - on - demand accelerator characteristic

6. Deceleration Regeneration Control

In the development of the new INSIGHT, efforts were made to enhance fuel economy by carrying out deceleration regeneration according to the brake fluid pressure. Also, in ECON ON mode, efforts were made to increase the regeneration in places where the brake fluid pressure was high, thereby increasing the amount of energy recovered. In places where the brake fluid pressure is low, the regeneration amount was the same in both the ECON ON and ECON OFF modes; therefore, the brake pedal touch feeling was the same in these two modes as well. Figure 14 shows the deceleration regeneration amount when varying break fluid pressure.

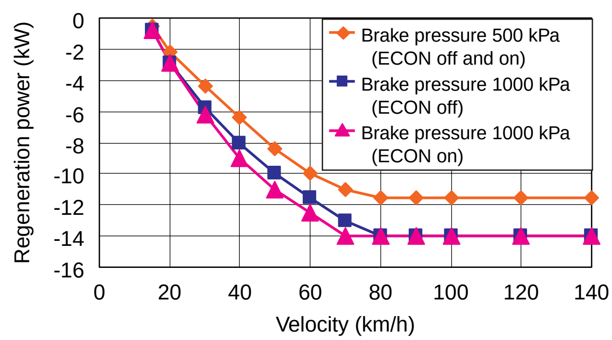

Fig. 14 Regeneration power

7. Air Conditioner Control

Air conditioner control involves using the ECON switch to select the following two items of control, aimed at enhancing the fuel economy in ECON ON mode:

(1) Enlargement of the "idling stop" zone

(a) During ECON OFF mode control, the "idling stop" time is determined by window fogging and comfort.

(b) In ECON ON mode, the "idling stop" time is determined by window fogging alone.

(2) Engine load reduction control at high air conditioner load operation

In ECON ON mode, engine load reduction was achieved by implementing the following three items:

(a) When the outdoor temperature is high, internal circulation is used, and the intake air load was reduced.

(b) The electrical load was reduced due to a reduction in the interior fan voltage in the cooling zone.

(c) The engine load was reduced due to a reduction in the frequency of the air conditioner clutch.

8. Fuel Economy Effect

A fuel economy effect confirmation was performed by 17 males and three females on a test course that took into account practical operation. The results confirmed that the average fuel economy was 9.5% higher in ECON ON mode compared to ECON OFF mode.

Figure 15 shows the results of confirming the fuel economy effect by comparing the fuel consumption when the ECON switch was in the ON and OFF positions, respectively.

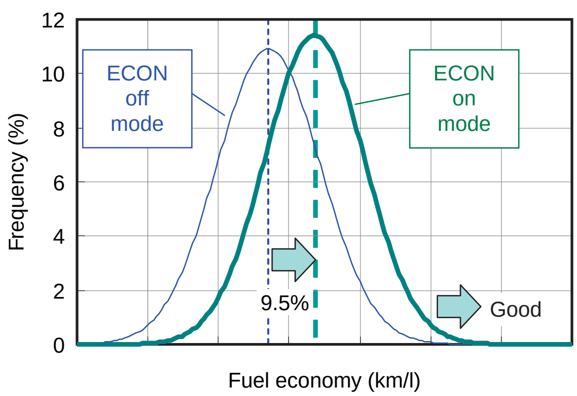

Fig. 15 Fuel economy frequency distribution

9. Conclusion

In summary, it has been shown that the new INSIGHT has both good fuel economy and good drive feeling.

(1) Fuel economy priority control can be selected with the ECON switch. In ECON OFF mode, the GF minimum target line during high fuel economy driving in which the accelerator operation amount is small can be traced. In ECON ON mode, the GF minimum target line can be traced, even during a rough accelerator operation, thus increasing fuel economy.

(2) The use of driving-force-on-demand control employing a driving-force-on-demand accelerator parameter resulted in drive feeling achieved by linear driving force and response characteristics with respect to accelerator operation, and linear increase in engine speed with respect to vehicle speed.

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■ Author ■

Toshihiko FUKUDA

Takahiro EGUCHI