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Power Train for a New Compact Sporty Hybrid Vehicle

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ABSTRACT

This paper presents a power train developed for a 2011-model compact sporty hybrid vehicle. The power train, developed based on existing mass-produced car components such as an engine, transmission, and Integrated Motor Assist (IMA) system, takes advantage of the IMA system to strike a good balance of driving performance, fuel economy, and low exhaust gas emissions. The conventional concept behind a hybrid design was to use motor output to compensate for a power reduction caused by smaller engine displacement. For the development of this power train, a new approach was taken to utilize the motor output to create a better driving feel. Making full use of a good motor response and directness, the power train realized this sporty driving feel, unlike anything offered by conventional cars.

INTRODUCTION

Fuel-efficient hybrid vehicles are drawing more and more attention, with concern growing for CO_2 emissions and hikes in oil prices. When attention is paid to existing sporty cars, many are characterized by large displacement, large horsepower, and a heavy body, which often lead to lower fuel efficiency. Hybrid vehicles, on the other hand, are more expensive than regular passenger cars, because they need an additional hybrid system including a motor, high-voltage battery, and power control unit (PCU). In the development of a new power train, the IMA technology was utilized in order to achieve a sporty car with both good driving performance and mileage. By the time the development started, a compact, lightweight, and low-cost IMA system and a proven engine transmission had already been mass produced. These components were combined to take full advantage of the IMA system, resulting in features expected of a sporty car, but at a low cost. These features include (1) use of motor torque in the low-rpm operating range, a characteristic of the IMA system, (2) fun of sporty driving derived from the manual transmission, and (3) stable control realized by a layout (low center of gravity) with the Intelligent Power Unit (IPU) located in the bottom of the trunk space. To bring the best out of these features, a 3-mode drive system was also developed. The three modes consist of the conventional Normal mode and ECON (Effective Control) mode, plus the new Sport mode. The three modes allow the driver to choose different power train features for different purposes, adding fun to practicality.

SUMMARY

CONCEPT BEHIND THE POWER TRAIN

In this development project, we combined a 1.5-L engine with a hybrid motor. The base model was the mass-produced 1.5-L, 4-valve engine, which was modified to incorporate the IMA system. Moreover, the one-intake-valve-idling VTEC (Variable valve Timing and lift Electronic Control) technology was applied to improve the environmental performance of the engine and clear the emissions levels set for the Advanced Technology Partial Zero-Emission Vehicle (AT-PZEV) rating by the California Air Resources Board (CARB). Regarding the power, the IMA system assists the engine during high-rpm operation to compensate for a reduction in power made to improve fuel efficiency. The IMA motor also increases torque during low-rpm engine operation, realizing a relatively flat output characteristic with respect to the engine speed. This contributes to a better power-train output response in the mid- to low-rpm ranges and ease of control in practical use (Fig. 1). Moreover, to realize sporty driving, a hybrid motor was combined with a six-speed manual transmission for the first time in the world. The six-speed manual transmission used as the development base was (1) modified to incorporate IMA, (2) modified to give the driver a sportive feeling, and (3) designed with gear

ratios that maintain a good balance between fuel economy and performance.

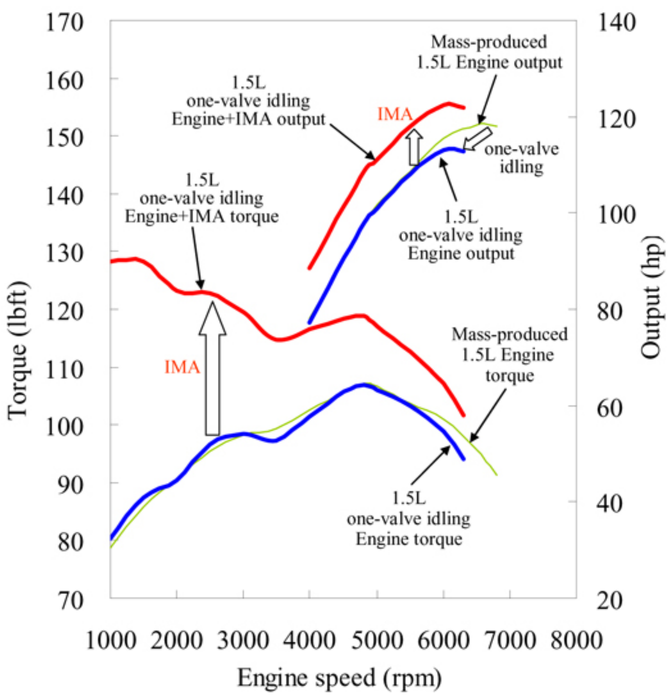


Fig. 1. Power train performance

1. ENGINE

MODIFICATIONS FOR IMA INCORPORATION

The alternating current generator (ACG) was removed from the conventional engine to mount the IMA system instead, and the starter previously installed in the engine was moved to the transmission. The engine was also equipped with an oil pan, water pump pulley, and some other carryover parts from the 2010 mass-produced hybrid vehicle. In the cylinder block, only minor modifications, such as bosses added to the mounting of the motor rotation sensor, were made to enable IMA system installation (Fig. 2).

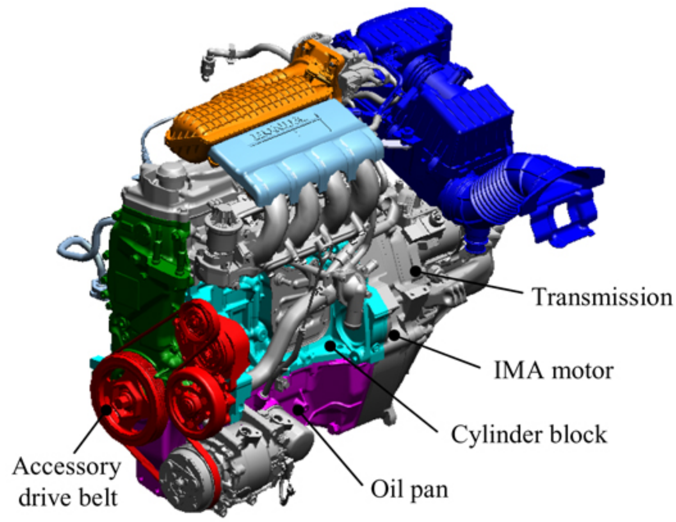


Fig. 2. Engine appearance

ENVIRONMENTAL MEASURES

To acquire AT-PZEV certification, the one-intake-valve-idling VTEC technology was used to generate intake swirl for improved the lean burn limit during cold condition. Fig. 3 outlines the one-intake-valve-idling VTEC operation. In parallel, a dual-electrode plug was introduced to improve combustion efficiency and bottom Brake Specific Fuel Consumption (BSFC) (Fig. 4). In addition, the catalytic converter originally designed for the 2010 mass-produced hybrid vehicle was used to enhance the exhaust gas processing capacity to meet the AT-PZEV requirements.

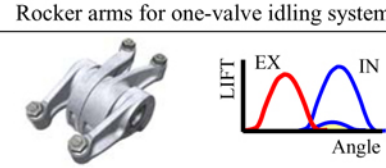
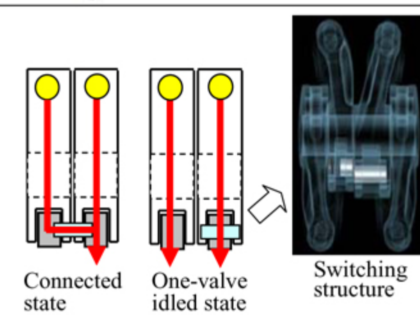
VTEC rocker arm: Valve actuation method	
	Rocker arms for one-valve idling system
R/A shape	
Actuation method	
Connecting method	Coaxial roller switching
VTEC type	One-valve idling

Fig. 3. One-intake-valve-idling VTEC operation

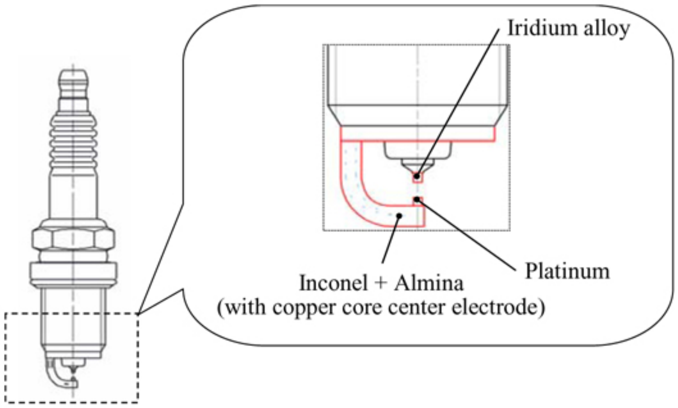


Fig. 4. Dual-electrode plug

2. TRANSMISSION

MODIFICATIONS FOR IMA INCORPORATION

A mass-produced six-speed manual transmission was used as the base and modified to allow for starter and motor installation. A neutral switch sensor necessary for the idling stop system was also added to develop a new IMA-exclusive clutch that can withstand motor torque increases.

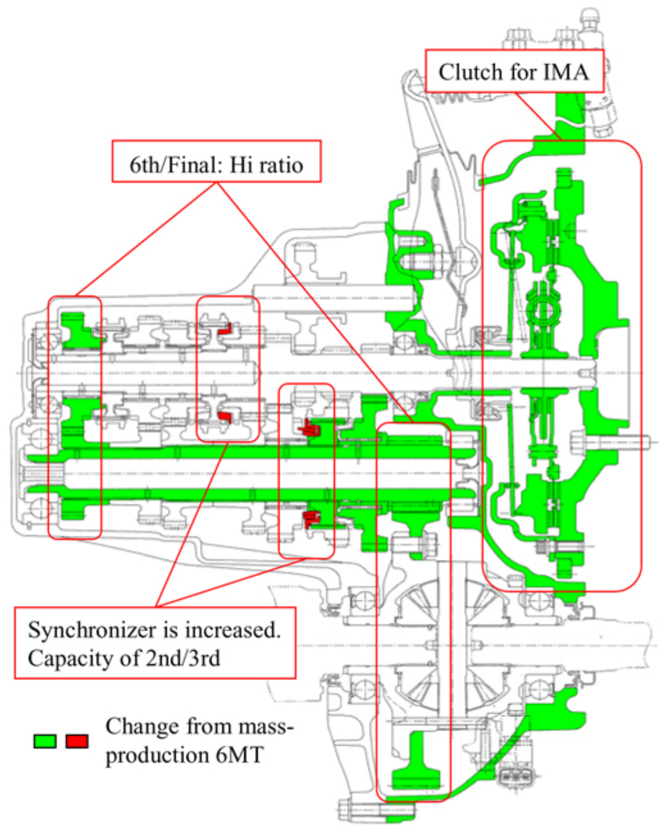


Fig. 5. Transmission structure

MODIFICATIONS FOR BETTER COMMERCIAL APPEAL

To give the driver a sportive feeling, the shift stroke was shortened from 50 mm to 45 mm. In addition, a 2-speed double cone synchronizer and a carbon synchronizer were introduced to reduce shift operation load. Fig. 5 is a schematic drawing of the modified transmission. Sportiness was also considered in designing the gear ratio. To strike a good balance between fuel economy and performance, gear ratios were set to give a sportier driving feel even at high ratios (Table 1). The final gear ratio is 4.3% higher than that of the conventional transmission to keep a lower engine rpm while driving and thereby reduce fuel consumption. The sixth gear ratio is 5.4% higher, for fuel efficiency during high-speed cruising. Although the new transmission has higher gear ratios, an engine assisted by the IMA motor produces better acceleration than a conventional one at low-rpm operation. Fig. 6 shows the comparison of acceleration performance.

Table 2. Emission measurements

In-house data

LA-4	CO (g/mile)	NMOG (g/mile)	NOx (g/mile)
Standard value	0.085	0.0068	0.0100
AT-PZEV Regulation Value	1.00	0.0100	0.0200

Table 1. Gear ratios

Main Specification		Developed Transmission	Mass-Produced 1.8L 6MT
Gear Ratio	1st	3.142 (44/14)	←
	2nd	1.869 (43/23)	←
	3rd	1.303 (43/33)	←
	4th	1.054 (39/37)	←
	5th	0.853 (35/41)	←
	6th	0.688 (31/45)	0.727 (32/44)
	RVS	3.307 (43/31/13)	←
	Final	4.111 (74/18)	4.294 (73/17)
Tire		195/55 R16	195/65R15

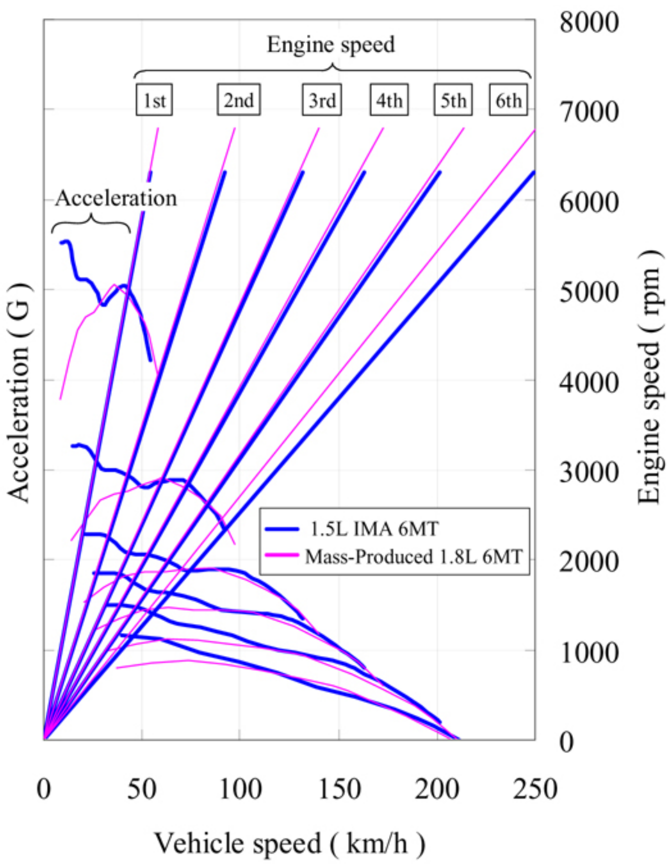


Fig. 6. Comparison of acceleration performance

3. IMA

The IMA motor, high-voltage battery, and PCU are carryovers from the 2010 mass-produced hybrid vehicle, as shown in Fig. 7. The cable was shortened to match the vehicle length, and the intake and exhaust ducts were modified to accommodate differences in vehicle shape.

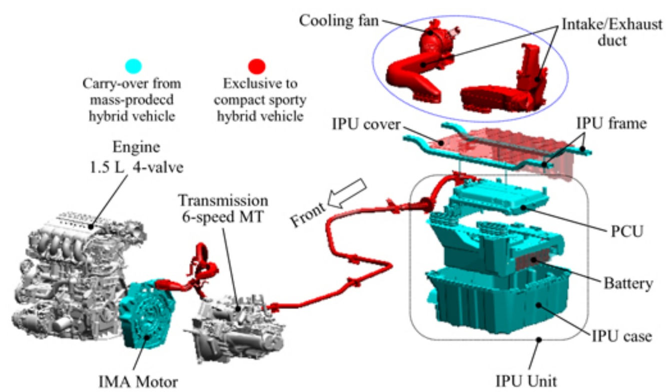


Fig. 7. IMA system hardware configuration

RESULTS

Table 2 shows the result of actual machine testing of the above power train configuration. The power plant comprises a 1.5-L engine, IMA, and 6-speed manual transmission, but its emission data clears the AT-PZEV regulation values as shown in Table 2.The 80-120 km/h acceleration vs. combined label fuel economy graph shows the relation between driving performance and fuel economy (Fig. 8). As shown here, the new power train delivers driving performance superior to a 1.8-L displacement engine, while ensuring an even better mileage than a 1.5-L displacement engine.

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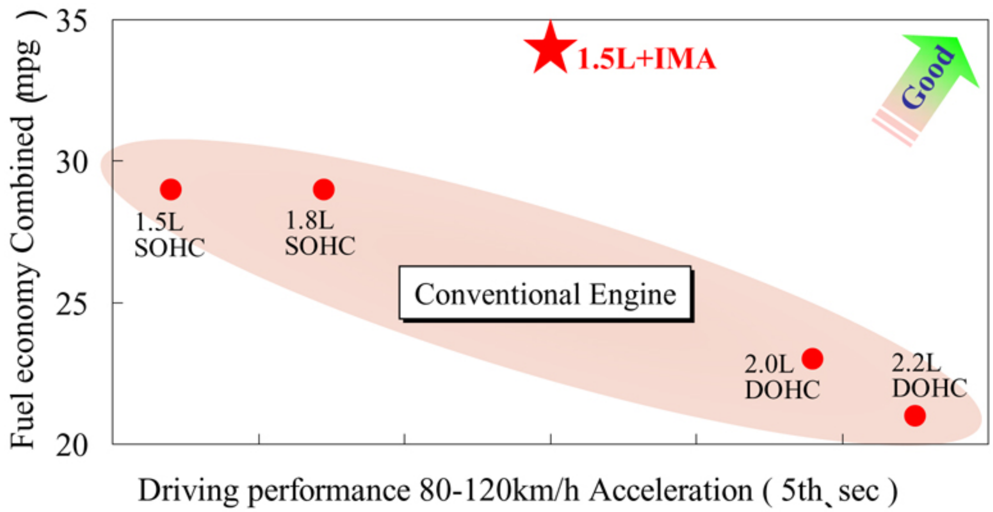


Fig. 8. Driving performance vs. fuel economy

Table 3. Main specifications of the power train

Power Train Specification (In-house data)		
Power Train Spec.		1.5L 4Cyl. 1valve idling + VTEC
Power	Engine	113 hp
	Motor	13 hp
	System	122 hp
Torque	Engine	107 lbft
	Motor	58 lbft
	System	128 lbft
T/M Spec.		6MT
Battery Voltage		100.8V
IPU Volume/Wt.		48L/38kg
FE EPA MPG Combined		34mpg

Table.3 lists the major specifications of the power train.

3-MODE DRIVE SYSTEM CONCEPT

<figure 9 here>

The new power train adopts a 3-Mode Drive System, which features the Sport Mode added to take full advantage of the IMA characteristics. Fig. 9 shows the 3-Mode switches and an outline of the system consisting of (1) Sport, (2) Normal, and (3) ECON modes for manual transmission. In the Sport Mode, the driver can feel strong power-train output that enhances driving enjoyment. The Normal Mode places emphasis on linearity that is derived from a good balance between driving performance and fuel economy. The ECON Mode gives priority to real-world fuel economy.

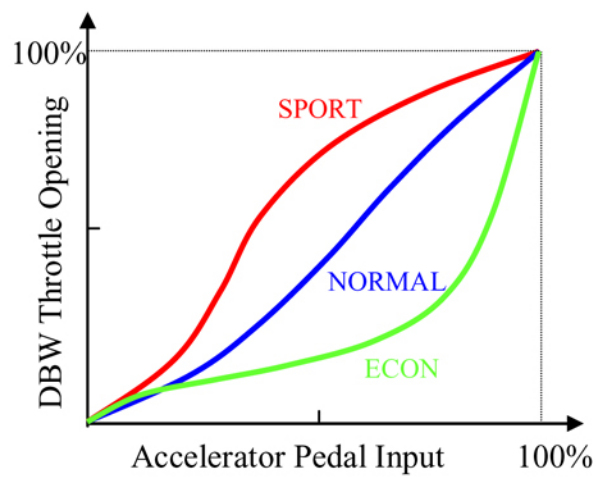
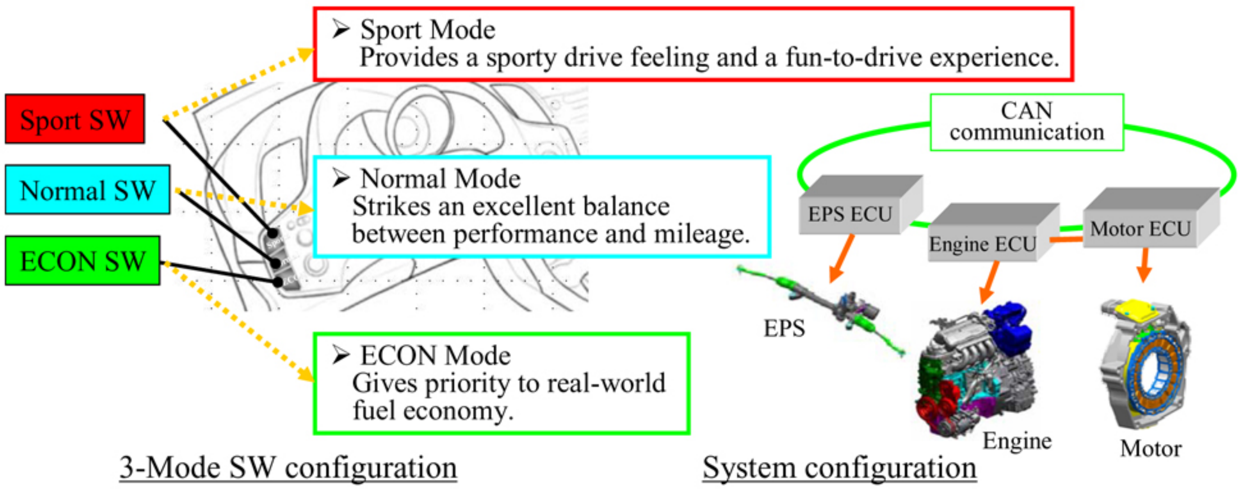


Fig. 10. Engine throttle characteristic



Mode SW	Steering effort	Engine response	Motor assist	Air conditioner
SPORT	Solid feel enhanced	Torque feel enhanced	Positive assist	Normal
NORMAL	Normal	Normal	Normal	Normal
ECON	Normal	Priority given to FE	Priority given to FE	Priority given to FE

Fig. 9. Outline of 3-Mode Drive System

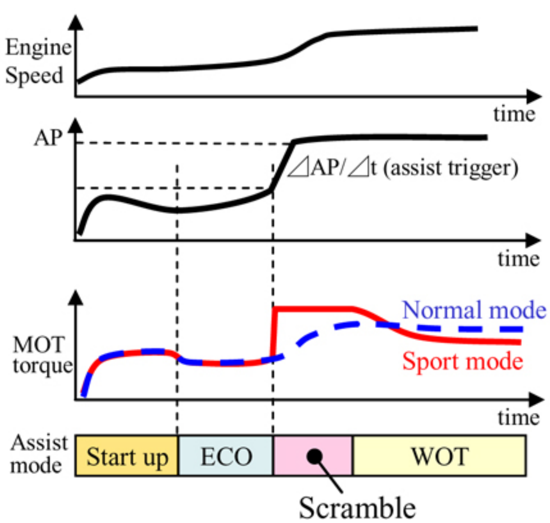


Fig. 11. IMA Operation in Sports mode

Fig. 10 and Fig. 11 show the engine and IMA settings in the three modes. Regarding the engine throttle characteristics, the Normal Mode delivers a linearity of engine throttle opening rates versus accelerator pedal(AP) input. In the Sport Mode, the throttle opens earlier in response to AP input, which enhances the feel of torque. In the ECON Mode, the throttle opening rate does not increase as fast in response to AP input, which allows the driver to drive the car in a more fuel-efficient manner (Fig. 10).There are roughly four patterns of motor assist methods: (1) startup assist, (2) ECO assist for fuel-efficient driving in a small AP opening range, (3) scramble assist triggered by a change in AP input (the driver intends to accelerate) in medium to large AP opening ranges, and (4) WOT (Wide Open Throttle) assist in a large AP opening range. The Sport Mode sets a lower threshold value for triggering the scramble mode assist, as well as drive-by-wire (DBW) control, so that a relatively small change in AP input sets off the motor assist operation (Fig. 11).As shown above, a combination of the DBW control setting and the motor assist setting realizes an IMA-enhanced system capable of three acceleration modes that the driver can choose from with the touch of a button. Fig. 12 is a graph that shows differences in the acceleration performance of the three modes.

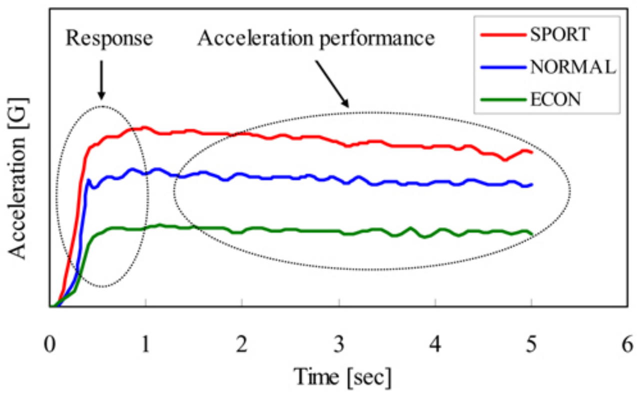


Fig. 12. Acceleration performance in 3 modes

CONCLUSION

A power train for a sporty compact vehicle was developed by combining a 1.5-L engine, IMA system, and six-speed manual transmission. The power train achieves a good balance of fuel economy, driving performance, and environmental performance.

1. Exhaust gas emissions are kept below the AT-PZEV regulation values.

2. Motor output is used not only for its original purpose of improving fuel efficiency, but also for an equivalent of increased displacement, enhancing both fuel economy and performance.

3. Taking advantage of IMA, the 3-Mode Drive System enables three types of acceleration settings: (1) ECON Mode for higher real-world fuel economy, (2) Sport Mode for a feel of sporty driving, and (3) Normal Mode for a balance between fuel economy and driving performance.

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