

Development of 2005 Model Year ACCORD Hybrid System

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ABSTRACT

The 2005 model year ACCORD Hybrid was developed to enhance the driving performance of a V6 luxury sedan while retaining the fuel economy of a compact-class, 4-cylinder CIVIC sedan. The base 3.0L V6 engine has been equipped with Variable Cylinder Management (VCM) to decrease parasitic pumping losses in the engine, while motor assist has been employed to extend the operating range of the 3-cylinder operation mode. Both these factors have contributed to improved fuel economy. The Integrated Motor Assist (IMA) system applies new technologies to the high-voltage electrical equipment, including fine patterning of the inverter chips as well as the use of an Interior Permanent Magnet (IPM) rotor. The result has been a 20% increase in maximum power and a 26% increase in maximum torque. A hybrid compressor fitted with a high-voltage drive has been employed to increase the commercial appeal of idle stop. In order to offset the increase in weight from the IMA system, aluminum has been employed in the bumper beams and certain other parts to reduce weight. All of these fuel saving technologies have resulted in a level of fuel economy, equal to that of the compact-class, 4-cylinder CIVIC sedan, achieving 29 mpg in US City mode and 37 mpg in US Highway mode.

1. Introduction

The demand for vehicles with high fuel economy and low emissions continues to increase, given the need to protect the quality of our air and slow the depletion of fossil fuel resources. A great deal of attention has therefore been focused on high fuel economy vehicles employing hybrid systems. In order to respond to the demands for improved fuel economy and reduced emissions, Honda released the ultra-high fuel economy hybrid vehicle Insight^{(1),(2)} in 1999, and the compact class CIVIC Hybrid⁽³⁾ in 2001. For the 2005 model year ACCORD Hybrid, Honda has equipped its 3.0L V6 engine with Variable Cylinder Management (VCM)⁽⁴⁾, a cylinder idling system with the capacity to disable multiple cylinders in

cruising mode. This, coupled with an efficient five-speed automatic transmission results in high cruising efficiency, increasing the vehicle's appeal in the US market. The IMA system employed in the ACCORD Hybrid was designed on the basis of the system fitted in the CIVIC Hybrid.

2. Issues in Achieving High Fuel Economy and Development Goals

To achieve high fuel economy in the CIVIC Hybrid, a motor assist system was employed while reducing the displacement of the engine from the base 1.5L to 1.3L. The increased power

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provided by the motor assist was not used to contribute to enhanced dynamic performance but to compensate for the reduction in power caused by the reduced displacement of the engine. The 3.0L V6 engine employed in the ACCORD Hybrid is provided with VCM, which means that the engine effectively runs at a displacement of 1.5L when the rear bank of three cylinders is closed. In this way, the VCM generates the same effect in terms of improved fuel economy as previously achieved by the reduction in displacement of the CIVIC Hybrid engine, which enables the increased power provided by the motor assist system to be used to enhance dynamic performance.

The development goal for the new system in the ACCORD Hybrid was therefore to employ VCM to effectively reduce the displacement of the engine, enabling the development of a mid-size hybrid vehicle combining superior dynamic performance to existing 3.0L models with fuel economy equivalent to that of the compact-class, 4-cylinder Civic sedan (Fig. 1). This paper will discuss the technologies employed to improve fuel economy, the IMA system and the vehicle technologies that were instrumental in enabling the achievement of the target fuel economy and driving performance.

3. Hybrid System and Technologies for Improved Fuel Economy

As Fig. 2 shows, the new IMA system employs the identical layout and configuration used in the CIVIC Hybrid system. The power train, located at the front of the vehicle, positions a motor between the engine and transmission, while an Integrated Power Unit (IPU), equipped with a high-voltage 144 V battery and a Power Control Unit (PCU), is located at the rear. The system is electrically connected by 3-phase high-voltage cables running between the front and rear of the vehicle. Figure 3 shows an exterior view of the power train.

Drive-By-Wire (DBW) and torque management control, which operates in cooperation with the cylinder idling system, were added to the existing idle stop, power assist and regeneration systems to improve fuel economy. In addition, the power of the electric motor and high-voltage electrical equipment was increased to enhance dynamic performance over the base vehicle. The ratio of contribution of each of the various systems to the improvement of fuel economy over the base vehicle is shown in Fig. 4. In the previous system, power assist was provided to aid mainly in increasing engine torque. In the new system power assist is also employed to increase the operating range of the cylinder idling mode, further improving fuel economy.

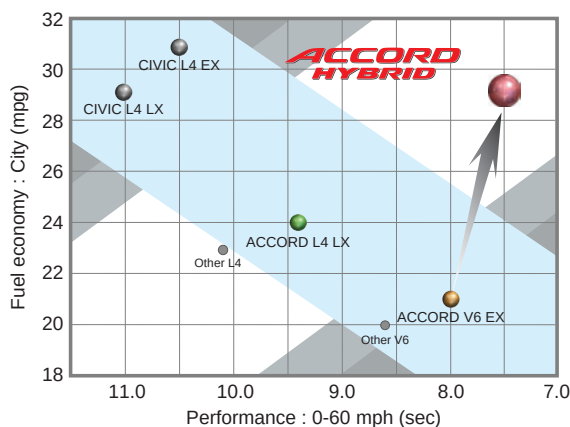


Fig. 1 Fuel economy vs. performance

To ensure the efficient use of energy and power, the driving pattern in which fuel consumption was lowest, as shown in Fig. 5, was employed as the basic control pattern for the system. Power from the electric motor is used to increase the frequency of cylinder idling. This enables 3-cylinder operation to be maintained even under gentle acceleration, whereas under the previous cylinder idling control the system would revert from 3-cylinder to 6-cylinder operation under these same conditions. In addition, monitoring of brake pressure has enabled power regeneration in the motor to be increased and cylinder idling to be activated under braking, thus increasing the amount of energy regeneration.

Figure 6 shows a conceptual diagram of the engine torque and electric motor torque in relation to the total torque output by the power plant during acceleration. Torque output and distribution of

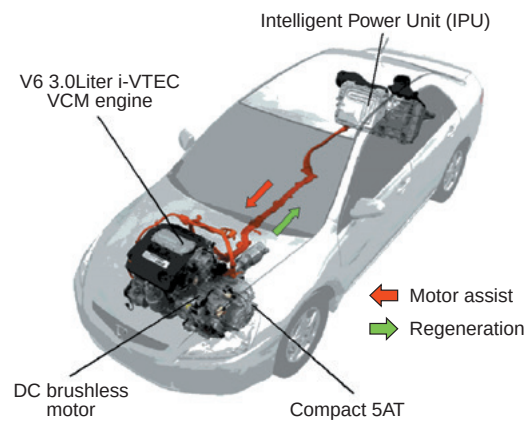


Fig. 2 IMA system configuration

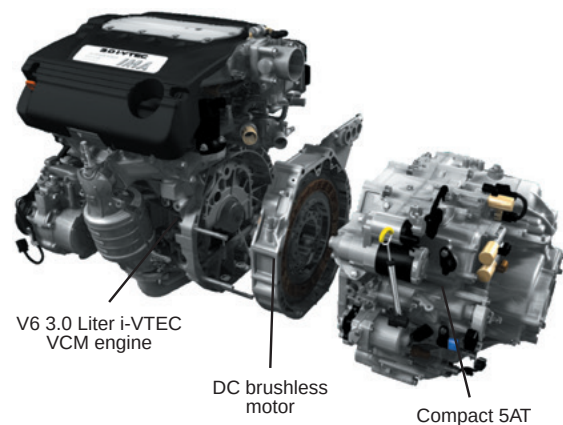


Fig. 3 Layout of IMA power plant

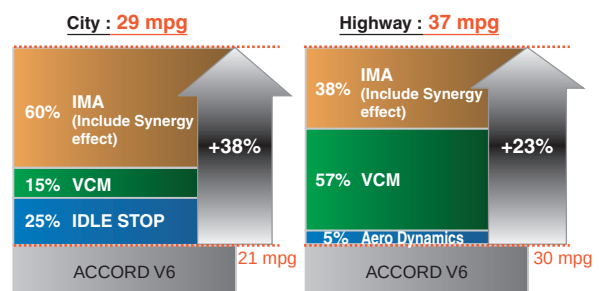


Fig. 4 Ratio of contribution of various systems of US LA4 mode fuel economy

the engine and electric motor are decided by target torque requirements at the crankshaft according to the energy management software. In addition to extending the range of cylinder idling discussed above, the system cuts fuel and draws torque from the electric motor to drive the vehicle when throttle opening is low, further improving fuel economy. Figure 7 shows the range of 3- and 6-cylinder operation in this system. The use of motor assist has enabled 3-cylinder operation in ranges that previously required 6-cylinders.

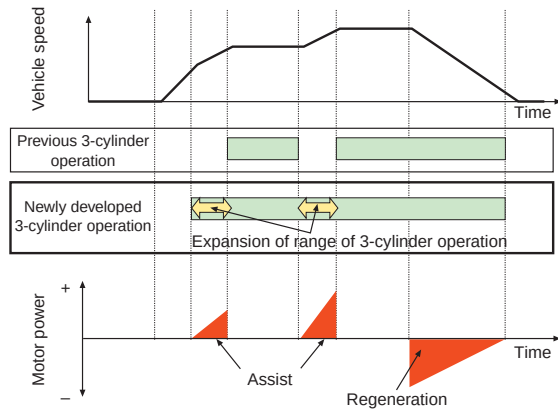


Fig. 5 Characteristics of 3-cylinder operation

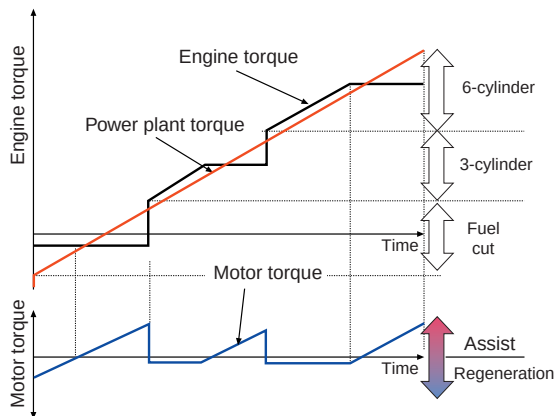


Fig. 6 Characteristics of torque output

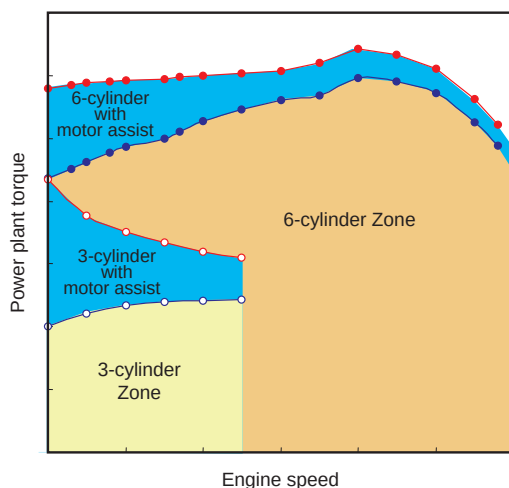


Fig. 7 Ranges of 3- and 6-cylinder operation

4. Power Plant Configuration and IMA System

4.1. Engine / Transmission

The 3.0L V6 engine used as the main power source in the ACCORD Hybrid has been equipped with the VCM system employed in the Japanese INSPIRE and the US Odyssey, enabling pumping losses to be reduced by means of instantaneous closure of the valves in one bank of cylinders and engaging 3-cylinder operation in response to changes in driving load.

To give the vehicle greater appeal in the US market, a 5-speed automatic transmission offering superior efficiency in cruising mode has been employed together with the newly developed trochoid-type electrical oil pump shown in Fig. 8. The electrical oil pump maintains oil pressure in the hydraulic circuits which are closed when the idle stop system is in operation, ensuring a solid coupling with the starting gear clutch to enable smooth takeoff (Fig. 9).

The highly responsive lock-up clutch shown in Fig. 10 has been employed to further improve fuel economy. The response time of the new clutch is one-third that of the former model, improving fuel economy by approximately 1.9% (Fig. 11).

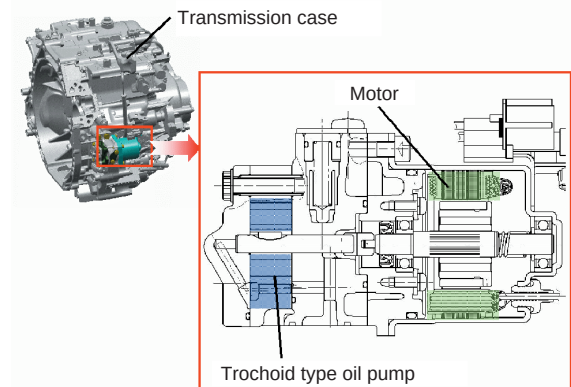


Fig. 8 Electric oil pump

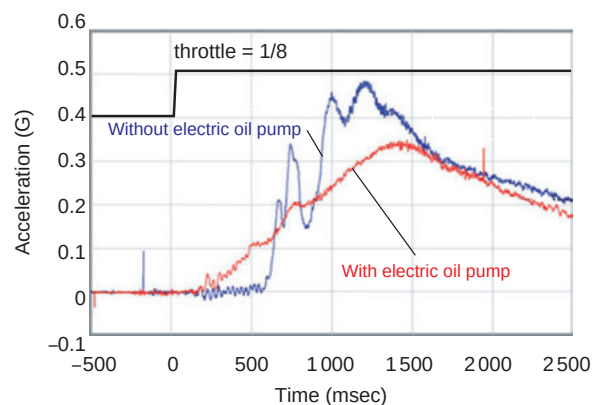


Fig. 9 Difference in acceleration with and without electric oil pump

4.2. IMA System

In addition to making the IMA system more advanced than the unit employed in the CIVIC Hybrid, power of the motor was increased while its size was reduced. Additionally, weight and size of the high-voltage electrical equipment and battery were reduced to better match them to the V6 engine and ACCORD body.

4.2.1. Electric motor

In the electric motor, the rotor type Surface Permanent Magnet (SPM) employed in the former model has been replaced by a rotor type Interior Permanent Magnet (IPM) to enable efficient use of reluctance torque (Fig. 12). In addition, the thermal resistance of the rare earth magnet built into the rotor has been enhanced, and its maximum energy production capacity increased by approximately 15%.

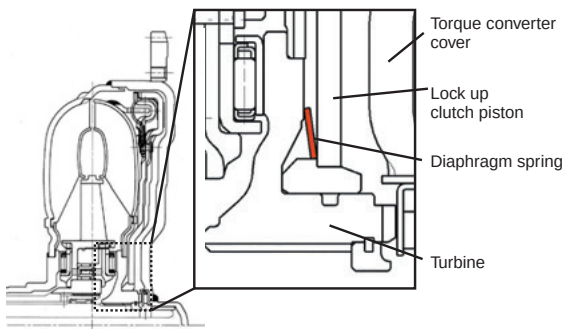


Fig. 10 High-speed lock-up clutch

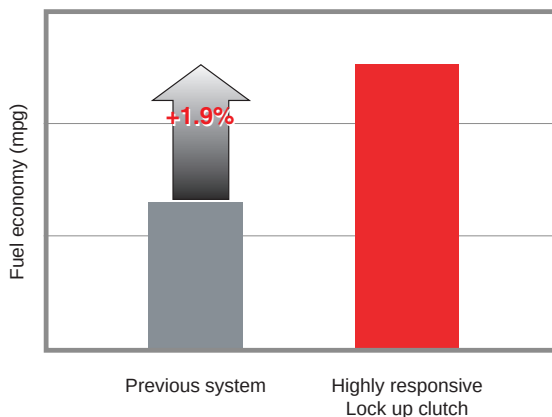


Fig. 11 Optimization of torsion damper for lock-up clutch

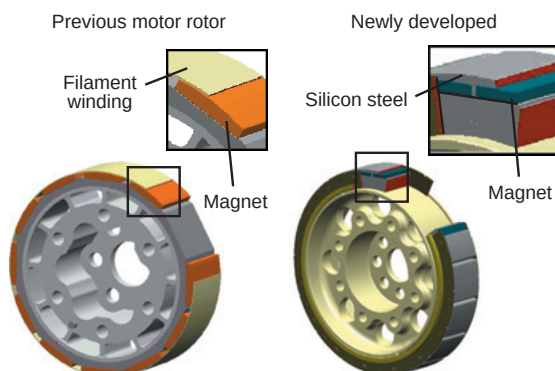


Fig. 12 Electric motor rotor

The magnetic pick-up sensor used formerly has been replaced by a resolver type sensor. Increased accuracy in the detection of rotor position as well as the application of vector control have also enabled efficiency to be increased. These enhancements have increased maximum torque by approximately 26%, maximum power by approximately 20%, and efficiency in all ranges by 1-3% over the electric motor employed in the CIVIC Hybrid (Fig. 13).

4.2.2. High-voltage unit

The size of the IPU was reduced to respond to increased power and to enable a hybrid compressor inverter (discussed below) to be fitted in a single high-voltage package. Figure 14 shows the configuration of the IPU.

Loss reduction achieved by fine patterning of the Insulated Gate Bipolar Transistor (IGBT) chips in the inverter fitted in the IPU, the employment of an inbuilt film condenser, and reduction of the number of components has resulted in a 50% reduction in the size of the inverter (Fig. 15).

Further, a Digital Signal Processor (DSP) has been employed in the DC-DC converter. The use of digital rather than analog control has enabled output current to be increased by 60% while the unit has undergone a 17% reduction in size (Fig. 16).

Despite the increase in the power of the IMA system, the development of these new technologies has enabled the volume of the IPU to be reduced by 5%, even with the installation of the hybrid compressor inverter.

4.2.3. High-voltage battery and battery box

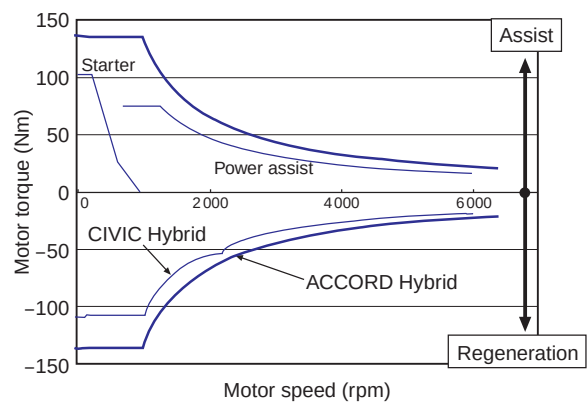


Fig. 13 Electric motor performance curve

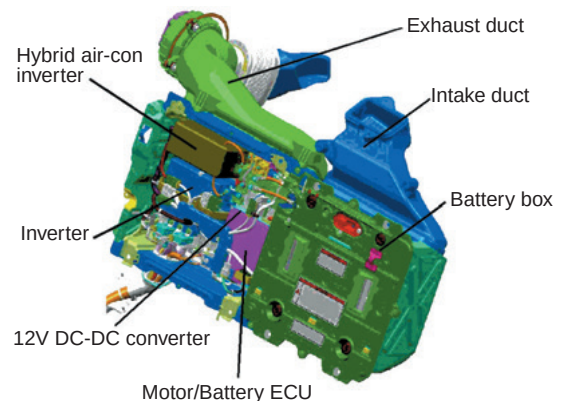


Fig. 14 IPU system

As in the CIVIC Hybrid, a Nickel Metal Hydride (Ni-MH) battery module was employed. Compared with lead-acid batteries, Ni-MH batteries have higher power density per unit weight, higher energy density, and longer life⁽⁵⁾ making them the better choice for the electrical power system. In the ACCORD Hybrid, modifications have been made to achieve the required increases in regenerated power and power assist. To increase power, the shape and form of the current collectors was modified to reduce internal resistance (Fig. 17). This enabled the number of welding points to be increased and equalized the current density in the collectors, resulting in a reduction of approximately 39% in internal resistance.

To enable the size of the battery box to be reduced, the previous

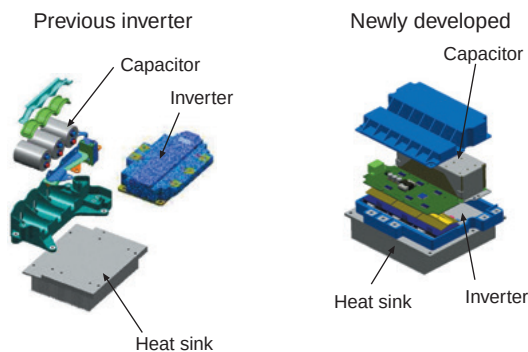


Fig. 15 View of inverter system

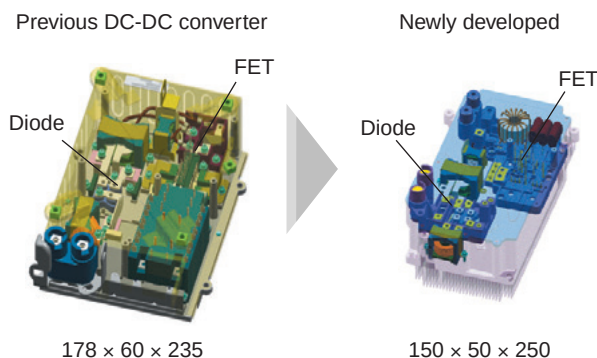


Fig. 16 Reduction in size of DC-DC Converter

	Previous battery	Newly developed
Current collector		
Number of welding points	56	104
Internal resistance	19.6 mΩ	12 mΩ

Fig. 17 Current collecting plate

integrated plastic-molded box⁽⁶⁾ was replaced by an assembled model. Reduction of size and integration of the component parts has both increased ease of assembly and reduction in size of the box by 10% (Fig. 18).

4.2.4. Cooling system

As in the CIVIC Hybrid, the cooling system in the ACCORD Hybrid is mounted in the trunk. The system takes in air through the intake duct in the rear tray and uses it to cool the high-voltage battery and equipment in IPU. The cooling channels employed in the ACCORD Hybrid enable some of the cooling air to be exhausted out the vehicle via the rear outlet as shown in Fig. 19. As Fig. 20 shows, this has resulted in a reduction of approximately 10°C in the temperature of the cooling air when the vehicle is driven after having sat for a period of time in warm quiescent air. This helps prevent any losses in power of the IMA system caused by increases

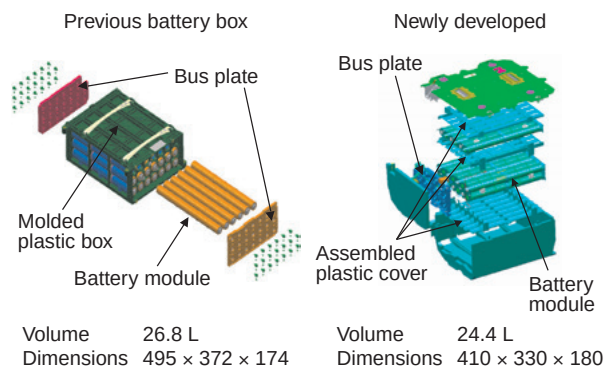


Fig. 18 Comparison of battery boxes

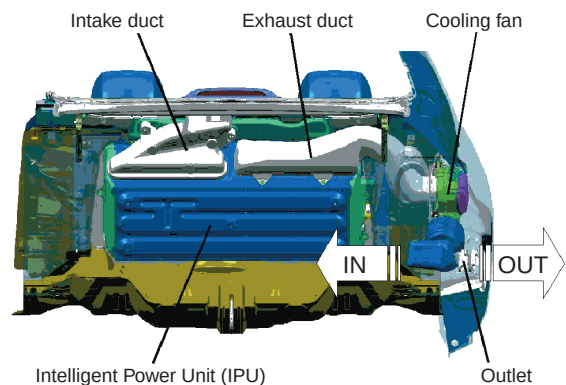


Fig. 19 Cooling system for IPU

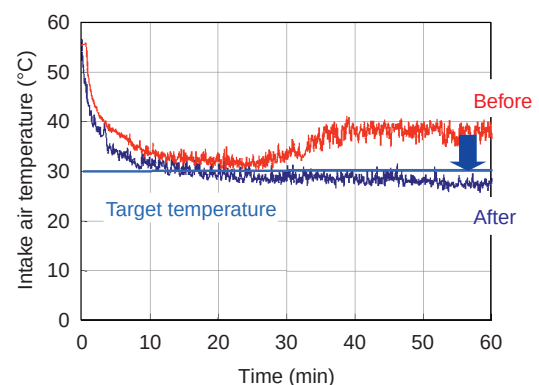


Fig. 20 Intake temperature

in the temperature of the high-voltage system.

The increased power of the motor and the high-voltage equipment discussed above has resulted in the achievement of a maximum power of 190 kW (255 hp) in the power plant (engine + motor). In contrast with the base ACCORD, the new ACCORD Hybrid produces more torque at lower engine speeds with much of the torque generated by the electric motor (Fig. 21).

5. Body Technologies

5.1. Hybrid Air Conditioner

To further increase the commercial appeal of the vehicle, a hybrid compressor with partial motor drive has been developed which enables the air conditioner to continue functioning when the engine is stopped (in idle stop mode). A motor-driven scroll compressor was added to a separate shaft at the end of the existing belt-driven scroll compressor, forming an integrated unit (Fig. 22).

The motor-driven scroll compressor goes into operation when

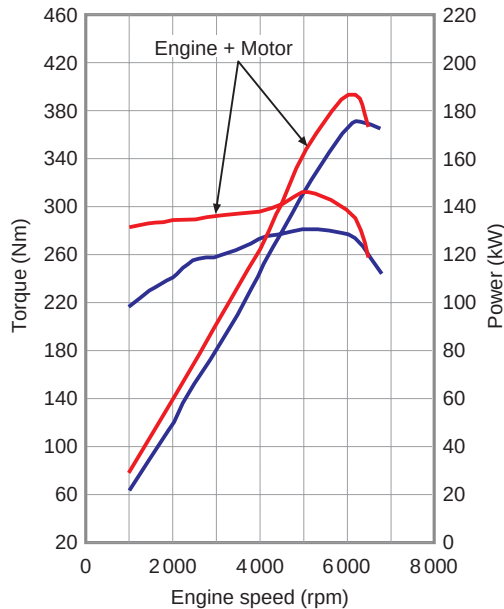


Fig. 21 Output performance of ACCORD Hybrid power plant

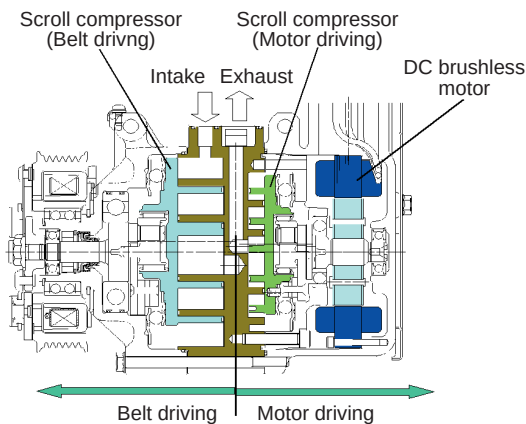


Fig. 22 Structure of hybrid compressor

the vehicle is in idle stop mode and the belt-driven compressor cannot operate, ensuring that a cool cabin temperature is maintained (Fig. 23).

A comparison of the estimated power consumed in operating the belt-driven compressor and the motor-driven compressor when the engine was running enabled a more efficient compressor drive mode to be selected, contributing to further reductions in actual fuel consumption.

5.2. ACM

The Active Control engine Mounts (ACM) system has been employed to counteract the increase in engine vibration when operating in 3-cylinder mode (Fig. 24). To respond to the increased operating range of the cylinder idling system the electromagnetic parts of the ACM have been enlarged in comparison to the previous

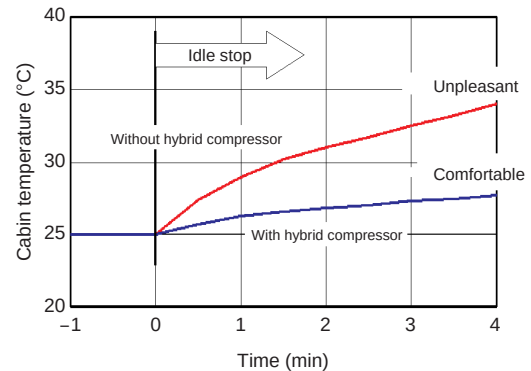


Fig. 23 Effect of hybrid compressor

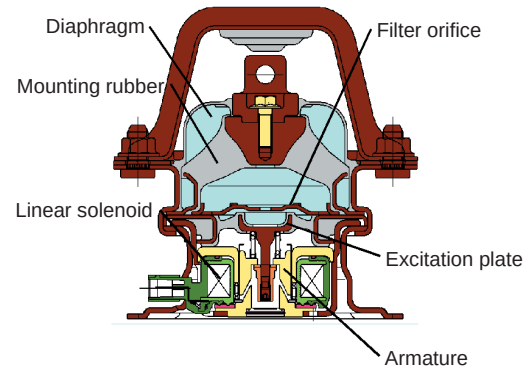


Fig. 24 Structure of ACM

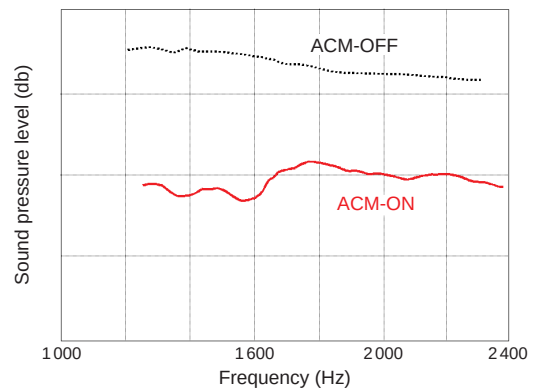


Fig. 25 Comparison of vibration level with ACM operation

model to increase its power. This has increased the level of vibration reduction by approximately 10 dB, reducing both booming noise and body vibration during cylinder idling (Fig. 25).

6. Weight Savings

In order to maintain a high level of performance despite the added weight of the IMA system, weight needed to be reduced in other areas. A reduction of approximately 80kg was achieved in the engine and various parts of the body to reach this goal.

In the body of the vehicle, aluminum has been employed in the rear knuckles, hood, and front and rear bumper beams, reducing weight by approximately 40 kg. In the engine, the use of magnesium in the intake manifold and head cover has resulted in a weight reduction of approximately 20 kg.

In addition, the spare tire has been replaced with a flat tire repair kit called the Instant Mobility System (IMS), further reducing weight (Fig.26).

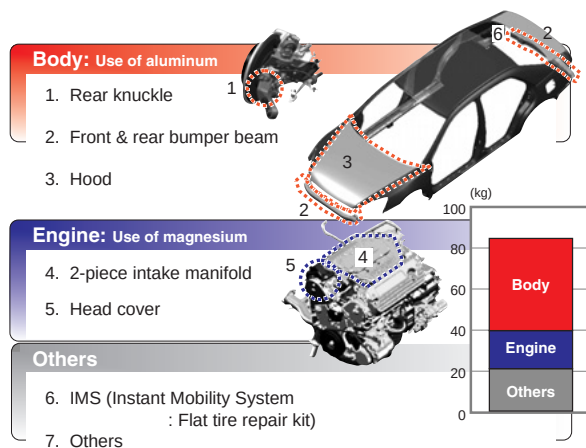


Fig. 26 Weight reduction

7. Conclusion

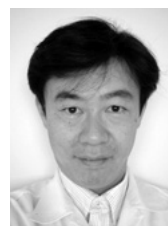
The major strategy for the improvement of fuel economy in the ACCORD Hybrid has been the employment of electric motor assist to increase the range of operation of the cylinder idling system. Together with the achievement of increased power in the IMA system and weight savings in the body, this has resulted in a vehicle that displays a level of dynamic performance exceeding that of the former V6 ACCORD as well as a level of fuel economy equivalent to that of the compact-class, four-cylinder CIVIC Sedan, with figures of 29 mpg in US City mode and 37 mpg in US Highway mode.

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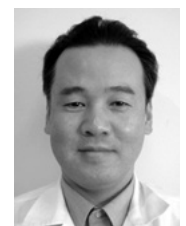
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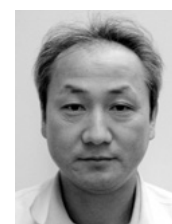
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