

Development of V6 ACCORD Hybrid 5 Speed Automatic Transmission System

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ABSTRACT

The 5-speed automatic transmission employed in the 2005 model year V6 Accord Hybrid was developed to enable the vehicle to display the powerful and refined driving performance of a V6 sedan, while achieving the fuel economy of a 4-cylinder compact sedan.

The Accord Hybrid represents the first combination of an IMA system and a stepped AT employing a torque converter. While its overall length has been reduced, the new AT has been designed with consideration of the high torque generated by the V6 3.0L i-VTEC engine and the IMA motor.

Expansion of the cylinder idling operating range and more effective regeneration of deceleration energy required a redesigned long torsion damper and a highly responsive lock-up clutch mechanism. The system has also been equipped with an electronic oil pump to enable smooth takeoff after idle stop, and a hydraulic system that employs a linear solenoid for direct control of all shift stages. The use of these new technologies has enabled the achievement of a superb balance of fuel economy and driving performance.

1. Introduction

Year by year, the demand for lower automotive emissions and higher fuel economy increases. In the United States, with its steep rise in gasoline prices due to the change in energy policies since September 11th 2001, the focus on low fuel consumption, and low polluting vehicles fitted with hybrid systems has been gaining steady momentum.

On December 10, 2004, Honda launched the V6 ACCORD Hybrid, in response to these market demands.

The IMA system for this ACCORD Hybrid is based on the IMA system employed in the CIVIC Hybrid but with enhanced motor generator performance. A V6 3.0L i-VTEC engine with Variable Cylinder Management (VCM) is incorporated in the system, and integrated control is carried out. This paper introduces the new

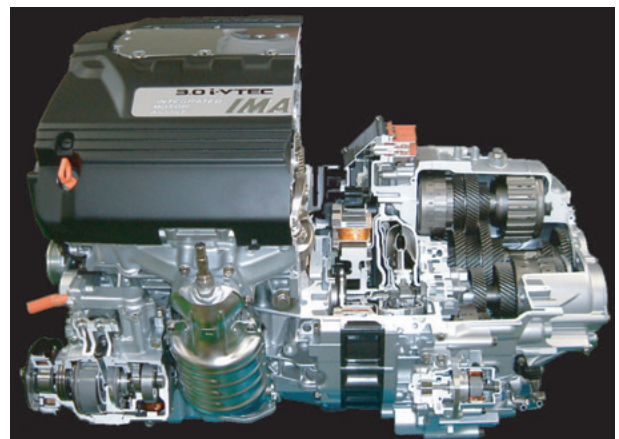


Fig. 1 ACCORD Hybrid powerplant cut model

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5-speed automatic transmission applied in this system along with its configuration, features, and performance^{(1), (2)}.

Figure 1 shows a photograph of a cut model of the power plant.

2. Configuration of 5-Speed Automatic Transmission for the ACCORD Hybrid

2.1. Basic Layout and Main Specifications

The IMA system power plant of the ACCORD Hybrid comprises the engine, motor, and transmission, and is fitted in a lateral series layout. In this development project, a dramatically shorter transmission length enabled the total increase in power plant length to be minimized, even with the addition of the IMA motor.

Adoption of a thin-walled torque converter having a flatness rate of 65%, and the addition of a thirdshaft for 3rd gear drive, reduced the transmission's total length by 60 mm compared to the 2003 model ACCORD V6 5-speed AT. Figure 2 and Table 1 give a section diagram of the 5-speed AT and its main specifications.

Along the thirdshaft are arranged the 3rd gear clutch, 3rd gear itself, and 4th gear. When driving in 3rd gear, torque is transmitted via the thirdshaft. Adding this shaft enables the length of the other shafts to be reduced, greatly contributing to a reduction in the overall length of the transmission.

In addition, moving the idle gear row from the rear end of the transmission to the center of the support bearing minimizes gear noise due to shaft flex.

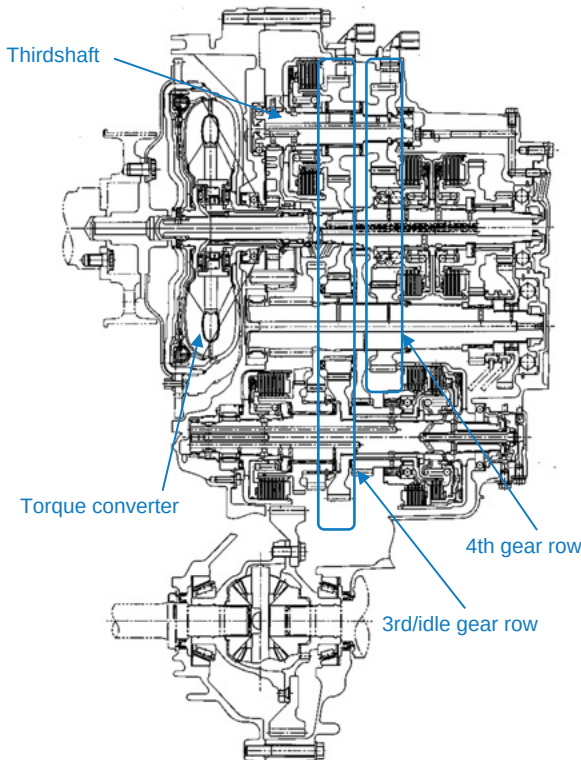


Fig. 2 Main section of ACCORD Hybrid 5AT

Table 1 Main specifications of ACCORD Hybrid 5AT

Type	4-Axis 5speed AT	
Ratio		O/A
1ST	2.685	11.747
2ND	1.565	6.849
3RD	1.023	4.476
4TH	0.729	3.190
5TH	0.530	2.321
RVS	1.888	8.263
Final	4.375	
Torque converter	$\tau_0=5.4$ $k_0=1.7$ (Long-torsion damper, Highly-responsive lock up clutch)	
Hydraulic system	All shift stage direct control Idle stop control	
Electric oil pump	Type: Trochoid rotor 3cc/rev Rating: 7.4L/min @ 343kPa	

2.2. Gear Ratio

Generally, the higher the gear ratio is, the better the highway fuel economy. With the ACCORD Hybrid VCM + IMA system, considering a balance with the cylinder idle range, the optimum gear ratio for the system is selected to achieve both driving and fuel economy performance.

Figure 3 shows the relationship between acceleration performance and mode fuel economy, while Fig. 4 shows that between the final gear ratio and mode fuel economy.

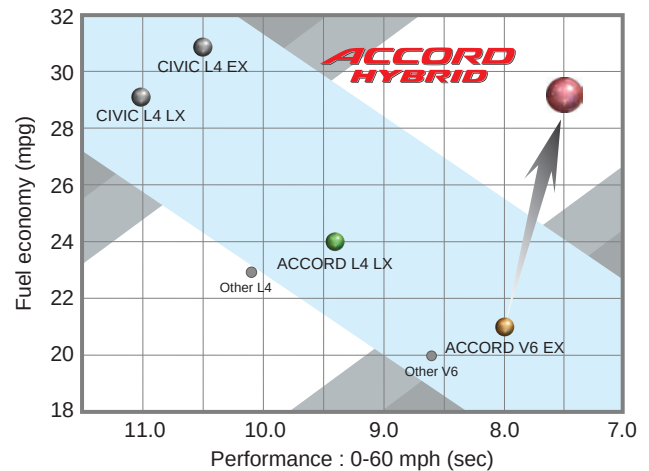


Fig. 3 Performance vs. fuel economy

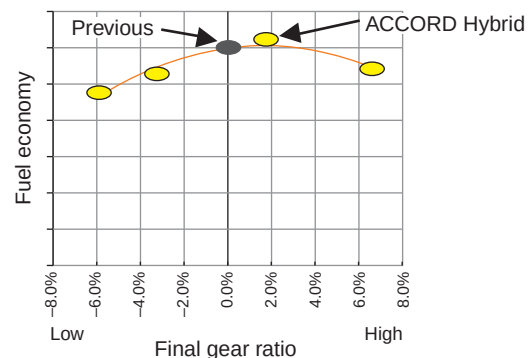


Fig. 4 Final gear ratio vs. fuel economy

2.3. Transmission Case Weight Reduction

When creating a hybrid vehicle, the addition of an IMA system increases the vehicle's weight compared to that of a conventional vehicle.

In order to minimize weight increases, CAE technology was employed for designing the new 5-speed AT system. The weight of the torque converter case and transmission case was reduced by 6%, while ensuring rigidity equal to or better than that of a conventional type AT. Figure 5 shows the results of a case stress simulation.

2.4. Electric Oil Pump

A trochoid type electric oil pump that operates during idle stop was newly developed in response to the IMA idle stop system.

With previous AT systems having only an oil pump that is driven by the engine, if an idle stop occurs, the oil pump stops and hydraulic pressure is not available. When the engine restarts there is a sudden rise in hydraulic pressure, causing a shock at start-off due to sudden clutch engagement. Therefore, in order to maintain the hydraulic pressure necessary for clutch engagement even during idle stop, an electric oil pump is employed, ensuring smooth start-off performance (Fig. 6).

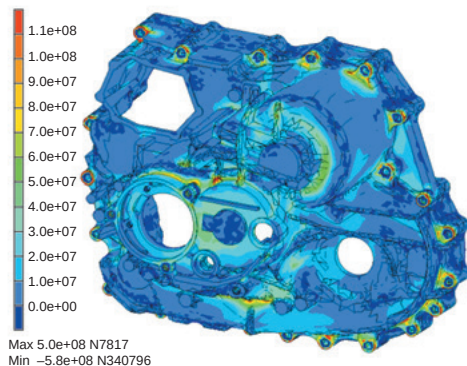


Fig. 5 Simulation of case stress

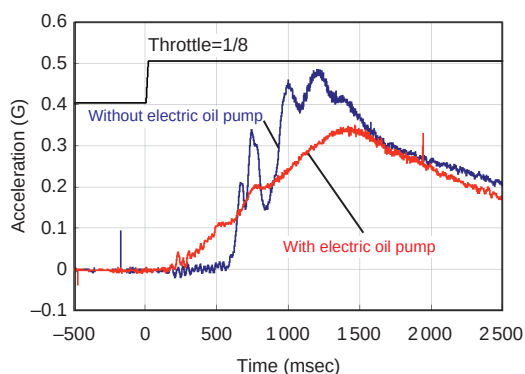


Fig. 6 IMA start characteristics

2.4.1. Electric oil pump system configuration

The electric oil pump system is composed of the pump assembly attached at the front of the transmission, and a driver unit.

The electric oil pump driver receives output torque requirement commands and sends information such as oil pump operation status, through two-way communications with the ECU. It controls the brushless motor in the electric oil pump assembly without a rotation sensor or current sensor. Figure 7 is a block diagram of the electric oil pump system.

During idling or when traveling, hydraulic pressure is supplied by the engine driven oil pump. During idle stop, pressure is supplied by the electric oil pump. To achieve this function, the hydraulic circuit configuration is such that the intake and discharge hydraulic passages are positioned parallel to the engine driven oil pump, and merge with the passage to the clutch. In addition, a check valve at the merge point with the discharge passage from the engine driven oil pump provides a simple device for switching the source of hydraulic pressure. Figure 8 shows the hydraulic circuit concept diagram.

The electric oil pump assembly is composed of the trochoid type oil pump and the brushless motor. The motor drive force is transmitted to the pump through an Oldham's coupling (Fig. 9).

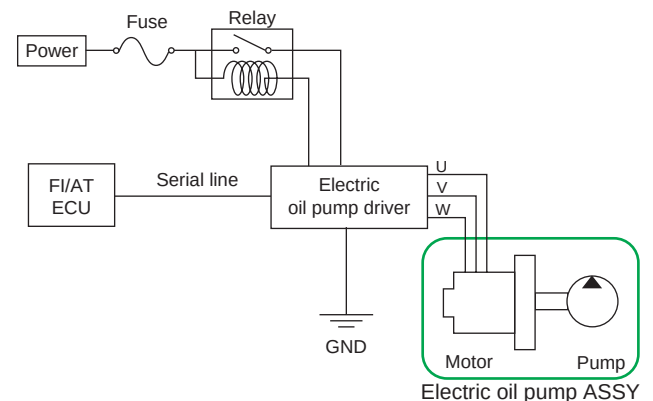


Fig. 7 Electric oil pump system

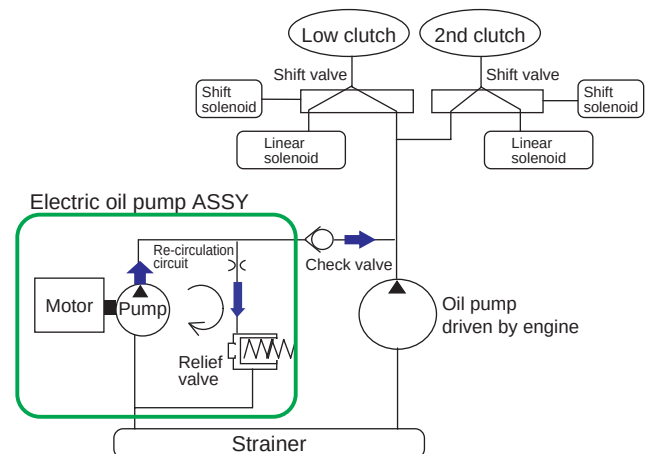


Fig. 8 Hydraulic circuit

2.4.2. Oil pump

To reduce friction, a small-diameter, wide trochoid rotor was adopted, minimizing side surface sliding resistance.

In addition, to minimize volumetric loss of efficiency at low viscosity high oil temperatures, the rotor housing is made of the same material as that of the rotor. Even at high oil temperatures, the pump side clearance can be maintained at a fixed minimum level, thereby achieving high efficiency in a compact and light-weight unit.

When the electric oil pump is activated, the discharge pressure from the engine driven oil pump closes the check valve. This blockage causes the motor speed to drop below the limit at which the current sensorless motor can turn stably. Another issue is that the motor load is initially light due to air bubbles being trapped in the pump while it's stopped, and it takes time until the motor speed stabilizes.

To address these issues, an internal recirculation circuit structure is provided in the unit. Before idle stop begins, the electric oil pump begins creating pressure and stands by at minimum speed or higher. By operating for a fixed period of time, the air bubbles inside the electric oil pump are diffused, minimizing load fluctuation when the check valve is released. With these measures, smooth starting after idle stop is possible.

2.4.3. Pump motor

The adoption of a brushless motor gives an increase in efficiency of approximately 20% over a DC brush motor of the same output.

A low noise motor was developed to drive the pump during idle stop when there is no noise from the engine or other devices. In order to reduce the noise from the bearings, which are a major source of noise from motors, the engagement dimensions were optimized and a preload spring installed, thereby minimizing bearing looseness.

These measures reduced noise in the cabin when the electric oil pump assembly is driven to less than 30 dB, the level of noise pressure in the cabin when the engine is stopped.

2.4.4. Electric oil pump driver

In order to minimize any electrical power loss due to wiring voltage drops, the electric oil pump driver is placed in the engine compartment. The location of the driver is on top of the wheelhouse, which has limited exposure to water, although a waterproof structure is also employed (Fig. 10).

The drive frequency is set outside of the audible range, cutting high frequency noise generated by the driver.

2.5. Long Torsion Damper

A new long torsion damper was developed to respond to an extended range of cylinder idle driving (Fig. 11). To attenuate torque fluctuations during cylinder idling, the torsion damper's spring constant was made 17% lower than that of the conventional unit. The resonance frequency was designed to be that of the lower limit speed of cylinder idle driving or less, thereby minimizing drive train vibration. This ensures good marketability, and at the same time contributes to enhanced fuel economy.

In addition, to reduce the shock from stepping on the throttle when the lock-up clutch is engaged, the torsion damper's operation angle is five times greater than that of a conventional unit (Fig. 12).



Fig. 10 Electric oil pump driver layout

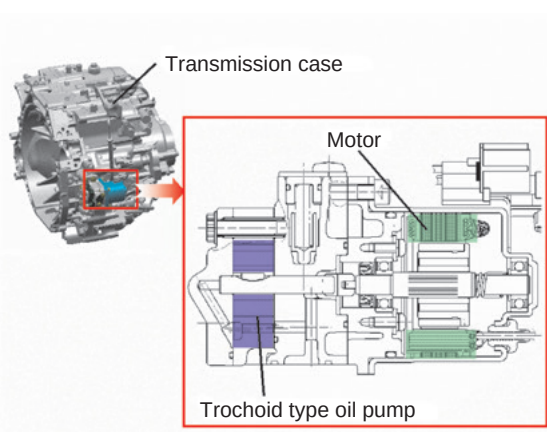


Fig. 9 Electric oil pump

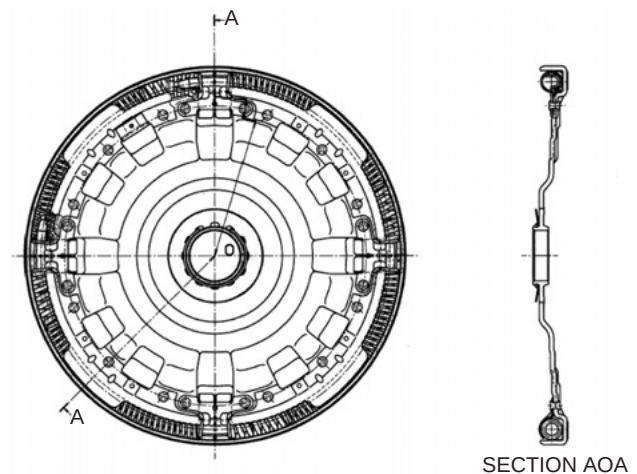


Fig. 11 Optimization of torsion damper characteristic for lock-up clutch

2.6. Highly Responsive Lock-up Clutch

As a means of increasing fuel economy when cruising or during deceleration regeneration, a highly responsive lock-up clutch, as shown in Fig. 13, was adopted.

An assistance mechanism, using a diaphragm spring, was added onto the backpressure chamber side of the lock-up clutch, making the response time one third to one fourth than that of a conventional lock-up clutch. This achieves a fuel economy increase of approximately 1.9%. (Fig. 13, 14)

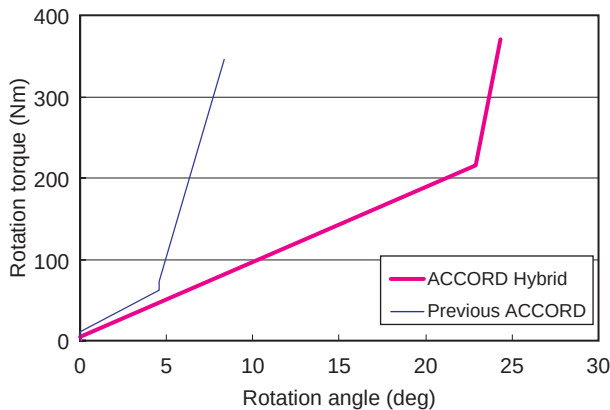


Fig. 12 Damper characteristics

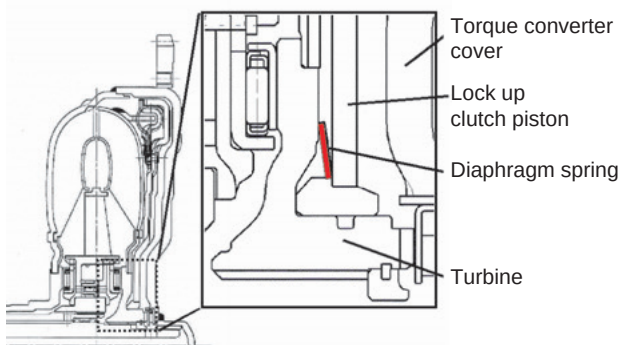


Fig. 13 Highly-responsive lock-up clutch

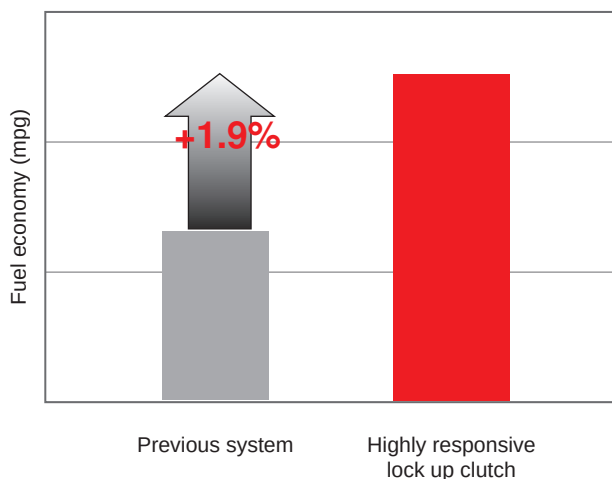


Fig. 14 Ratio of contribution to fuel economy

3. ACCORD Hybrid 5-Speed AT Controls

In addition to the idle stop, power assist, and the regeneration systems adopted in the CIVIC Hybrid, the ACCORD Hybrid introduces Drive by Wire throttle (DBW) and torque management control which work in cooperation with the cylinder idling system to increase fuel economy.

In order to achieve both low fuel consumption and high gearshift marketability, direct control was adopted for all clutches, including 1st.

3.1. 2nd Gear Start-off Control

In order to minimize wasted acceleration energy that accompanies engine revolution rise at start-off, start-off in 2nd gear is carried out with normal acceleration pedal openings. This provides a 0.1 mpg fuel economy increase. Under this condition DBW cooperative control is utilized, and sufficient start-off acceleration according to the accelerator pedal position is ensured.

If more acceleration is required, it is possible to have a smooth start-off in Low gear utilizing the advantages of direct control. An acceleration rate of 60 mph in 7.5 seconds can be achieved without spoiling the motor assist effect at start-off.

3.2. Deceleration Regeneration Control

To minimize fuel consumption during deceleration, it is necessary to increase electrical power regeneration and minimize the amount of injected fuel.

To increase electrical power regeneration during deceleration, the engine shifts to a 3-cylinder mode which reduces pumping losses. Lock-up clutch engagement is maintained and down shifting occurs such that the engine revs remain above the fuel cut maintenance revs. This allows fuel cut and energy regeneration in nearly the entire range of deceleration until idle stop, minimizing fuel consumption. Figure 15 shows operation during deceleration.

For a marketability benefit, the motor regeneration momentarily weakens at the instant of down-shift reducing the energy borne by the clutch and enhancing down-shift shock. In addition, by controlling the clutch engagement force before and after engine stop, the engine stop energy is not transmitted to the vehicle body, achieving a smooth stop feeling.

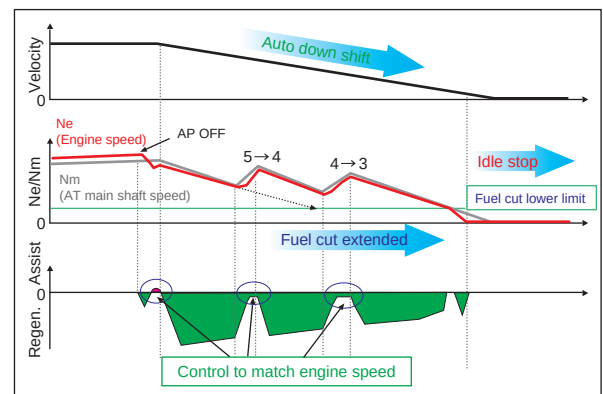


Fig. 15 Chart of deceleration regeneration operation

4. Conclusion

The ACCORD Hybrid 5-speed automatic transmission takes as its focus enhanced fuel economy by expanding the cylinder idling range with motor assist. An increase in IMA system output performance, AT idle stop measures, and maximum deceleration regeneration were achieved, without the loss of marketability.

As a result, it was possible to achieve both the powerful and refined driving performance of a V6 sedan, surpassing that of the current model, and the fuel economy of US City 29 mpg and US Highway 37 mpg, equivalent to that of a 4-cylinder compact sedan.

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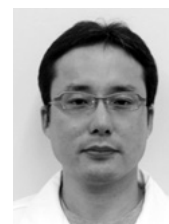
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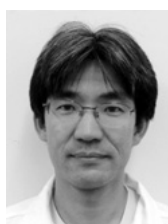
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