

Development of 7-speed Dual Clutch Transmission for SPORT HYBRID i-DCD

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ABSTRACT

A 7-speed dual-clutch transmission was developed for SPORT HYBRID i-DCD to achieve the aims of compactness and efficiency. For compactness, the motor was built into the transmission, and the planetary gear that makes up first gear was located on the interior side of the motor. This created a lightweight and compact transmission structure with one motor, which was optimized for small-sized vehicles like the FIT. Maximum input torque of up to 190 Nm is supported. For efficiency, the structure of a manual transmission capable of high transmission efficiency is used as the base and its efficiency enhanced by using an electric actuator and dry clutch. In terms of driving, the transmission has two clutches, one for odd-numbered gears and one for even-numbered ones, and the next gear stage up from the current one is put in standby in advance. Alternating between the two clutches while shifting through the gears reduces the time lag when shifting so that power transmission is seamless, and at the same time it achieves acceleration that feels direct, as with a manual transmission.

1. Introduction

Globally, initiatives in recent years have sought to protect the environment and lower burdens on it.

The automobile industry is under pressure to improve fuel economy, which has led to the introduction of a variety of technologies. These include technologies to boost engine efficiency, lower drive system friction, reduce vehicle cruising resistance, and use an idling-stop function, as well as hybrid, electric, and fuel cell vehicles.

Honda developed the Integrated Motor Assist (IMA) system and applied it to the INSIGHT in 1999. Since then, it has expanded the system to the CIVIC, Accord, and FIT⁽¹⁾. The CIVIC Hybrid sought to increase fuel economy with the Variable Valve Timing and Lift Electronic Control (VTEC) valvetrain system that increases electric energy with deceleration regeneration⁽²⁾.

To achieve greater fuel economy increases than the existing IMA system, Honda developed the SPORT HYBRID Intelligent Dual-Clutch Drive (SPORT HYBRID i-DCD). An inexpensive system that could be used on small-sized vehicles was needed to promote hybrid vehicles and thus lower environmental burden. To achieve this, Honda developed this system as a hybrid system with one motor and used it on the third-generation FIT. By

combining a 7-speed dual-clutch transmission with built-in high-output motor and a lithium-ion battery with the newly developed in-line four-cylinder 1.5 liter engine, Honda achieved an efficiency boost of more than 30% compared to a conventional one-motor hybrid system⁽³⁾.

Increasing fuel economy requires improving operations wherein energy is converted to waste heat, and it is important to increase electric energy during deceleration regeneration and reduce energy loss during takeoff.

Hybrid vehicles use regenerative brakes during deceleration, turning kinetic energy into regenerated electric power that is recovered and can be used to increase fuel economy. In conventional IMA systems, the engine and motor cannot be separated from each other. As a result, the electric power regenerated during deceleration is wasted to the extent that there is engine friction. Moreover, takeoff with a conventional clutch is accomplished by sliding the clutch, so there is loss that occurs as thermal energy. The newly developed system uses the motor for takeoff, which reduces energy loss as compared to takeoff with conventional clutches and torque converters. It also separates the engine and motor, which reduces loss during EV driving and during deceleration regeneration.

This paper explains the transmission of the SPORT HYBRID i-DCD system.

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2. Aim of Development

The purpose of developing a 7-speed dual-clutch transmission (DCT) for SPORT HYBRID i-DCD was to build a one-motor hybrid electric vehicle (HEV) transmission small enough to go on a model with an in-line four-cylinder engine. Specific development aims were as follows.

- (1) Enable EV driving and deceleration regeneration with the engine separated.
- (2) Make the transmission lightweight and compact enough to go on the FIT class.
- (3) High transmission efficiency

3. Basic Layout and Major Specifications

The main sectional view and perspective view of the 7-speed DCT for SPORT HYBRID i-DCD are shown in Figs. 1 and 2, respectively, and the specifications are given in Table 1.

The transmission uses a dual dry clutch (DDC), which is operated by an electric actuator. First gear consists of a planetary gear located on the interior side of the motor. Odd-numbered stages are located on the main shaft and even-numbered stages on the secondary shaft, and these share the driven gear on the counter shaft. The actions of the two clutches cause the gears to shift, and also cause the engine and motor to engage or disengage. EV driving and deceleration regeneration are enabled with the engine separated.

Table 1 Specifications of FIT

Engine	Type	In-line 4 1.5 L Port injection
	Max. power	81 kW (6000 rpm)
	Max. torque	134 Nm (5000 rpm)
Motor	Max. power	22 kW
	Max. torque	160 Nm
Transmission	Type	7-speed DCT
	Size	420.8 mm
	Weight	70.6 kg (Without motor parts)
	Gear ratio	1st 4.148
		2nd 2.007
		3rd 1.481
		4th 1.098
		5th 0.810
		6th 0.605
		7th 0.446
		Reverse 3.221
		Final 4.842

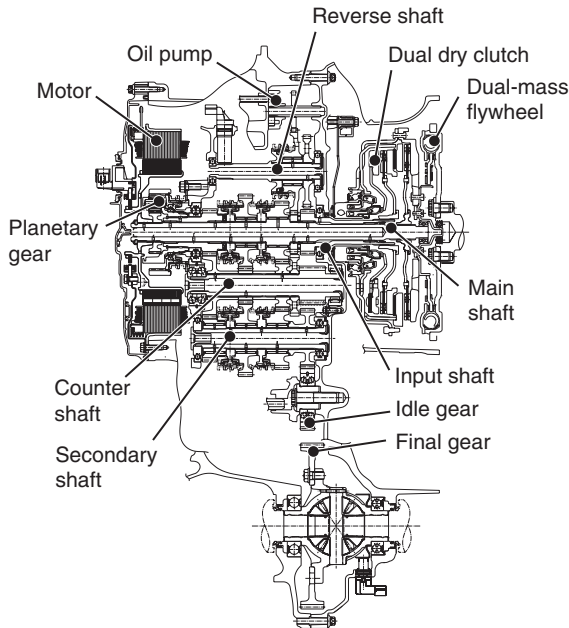


Fig. 1 Main sectional view of developed DCT

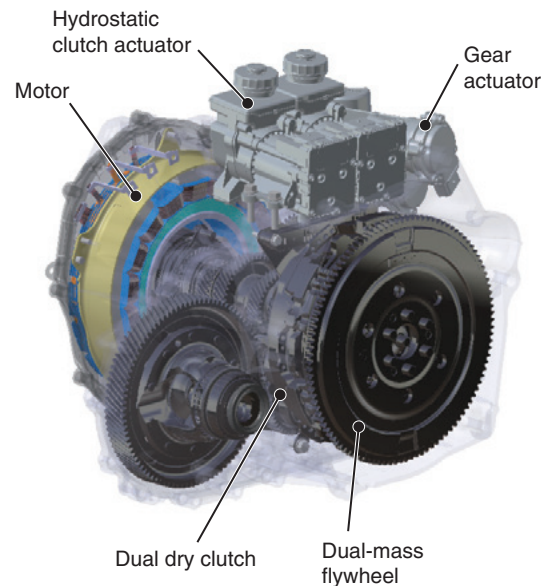


Fig. 2 Perspective view of developed DCT

4. Major Technologies

4.1. EV Driving and Deceleration Regeneration with the Engine Separated

The motor is installed on the main shaft, and the engine and motor are separated by disconnecting the dual clutch. Examples of the action of the DCT are given in Fig. 3.

When the motor connected to the main shaft and the sun gear of the planetary gear cause the transmission to enter first gear, the ring gear becomes fixed. EV driving in first gear is enabled through third gear, which is connected to the carrier. The ring gear is released and the transmission goes into third gear, enabling EV driving in third gear. EV driving and deceleration regeneration can only be accomplished through odd-numbered-stage gears (EV drive mode and EV regeneration mode).

From EV driving, it is possible to start the engine and go into motor-assisted driving by engaging the clutch for odd-numbered stages or the clutch for even-numbered stages through any of the even-numbered stages. Even if driving in an even-numbered stage without a connection to the motor, it is possible to get assistance from the odd-numbered stage side, which is connected to the motor (hybrid mode).

It is also possible to drive without even using motor assist (engine drive mode).

Additionally, by shifting to neutral and connecting the odd-numbered-stage clutch, thus separating the drive to the tires, it is possible to connect the engine and motor and recharge with the car parked.

It is possible not only to shift the DCT clutch, but also

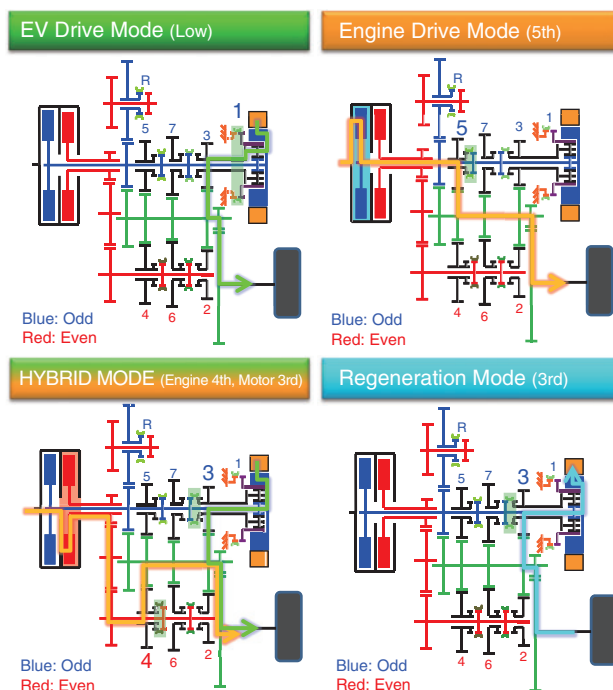


Fig. 3 DCT operation modes

to use engaging or disengaging of the engine and motor. This enables EV driving and deceleration regeneration with the engine separated, even in a lightweight and compact structure. Combining a gear-shift stage and clutch enables motor-assisted driving in each shifting stage, helping to increase the efficiency of the SPORT HYBRID i-DCD system. Additionally, the layout of the odd-numbered gears that perform motor driving and regeneration allows highly efficient motor driving and deceleration regeneration with minimum numbers of gear engagement.

4.2. Lightweight and Compact Design

A transmission has to be lightweight and have a short overall length to be mounted on an in-line four-cylinder engine. The following correspondence was made to make this possible. The gear structure is shown in Fig. 4.

- (1) The IMA motor was built into the transmission and the motor housing was eliminated. In addition, the motor is cooled with automatic transmission fluid (ATF) in order to lower the amount of heat radiated. These steps allow the motor to be more compact.
- (2) First gear consists of a planetary gear, the sun gear is connected to the main shaft, and the ring gear is fixed,

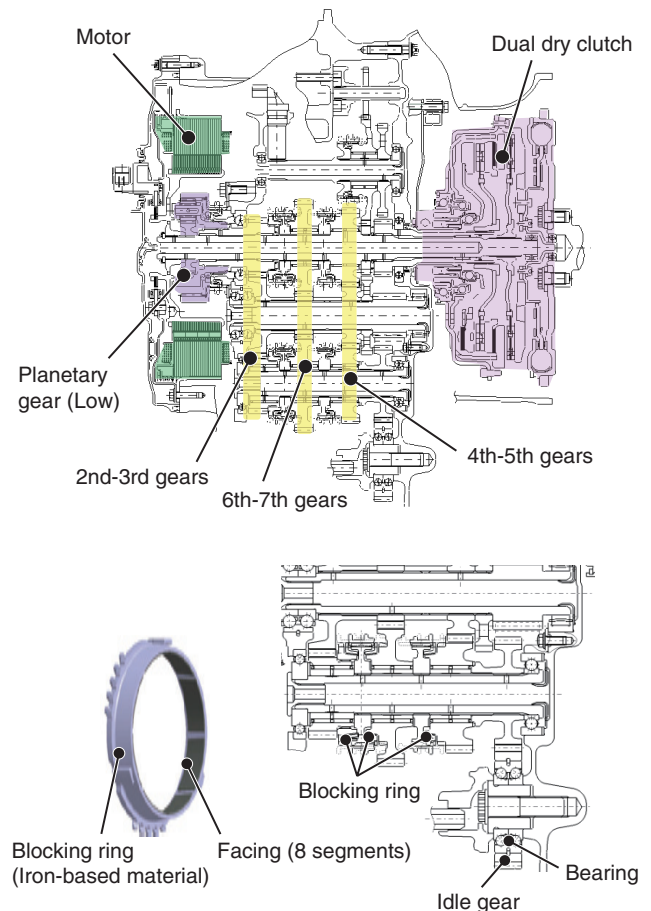


Fig. 4 Structure of gear train

thus forming first gear. The carrier's output is shared with third gear. Placing the motor on the outer periphery of the planetary gear shortens the transmission's overall length. The carrier is made of aluminum, which reduces weight.

- (3) Odd-numbered-stage gears and the motor are located on the main shaft. Even-numbered-stage gears are located on the secondary shaft. Power to the secondary shaft is transmitted from the input shaft via the idle shaft. The trains for second and third gear, fourth and fifth gear, and sixth and seventh gear share the driven gear located on the counter shaft. This reduces the overall length.
- (4) A high-capacity synchronizer was developed that is compatible with ATF. The high-capacity design makes the synchronizer more compact and lets it go under the gears, reducing overall length. The base material was switched from hot-forged brass to press-formed steel, and the friction material switched from powder molded to sheet molded. This ensured capacity and durability when exposed to ATF and helped to cut costs and reduce waste during production.
- (5) Small-diameter, high-capacity four-point contact bearings were used, making it possible to reduce the space between shafts. Making the bearings smaller also helps reduce friction torque, contributing to efficiency.
- (6) The idle gear has a rigid cantilever support structure, and the bearings are located below the gears, making it possible to increase the diameter of the bearings. This ensures rigidity while reducing the space between shafts, enabling a smaller and lighter transmission. Additionally, aligning the final gear with the direction of the shaft reduced the overall length. Similarly, aligning the reverse gear and parking gear with each other helped to make the transmission smaller and lighter.
- (7) Aluminum bolts are used to fasten the clutch case (C case) and transmission case (M case) to each other and to fasten the M case and side cover to each other. Specific gravity of the aluminum bolts is only about one-third that of conventional steel bolts, but aluminum bolts are also weaker, having only about one-half the tensile strength. The design process considered the following aspects to make up for the loss of tensile strength. The coefficient of thermal expansion of aluminum bolts is equal to that of the cases of the members being fastened, so the increase in axial force during heat treatment is an advantage over steel bolts. In addition, using an angle tightening method controls axial force variance when fastening, while surface treatment stabilizes the torque coefficient and minimizes changes in it when liquid packing or oil adhere to the components. As an overall result, the aluminum bolts achieved the same level of residual axial force as conventional steel bolts, taking variance into account. It was therefore possible to satisfy the fastening conditions with the same number of aluminum bolts as steel bolts. The locations where members were fastened with aluminum

bolts are shown in Fig. 5. The total weight of bolts used for case fastening was reduced by about 300 g by using aluminum for the 17 M8 bolts fastening the M case and C case to each other and the nine M6 bolts fastening the M case and side cover to each other.

- (8) For the motor's rotor, the M case was given a cantilever support structure. This eliminated the need for bearing support, so resin was used for the side cover. The structure of the side cover is shown in Fig. 6.

The seal structure of the connector area of the resolver, which senses motor rotation, consists of an annular spring (providing tightening force), a rubber sealing member, and a resin ring.

The resin side cover undergoes radial and thrust displacement owing to heat and absorbed water. The sealing member is shaped to allow such displacement. Additionally, using a ring made of resin made it possible to weld it to the resin cover, reducing both cost and the number of parts.

The oil guide, carrying oil from the oil pump, was welded in the same fashion as the seal area to create a single piece. The oil put out by the oil pump lubricates the main shaft interior, the planetary gear, and the

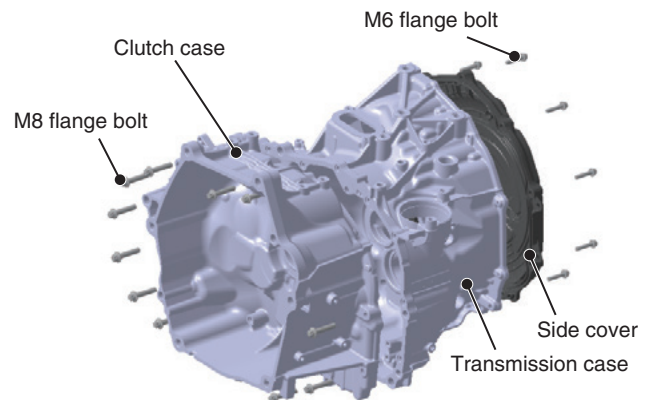


Fig. 5 Locations of aluminum bolts

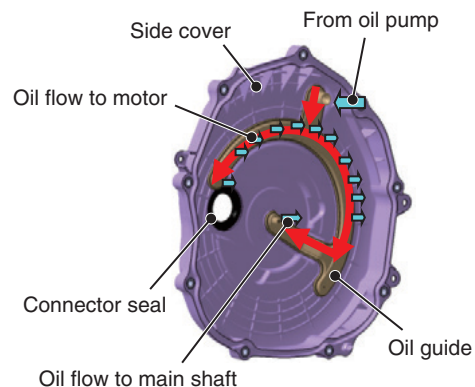


Fig. 6 Structure of side cover

pinions, while cooling the motor winding through the resin cover's oil guide. Using resin as the material made it unnecessary to provide an insulating distance from the motor. This fact, along with the layout freedom allowed by resin molding, enabled an oil guide to be constructed in a place where the motor could be cooled efficiently. This contributed to making the motor smaller and enabled lightening and shortening of the overall transmission length.

As a result of the above, the transmission's overall length is equal to that of the existing IMA system (motor and CVT), and is lightweight and compact enough to go on the FIT series.

4.3. High Transmission Efficiency

The newly developed transmission is based on the more efficient manual transmission (MT) technology. The clutches and gears are divided into two systems (odd-numbered and even-numbered stages), and the transmission switches between the two systems as it shifts through the gears.

For the clutch, which engages and disengages with the engine, a dry clutch is used to reduce drag. The clutch consists of LuK's DDC and a hydrostatic clutch actuator (HCA) that generates and controls clutch hydraulic oil pressure. The HCA is driven by an electric motor. The gear is chosen when the gear change actuator (GA) causes the shift fork to shift and select a gear. The configuration of the GA is shown in Fig. 7.

When the GA acts in the direction of the shaft, a shift rail is selected, then depending on the direction of rotation, the shift fork's rail is moved and the shift action is accomplished. Parking action is also accomplished by the action of the GA. The HCA and GA both drive an electric motor, which eliminates the need for an oil pump to generate hydraulic pressure and increases efficiency. This

also enables the use of shift-by-wire, eliminating the need for shift to the auto body side and for a select cable. This increases the freedom to locate the shifter part, helping to expand design potential.

Low-viscosity ATF is used as the transmission's lubricating oil, which reduces friction. Because conventional MTs use manual transmission fluid, a high-capacity synchronizer and shift fork were developed to work with ATF in this transmission.

A polyamide-based resin was used for the tips of the shift fork to ensure abrasion resistance. The structure of the shift fork is shown in Fig. 8. Molding resin tips on a steel shift fork as a single unit achieved abrasion resistance while also reducing the number of processes and lowering the cost as compared to conventional hard chrome plating.

The lubrication structure is shown in Fig. 9. To reduce friction, baffle plates were put on the final gear and secondary shaft to reduce agitation. The gutter plate allows efficient lubrication even with a low fluid surface to ensure that the bearings of the differential are efficiently lubricated by the final gear as it scoops up oil.

The main shaft, motor, and so on are lubricated by the

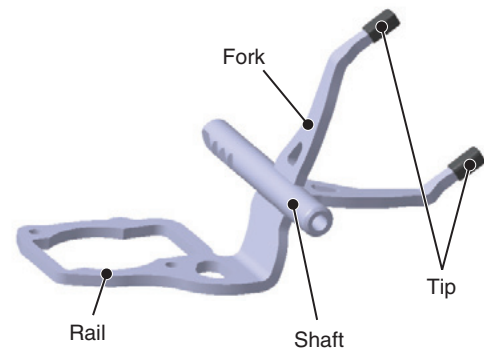


Fig. 8 Shift fork

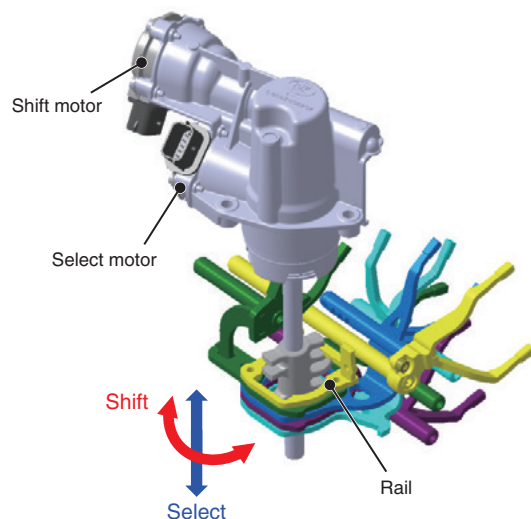


Fig. 7 Configuration of GA

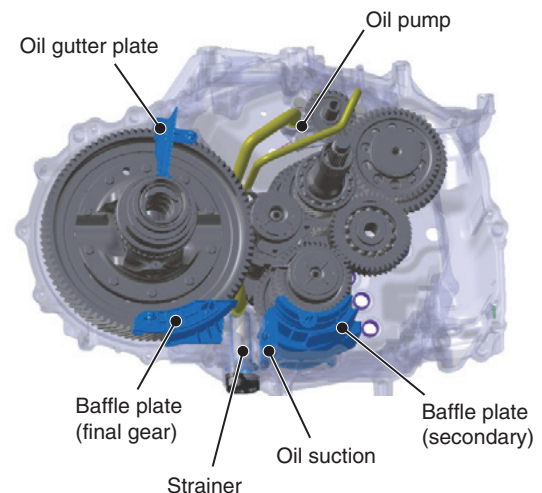


Fig. 9 Lubricating system

oil pump. However, if the amount of oil is reduced, air could be sucked in from the oil inlet if the fluid surface tilts when turning or on a hill. The location of the strainer is limited by the layout, so it cannot be placed in an appropriate inlet position when the inlet area is on the case. If the amount of oil is increased to prevent air from being sucked in through the oil inlet, agitation resistance and weight are increased as well. Therefore, this inlet was made a single piece with the secondary baffle, optimizing the oil inlet location without adding any parts. This made it possible to reduce the amount of oil and agitation resistance.

These measures increased transmission efficiency by about 5% compared to a conventional AT.

5. Conclusion

A 7-speed DCT with the following characteristics was developed as a SPORT HYBRID i-DCD transmission.

- (1) By using a dual clutch and locating the motor on the main shaft, EV driving and deceleration regeneration are enabled with the engine separated.
- (2) By locating the planetary gear that comprises first gear on the interior side of the motor, by using a shared gear train structure, etc., and by using alternative materials, a smaller and lighter transmission was achieved.
- (3) By using a dry clutch and electric actuator and reducing oil agitation, high transmission efficiency was achieved.

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