Drivetrain

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1 Introduction

Improving vehicle fuel efficiency has become an increasingly important development theme in recent years as a result of active measures being implemented around the world to combat global warming by reducing CO_2 emissions, in addition to energy issues created by increasing crude oil demand in emerging markets as vehicle markets expand. Global vehicle sales around the world have increased from 77.9 million in 2011 to 81.7 million in 2012 [(1)]. In the same time frame, sales of so-called next-generation vehicles, such as hybrid, electric, and plug-in electric vehicles (HEVs, EVs, and PHEVs) increased by 80% from 960,000 to 1.73 million [(2)]. These vehicles now make up 2.1% of the overall vehicle market. With this background, current drivetrain trends include the reduction of component losses, increases in the number of shift speeds and wider gear ratio ranges for conventional transmissions that also consider the goal of commonization, and the evolution and popularization of fuel efficiency improvement technologies such as idling stop systems. Next-generation automotive transmissions have been developed with single-motor systems shared with conventional transmissions, as well as dual-motor systems with driving modes with a fixed gear ratio. Technologies have also been developed to help enhance driving enjoyment, including measures to improve shift operability and continuous advances in technology to boost perceived performance such as accelerator and shift response.

2 Clutch Trends

A torque converter with a built-in centrifugal pendulum vibration absorber was adopted in a vehicle with a cylinder deactivation mechanism (the Mercedes Benz SLK55 AMG). The pendulum order is applied when the V8 engine is in 4-cylinder mode [(3)].

3 Manual Transmission Trends

The Porsche 911 uses the world's first 7-speed manual transmission (MT) for a passenger vehicle (gear ratio range: 5.50, manufactured by ZF Friedrichshafen AG). This transmission shares the gear arrangement of the ZF 7-speed dual-clutch transmission (DCT) and adopts a gear-select mechanism that enables an H-type shift pattern for MTs [(4)]. As an example of a loss-reduction technology, a 300 Nm input torque class transverse 6-speed MT has been developed with ball bearings on the differential side by enhancing lubrication at low speeds [(5)]. Furthermore, as an example of a technology for improving shifting feel, Mazda has developed a new structure for the selecting mechanism that moves the control rods up and down with the aim of reducing the effort required to shift up. This structure uses the weight of the upper control rod parts to move the rods down when the driver shifts up by arranging the first and second gear select positions in an upward position (Fig. 1) [(6)].

For commercial vehicles, Hino has developed a 9-speed MT for the large Profia 25-ton class truck to help improve fuel and installation efficiency by enabling a wider gear ratio range and increasing the number of shift speeds. This was achieved by reducing the size and weight of the unit while achieving a wider gear ratio

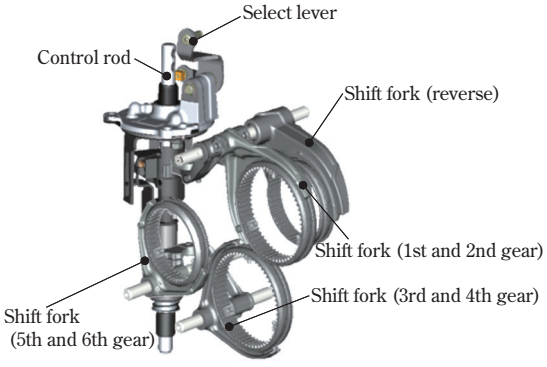


Fig. 1 Mazda 6-speed MT shift mechanism.

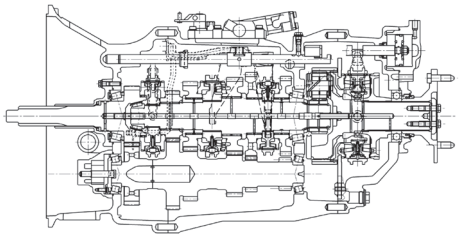


Fig. 2 Section view of 9-speed MT (M009) for the Hino Profia[7].

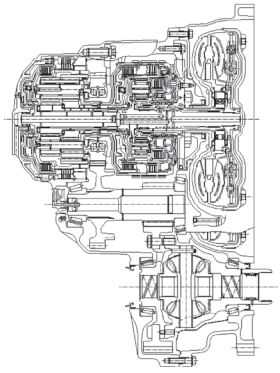


Fig. 3 Section view of 6-speed AT for the Lexus RX.

range compared to the conventional 7-speed transmission. This 9-speed MT has a high/low switchover function using a planetary gear-type auxiliary transmission (Fig. 2).

4 Automatic Transmission Trends

The number of shift speeds is also being increased for automatic transmissions (ATs). The Lexus RX350 F SPORT features the world's first transverse 8-speed AT (gear ratio range: 7.58). This transmission is the same size as the conventional 6-speed AT due to a compact configuration using one additional clutch (Fig. 3).

Idling stop mechanisms are also becoming more widespread. For conventional ATs, the BMW 8-speed AT (gear ratio range: 7.06) has been installed on the X3 and X1, the 3-Series and 5-Series diesel variants, the 7-Series, and so on. In the 7-Series, the transmission and the engine are automatically disengaged when the driver releases the accelerator at speeds above 50 km/h to allow the vehicle to coast and reduce driving resistance [8]. For DCTs, the VW Golf, Polo, and other models use a dry-clutch 7-speed DCT, and the Tiguan uses a wet-clutch 6-speed DCT. In addition, the VW up! uses a MT-based 5-speed transmission with an automatic shifting mode [9].

As an example of the trend to commonize conventional and next-generation transmissions, the ZF transverse

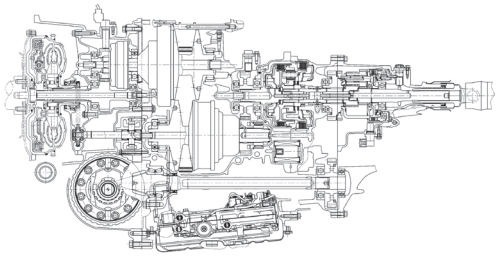


Fig. 4 Section view of the Subaru Legacy Lineartronic CVT for high-torque applications[15].

9-speed AT (gear ratio range: 9.84) has been designed with a completely modularized configuration. The gear shifting portions are common for all variants, allowing the adoption of various starting mechanisms and hybrid systems [10]. Getrag has developed a transverse 7-speed wet-clutch DCT (the 7DCT300) with a gear ratio range of 8.6. This transmission is compatible with idling stop and coasting functions. Getrag has also developed a 1-motor type hybrid specification transmission based on the 7DCT300 called the 7HDT300 [11].

For enhanced driving enjoyment, the 6-speed AT installed in the Mazda Atenza and CX-5 uses a kick-down switch in the shift control to improve shifting controllability by the driver [12]. The Toyota Crown 8-speed AT features a control that suppresses unnecessary up-shifts while cornering using a G-sensor to determine the deceleration and cornering force. This function optimizes the engine braking and drive force when exiting a turn [25].

5 Continuously Variable Transmission (CVT) Trends

CVTs with wider gear ratio ranges and chain-driven CVTs that increase torque and efficiency are being developed. In the case of belt-driven CVTs, the Honda Step Wagon features a 250 Nm input torque class CVT with a gear ratio range of 6.54 (compared to the conventional 5.48) by adopting measures such as a wider interval between pulleys (increased from 170 mm to 180 mm) [13].

The CVT in the Nissan Altima features a gear ratio range of 7.0 (compared to the conventional 6.0), which was achieved by reducing the diameter of the pulley shafts [14]. For chain-driven CVTs, the adoption of short pitch chains is expanding and the Subaru Legacy features a 400 Nm input torque class CVT with a gear ratio range of 6.44 (compared to 6.3 with the standard chain) (Fig. 4). In addition, the Nissan Altima features a 380 Nm input torque class CVT with a gear ratio range of 6.3 (compared to 5.4 with the conventional belt) [14].

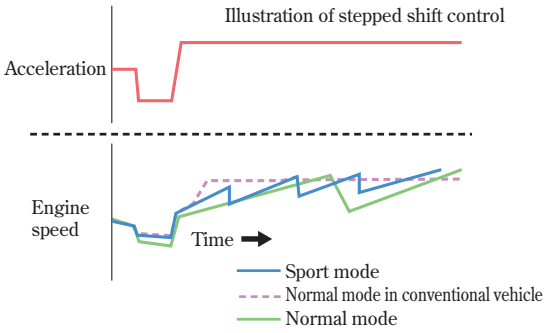


Fig. 5 Illustration of shift control in the Auris CVT[25].

The adoption of CVTs with auxiliary transmissions with a wide gear ratio range of 7.28 has expanded in compact vehicles, such as the Mitsubishi Mirage, Nissan Note and Latio, and Suzuki Wagon R.

More vehicles are also using idling stop mechanisms with an electric oil pump, such as the Honda Step Wagon, Toyota Corolla and Auris, Mitsubishi Mirage and Outlander, Nissan Note and Latio, Suzuki Wagon R, and Subaru Impreza. Engine-stop mechanisms that facilitate re-starting from engine coasting are also becoming more widespread in vehicles such as the Impreza, Corolla, Auris, Wagon R, and the like. These use a tandem solenoid starter that enables extrusion of the pinion gear and independent application of power to the motor.

Loss-reduction technology is also making advances. The oil pump is responsible for the largest proportion of energy loss in a CVT. Technology to reduce the drive torque of the oil pump includes the adoption of two outlet ports in a single oil pump and a mechanism to switch the flow between them [13]. This mechanism has a new low-pressure port for lubrication in addition to the conventional high-pressure port [16].

Shifting control-related technology for enhancing driving enjoyment has been adopted in the CVT in the Subaru Legacy. This CVT increases the number of shift speeds in manual mode and also enables the selection of an 8-speed mode [15]. The Toyota Wish, Corolla, and Auris feature a control that suppresses unnecessary upshifts during cornering after a downshift to enter a corner, using a G-sensor to detect deceleration and cornering force. The CVT control in the Auris also emphasizes the up-shift feeling when the driver depresses the accelerator through a stepped shifting mode that feels like a conventional transmission (Fig. 5).

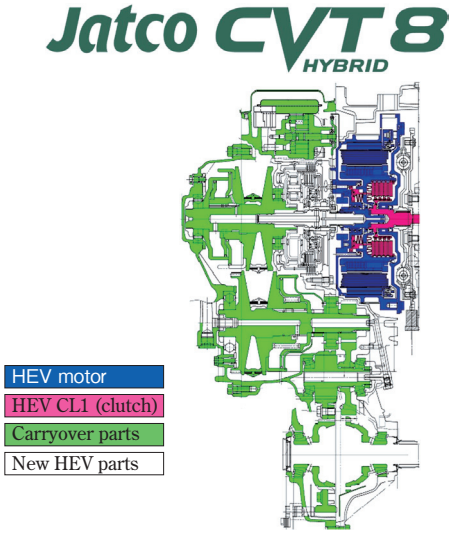


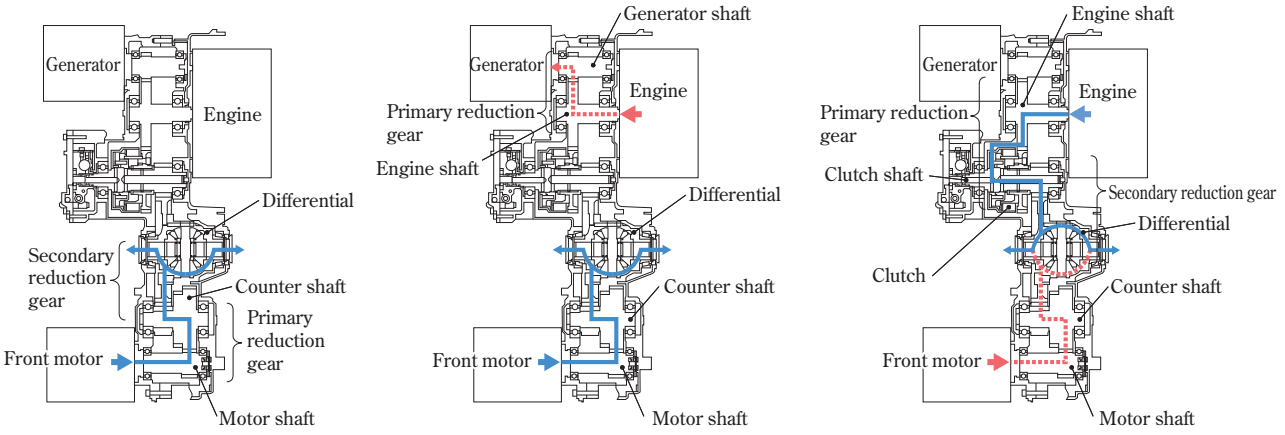
Fig. 6 Jatco CVT8 Hybrid.

6 HEV Drivetrain Trends

On example of a drivetrain that combines a single motor with a conventional transmission is the system used in the BMW 3-, 5-, and 7-Series that mates a ZF-manufactured 1-motor 2-clutch mechanism to an 8-speed AT [8]. Jatco has also developed a system that combines a 1-motor 2-clutch mechanism with a CVT (Fig. 6). The Mercedes Benz E300 Blue Tec combines a diesel engine with a 1-motor 7-speed AT through a clutch [17]. The VW Jetta HV features a system that also combines an engine with a 1-motor 7-speed DCT through a clutch. In all cases, these transmissions automatically disengage the transmission and engine when the driver releases the accelerator pedal at high speeds.

HEV drive systems with two motor-generators (MGs) use a planetary gear mechanism to control the engine and two MGs simultaneously. Examples include those used in the Toyota Prius and Ford Fusion HV. In contrast, another type of system has been developed without a planetary gear mechanism. In this system, the engine and generator, and the motor and differential are directly connected by fixed gear ratios. A clutch is provided between the engine and differential. Engaging this clutch activates a parallel driving mode at a fixed gear ratio suitable for high-speed driving. This system is used on the Mitsubishi Outlander PHEV and Honda Accord PHV (Fig. 7).

In the commercial vehicle field, the Isuzu Erga HV is installed with a parallel hybrid system designed for route transit buses that connects the engine with a MG and



(a) EV mode (b) Series driving mode (c) Parallel driving mode

Fig. 7 Driving modes of Mitsubishi Outlander PHEV[18].

Fig. 8 Appearance of transmission for Isuzu Erga HV[24].

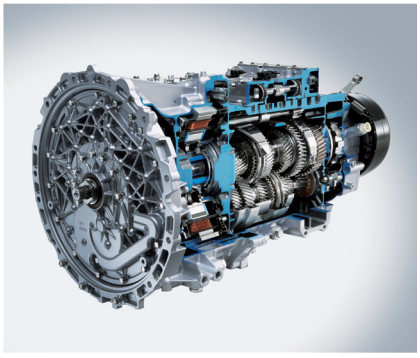


Fig. 9 Transmission for Mitsubishi Fuso Canter HV.

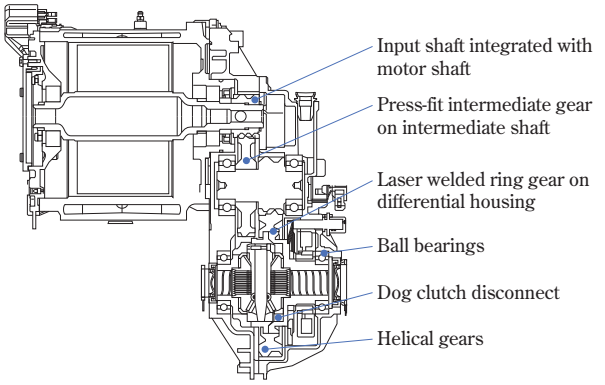


Fig. 10 Section view of Peugeot 3008 rear unit.

6-speed automated MT (manufactured by Eaton Corporation) through a clutch. This system is specifically designed for buses that have frequent starts and stops and allows motor drive on start ups and energy regeneration when stopping (Fig. 8) [19].

The Hino 195h small truck uses a parallel hybrid system (manufactured by Aisin Seiki Co., Ltd.) that connects the engine with a MG and 6-speed AT through a clutch. The Mitsubishi Canter is installed with a parallel hybrid system that adds a motor (40 kW, 200 Nm) to the outside member of the dual clutch system (the even-number gear side) (Fig. 9). Both cases use a conventional starter.

7 Four-Wheel Drive Device Trends

The Peugeot 3008 Hybrid4 includes an electric motor drive unit manufactured by GKN plc for driving the rear wheels. The engagement mechanism for the differential housing on the input side driven by the electric motor and the pinion pin supporting member on the output side uses a dog clutch to reduce loss when disconnected (Fig. 10).

8 Drivetrain Research Trends

For half-toroidal CVTs, research is aiming to expand the gear ratio range by reducing the pressing force between the disc and power roller, improving the accuracy of contact point prediction, improving the oil traction coefficient, and the like. It may be possible in the future to expand the gear ratio range from 4.33 to 8.0 [20]. In addition, a new model was

proposed for estimating the temperature within the oil film for improving the accuracy of traction coefficient estimation. The improvement in estimation accuracy was then confirmed by verification tests [21].

Research is also aiming to improve the quietness and reliability of a planetary gear type torque-sensing limited slip differential (LSD) during differential operation. The μ-v characteristics of the positive gradient can be maintained by applying the appropriate surface roughness to the sliding portions, adopting a carbon-based hard coating, and keeping the surface pressure of the sliding portions below the ideal threshold [22]. Another report describes a measure related to the automation of the enormous amount of calibration operations required for shift control systems as the gear ratio range of ATs expands and the number of shift speeds increases to improve fuel efficiency and driveability [23].

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