DRIVETRAIN

1 Introduction

New vehicle sales in Japan (including mini-vehicles)[1] in 2017 increased by 5.3% compared to the previous year. Registered vehicles sales increased for two consecutive years, and mini-vehicles sales increased for the first time in three years. Sales of ordinary passenger cars are moving back to the level before the rise in the consumption tax, and sales of mini-vehicles to the level before the rise in mini-vehicle tax.

Fuel economy regulations are becoming stricter in response to the increasing global spread of environmental awareness. In France, where nuclear power plants emitting little carbon account for approximately 80% of all electricity generation, the diesel vehicle emissions scandal prompted the government to announce a ban on sales of internal combustion engine vehicles by 2040. China and India, which have grown to become the world's main market, also plan to increase the proportion of electric vehicles through regulations and subsidies. In addition to technological development spurred by the growing popularization of electric vehicles, steady improvement is being made in drivetrain performance, which is strongly tied to the intrinsic running and turning performance of vehicles. This article summarizes the latest power transmission systems released in the automotive industry in 2017, and also takes a look at the technological trends paving the way for next-generation power transmission systems.

2 Manual Transmission (MT) Trends

2. 1. MT for Honda Civic Type R[2]

The sixth generation Civic Type R launched in September 2017 was developed with the goal to provide users with the world's highest level of driving pleasure in its segment. To make the most of the engine's potential, close ratio 6-speed MT was selected and the final gear ratio has been lowered from the previous model. The 40 mm shift stroke achieves smart gear shifting, realizing smooth maneuverability. In addition to a lightweight single-mass flywheel to improve acceleration response, Rev Match Control System, which provides automatic synchronization with engine speed during gear changes and enables smooth MT shifting to stabilize vehicle behavior was introduced by Honda for the first time. Using information from a sensor in the clutch pedal as well as the neutral position and engine speed sensors in the transmission, the system detects driver's operations and automatically optimizes the engine speed to match the intended gear. Automating rev matching, a technique that requires high driving skill, allows the driver to concentrate more on steering and braking operation. The Rev Match Control System can be turned off by the driver.

3 Automatic Transmission (AT) Trends

3. 1. Nine-Speed Dual Clutch Transmission (DCT) for Honda NSX[3]

The second generation NSX launched in February 2017 was developed to offer users a new delight in vehicle handling referred to as the New Sports eXperience. The world's first longitudinal rear-wheel drive 9-speed DCT boasts a high capacity maximum torque of 550 Nm while being compact, and both further improves super sport performance and provides smooth and comfortable driving on public roads. The transmission uses dual clutches arranged independently for the odd- and even-numbered gears to reduce shifting time, adopting a dual wet clutch (DWC) for its small size and excellent cooling performance. In an effort to achieve quick start acceleration performance and quiet cruising performance at high speeds, the following structures were adopted to suppress yaw moment during cornering while reducing the total length. (a) The 1st gear is driven by a one-way clutch (OWC), eliminating the shift mechanism and using the 1st driven gear as the parking gear, (b) The 4th and 5th, 6th and 7th, and 8th and 9th gear pairs are mounted

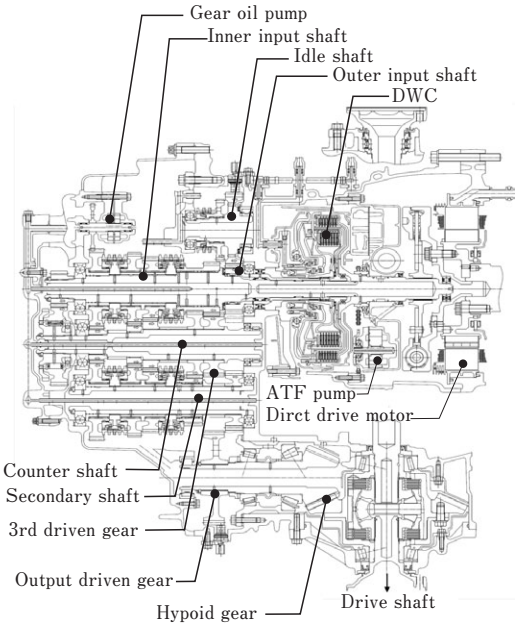

Fig. 1 Structure of Honda NSX 9-speed DCT

in parallel and have common driven gears, and (c) The 3rd driven gear is shared by the output drive gear and the reverse driven gear (Fig. 1).

A dedicated gear oil and ATF are respectively applied to the gear and DWC chambers. The oil pump in the gear chamber discharges an amount of oil proportional to the vehicle speed to the shaft center and the engaged portion through forced lubrication. The oil pump in the clutch chamber provides lubrication according to the heat generated by the clutch. Based on the operating state, valves switch the amount of discharged oil proportional to the engine speed in two steps. Since start and stop driving increase clutch temperature whereas high load/speed driving increase gear temperature, oil cooler was adopted to exchange heat between the ATF and the gear oil.

3. 2. Twelve-Speed AMT Shift Pilot for Mitsubishi Fuso Truck and Bus Corporation Super Great[3]

In the field of heavy-duty vehicles, the evolution of control technology has been accompanied by improvements in shift quality, and AMT have become mainstream, except in North America. Shift Pilot mounted on new Super Great released in May 2017 is a 2-pedal 12-speed AMT. This dedicated transmission removes the Daimler synchronizing mechanism consisting of a 2-speed splitter auxiliary transmission, 3-speed main transmission, and 2-speed range auxiliary transmission. Improved cooperative control of the engine, transmission, and brakes results in excellent comfort, operability, and economic efficiency. Detecting the brake pedal stroke at start off and controlling the clutch stroke to engage the clutch when the brake pedal is released provides creep driving comparable to that of an AT with a torque converter even with the use of a dry single plate clutch. Creep control can be canceled using the rocking free mode switch to allow the vehicle to escape if stuck in a muddy road. Minute coordination between the throttle valve and clutch controls is carried out before the clutch disengages to reduce the torsional vibration of the drive system due to the release of drive force caused by the clutch disengagement. Using the countershaft brake appropriately and synchronizing engine speed achieve seamless gear changes without time lags. Upon determining that drive or braking force is unnecessary when operating in auto mode, the Eco-Roll control sets the gear in neutral position, cutting off the transmission of drive force and contributing to improving fuel economy.

4 Continuously Variable Transmission (CVT) Trends

4. 1. Honda N-BOX CVT[4]

The CVT installed in N-Box released in September 2017, features such as a two-discharge port oil pump, new CVT fluid, a larger pulley piston diameter decreasing the work of the oil pump, and friction and improving transmission efficiency by 2% compared to the 2012 model CVT.

The two-discharge port oil pump contains a pair of oil pump rotors with independent discharge circuits, and the main regulator valve constantly matches the discharge pressure of the main rotor to the line pressure. The sub-rotor structure uses a switch valve in the discharge oil path sending discharge oil to the main regulator and adjust to the line pressure (high pressure mode) or to lubrication regulator valve and adjust to the lubrication pressure (lubrication mode). When pulley-side requires a high pressure and flow rate, such as sudden shifting, the discharge pressure of both rotors is adjusted to the line pressure to ensure a sufficient discharge, while under steady operation or slow acceleration, the discharge of the sub rotor is adjusted to the lubrication pressure to reduce work loss. The flow balance is constantly calculated and appropriate discharge mode is selected based on the calculation results. Powertrain cooperative control and new gear shifting control focused on

driving force provide quick response to driver's intents and maintain strong acceleration to offer an exhilarating driving experience.

5 Drive Systems for Hybrid Vehicles

5. 1. Suzuki Swift Hybrid Automated Manual Transmission (AMT)[3]

The AMT installed in Swift released in June 2017 is a dedicated hybrid vehicle unit based on Auto Gear Shift (AGS) design that adds an electric hydraulic actuator to a 5-speed MT to automate shifting. To further improve both fuel efficiency and the shift feeling while making the most of the AGS advantages, a second countershaft transfers the output of the compact drive motor (MGU) to the AGS output shaft via a speed reducer. To avoid oil agitation in the MGU input shaft driven by the higher gear of the speed reducer, the MGU is placed at the top, and a silent chain connects the MGU input shaft and second countershaft to secure quietness during EV driving (Fig. 2).

Furthermore, the speed reducer is separated from the AGS unit to shut off the oil flow. When driving at a constant speed of 60 km/h or less, the engine is stopped, and the torque from MGU is transmitted to the output shaft while the clutch is disengaged to enable EV driving. Energy is recovered during deceleration. In the AGS, clutch release causes a temporary torque loss during gear shifting, and assistance from the MGU torque has improved the shift feeling (Fig. 3).

5. 2. Toyota New Prius PHV Plug-in Hybrid[3]

The dual motor drive system installed in new Prius PHV released in February 2017 is based on the transaxle equipped in the 4th generation Prius, with a one-way clutch (OWC) added between the input shaft and the case (Fig. 4). The generator output torque is added to the conventional motor output torque when the engine is stopped, contributing to improved driving performance in EV mode (Fig. 5).

The adoption of an electric oil pump enables oil lubrication when the engine stops, raising the frequency of EV mode travel.

6 4WD Devices

6. 1. Mazda New CX-5 and CX-8 All-Wheel Drive (AWD)

Based on the 2012 model that achieved a breakthrough in the trade-off between environmental performance and

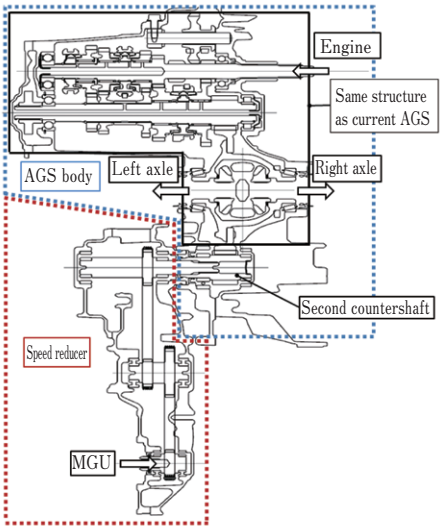

Fig. 2 Structure of Suzuki hybrid AMT

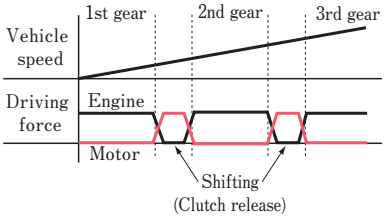

Fig. 3 Visualization of motor assist in the Suzuki AGS and MGU during shifting

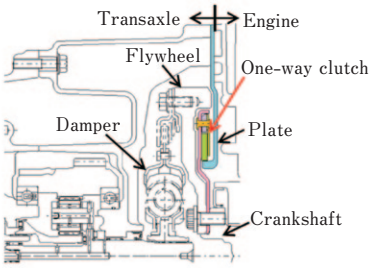

Fig. 4 Structure of the Toyota Prius PHV transaxle

fun and safe driving on any road, i-ACTIV AWD installed in the new CX-5 released in February 2017 was given a major update with power take-off, lower viscosity rear differential unit oil, tandem ball bearings and other enhanced technologies that halve the energy loss in AWD mode.

7 Drivetrain Research Trends

In November 2017, GKN Driveline announced eTwinsterX[3]. Structurally, it consists of an axle unit with a 120 kW small-size motor, a 2-speed transmission with a planetary gearset, and a differential with a twin clutch sys-

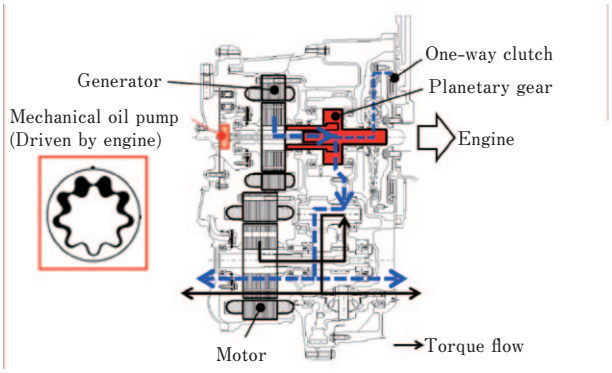

Fig. 5 Torque flow in Toyota Prius PHV dual motor drive

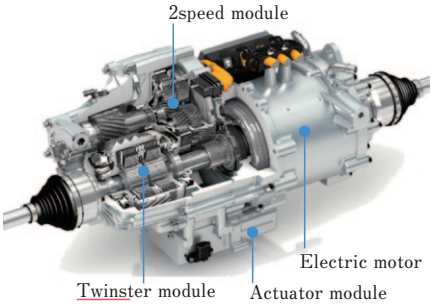

Fig. 6 Appearance and structure of the GKN eTwinsterX

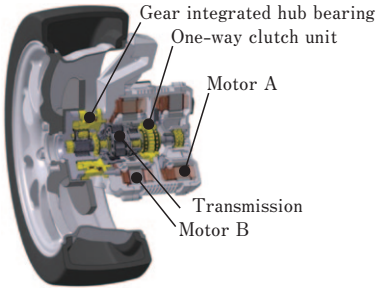

Fig. 7 Structure of NSK wheel hub motor with transmission

tem that uses electrohydraulic control to precisely distribute torque to the left and right wheels, all on the same shaft (Fig. 6). Seamless gear changing achieves both improved acceleration performance and a top speed of 250 km/h. The eTwinsterX can serve as a pure EV primary drivetrain, or act as a disconnect AWD system by replacing the driven axle of engine-powered vehicles or EVs.

The wheel hub motor not only contributes to expanding cabin space and reducing weight by decreasing the number of power transmission parts, but also allows free control of the driving force transferred to each wheel. Making a wheel hub motor that meets drive force requirements while being compact and lightweight enough to mount within the wheel has proven difficult and has yet to be put into practical use. Focusing on downsizing, NSK Ltd. developed a wheel hub motor equipped with a transmission[3], which includes two small inner rotor motors, a transmission consisting of two planetary gears and an OWC, and a hub unit bearing containing a planetary gear acting as a final reduction gear. Vehicle road tests have confirmed that shifting occurs without shock.

Recently the service lives of transmission gears have been determined by the strength of teeth surfaces. There is growing interest in nondestructive technologies to estimate the remaining service life of transmission gears[5], especially in heavy-duty commercial vehicles. The half widths of gear teeth surfaces were measured by X-ray diffraction technique with a microscopic x-ray residual stress measurement device and the characteristic curve was obtained nondestructively to estimate the remaining service life of gears with the same material, heat treatment and other properties.

As described earlier, electrification has become essential in the development of power transmission mechanisms.

Even though varying environmental measures in developed countries and emerging countries lead to alternating between internal combustion, hybrid systems, or electricity as sources of power, the function of transmitting power to the wheels remains indispensable. The car manufacturers' responsibility is to respond flexibly to increasingly diversified technology development and mechanisms designed to improve environmental performances. Although it is natural to select, and focus on, superior technology, the cooperation of industries, academias and the government as Team Japan is essential to improve the efficiency and accelerate the speed of theoretical research on powertrain. Preliminary trial research by Powertrain Joint Research Promotion Committee has started. Successful results from the future activities are expected.

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